America's ZERO CARBON ACTION PLAN

The Zero Carbon Consortium

2020

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About SDSN USA

The SDSN USA network brings together researchers, knowledge creators, and thought leaders to mobilize expertise on the advancement of the Sustainable Development Goals (SDGS) in the United States. The network was launched in December 2018 and has quickly grown to become the largest network within SDSN. For more information, please visit www.sdsnusa.org or email usa@unsdsn.org.

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Acronym	Meaning
AB	Assembly Bill
ACCC	American Cities Climate Challenge
ACEEE	American Council for an Energy Efficient Economy
ACEP	Agricultural Conservation Easement Program
AEO	Annual Energy Outlook
AML	Abandoned Mine Land
ANEE	Alaska Network for Energy Education and Employment
ARPA	Advanced Research Projects Agency
ARPA-E	Advanced Research Projects Agency-Energy
ARPA-Land	Advanced Research Projects Agency-Land
ARRA	American Recovery and Reinvestment Act
ATR	auto-thermal reforming
AV	automated vehicles
BAU	business as usual
BECCS	bioenergy with carbon capture and storage
BEV	battery electric vehicle
BF-BOF	Blast Furnace-Basic Oxygen Furnace
BLM	Bureau of Land Management
BRT	Bus Rapid Transit
BTX	benzene, toluene, and xylene
CACFP	Child and Adult Care Food Program
CAFE	Corporate Average Fuel Economy
CARB	California Air Resource Board
CBECS	Commercial Buildings Energy Consumption Survey
CCA	community choice aggregation
CCS	carbon capture and storage
CCS	carbon capture and sequestration
CCUS	carbon capture utilization and storage
CE	circular economy
CfDs	contracts for difference
CHP	Combined Heat and Power
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
CSP	Conservation Stewardship Program
DAC	Direct Air Capture
DARPA	Defense Advanced Research Projects Agency
DER	distributed energy resources
DGS	Department of General Services

DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DRI	Direct Reduced Iron
DRI	dietary reference intake
E&I	Energy and Industry
EAF	Electric Arc Furnace
EE	energy efficiency
EECBG	Energy Efficiency and Conservation Block Grant
EEOC	Equal Employment Opportunity Commission
EFI	Energy Futures Initiative
EFRP	Emergency Forest Restoration Program
EISA	Energy Independence and Security Act
EPA	Environmental Protection Agency
EPC	engineering, procurement, and construction
EPR	extended producer responsibility
EQIP	Environmental Quality Incentives Program
ESA	Endangered Species Act
EV	electric vehicles
FAA	Federal Aviation Administration
FABLE	Food, Agriculture, Biodiversity, Land Use and Energy
FAST Act	Fixing America's Surface Transportation
FEMP	Federal Energy Management Program
FERC	Federal Energy Regulatory Commission
FINI	Food Insecurity Nutrition Incentive
FIT	Feed-in-tariff
FLP	Forest Legacy Program
FSA	Farm Service Agency
GDP	Gross Domestic Product
GDP	gross domestic product
GHG	greenhouse gas
GPC	Global Protocol for Community-Scale Greenhouse Gas Emission Inventories
GSA	General Services Administration
GW	gigawatts
GWMO	Global Waste Management Outlook
HCF	Household carbon footprint
HCRI	Hazard and Climate Resilience Institute
HDPE	high density polyethylene
HDV	heavy duty vehicles
HECO	Hawaiian Electric Company

HFC	hydrofluorocarbons
HFRP	Healthy Forests Reserve Program
HHS	Health and Human Services
HUD	Department of Housing and Human Development
HVAC	heating, ventilation, and air conditioning
HVAC	high-voltage alternating current
HVDC	high-voltage direct current
I-O	input-output
ICE	internal combustion engines
ICLEI	Local Governments for Sustainability
IEA	International Energy Agency
IMF	International Monetary Fund
IOU	investor-owned utilities
IPCC	Intergovernmental Panel on Climate Change
IRPs	integrated resource plans
ISOs	Independent System Operators
ISWA	International Solid Waste Association
ITC	Investment Tax Credit
LCFS	Low-Carbon Fuel Standard
LDPE	low density polyethylene
LDV	Light-duty vehicles
LED	light emitting diode
LEED	Leadership in Energy and Environmental Design
LNG	Liquefied natural gas
MATTER	MATerials Technologies for greenhouse gas Emission Reduction
MDV	Medium-duty vehicle
MEPs	Mandatory Energy Performance Standards
mHa	millihectare
MPO	metropolitan planning organization
MRF	materials recovery facility
MRFs	materials recycling facilities
MRV	Monitoring, reporting and verification
MRV	measurment, reporting, verification
MSW	municipal solid waste
MW	megawatt
NASA	National Aeronautics and Space Administration
NASEO	National Association of State Energy Officials
NECB	National Energy Code for Buildings
NEPA	National Environmental Policy Act
NERC	North American Electric Reliability Corporation

NETs	negative emission technologies
NFF	non-fossil fuel
NG	Natural Gas
NGOs	non-governmental organizations
NHTSA	National Highway Traffic Safety Association
NIBs	National Institute of Building Sciences
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NOAA	National Oceanographic & Atmospheric Administration
NRCS	Natural Resources Conservation Service
NREL	National Renewable Energy Laboratory
NSF	National Science Foundation
NYIT	New York Institute of Technology
NYSERDA	New York State Energy Research and Development Authority
OCAW	Oil Chemical and Atomic Workers union
OFCCP	Office of Federal Contract Compliance Program
OGCI	Oil and Gas Climate Initiative
PACE	Property Assessed Clean Energy
PAYT	pay-as-you-throw
PBGC	Pension Benefit Guarantee Condition
PEM	polymer electrolyte membrane
PET	polyethylene terephthalate
PEV	plug-in electric vehicle
PGP	power-to-gas-to-power
PGP	Public Generating Pool
POPs	Persistent Organic Pollutants (POPs)
PPA	Power purchase agreements
PREPA	Puerto Rico Electric Power Authority
PTC	Production Tax Credit
PUC	Public Utility Commission
PV	photovoltaic
PVC	polyvinyl chloride
R&D	Research & Development
RCRA	Resource Conservation and Recovery Act
RDD&D	Research, Development, Demonstration and Deployment
RDDD&D	Research, Development, Demonstration, Deployment, and Diffusion
REAP	Rural Energy for America Program
ReNW	Renewable Northwest
ROI	return on investment
RPS	Renewable Portfolio Standard

RTOs	regional transmission operators
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RTOs	Regional Transmission Operators
SAF	sustainable aviation fuel
SAYT	save-as-you-throw
SB	Senate Bill
SCC	Social Cost of Carbon
SCMs	Supplementary Cementitious Materials
SDG	Sustainable Development Goal
SDSN	Sustainable Development Solutions Network
SEP	state energy program
SMM	sustainable materials management
SMR	steam methane reforming
SNAP	Supplementary Nutrition Assistance Program
TNC	transportation network companies
TNCs	Transportation Network Company
UCCRN	Urban Climate Change Resource Institute
UDCW	Urban Design Climate Workshop
ULI	Urban Land Institute
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
V2G	vehicle-to-grid
Vermont GREEN	Vermont Growing Renewable Energy/Efficiency Employment Network
VMT	Vehicle miles traveled
VPPA	Virtual power purchase agreement
VRE	variable renewable energy
WARM	waste reduction model
WIC	Special Supplemental Nutrition Program for Women, Infants, and Children)
WTO	World Trade Organization
WVR	Wabash Valley Resources
ZCAP	Zero Carbon Action Plan
ZEV	zero emission vehicle
ZWIA	Zero Waste International Alliance

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Executive Summary

Climate change represents a profound policy challenge to America and the world – requiring a response at a sweeping scale and with unprecedented speed centered on remaking the energy foundations of our society. The move to a clean and renewable energy future must be advanced at the same time America works to recover from the most serious pandemic in a century and the parallel economic collapse triggered by Covid-19. The Zero Carbon Action Plan (ZCAP) presented in this document responds comprehensively to this multidimensional policy imperative.

As spelled out below, the ZCAP lays out a strategy for putting Americans back to work building a vibrant 21st century U.S. economy based on advanced technologies, good jobs, clean energy, climate safety, and economic security. It offers a pathway to achieve net-zero emissions of greenhouse gases by 2050 – thereby providing a basis for a dramatically ramped-up American contribution to the Paris Climate Agreement. The ZCAP agenda would promote efforts to limit global warming to 1.5°C, the ambitious goal that the 2019 Intergovernmental Panel on Climate Change Special Report tells us that society should adopt to avoid the worst effects of global warming including sea level rise, increased hurricane damage, and changed rainfall patterns that might dramatically affect agricultural productivity as well as resulting in more floods, droughts, and wildfires.

Taken as a whole, the ZCAP would position America as a climate change leader and provide a basis for holding other countries accountable for climate safety as well. Carefully structured to be economically efficient as well as environmentally effective, the ZCAP would spur innovation and investment, generate millions of new jobs, and ensure that American industry will not be undercut by polluting competitors abroad. It thus offers a comprehensive climate change policy strategy with both domestic and international dimensions.

In the following pages, decision-makers will find a clear outline of the technologies, investments, and policies needed to achieve net-zero carbon emissions by 2050. Building on the results of an in-depth energy infrastructure modeling exercise, this policy action plan is based on a rigorous technical quantification of the infrastructure upgrades and technology investments needed in our buildings, power, transportation, and industrial sectors. Furthermore, this plan demonstrates that not only is this energy transition possible, but it is feasible and affordable. In fact, the overall incremental costs of the transition will be just 0.4 percent GDP in 2050, a small fraction of America's annual energy spending.

The ZCAP draws from and expands upon two prior Sustainable Development Solutions Network (SDSN) reports, *Pathways to Deep Decarbonization in the United States* (2014) and *Policy Implications of Deep Decarbonization in the United States* (2015). It outlines in detail what needs to happen to maximize the gains and minimize the costs of the required energy transition. It promises economic vitality and robust job growth while reaching net-zero emissions by 2050.

The ZCAP builds on carefully structured technological analyses and transition pathways that demonstrate the feasibility of reaching zero emissions by 2050. It presents detailed background analyses of key sectors and covers all regions of the country and all major elements of our energy system.

The action items identified build on technologically and economically sound options and fit within the institutional framework of the U.S. federal system – with important roles for state and local governments as well as federal authorities. It offers a mix of top-down direction and bottom-up implementation with an emphasis on government leadership and private sector participation.

The ZCAP promises strategies of widespread experimentation, active learning, and adaptive management in the years ahead – as a way to build on the innovation capacities of both the private and public sectors as well as the creative spirit of the American people. It provides a path forward that allows federal, state and city governments to act ambitiously despite uncertainty, addressing risks with the promise of flexibility.

The ZCAP policy framework has been designed with an economic logic, analytic rigor, and political appeal that can win majority support with the public throughout the entire country and across party lines. It offers a basis for addressing the needs of the economic sectors, communities, and people who might be dislocated by the transition to a low-carbon future. Thus, while advancing a deep decarbonization agenda, it aims to provide for a just transition and promises economic opportunity for all Americans in the decades ahead.

The Zero Carbon Action Plan centers on the six major energy-producing and energy-consuming sectors:

- power generation;
- transportation;
- buildings;
- industry;
- land use for agriculture, forestry, and other purposes; and
- materials.

These six sectors account for almost all of U.S. CO_2 emissions. The analysis offered in support of the ZCAP focuses mostly on CO_2 emissions but also highlights the importance of other greenhouse gas (GHG) emissions including methane, nitrous oxide, and various industrial gases. Because CO_2 emissions account for 81 percent of overall U.S. emissions, any serious plan for climate neutrality by 2050 (that is, zero net emissions by 2050) must center on CO_2, but not ignore other GHGs.

The key components required for the new green-growth model presented in this document include: (1) Rapid upscaling of renewable energy; (2) Electrification; (3) Transition to hydrogen, advanced biofuels, and other clean fuels; (4) Sustainable forest and agricultural lands; (5) Reduced material wastes through Sustainable Materials Management; (6) Rejuvenation of the industrial heartland of America with a special focus on the Appalachian Region and the Midwest; (7) Government-backed financing, investments, and regulatory support; and (8) a national Research, Development, Demonstration and Deployment (RDD&D) strategy.

The ZCAP offers a framework for large-scale change that has four core elements. The first element is *technological*. The U.S. economy requires deep technological changes to continue defining the forefront of new global industries. The strategy of this plan is based on regulations and market incentives to promote high-speed innovation and rapid adoption of zero-emission technologies.

The second core element builds on *American federalism*. Large-scale change must rely on clear national goals, supported by the cooperative efforts of federal, state, and local governments with an appropriate division of labor among the levels of government and between the public and private sectors. Success in delivering on the ZCAP vision and building a resilient clean energy economy will require a national effort and the participation of all Americans.

The third core element is *foreign policy*. The U.S. share of global GHG emissions is currently around 15 percent. The world's climate future depends on global actions, not just the actions of any one country alone. The proposed new U.S. energy strategy must therefore include a strong foreign policy dimension, so that what happens domestically is matched and magnified globally. The United States must not only rejoin the Paris Climate Agreement, but also help to lead the world toward decarbonization at the needed pace.

The fourth core element is a 21st century *industrial policy* – using the heft of the U.S. government to promote new high-tech industries and advanced technologies as has been done successfully in many other areas that promised important economic prospects -- including advanced semiconductors, the space industry, the Internet, and biotechnology.

Energy and Infrastructure Pathways

The ZCAP strategy for transitioning from a high-carbon to a low-carbon energy system builds on three main pillars: (1) using energy more efficiently; (2) decarbonizing electricity; and (3) switching from fossil fuel combustion to electricity in most current uses. The underlying analysis recognizes that reaching net-zero or net-negative emissions requires an additional pillar: (4) carbon capture. Whether captured carbon is stored geologically or used to synthesize fuels depends on societal choice and relative economics.

The ZCAP team – including nearly a hundred researchers from dozens of research centers, academic institutions, think tanks, and other organizations -- developed six scenarios for meeting the net-zero target while meeting the same demand for energy services as the baseline reference scenario based on the Department of Energy's long-term forecast, the Annual Energy Outlook (AEO). The six scenarios include: a Central case (least cost); Limited land; Delayed electrification; 100 percent renewable primary energy; Low demand; and Net negative. The key finding across these scenarios was that while technology options change among the scenarios after 2030, as cost uncertainty increases and conditional variables reduce technological options, the scenarios aligned on key technology options within the first decade of action as described below.

The scenarios were modeled using two sophisticated analytic tools, EnergyPATHWAYS (EP) and RIO, which provide a high level of detail in sector (more than 60 subsectors), time (annual turnover of equipment stocks plus an hourly electricity dispatch), and geography (16 different regions of the United States, modeled separately).

This study focuses on how to eliminate CO_2 from the use of fossil fuel for energy and industrial feedstocks, which constitutes more than 80 percent of current U.S. GHG emissions. The scope of this analysis does not include negative CO_2 emissions from the "land carbon sink" or the emissions of non-CO_2 GHGs such as methane and nitrous oxide. Combined, these currently have net emissions of about +500 MMT CO_2e. Mitigation in these areas, from a combination of increasing the sink and reducing non-CO_2 GHG emissions, will be needed for total U.S. GHG emissions to reach net-zero or below, even if the energy system by itself is carbon neutral. Suggestions for doing so are covered by our chapters on the federal framework, land use, and materials.

In the modeling results, the shares of fossil fuel in the primary energy supply decrease dramatically from today's level -- replaced mainly by power from wind, solar, and biomass. Under the ZCAP strategy coal, which has a very high carbon content per unit of energy, is eliminated entirely. Natural gas (~75 percent reduction) and petroleum (~90 percent reduction) are reduced to niche roles including industrial feedstocks, certain forms of transportation, and a limited amount of natural gas power generation needed to maintain reliability in an electricity system composed primarily of wind and solar generation. Electricity increases to meet 50 percent of end-use demand, with zero-carbon drop-in fuels providing most of the rest. Conversion processes that play a minimal role today – advanced biofuel refining, and the production of hydrogen and synthetic fuels from electricity – become key components of a carbon-neutral energy system. CO_2 emissions from the small remaining fossil fuel use in energy and industry are captured directly or offset using carbon capture and storage.

Despite all of the heated debate surrounding the energy transformation, the ironic fact is that the incremental cost of running the U.S. economy on clean energy as opposed to fossil-fuel energy is very small. We find that as of 2050, the clean-energy economy costs only 0.4 percent of GDP more per year than the fossil-fuel economy. In other words, for less than one-half of 1 percent of GDP, we can fundamentally shift to a clean energy foundation for our economy – and thus avoid climate disaster.

Implications for Key Sectors

The single most important transformation occurs through the decarbonization of power generation, which accounts for around 32 percent of total CO_2 emissions from energy and industry in 2019 (see Table 1.1). The ZCAP analysis anticipates a major shift to wind and solar energy -- with continued production from other zero-carbon sources, notably nuclear and hydropower. For purposes of maintaining electricity system reliability, a substantial fleet of gas-fired power generators needs to remain in place in 2050, roughly comparable to today's level of capacity. However, these generators will run much less often than they do at present, comprising only a few percent of total electricity generation.

The **transportation** sector includes light-duty vehicles, heavy-duty vehicles (trucks), off-road vehicles, buses, rail, shipping, and aviation. Transportation emissions accounted for 37 percent of total CO_2 emissions from energy and industry in 2019. The principal strategy for decarbonizing transportation is electrification (including battery, plug-in hybrid, and hydrogen fuel cells) of all light-duty vehicles, urban-based trucks and buses, rail, much of long-haul trucking, and some short-haul shipping and aviation. For long-haul aviation and long-haul ocean shipping, advanced low-carbon biofuels and synthetic liquids or gases produced with renewable energy are the leading energy contenders. The second strategy builds on initiatives to reduce vehicle use and miles traveled while enhancing accessibility to health, education, jobs, and other services for the mobility disadvantaged. This transition will require a variety of actions by federal, state, and local governments as spelled out in detail in the report that follows.

Buildings, both residential and commercial, account for 12 percent of direct CO_2 emissions. Buildings built between now and 2050 will comprise 30 percent of the building stock in 2050, making low-carbon buildings an essential element of any deep decarbonization strategy. In this regard, the ZCAP proposes a new National Energy Code for Buildings (NECB) to ensure that new buildings constructed after 2025 will not burn fossil fuels onsite, will be highly energy efficient, and will be constructed using low-carbon techniques and materials. The NECB and federal appliance standards should also ensure that replacement equipment and appliances in existing buildings will be energy efficient and largely electrified.

Industry accounts for 20 percent of CO_2 emissions from energy. A relatively large share of industry emissions from light industries such as manufacturing of durable goods, food and textile processing, and even mining and non-ferrous metal production may be avoided by coordinated efficiency improvements, electrification, and decarbonization of electricity generation. Other industries – such as iron and steel, cement, and feedstock chemicals – are of particular interest in a decarbonization context precisely because their conventional production processes entail emissions that are difficult to avoid and their capital infrastructure tends to be long-lived. Fortunately, even for these sectors, there are technical solutions available such as carbon capture and storage (CCS) at industrial facilities, hydrogen, supplementary materials and fillers, and other synthetic fuel replacements and substitutions.

Land use policies impact every aspect of the transition to zero greenhouse emissions, including: siting of renewable energy, next generation biofuels, reforestation, soil carbon, and emissions from agriculture and livestock. The complexity of policy choices in this area will require new efforts at RDD&D, new inter-agency planning, and enhanced cooperation of all levels of government with each other and with impacted communities.

Finally, the ZCAP calls for a new national framework for Sustainable **Materials** Management (SMM) and a Circular Economy (CE) based on the pillars of "reduce, reuse, recycle." Much of the negative climate impact in the United States comes from the materials and food consumed. This includes the entire materials supply chain, from manufacturing, transportation and usage, to final disposition of materials. An integrated SMM and CE approach would help to reduce pollution, drive job creation, spur energy efficiency, and lower GHG emissions. SMM and CE objectives should thus be incorporated into a range of federal policies as well as free-trade agreements and the work of international organizations.

Job Creation and an Equitable Transition

By comparing the investment patterns of the main *central scenario* and baseline *reference scenario*, and then using an Input-Output analysis, we can estimate the number of new jobs created net of the jobs that will be lost in the fossil-fuel-related industries. The full set of investments to achieve a net zero emissions U.S. economy between 2020 – 2050 will generate about 2.5 million jobs per year, considering jobs created through "direct" channels, such as manufacturing electric cars, and "indirect" channels (i.e., jobs along the supply chain to manufacture electric cars). Over four million jobs per year will be created if we also include jobs generate through "induced" channels (i.e., multiplier effects of newly-employed workers spending their earnings). Government policy at all government levels should commit to industrial policies that will support domestic clean energy investments, especially in manufacturing. Effective industrial policies can increase total job creation by up to about 10 percent.

Public policy at all levels should commit to ensuring that that the jobs created through clean energy investments are high-quality in terms of wages, benefits, and working conditions. Strong labor unions and effective job training programs are both necessary to promote high-quality job opportunities and support a just transition. Since climate change affects people and communities of color in distinct and significant ways, policies to reduce GHG emissions and other pollutants should be crafted and implemented with engagement of those most affected. Attention to procedural fairness as well as substantive equity can also help to ensure that women and people of color have equal access to the emerging clean energy jobs. These groups are currently underrepresented in all areas of the U.S. energy sector.

The federal and state governments should also enact *just transition* policies for workers and communities that are currently dependent on the fossil-fuel economy. About 12,000 workers per year in the coal industry will face job displacement between 2021 – 2030 as the coal industry is phased out as of 2030. About 34,000 workers per year in the oil and gas industry will face displacement as oil and gas are significantly phased down between 2031 - 2050. All displaced workers should receive pension and re-employment guarantees, as well as generous income, retraining and relocation support. The combined overall cost of such a generous program will be modest. Fossil-fuel dependent communities should receive major federal and state-level support to reclaim and repurpose land and generate new investment projects, including in a range of clean energy areas.

Key Federal Actions in 2021 should include commitments to:

- Rejoin the Paris Climate Agreement and establish a new and stronger Nationally Determined Contribution for U.S. greenhouse gas emissions – including the goal of net-zero or net-negative anthropogenic GHG emissions by 2050 and an updated interim goal for 2030.
- Adopt a Zero Carbon Action Plan by legislation committing the nation to net-zero GHG emissions by no later than 2050.
- Require a Presidential report to Congress in January 2022 that provides a detailed roadmap to put the country on the path toward carbon neutrality by 2050.
- Invite the Department of Energy, Environmental Protection Agency, Department of Transportation, and other relevant agencies to translate the Zero Carbon Action Plan into intermediate and sector-specific emissions reduction goals and timelines for power, transport, industry, buildings, land use and materials, and a process for updating such goals.
- Establish a White House Office on Climate Change to coordinate federal agency climate-change activities for both mitigation and adaptation, and to the extent authorized by law, direct the development of plans, establish program metrics, track progress, and otherwise oversee these activities.
- Provide funding for the first four years of the ZCAP at a minimum of $2 trillion and provide long-term mechanisms for adequate future funding, including federal support for state and local actions.

- Enact a national clean energy standard for electricity to reduce emissions compared to the present by at least 60 percent by 2030, 80 percent by 2040, and >95 percent by 2050.
- Accelerate the transition to electric cars, trucks, buses, and other vehicles through the implementation of new vehicle performance standards, expansion of the incentives for zero-emissions vehicle purchases, and investments in electric vehicle charging station infrastructure.
- Establish a mechanism by which states, territories, and tribes specify how they will achieve their specific Zero Carbon Action Plan milestones.
- Make operational through procedural and substantive commitments the principle that environmental and jobs benefits of the energy transition are to be shared equitably in terms of geography, race, gender, and ethnicity – thereby ensuring that disadvantaged communities benefit fully.
- Invest directly in key parts of the national energy system, including inter-state power transmission, public land use for power generation, and supporting infrastructure.
- Launch innovative green financing mechanisms, such as government guarantees for green bonds, tax incentives on utility bonds for renewable energy, direct equity, and funding of state-level green banks.
- Promulgate new Securities and Exchange Commission (SEC) reporting requirements that require disclosure of climate-change-related risks and broader Environmental/Social/Governance impacts.
- Accelerate, intensify, and fully fund research and development for zero-greenhouse-gas emitting technologies, energy efficiency technologies, and carbon removal technologies.
- Clarify the National Environmental Policy Act (NEPA) requirement that all federal action should be undertaken with an eye toward environmental impacts.
- Each federal agency should exercise its existing powers and duties to contribute to the fullest possible extent to the achievement of the Zero Carbon Action Plan including national climate change goals and with specific emission reduction targets.
- Specify a Social Cost of Carbon or shadow cost of carbon to guide policy formulation and regulatory decision-making as well as to serve as the basis for market mechanisms such as clean-energy subsidies, carbon taxes, feed-in tariffs and auctions, and other market-based instruments that will vary by sector and over time.

Key State Actions in 2021

- In line with the National Clean Energy Standard and the associated goal of net-zero emissions by 2050, all states should prepare Renewable Portfolio Standards (RPS) or equivalent Zero Carbon Energy Standards for the goal of zero-carbon power by 2050. Currently 31 states have RPS of which 8 have the goal of 100 percent renewable energy on or before 2050.
- All states should prepare a comprehensive plan for net-zero GHG emissions by 2050 covering transport, buildings, and industry.
- All states should prepare financing strategies to align with new federal funding programs
- States and cities should implement land use policies that promote densification, transit-oriented development, and complete streets.

Key Local Actions in 2021

- Local governments, working in tandem with state and federal agencies, should prepare local plans for net-zero greenhouse emissions by 2050 covering all local sectors.
- Cities and local governments should adopt building codes and practices that encourage or require zero-emission, all-electric buildings so that all new buildings are 100 percent electric and retrofits for existing buildings are actively underway.
- Cities should align incentives and programs for building retrofits with state climate goals and begin efficient retrofit of existing buildings.

1. OVERALL POLICY FRAMEWORK

Jeffrey Sachs, Sustainable Development Solutions Network (SDSN)

1.1 Goals and Scope

The Zero Carbon Action Plan (ZCAP) aims to put Americans back to work to build a vibrant 21st century U.S. economy based on advanced technologies, good jobs, clean energy, climate safety, and economic security. It is designed to achieve net-zero emissions of greenhouse gases by 2050 as America's contribution to the Paris Climate Agreement to pursue efforts to limit global warming to 1.5°C, a goal later underscored by a special report of the Intergovernmental Panel on Climate Change. It will hold other countries accountable for climate safety as well, ensuring that American industry will not be undercut by polluting competitors abroad.

In this effort, the U.S. will not be alone. The European Union has recently adopted the European Green Deal to achieve net-zero emissions by 2050, and by 50-55 percent as of 2030 compared with 1990. The European Green Deal is backed by a new €750 billion recovery fund, including funds for research and development (R&D) on the new clean energy technologies. China's high-technology program, Made in China 2025, involves massive outlays to propel China's technological advance in key green technologies, including renewable energy, smart grids, electric vehicles, and advanced technologies in rail, shipping and aviation.

The new clean-tech economy will help to save the planet from human-induced climate change while creating millions of good jobs, many more than will be cut in the fossil-fuel industry, and smart federal policies can magnify those favorable job trends. Yet there is currently no strategy at the federal level to support these new job-creating sectors. Private businesses are stymied, not able to invest at scale because the accompanying public investments in infrastructure (e.g., an upgraded national power grid, charging stations on the Interstate Highway for electric vehicles, national connectivity for 5G) have not been made. The U.S. currently spends around $20 billion annually to subsidize old polluting companies and sectors that have limited long-term prospects, while our competitors in Europe and Asia are building the industries of the future such as photovoltaics, wind turbines, long-distance transmission systems, 5G enabled smart grids, advanced batteries, and others.

We estimate that the clean energy sector and its supply chains will create around 2.5 million net jobs per year on average between 2020 and 2050, taking into account the decline in jobs in the fossil-fuel industries, with many industrial jobs created in America's industrial heartland in the Appalachian region and Midwest. This estimate includes the direct and indirect job creation in the clean-energy economy and subtracts the job losses in the fossil fuel industries. In other words, the shift to clean energy is a net job creator. The new jobs will include the large-scale production and installation of zero-carbon power generation and distribution based on solar, wind, and hydro power, and the manufacture of electric vehicles, batteries, wind turbines and solar panels, green hydrogen and other green fuels, and related technologies. In addition, there will be around 800,000 new jobs per year associated with investments in energy efficiency, such as retrofitting buildings for insulation and electrification.

The ZCAP is based on detailed technological pathways that demonstrate the feasibility of reaching zero emissions by 2050, as well as detailed background analyses of key sectors. These pathways are described in detail in Chapter 2. The pathways cover all regions of the country and all major sectors of our energy system. The action items identified build on technologically and economically sound options and fit within the institutional framework of the U.S. federal system. We believe the policy framework advanced here has both an economic logic and a political appeal that can win majority support with the public throughout the entire country, and at all levels of government: federal, state, and local.

Building a new energy and jobs strategy cannot be left to either the private or public sector alone, and it cannot be a short-term policy. We require clear goals and policies that will enable a long-term transition that will require 30 years to complete. The long-term nature of the transition is the result of one simple fact: greenhouse gas emissions are mainly due to the long-lasting capital stock that as of now relies heavily on fossil fuels: power plants, vehicles, buildings, and factory output. This capital stock will roll over during the next thirty years. The main process of energy-system transformation is to replace the fossil-fuel-using capital stock as it is retired with new zero-carbon capital that depends on clean power and green fuels.

The private sector today is held back by the lack of clear federal policies. Private companies need clear goals, credible incentives, support for research, development, demonstration and deployment (RDD&D) support, and reasonable protection from foreign competitors that use fossil-fuel intensive technologies. It needs supporting regulations for siting new clean-energy projects. It needs public infrastructure that is complementary to private investments. Since the Federal Government has no long-term plans for sustainable 21st century infrastructure and the green transformation of the energy system, the private sector cannot invest at scale. Trillions of dollars of private investments will sit on the sidelines until there is clarity and movement on long-term U.S. energy and infrastructure policies.

Nor can the Federal Government alone provide the needed leadership in our federal system. States and localities must also play key leadership roles. In fact, a number of governors and mayors have already staked out leadership positions on renewable energy and vehicle electrification and have put forward policy innovations that offer important learning and demonstration effects. In addition, the states oversee much of the core energy infrastructure including power plants and roads and bridges.

Even more critically, these subnational governments have jurisdiction over critical regulatory and management functions. Notably, state public utility commissions regulate electric utilities and cities and states establish building codes and thus are positioned to determine the energy efficiency of much of the built environment. Local governments also invest in mass transit and roads, and regulate land use and housing. Further, states and cities have the ability to change more rapidly and can design transition strategies tailored to their local resources and communities. Success, however, will require the backing of the Federal Government with regard to regulatory frameworks, carbon reduction targets, and incentives as well as financing and federal investments. Further, states and cities have the ability to go further faster and can design transition strategies tailored to their local resources and communities.

The Zero Carbon Action Plan centers on the six major energy-producing and using sectors: power generation, transportation, buildings, industry, land use for agriculture, forestry and other purposes, and materials. These six sectors account for almost all of the CO_2 emissions of the U.S. We focus mostly on CO_2 emissions but also note the importance of non-CO_2 greenhouse gas emissions (GHG) including methane, nitrous oxide, and various industrial gases. In fact, CO_2 emissions account for 81 percent of overall U.S. GHG, so any serious plan for climate neutrality by 2050 (that is, zero net emission by 2050), must start with CO_2 emissions.[1]

The *key components required for the new green-growth model* include:

- **Rapid upscaling of renewable energy.** While the shift away from a fossil-fuel-based economy will be challenging, the utility sector is already moving in the right direction and can move far more rapidly and deeply with the right incentives. Indeed, power generation is currently the only major sector that shows signs of shallow decarbonization while nearly all other sectors have flat or rising emissions.
- **Electrification** of the economy wherever electricity-based energy is economically feasible and practical – including in ambient heating and ventilation (both new buildings and retrofits), and light, medium- and even heavy-duty vehicles, including much of trucking (urban delivery, drayage at ports), buses, rail, and some industrial applications – recognizing that the electric sector must fully transition to emissions-free clean power options to deliver the benefits of electrification.
- **Transition to hydrogen, advanced biofuels, and other clean fuels** manufactured with zero-carbon power for "hard-to-abate" existing buildings and industrial sectors such as steel, cement, chemicals, aircraft, and ocean-shipping. Each of these transitions will require a tailored strategy that reflects the technological requirements and industrial organization of the sector.
- **Sustainable forest and agricultural lands** based on large-scale reforestation, increased soil carbon through improved farm practices, next-generation biofuels that do not compete with the food supply or ecological needs, healthier diets with greater reliance on plant-based proteins, and reduced food losses and waste.
- **Reduced material wastes through Sustainable Materials Management (SMM)** industrial processes, reduced utilization of single-use plastics and other polluting goods, advanced materials, and the scale-up of recycling and other components of the circular economy, based on "reduce, recycle, and reuse" materials.
- **Rejuvenation of the industrial heartland** of America in the Appalachian Region and the Midwest to build the wind turbines, solar panels, electric vehicles, advanced biofuels and hydrogen systems, transmission grids, and the smart software for efficiency of the energy system.
- **Government-backed financing, investments, and regulatory support** at all critical stages of the transformation, including for job training in the new sectors; utility financing for rapid scale-ups of renewable power generation and energy efficiency in the residential, commercial, and industrial sectors; industrial restructuring in motor vehicle manufacturing and heavy industry; public infrastructure, including a revamped transmission grid, charging stations for electric vehicles, and advanced public transport services in urban areas; and research and development for cutting-edge zero-carbon technologies;
- **A national RDD&D strategy** (research, development, demonstration & deployment) to ensure that America stays at the technological forefront of the new clean-energy economy, including smart grids and smart homes, distributed generation, advanced renewable power, high-efficiency batteries and other energy storage, fuel-cell technologies, and other areas.

1.2 The Overwhelming Case for a Clean-Energy Economy

The U.S. economy is still largely geared to the era of fossil-fuels: electricity produced by fossil fuels (around 63 percent), transport based on petroleum (around 95 percent), buildings heated by oil and gas, industry powered by coal and gas, and so forth. Meanwhile, the European Union, China, and other countries are increasingly focused on the green technologies of the future. In 2015, all 193 member countries of the United Nations signed the Paris Climate Agreement to pursue efforts to limit global warming to 1.5°C, a goal later underscored by a special report of the Intergovernmental Panel on Climate Change. Only the U.S. has announced its withdrawal from the agreement (effective November 4, 2020), while all other 192 countries have remained. The U.S. risks falling far behind in global competitiveness in the clean-energy sector, especially as China continues with its Made in China 2025 strategy, which focuses heavily on advanced green technologies, and as the European Union implements the newly adopted European Green Deal.

1.3 Framework for Large-Scale Change

This plan offers a framework for large-scale change that has four core elements. The first element is *technological*. The American economy requires deep technological changes to continue defining the forefront of new global industries. The strategy of this plan is based on regulations and market incentives to promote high-speed innovation and rapid adoption of zero-emission technologies.

The second core element builds on *American federalism*. Large-scale change must rely on clear national goals, supported by the cooperative efforts of federal, state, and local governments with an appropriate division of labor among the levels of government and between the public and private sectors. The new economic growth model will require both top-down leadership and bottom-up innovation and implementation. Moreover, a strategy based on federalism that actively engages all levels of government will have greater credibility and staying power than a program designed to operate only by top-down policies.

The third core element is *foreign policy*. The U.S. share of global GHG emissions is currently around 15 percent. The world's climate future depends on global actions, not the actions of any one country alone. The new U.S. energy strategy must include a strong foreign policy dimension, so that what happens domestically (and in other countries where serious decarbonization strategies are put into play) is matched and magnified globally. The U.S. must not only rejoin the Paris Climate Agreement, but also help to lead the world toward decarbonization at the needed pace. The U.S. must promote a global trading system that favors innovation and clean-energy technologies and that prevents free-riding by countries that try to shirk their global responsibilities for action.

The fourth core element is *industrial policy* – using the heft of the U.S. government to promote new high-tech industries as has been done successfully in many other areas, including advanced semiconductors, space industry, the Internet, biotech, and other areas of advanced technologies.

The following will consider these four core elements in turn: technological transformation, federalism, foreign policy, and industrial policy.

1.3.1 Technological

Looking to history, profound technological changes often begin in niches and then diffuse more widely – ultimately reconfiguring entire markets. This element of the following framework of change means that one must understand, sector-by-sector, the state of play of technology – and the challenges and opportunities that must be addressed. The policy interventions needed will depend on that state of play:

- For early stage technologies, policies that promote broad-based investment in RDD&D will be critical. Indeed, because new ideas are public goods (freely provided to all), testing of a range of new ideas and learning quickly what works is essential. Likewise, it is crucial to the innovation process to take risks and make mistakes but also move quickly to cut losses and double down on successful breakthroughs. Markets for these new technologies may need to be "made" –such as through government procurement, creative financing (e.g., green banks), guaranteed offtake arrangements (e.g., power purchase agreements), and other strategies that provide predictability and revenue flows that make investments in these emerging technologies "bankable."
- For diffusion and reconfiguration of existing technologies, the policy instruments required will be different because the tasks are different. In more mature areas of technological change, the options are better known and the goal must therefore be to encourage more widespread adoption, additional learning through experience, and ultimate reconfiguration of markets around deep decarbonization. Here the requisite policies will include regulatory requirements including performance standards, carbon pricing, and harm charges more generally. These should be designed to ensure the objective of zero net emissions by 2050 in the most efficient manner.

Big changes in technology will require a major financing effort by both the public and private sectors, combined with clear goals and strong regulations and incentives at all levels of government. Every sector of the energy system is interconnected with the others. Renewable energy will require a modernized power grid to support it. A new electric vehicle industry will require a national supply chain of advanced battery production, as well as charging stations along the nation's roadways and smart grids working efficiently with the electric vehicle fleet. The massive investments needed in zero-carbon wind and solar power will require that federal, state, and local authorities support access to the required land, consider tradeoffs between renewable siting and priorities in agriculture and local ecosystems, and ensure that low-cost financing is available. In short, the complementary pieces of private investment, public investment, RDD&D, and job training, must all work together.

1.3.2 Federalism

The Zero Carbon Action Plan will operate across all levels of government – federal, state and local. Some elements of this policy will be broad-based and cover the whole economy – for example, investments in early stage RDD&D, carbon-emission standards in transportation and electricity, and carbon pricing in some sectors to help point innovation in the right direction – often through hybrid regulatory-market policies such as trading of vehicle emission credits. Most of the leverage will come from detailed actions in specific sectors and locales. The various chapters provide a framework for this action agenda across economic sectors and levels of government.

Federal Government

The Federal Government must take the lead in setting clear national goals and milestones for all key CO2 emitting sectors – power, transport, buildings, and industry – to achieve zero net emissions no later than 2050. To achieve those goals, the Federal Government should partner with the best minds in the private sector, NGOs and academia and develop technology roadmaps for each major sector, or to create new programs for rapid learning as in the past successes of the National Aeronautics and Space Administration (NASA), Defense Advanced Research Projects Agency (DARPA), Advanced Research Projects Agency-Energy (ARPA-E), National Institutes of Health (NIH), and the National Science Foundation (NSF).

The sector chapters included within provide a starting point for such technology roadmaps and more open-ended RDD&D programs. In turn, the RDD&D priorities identified should help to guide substantially increased federal outlays on RDD&D for zero-carbon energy technologies. The Federal Government will also invest directly in key parts of the national energy system, including inter-state power transmission, public land use for power generation, and supporting infrastructure. The Federal Government will also engage in innovative green financing, such as government guarantees for green bonds, tax incentives on utility bonds for renewable energy, direct equity, funding of state-level green banks, and others. All of this will be supported by clear mandates for all key federal agencies, including the science agencies (NSF, NOAA, DOE, etc.) and the regulatory agencies (DOT/NHTSA, EPA, Interior, FERC, etc.). Finally, the Federal Government will provide foreign policy leadership, including re-entry into the Paris Climate Agreement, participation in global technology partnerships and standard setting, new financing for low-income countries, and border taxation and regulation for trade in energy-intensive products.

State Governments

State governments are responsible for power generation and within-state distribution – and play a role in coordinating regional grids. Well over half the states have enacted Renewable Portfolio Standards (RPSs) for their state utilities, typically overseen by public service commissions and departments of energy in the state government. The most important single step will be to adopt a national timeline and goal for net-zero emissions by 2050, implemented through a national clean energy standard, which serves as a framework and "floor" for states to build on their existing RPS goals. Some states will move faster than the federal timeline, and should be encouraged and enabled to do so. Many states have already adopted zero-emission vehicle sales requirements, low-carbon fuel standards for transportation energy, and are currently pursuing more aggressive GHG performance standards for vehicles than the Federal Government. States are working together to develop innovative pricing and investment policies, through collaborations like the Regional Greenhouse Gas Initiative and the Transportation and Climate Initiative. Many states are already committed to timelines to decarbonize electricity generation and transportation before 2050. Incentives need to be established to get other states on the same trajectory.

State governments are also leaders of local economic development initiatives, at the state, regional, or metropolitan scales. State policies will continue to support manufacturing of green technologies, such as solar panels, wind turbines, components for electric vehicles, software and hardware for smart grids, and the like.

State government instruments include public investments, regulation of the utility sector, tax and other incentives for industrial location, transportation planning, design and retrofitting of state buildings and transportation fleet, public transportation policies, state building codes, and public infrastructure (e.g., charging stations on state roads).

Local Governments

Local governments, like state governments, have often been leaders on climate and sustainability. Local governments also have jurisdiction over urban land use, building codes, roads, transit, and much more. They are on the front lines for many of the changes needed to decarbonize, and are often willing to take the lead on environmental commitments, but generally have limited capacity and resources. The Federal Government can provide resources, for instance to support a transition from single-occupant vehicles to transit and to shared and pooled services in ways that enhance accessibility by disadvantaged travelers. The Federal Government can restructure transportation funding and can empower local governments to decarbonize travel and better organize land uses.

1.3.3 Foreign Policy

The Zero Carbon Action Plan must also be incorporated into America's foreign policy and diplomacy for four major reasons.

- First, and foremost, climate safety can be achieved only by a global transformation to net-zero emissions by mid-century. The U.S., for example, emits roughly 15 percent of the total worldwide CO_2 emissions from energy and industry. Even if U.S. domestic emissions achieved the net-zero goal, the CO_2 problem would persist unless there is comparable progress across the globe. The U.S.s will best promote action abroad in four ways: remaining at the forefront of new clean-energy technologies, exporting clean-energy solutions, rejoining the Paris Climate Agreement, and insisting that other countries clean up their own energy systems in order to keep their access to the U.S. marketplace
- Second, the pace of the U.S. energy transformation will affect competitiveness in the global market. Other nations, notably the EU, China, Japan, and Korea, are already advancing in high-tech, low-carbon technologies. U.S. companies will need to move faster to maintain their global competitiveness.
- Third, the new U.S. clean-energy industries will need reasonable protection from products overseas by CO_2-intensive industries. America should deploy a new system of "border tax adjustments" to ensure that fossil-fuel-intensive competitors are not able to take advantage of the new clean-energy industries. Such border adjustment mechanisms are also part of the European Green Deal. Fossil-fuel based American firms will likely face border taxes when exporting to the EU.
- Fourth, the global technological transformation to clean energy will involve new technology standards for vehicles, aviation, ocean shipping, power generation, cross-border power transmission, energy efficiency, smart grids, artificial intelligence, and other parts of the new energy economy. The United States should play a leadership role in setting these new standards.
- Fifth, the U.S. will have to work with other nations to update the global trade and investment rules at the World Trade Organization (WTO) and elsewhere to ensure that the rules and procedures of the international trading system reinforce the global commitment to sustainability in general and decarbonization in particular.

1.3.4 Industrial Policy

As the entire world moves towards clean-energy technologies, U.S. competitiveness, national security, and global leadership will depend on its capacity to build world-leading, large-scale industries in each critical part of the new energy system. The U.S. has considerable experience and success with technology-based industrial policy domestically, and it confronts similar policies in foreign relations, most notably in China. The U.S. has successfully promoted major private industries based on public-private technological initiatives. Key industrial sectors for the future include: renewable energy (e.g., photovoltaics, wind power); power transmission and distribution; smart grid with 5G backbone; electric vehicles; advanced batteries at grid, vehicle, and household scale; fuel cells; low-carbon aviation; zero-emission buildings; hydrogen and other zero-carbon fuels such as advanced biofuels; new materials replacing petroleum-based products; carbon-capture and storage; and potentially advanced nuclear power (e.g., modular, fourth-generation, passive safety systems, new fuel cycles, fusion). These technologies will spur further advances in nanotechnologies, new materials, robotics, artificial intelligence, and other systems.

1.4 Transformation of Six Key Sectors

Six sectors of the economy account for almost all CO_2 emissions, and most emissions of other greenhouse gases. The key, therefore, is the deep transformation of these sectors by 2050, which may be summarized as follows:

Power

Power. The single most important transformation is the decarbonization of power generation, which accounted for around 32 percent of total CO_2 emissions from energy and industry in 2019 (see Table 1.1). The major shift is to wind and solar energy, with continued production from other zero-carbon sources, notably nuclear and hydropower. For purposes of maintaining electricity system reliability, a substantial fleet of gas-fired power generators needs remain in place in 2050, roughly comparable to today's level of capacity. However, these generators will run much less often than they do at present, comprising only a few percent of total electricity generation. The fuels used in this generation can be made carbon-neutral, or their emissions can be offset elsewhere in the system. Since wind and solar power are already at or near grid parity with coal-fired and gas-fired power generation, inclusive of energy storage, the incremental energy costs compared with business-as-usual (BAU) associated with the green transformation of the power sector are small. As part of decarbonizing the economy, the power sector will need to grow in order to absorb new loads from transportation, buildings, and industry, as those sectors electrify. In order to keep the cost of a larger grid (including generation, transmission, and distribution) affordable nationally, our analysis assumes a 40 percent efficiency improvement in per capita energy use by 2050.

Transport

The transportation sector includes light-duty vehicles, heavy-duty vehicles (trucks), off-road vehicles, buses, rail, shipping, and aviation. Transportation emissions accounted for 37 percent of total CO_2 emissions from energy and industry in 2019. The principal strategy for decarbonizing transportation is electrification (including battery, plug-in hybrid, and hydrogen fuel cells), including all light-duty vehicles, urban-based trucks and buses, rail, much of long-haul trucking, and some short-haul shipping and aviation. For long-haul aviation and long-haul ocean shipping, advanced low-carbon biofuels and synthetic carbon-based liquids or gases produced with renewable energy are the leading energy contenders. The second strategy is to reduce vehicle use and miles traveled while enhancing accessibility to health, education, jobs, and other services for the mobility disadvantaged, which involves a variety of actions by federal, state, and local governments.

Buildings

Buildings, both residential and commercial, account for 12 percent of direct CO_2 emissions; this rises to 32 percent when the building share of electricity emissions are taken into account. Buildings built between now and 2050 will comprise 30 percent of the building stock in 2050. A new National Energy Code for Buildings (NECB) should ensure that new buildings constructed after 2025 will not burn fossil fuels onsite, will be highly energy efficient, and will be constructed using low-carbon techniques and materials. The NECB and federal appliance standards should also ensure that replacement equipment and appliances in existing buildings will be energy efficient and largely electrified.

We recommend that around 5 percent of the national RDD&D budget (rather than less than 1 percent today) should be committed to advanced building technologies, building science, and building policies including through joint ventures with National labs and state analogues. Investment in RDD&D should be paired with the development of a national manufacturing policy that would ensure that a large percentage of green building products are manufactured domestically. In addition to funding federal government building retrofits and new builds to meet the national carbon goals, the Federal Government should provide financial resources via grants to states, counties, and cities, for extensive building retrofits. It should leverage its financial tools, such as tax policy and mortgage underwriting criteria, to encourage low-carbon buildings. The Federal Government should also assist state and local authorities in creating policies for reducing GHG emissions from buildings that exceed national policies and policies for compact, low-carbon development.

Industry

Industry accounts for 20 percent of CO_2 emissions from energy, of which 68 percent are related to energy demands (electricity and heat) and the other 32 percent result from various industrial processes. As such, a relatively large share of industry emissions from light industries such as manufacturing of durable goods, food and textile processing, and even mining and non-ferrous metal production may be avoided by coordinated efficiency improvements, electrification, and decarbonization of electricity generation. Other industries – such as iron and steel, cement, and feedstock chemicals – are of particular interest in a decarbonization context precisely because their conventional production processes entail emissions that are difficult to avoid and their capital infrastructure tends to be long-lived.

Fortunately, even for these sectors, there are technical solutions available such as Carbon Capture and Sequestration (CCS) at industrial facilities, hydrogen, supplementary materials and fillers, and other synthetic fuel replacements and substitutions. Federal and state governments should work together to revise building and infrastructure codes and to create lead markets to incentivize the commercialization of green industrial products.

Land use (agriculture, forests, other non-urban)

Land use policies impact every aspect of the transition to zero greenhouse emissions, including: siting of renewable energy, next generation biofuels, reforestation, soil carbon, and emissions from agriculture and livestock. The complexity of policy choices in this area will require new efforts at RDD&D, new inter-agency planning, and enhanced cooperation of all levels of government with each other and with impacted communities. Key recommendations include the following:

- A new Advanced Research Projects Agency for Land (ARPA-Land) with a focus on soil carbon sequestration, next-generation biofuels, low-carbon animal protein substitutes, reducing food loss and waste, integration of renewable energy with agricultural land use
- A new inter-agency task force on land to coordinate the multiple issues relevant to U.S. lands in the context of deep decarbonization
- The development and use of integrated models to support long-term pathways towards sustainable land use and food systems
- Integrated spatial planning and transparent processes and financing mechanisms for renewable energy project development and transmission infrastructure;
- Financing incentives for agri voltaics and distributed generation, as well as renewables development, on existing structures on agricultural land and contaminated and underutilized sites
- Regulations to address jurisdictional overlaps among state, federal government, regional transmission operators (RTOs), and the ability of one or a few states to veto an interstate expansion to balance regional and local interests
- Policies to assess impacts on host communities and engage impacted communities in the siting process and decisions on compensation
- Development of a national reforestation goal by 2050, supported by various incentive policies and federal acquisition of private lands for reforestation where feasible and useful
- Policies to increase the storage of carbon in agricultural soils built around incentives, monitoring, reporting
- Transformation to next-generation biofuels through increased RDD&D funding, a new low-carbon fuel standard, and new federal procurement standards
- Promoting dietary shifts to foster healthier diets produced by a food system with lower GHG emissions
- Policies to reduce food loss and waste.

Materials

ZCAP calls for a new national framework for SMM and Circular Economy (CE) based on the pillars of “reduce, reuse, recycle.” Both SMM and the CE will lead to reduced pollution, energy efficiency, and reduced GHG emissions. Specific SMM and CE policies include: mandatory recycling and composting; national bans on plastic bags, polystyrene, and other polluting materials; SMM plans for materials management; green public procurement criteria and targets; restrictions of waste exports; and embrace of Basel Convention standards for electronic recycling.

Table 1.1 EIA Total U.S. Energy-Related Carbon Dioxide (CO_2) Emissions 2019.[2]

	Buildings		Industry	Transportation	Power	Source total
	Residential	Commercial				
Sector total (CO_2 million metric tons)	343	254	1,012	1,902	1,619	**5,131**
Percent total	11.6%		19.7%	37.1%	31.6%	100%

Carbon dioxide (CO_2) emissions were about 5,131 million metric tons in 2019. The above numbers show the direct emissions from each sector without double counting electricity.[3]

1.5 Economic Costs of Reaching Net-Zero Emissions

Despite all of the heated debate surrounding the energy transformation, the ironic fact is that the incremental cost of running the U.S. economy on clean energy as opposed to fossil-fuel energy is very small. The costs of renewable energy for power generation, electric vehicles, electric heating of buildings, and other technologies are already so low that moving from fossil fuels to clean-energy solutions will add very little economic burden. There are various ways to summarize this burden, for example, comparing the annual outlays of a reference energy path to 2050 and a clean-energy path to 2050. On this basis, the annual outlays on the clean energy path are on average 1-2 percent of GDP higher than on the reference path during 2020-2050, a modest incremental outlay. Yet such a calculation overstates the true costs of the transformation since the outlays after 2050 are much lower for the clean-energy economy. To account for this, we can calculate a “levelized” cost of the clean-energy economy versus the fossil-fuel economy. In this alternative calculation, we measure the annual recurrent costs of the energy system plus the annualized capital charges on the installed capital stock (essentially the cost of capital multiplied by the capital stock). We find that as of 2050, the clean-energy economy is only 0.4 percent of GDP more costly per year than the fossil-fuel economy (and lower than that up to 2050). In other words, for less than one-half of 1 percent of GDP, we can shift the energy system to avoid climate disaster. (Another simple way to think about the levelized cost of the energy system is to assume that all energy-system capital outlays are financed with debt. The levelized calculation then compares the annual costs of servicing the energy-sector debt plus annual recurrent costs, measured relative to GDP.)

1.6 Setting Goals and Adjusting Course

All great national efforts require bold visions and plans, and the ability to adjust course along the way. President John F. Kennedy declared in May 1961, "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the Earth." At the time that Kennedy set this goal, the U.S. had put a single astronaut into space for just 15 minutes. In other words, the bold goal was set before many of the key steps were known or knowable. Kennedy had confidence in America's engineering and problem-solving abilities. Indeed, he famously declared in a speech the following year: "We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too."

Of course the New Deal also comes to mind. In the Great Depression, President Franklin Delano Roosevelt led the country at a time of mass unemployment and despair, and boldly devised new strategies to confront the crisis. He called for bold action and learning by doing. As FDR famously declared: "The country needs, and unless I mistake its temper, the country demands bold, persistent experimentation. It is common sense to take a method and try it. If it fails, admit it frankly and try another. But above all, try something."[4]

In the case of reaching zero emissions by 2050, there are pieces of the puzzle that are already solved, but also many that are still to be determined. This task is our generation's moonshot, but thanks to bold work of many pioneers in recent years, we have much greater knowledge of how we can reach our goals than the American people had in 1961 regarding the moonshot. We must set the goal for mid-century, embark boldly on what we know, and prepare in the spirit of FDR to experiment, learn and adjust course along the way. As demonstrated by this plan, many of the technological solutions are understood but lack the institutional coordination, political support, and market incentives to scale.

We can make three generalizations. First, the most straightforward CO_2 reductions will be achieved in power generation, followed by transport and buildings, with the greatest uncertainties remaining in parts of industry. Second, all sectors face a rising marginal cost of emissions reduction. A substantial proportion of current emissions in each sector can be abated at a low cost (or even at a saving compared with the current situation), but getting the remaining emissions down becomes increasingly costly as we move towards zero emissions. Third, the costs associated with many low-carbon technologies are declining over time, and are likely to continue to decline. As a result, many actions that seem more costly now are likely to become less costly in the future. Fourth, the solutions required to put us on the path to decarbonization by mid-century are fairly well understood throughout the next decade and then diverge in the following decades depending on innovation breakthroughs and unknown market behaviors. This means that there are some clear "no-regrets" steps that we can take in this decade and then expect to learn about the preferred pathways for later steps as our knowledge progresses.

A brief summary is the following. Decarbonizing the power sector (electricity generation and distribution) will be accomplished mainly by shifting power generation from fossil-fuel primary sources to renewable energy sources, notably solar and wind power. The costs of renewable energy, even with storage, have fallen sharply, and are at grid-parity with fossil-fuel-based power in certain contexts.

The shift in energy sources from coal and natural gas to wind and solar power can be achieved economically with high confidence. Nonetheless, there are complex and well-known issues of managing the power grid with a high penetration of renewable energy (including storage of intermittent renewable energy and dispatchability of power during peak loads). Because of these complexities it may even be economical as part of a zero-net emission strategy to retain a small capacity in gas-fired power generation. In short, low-cost emission reduction of 80 percent of power generation is in clear sight, with future learning and technological improvements needed for the remaining 20 percent.

In the case of transport, we are well positioned for a shift from internal combustion engines (ICE) to electric vehicles (EV) for light-duty vehicles, with automotive supply chains in place and plans to roll out an expanding suite of EV models. By the late 2030s, most or all new light-duty vehicles sold must be zero-emission vehicles in order to meet the 2050 timeline. While the auto industry is well prepared to transition from ICEs to EVs, it will involve a major overhaul, with some companies and countries further ahead. The financial markets are embracing this transformation, with EV-leader Tesla the highest-valued automobile manufacturer in the world today, ahead of General Motors, Ford, and Toyota, and a number of EV startups also valued in the billions of dollars, and every major auto company is now rolling out EVs. Of course consumers are also waiting for charging stations and other EV-friendly infrastructure. Incentive pricing will also make a difference, e.g., subsidizing EVs according to the savings on carbon emissions or phasing in taxes of emissions on ICEs, especially as the infrastructure for EVs is expanded.

Electrification of trucking is lagging, but it is now expected that, because of rapidly dropping battery costs, most trucks can also be electrified in the coming decades. California adopted regulations in June 2020 requiring that 75 percent of medium duty trucks and 40 percent of long-haul trucks sold by 2035 must be electric (including plug-in hybrid and hydrogen fuel cell electric vehicles).

More energy-dense fuels, similar to petroleum, are needed for aviation and shipping, as well as some long-haul trucks. These will be the next-generation biofuels and synthetic liquid fuels (e.g., hydrocarbons synthesized from CO_2, and water using renewable energy). Thus, part of the solution to transport will involve the build-up of a new fuel sector based on hydrogen, biofuels, and synthetic fuels.

We note that reining in and even reducing vehicle use is a key part of achieving massive reductions in greenhouse gas emissions via vehicle electrification. First, the energy used to manufacture EVs and batteries is large (roughly 20 percent of total lifetime emissions of today's EVs). Second, the challenge of electrifying vehicles is much easier and less expensive if fewer vehicles are needed (currently vehicle use is increasing). Third, shifting travel to few vehicles and low-carbon modes is key to enhancing accessibility and mobility to mobility-disadvantaged travelers.

In the case of commercial and residential buildings, it will be relatively straightforward to build highly energy-efficient, zero-emission new buildings by shifting from on-site of heating oil and natural gas, to onsite electrification, and by using more advanced strategies for building insulation, heating, and ventilation. Millions of existing buildings that currently rely on fossil-fuel combustion will also be retrofitted or replaced depending on costs and context. Retrofitting buildings, including retrofitting for energy efficiency, will potentially provide hundreds of thousands of jobs per year, given that there are around 140 million housing units and nearly 6 million commercial buildings in the United States.

The largest challenges will come in a few energy-intensive industries, where fossil-fuels are used either as feedstocks (as in petrochemicals) or for process heating (as in metallurgy), or where CO_2 is emitted as part of material transformation (as in cement). These sectors will require sector-by-sector, and even product-by-product solutions. Some parts of industry, such as niches in metals production, can be electrified. Some part of the petrochemical industry will shift from processing petroleum to synthesizing alternative fuels including hydrogen. Some parts of the industry will close down in a post-fossil-fuel era, and one that has shifted away from single-use plastics. Yet across the industrial sector, alternative materials, new fuels (hydrogen or synthetic fuels), and new production processes will be needed. Perhaps half of the CO_2 emissions from industry, or about 10 percent of current total CO_2 emissions , will require innovative solutions from new technologies.

The ZCAP calls for rapid scale-up of investments in the known areas, including renewable energy generation and transmission, electric vehicles, and zero-emission buildings and retrofits. It also calls for a massive increase of public-private efforts to achieve zero emissions by 2050 in the hard sectors, notably heavy trucking, shipping, aviation, and selected industries. For these sectors, we recommend a mix of industrial policies including: public-private partnerships on advanced technologies; border taxes on embedded CO_2 to protect the use of low-emission technologies in the U.S.; public procurement policies to incentivize zero-emission technologies; and gradually rising taxes on CO_2 emission to incentive the shift from fossil fuels to renewable energy sources and green fuels (e.g., hydrogen, and synthetic fuels).

1.6.1 Job Creation and Just Transition

The Zero Carbon Action Plan will create more than 2.5 million net new jobs per year as part of the energy transition. The net job creation is described in detail in Chapter 3. Jobs will be created in installing the new energy systems, in the manufacture of the equipment, and in the investments to raise energy efficiency such as building retrofits. By comparing the investment patterns of the main central scenario and baseline reference scenario, and then using an Input-Output analysis, we can estimate the number of new jobs created net of the jobs that will be lost in the fossil-fuel-related industries. Our estimates take into account the direct job creation in the end-use sectors (such as the manufacture and installation of renewable energy systems) as well as the indirect job creation in the upstream industries that supply intermediate inputs to the end-use sectors.

Public policy at all levels should commit to ensuring that the jobs created through clean energy investments are high-quality in terms of wages, benefits and working conditions.

- Strong labor unions and effective job training programs are both necessary to promote high-quality job opportunities.
- Additional policies are necessary to ensure that women and people of color have equal access to clean energy jobs. Both groups are currently underrepresented in all areas of the U.S. energy sector.

The federal and state governments should enact just transition policies for workers and communities that are currently dependent on the fossil-fuel economy.

- Between 2021 – 2030, about 12,000 workers per year in the coal industry will experience displacement between 2021 – 2030. Between 2031 – 2050, about 34,000 workers in the oil and gas industry will face displacement.
- All displaced workers should receive pension and re-employment guarantees, as well as generous income, retraining and relocation support. The combined overall cost of such a generous program will be modest.
- Fossil-fuel dependent communities should receive major federal and state-level support to reclaim and repurpose land and generate new investment projects, including in a range of clean energy areas.

1.6.2 Federal Financing

Federal financing of the energy transition will involve two main categories of outlays:

- Direct outlays in the budget
- Loan guarantees for outlays by others (e.g., investments by private-sector utilities in clean-power generation and distribution).

Direct outlays by the federal government should include the following:

- Research, development and demonstration programs by the Department of Energy, National Science Foundation, Department of Defense, and others;
- Federal investments in infrastructure, including interstate power transmission, charging stations along the Interstate Highway System and other federal roads, and other related investments;
- Federal outlays for a Just Transition Fund, to cover the needs of workers displaced by the decline of fossil-fuel-related sectors, and of communities adversely impacted by the energy transition;
- Federal procurements of low-carbon vehicles, equipment, and buildings for federal use;
- Federal grants to state governments for retrofitting buildings;
- Federal grants to local communities and farmers for reforestation, soil carbon storage, and other sustainable land use practices.
- Federal outlays to support global funding for low-income countries in mitigating and adapting to climate change.

Federal loan guarantees to accelerate private investments in clean-energy systems should include:

- Federal financing of private and public utilities for investments in zero-carbon power generation and distribution;
- Federal financing to support the sales and leasing of electric vehicles;
- Federal financing to support state and local governments in low-carbon infrastructure investments in state and local buildings, local transport, and zero-emission vehicles.

The specific allocations of federal outlays and loan guarantees according to these categories will depend on the pace by which federal, state, and local programs can be designed and implemented. It would be reasonable to assume incremental direct outlays of at least 1 percent of GDP per year during the fiscal years 2021-2025, and incremental loan guarantees of another 1 percent of GDP per year during the period. This would amount to roughly $500 billion per year in incremental federal financing during 2021-2025, or $2 trillion during the four-year period.

1.7 Recommendations for All Levels of Government

1.7.1 Key Federal Actions in 2021

- Rejoin the Paris Climate Agreement and establish a new and stronger Nationally Determined Contribution for U.S. greenhouse gas emissions – including the goal of net-zero GHG emissions by 2050 and an updated interim goal for 2030.
- Adopt a Zero Carbon Action Plan by legislation committing the nation to net-zero GHG emissions by no later than 2050.
- Require a Presidential report to Congress in January 2022 that provides a detailed roadmap to put the country on the path toward carbon neutrality by 2050.
- Invite the Department of Energy, Environmental Protection Agency, Department of Transportation, and other relevant agencies to translate the Zero Carbon Action Plan into intermediate and sector-specific emissions reduction goals and timelines for power, transport, industry, buildings, land use and materials, and a process for updating such goals.
- Establish a White House Office on Climate Change to coordinate federal agency climate-change activities for both mitigation and adaptation, and to the extent authorized by law, direct the development of plans, establish program metrics, track progress, and otherwise oversee these activities.
- Provide funding for the first four years of the ZCAP at a minimum of $2 trillion and provide long-term mechanisms for adequate future funding, including federal support for state and local actions.
- Enact a national clean energy standard for electricity to reduce emissions compared to the present by at least 60 percent by 2030, 80 percent by 2040, and >95 percent by 2050.
- Accelerate the transition to electric cars, trucks, buses, and other vehicles through the implementation of new vehicle performance standards, expansion of the incentives for zero-emissions vehicle purchases, and investments in electric vehicle charging station infrastructure.
- Establish a mechanism by which states, territories, and tribes specify how they will achieve their specific Zero Carbon Action Plan milestones.
- Make operational through procedural and substantive commitments the principle that environmental and jobs benefits of the energy transition are to be shared equitably in terms of geography, race, gender, and ethnicity – thereby ensuring that disadvantaged communities benefit fully.

- Invest directly in key parts of the national energy system, including inter-state power transmission, public land use for power generation, and supporting infrastructure.
- Launch innovative green financing mechanisms, such as government guarantees for green bonds, tax incentives on utility bonds for renewable energy, direct equity, and funding of state-level green banks.
- Promulgate new Securities and Exchange Commission (SEC) reporting requirements that require disclosure of climate-change-related risks and broader Environmental/Social/Governance impacts.
- Accelerate, intensify, and fully fund research and development for zero-greenhouse-gas emitting technologies, energy efficiency technologies, and carbon removal technologies.
- Clarify the National Environmental Policy Act (NEPA) requirement that all federal action should be undertaken with an eye toward environmental impacts with a directive to each federal agency to exercise its existing powers and duties in a manner that will contribute to the fullest possible extent to the ZCAP agenda and goals.
- Specify a Social Cost of Carbon or shadow cost of carbon to guide policy formulation and regulatory decision-making as well as to serve as the basis for market mechanisms such as clean-energy subsidies, carbon taxes, feed-in tariffs and auctions, and other market-based instruments that will vary by sector and over time.

1.7.2 Key State Actions in 2021

- In line with the National Clean Energy Standard and the associated goal of net-zero emissions by 2050, all states should prepare Renewable Portfolio Standards (RPS) or equivalent Zero Carbon Energy Standards for the goal of zero-carbon power by 2050. Currently 31 states have RPS of which 8 have the goal of 100 percent renewable energy on or before 2050.
- All states should prepare a comprehensive plan for net-zero GHG emissions by 2050 covering transport, buildings, and industry.
- All states should prepare financing strategies to align with new federal funding programs
- States and cities should implement land use policies that promote densification, transit-oriented development, and complete streets.

1.7.3 Key Local Actions in 2021

- Local governments, working in tandem with state and federal agencies, should prepare local plans for net-zero greenhouse emissions by 2050 covering all local sectors.
- Cities and local governments should adopt building codes and practices that encourage or require zero-emission, all-electric buildings so that all new buildings are 100 percent electric and retrofits for existing buildings are actively underway.
- Cities should align incentives and programs for building retrofits with state climate goals and begin efficient retrofit of existing buildings.

References

1. “Inventory Of U.S. Greenhouse Gas Emissions And Sinks | US EPA”. 2020. *US EPA*. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.
2. “Frequently Asked Questions (Faqs) - U.S. Energy Information Administration (EIA)”. 2020. *Eia.Gov*. https://www.eia.gov/tools/faqs/faq.php?id=75&t=11.
3. “Frequently Asked Questions (Faqs) - U.S. Energy Information Administration (EIA)”. 2020. *Eia.Gov*. https://www.eia.gov/tools/faqs/faq.php?id=75&t=11.
4. “Remembering FDR’s Commencement Speech At Oglethorpe - *The Source*”. 2020. The Source. https://source.oglethorpe.edu/2012/05/22/remembering-fdrs-commencement-speech-at-oglethorpe/.

2. TECHNOLOGY PATHWAYS TO NET-ZERO

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Ryan Jones, Evolved Energy Research
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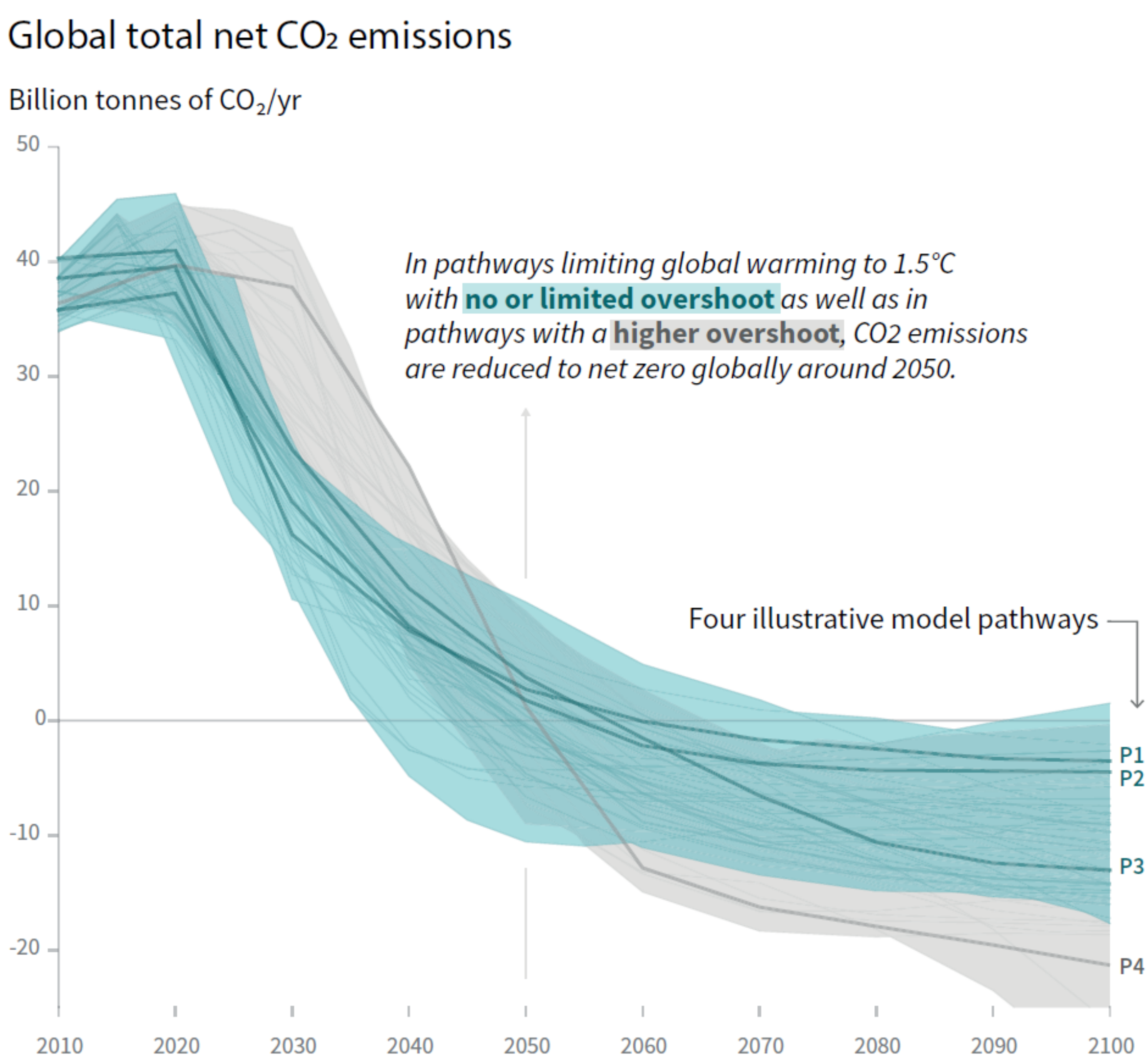
2.1 Introduction

The Paris Climate Agreement calls for "holding the increase in the global average temperature to well below 2°C above pre-industrial levels." A recent IPCC report has catalyzed a new consensus that even a 2°C increase is too high and that warming should be kept below 1.5°C to avoid dangerous climate change. This will require reaching zero net emissions of CO_2 globally by mid-century (Figure 2.1a).[1] Some scientists further assert that a return to 1°C by the end of the century will be necessary to avoid irreversible changes to the climate system, requiring not only decarbonization of the economy but negative net emissions that draw CO_2 out the atmosphere (Figure 2.1b).[2] Following the scientific evidence, jurisdictions around the world have begun adopting the goal of reaching carbon neutrality, or "net-zero," by mid-century.



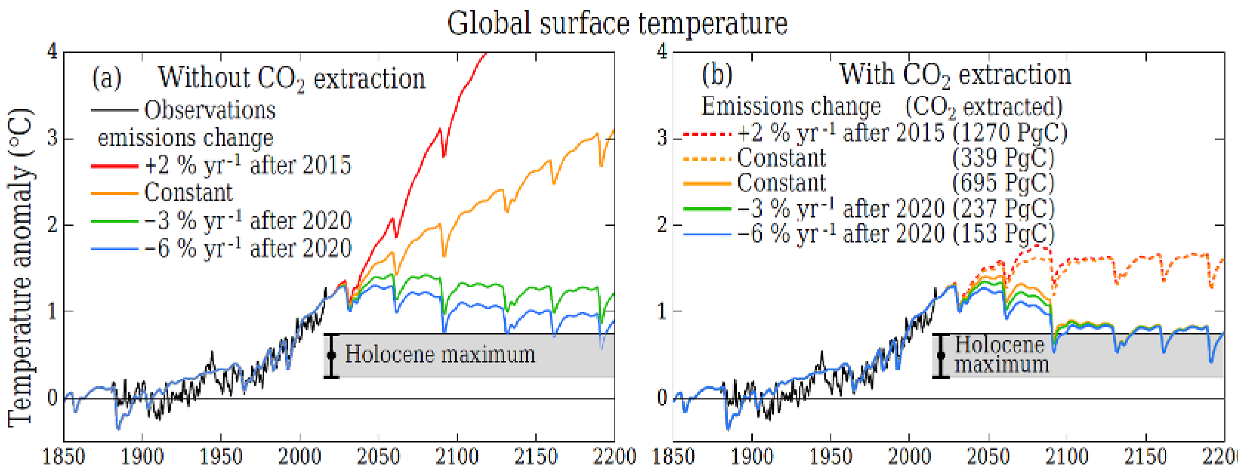


Figure 2.1. (a) Global CO_2 emissions trajectories consistent with limiting warming to 1.5°C or less. (IPCC, 2018) (b) Trajectories for returning warming to less than 1°C by 2100 (Hansen et. al, 2017).

Below we describe technology pathways by which the United States can achieve carbon neutrality by 2050. The descriptions are based on an in-depth modeling study of the decarbonization of the U.S. energy system currently under review at a scientific journal, which will be attached to this report as a technical reference upon publication. We draw here on the main results of that study. This chapter addresses technical and cost aspects of reaching carbon neutrality, leaving policy and societal aspects to other chapters.

We modeled the infrastructure changes required in each year from 2020 to 2050 to keep net CO_2 emissions decreasing in a straight line path from the current level of 5.2 billion metric tons to zero at mid-century (Figure 2.2). This is a four percent per year rate of reduction in net emissions, and a reduction in cumulative emissions of more than 60 billion metric tons of CO_2 compared to business-as-usual.

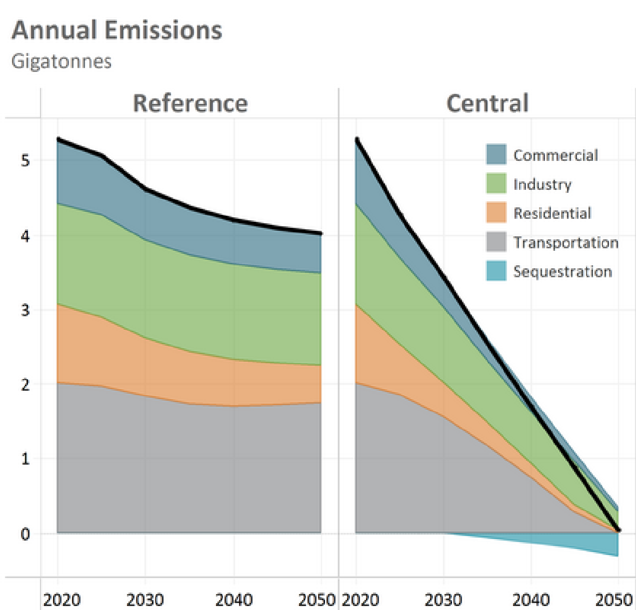


Figure 2.2. Emissions trajectories for the *reference scenario* and carbon neutral *central scenario*. In the latter, residual gross emissions of 316 MMT (million metric tons) CO_2 in 2050 are offset by sequestration.

This analysis focuses on how to eliminate CO_2 from the use of fossil fuel for energy and industrial feedstocks, which constitutes more than 80 percent of current U.S. GHG emissions.[3] The scope of the analysis does not include negative CO2 emissions from the "land carbon sink" or the emissions of non-CO_2 GHGs such as methane and nitrous oxide. Combined, these currently have net emissions of about +500 MMT CO_2e. Mitigation in these areas, from a combination of increasing the land sink and reducing non-CO_2 GHG emissions, will be needed for total U.S. GHG emissions to reach net-zero or below, even if the energy system by itself is carbon neutral.

We developed six scenarios for meeting the net-zero target, following the approach in our previous work, *Pathways to Deep Decarbonization in the United States* (2014) and *Policy Implications of Deep Decarbonization in the United States* (2015).[4] A baseline reference scenario is based on the Department of Energy's long-term forecast, the Annual Energy Outlook (AEO). For comparability, decarbonized scenarios used the same AEO assumptions for population, GDP, and industrial production, and were required to meet the same demand for energy services as the reference case. Only commercial or near-commercial technologies were assumed to be available options for reaching the emissions target.

Among the carbon-neutral scenarios, the *central scenario* was the one that reached zero net emissions in 2050 at the lowest net cost. Other carbon-neutral scenarios were developed to test the robustness of the *central scenario* against assumptions about future costs, and limits on what decarbonization options were available. The constraints include limits on land use for building electricity supply infrastructure; limits on biomass use; limits on the use of any non-renewable form of primary energy, including fossil fuel and nuclear power; and delayed adoption by consumers of critical low-carbon technologies such as EVs and heat pumps. One scenario requires going well beyond carbon neutrality to meet net negative emissions of -500 Mt CO_2 in 2050. Finally, one scenario explores the effects of a high level of behavior-based conservation (but for this reason is not comparable to the reference scenario in terms of energy services provided).

The scenarios were modeled using two sophisticated analysis tools, EnergyPATHWAYS (EP) and RIO, which provide a high level of detail in sector (more than 100 subsectors), time (annual turnover of equipment stocks plus an hourly electricity dispatch), and geography (14 different regions of the U.S., modeled separately). Demand for energy was developed bottom-up in EP and fed into RIO, which then developed the least-cost supply of energy to satisfy this demand while meeting emissions, policy, and reliability constraints. These modeling tools allowed us to rigorously analyze technical feasibility and the cost of supplying and using energy.

2.2 Pathways to Carbon Neutrality

There is no doubt that moving from an economy based primarily on fossil fuel use to one based primarily on decarbonized energy sources within thirty years involves a monumental transformation. Yet, as our analysis shows, from a technical and cost standpoint, carbon neutrality is an achievable outcome if the right policies are in place.

The sections below describe:

- the main strategies of decarbonization ("the four pillars")
- the energy system transition
- the pace and scale of infrastructure transformation needed
- the cost and reliability of a high-renewables electricity system
- the production of low-carbon fuels for use in hard-to-electrify applications in industry, aviation, and freight transport
- the integration of carbon capture, utilization, and storage (CCUS) within the energy system
- the effects of resource constraints and societal tradeoffs
- priority actions for the next decade

2.2.1 Four Pillars of Deep Decarbonization

The transition from a high-carbon to a low-carbon energy system in general is based on three main strategies: (1) using energy more efficiently (2) decarbonizing electricity; and (3) switching from fuel combustion in end uses to electricity.[5] Reaching net-zero or net-negative emissions requires an additional strategy: (4) carbon capture.[i] Mid-century benchmarks for each of the strategies are shown in Figure 2.3 for the central scenario. Carbon intensity of electricity was reduced by 95 percent. The share of electricity in meeting final energy demand tripled, from 20 percent to 60 percent, including fuels derived from electricity. Per capita energy use was reduced 40 percent, and energy intensity of GDP reduced by two-thirds, as a result of increased efficiency. Carbon capture reached 800 Mt CO_2 per year, up from negligible levels today. The emissions reduction impacts of these strategies are multiplicative, so they must be simultaneously applied to achieve their full potential (for example, electrification is much less effective in reducing emissions if electricity still has a high carbon intensity). Thus, successful implementation requires economy-wide coordination of the four foundational strategies across all sectors. Note that these strategies are the common elements across all scenarios that reach net-zero; additional measures may be required.

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i *Carbon capture* is not identical to carbon capture and storage (CCS), in which the captured carbon is geologically sequestered. Much of the captured carbon in these scenarios is not sequestered but utilized in the production of fuels and feedstocks. Even the 100% primary renewable energy pathway requires captured carbon for producing renewable fuels, but there is no sequestration in this case. See Fig. 2.15.

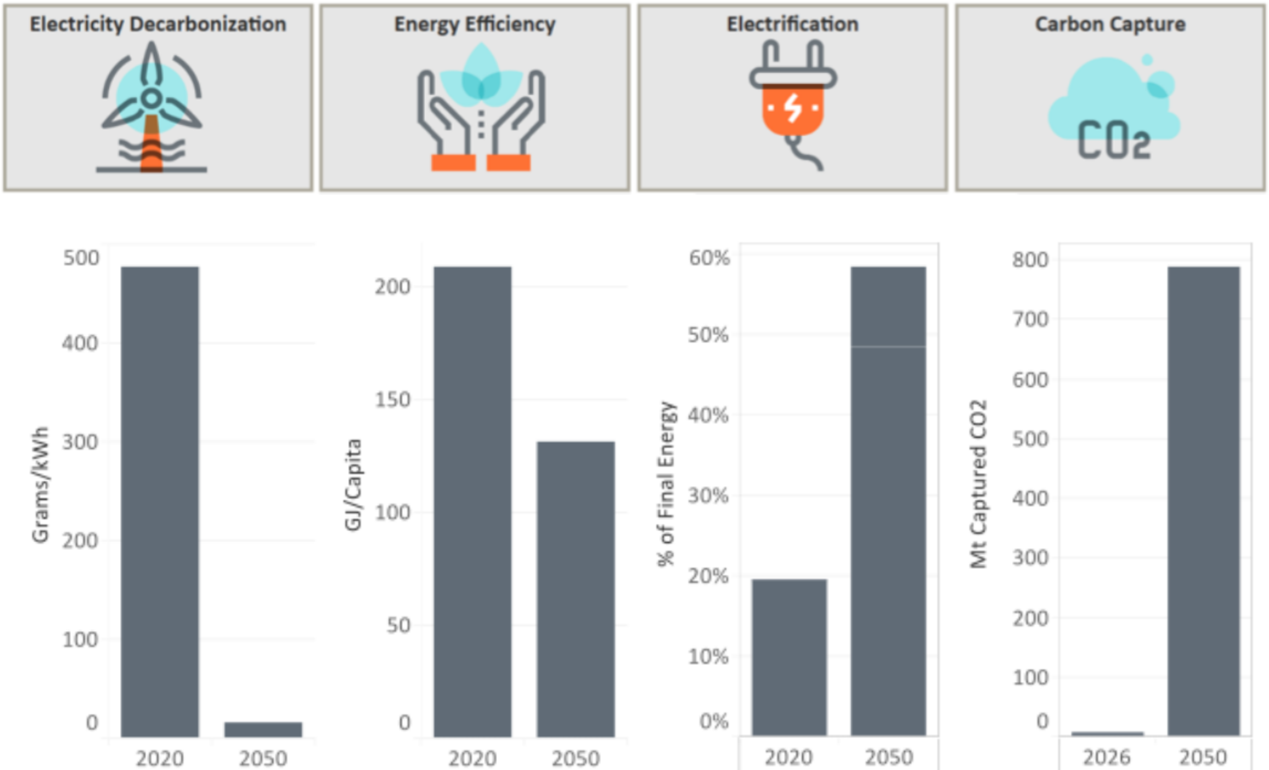

Figure 2.3. Four main strategies of carbon neutrality, comparing current values to 2050 *central scenario*.

2.2.2 The Energy Transition

The "Sankey diagrams" in Figure 2.4 illustrate the energy system transformation resulting from applying the strategies described above. The diagrams show the forms of primary energy used in the U.S. economy on the left side of the figure, with energy conversion processes in the middle, and final energy consumption on the right side. The upper diagram shows the current system in 2020 and the lower diagram shows the 2050 *central scenario*. Illustrating the importance of greater energy efficiency, in the *central scenario* both primary energy supply and final energy consumption are substantially lower (30 percent and 20 percent lower, respectively) than today's level despite 30 years of rising energy service demand that comes with population and GDP growth.

The shares of fossil fuel in the primary energy supply decrease dramatically from today's level, replaced mainly by wind, solar, and biomass. Coal, which has a very high carbon content per unit of energy it provides, is eliminated entirely. Natural gas (~75 percent reduction) and petroleum (~90 percent reduction) are reduced to niche roles including industrial feedstocks, certain forms of transportation, and a limited amount of natural gas power generation needed to maintain reliability in an electricity system composed primarily of wind and solar generation. Electricity increases to meet 50 percent of end-used demand, with zero-carbon drop-in fuels providing most of the rest. Conversion processes that play a minimal role today – advanced biofuel refining, and the production of hydrogen and synthetic fuels from electricity – become key components of a carbon-neutral energy system. Not shown in the figure, CO_2 emissions from the small remaining fossil fuel use in energy and industry are captured directly or offset using CCUS.

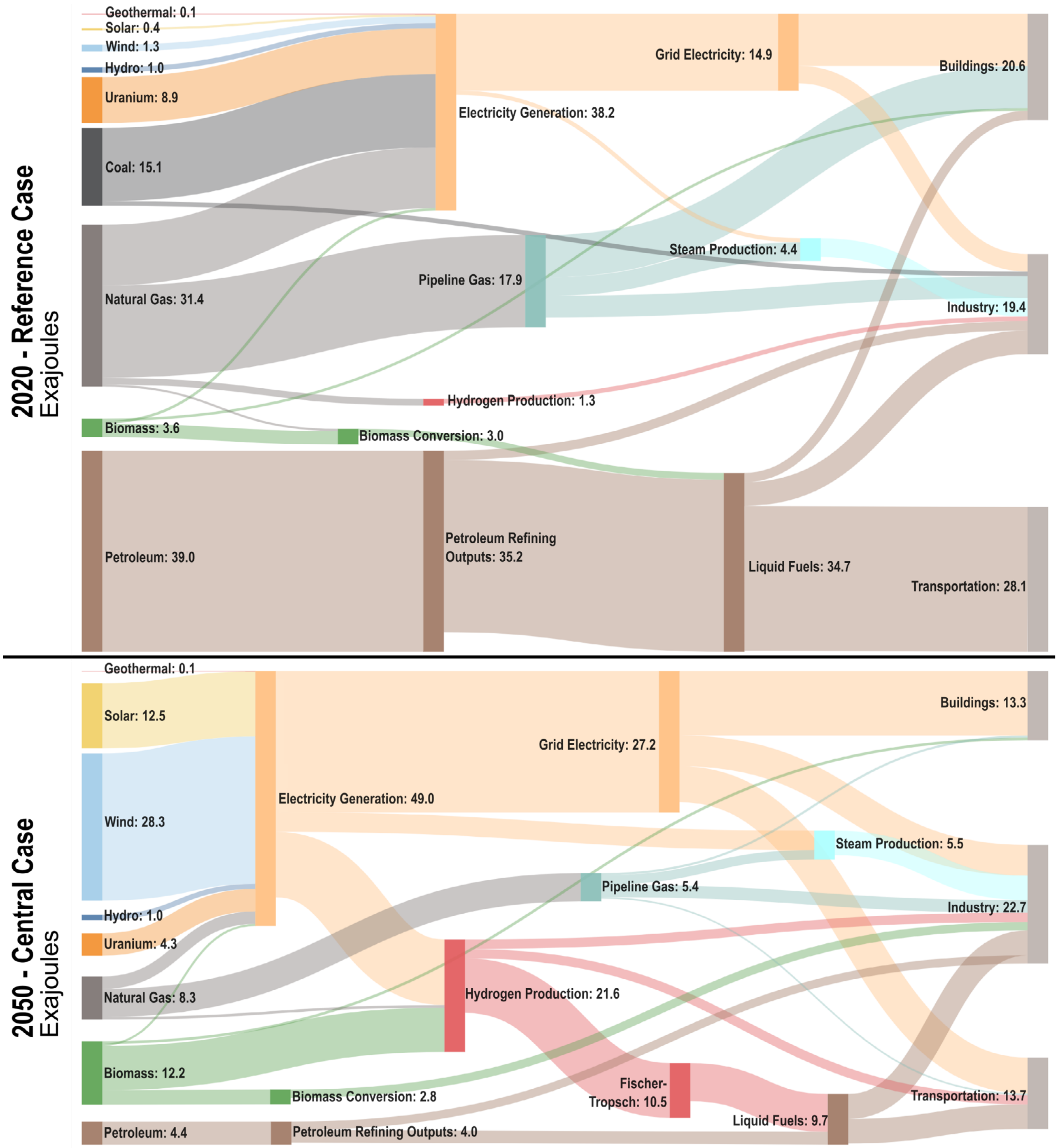

Figure 2.4. Sankey diagrams for the U.S. energy system: (a) current system in 2020 (b) *central scenario* in 2050.

2.2.3 Transforming the Infrastructure

Decarbonizing the U.S. energy system requires an infrastructure transition over the next three decades that implements the four pillars (Figure 2.3). This transition is methodical in pace, following the natural turnover of infrastructure stocks, but thoroughly changes the underlying technologies. At the end of its normal economic lifetime, high-emitting, low-efficiency, and fossil-fuel consuming infrastructure is replaced by low-emitting, high-efficiency, and electricity-consuming infrastructure; only coal and certain petroleum-burning power plants need to be retired early to stay on the net-zero emissions path. Figure 2.5 and Figure 2.6 illustrate the infrastructure transition in three sectors that comprise about two-thirds of current U.S. CO_2 emissions: electric power generation, on-road vehicles, and space and water heating in buildings.

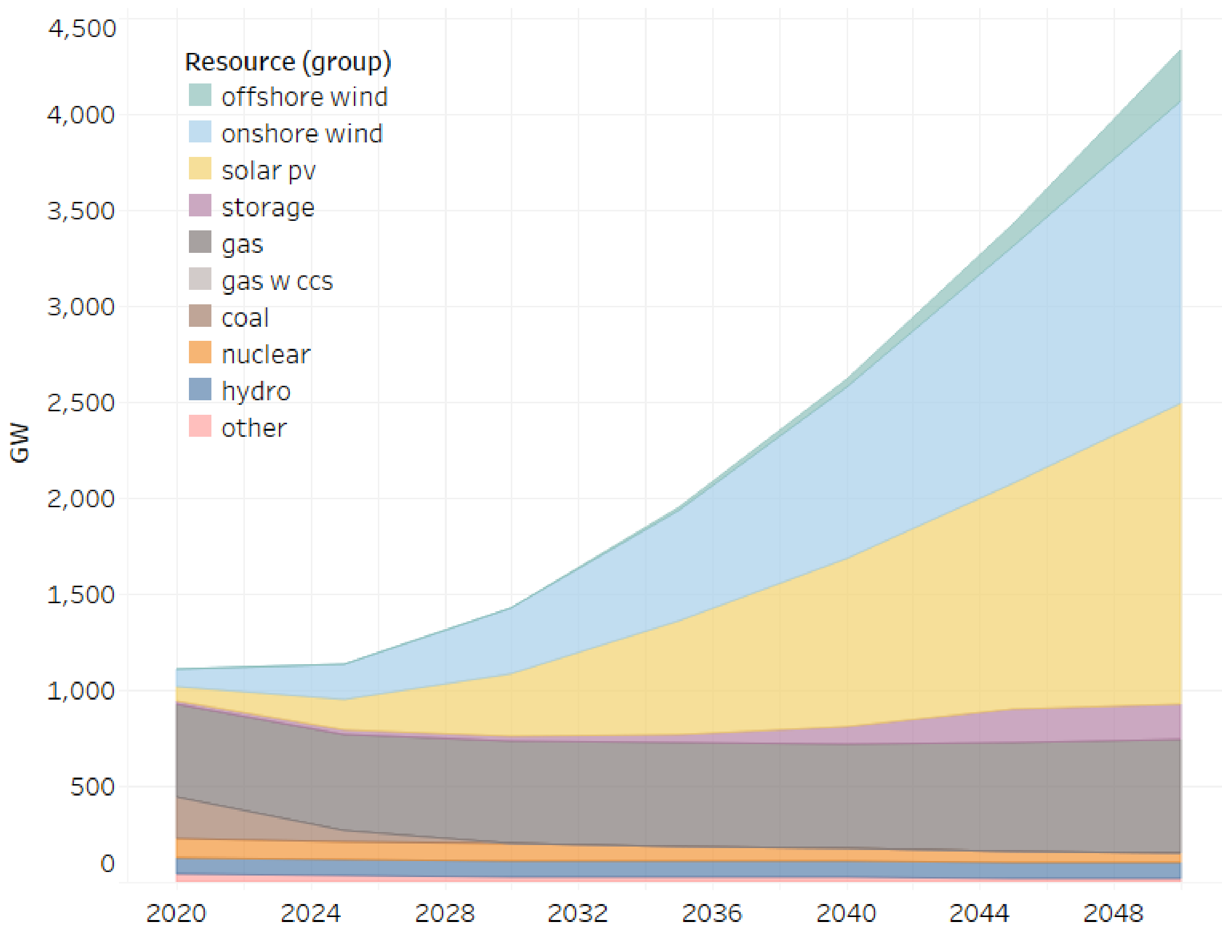

Figure 2.5 Electric generation capacity, central scenario.

Electric generating capacity increases dramatically as required to simultaneously decarbonize the electricity supply and meet growing demand from newly electrified end uses. By 2050, generation capacity increases by 3000 GW, with virtually all of the net increase coming from wind and solar, an average rate of about 100 GW per year. Meanwhile, coal generating capacity is fully retired by 2030.

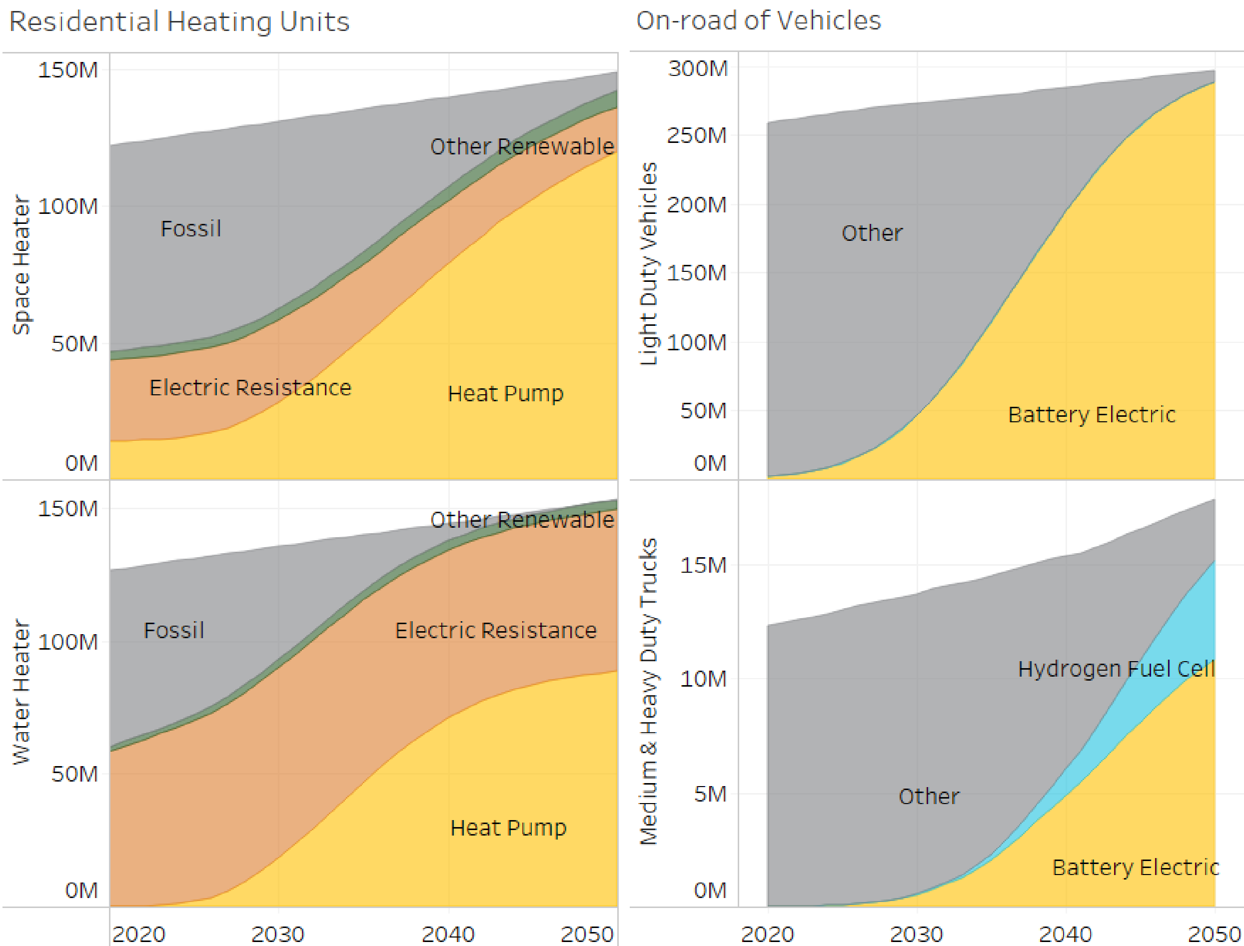

Figure 2.6 Infrastructure transition on the demand side, *central scenario*. (Top left) Residential space heating. (Bottom left) Residential water heating. (Top right) Cars and light trucks. (Bottom right) Medium and heavy duty trucks.

Efficiency and electrification produce similar changes in demand-side infrastructure that complement the decarbonization of energy supplies. By 2050, more than 260 million out of 280 million cars and light trucks are battery electric vehicles, almost entirely replacing internal combustion vehicles with more efficient electric alternatives. Eighty percent of medium- and heavy-duty trucks are battery-electric or hydrogen-powered vehicles. In residential buildings, electric heat pumps constitute 110 million out of 140 million space heating units, and 80 million out of 150 million water heating units, with electric resistance heaters comprising most of the remainder. This enables residential buildings to heat with the lowest-cost source of decarbonized energy, which is renewables-based electricity.

2.2.4 Low-Carbon Electricity

There is no longer uncertainty regarding what is the lowest cost form of decarbonized electricity supply: renewables, nuclear, or fossil generation with CCS. Ongoing declines in the cost of wind and solar have made renewable energy not only the least-cost form of electricity generation in a decarbonized system, but in many cases the least-cost form of decarbonized primary energy supply economy-wide. As a result, carbon-neutral electricity systems are organized around very high levels of renewable generation, even when that requires investment in complementary technologies and new operational strategies.

In the *central scenario*, the optimal electricity generation mix is 90 percent wind and solar. Reliable operation of such a system requires an approach to balancing supply and demand in real-time that is different from conventional power systems, with a suite of solutions that are deployed based on the time scale of the imbalance (e.g., hours, days, weeks) and whether there is an energy deficit or an energy surplus. The most cost-effective approach to balancing combines thermal generation to provide reliable capacity during times of deficit with transmission, energy storage, and flexible loads that move surplus energy in time or space, plus curtailment.

Figure 2.7 illustrates the problem of balancing in a high renewables system for the specific case of a northeastern state that relies primarily on wind for decarbonized electricity. On a high wind day, wind and solar production exceed load in most hours of the day, with the over-generation being partly exported to other states, partly converted to hydrogen by means of electrolysis, partly used to heat water in industrial boilers, and partly shifted in time with storage and flexible loads. Thermal generation is not required. On a low-wind day, by contrast, to meet load a combination of high levels of thermal generation and high transmission imports is required. In general, extended periods of low renewables output combined with high loads determine the amount of thermal capacity required for reliably meeting demand.

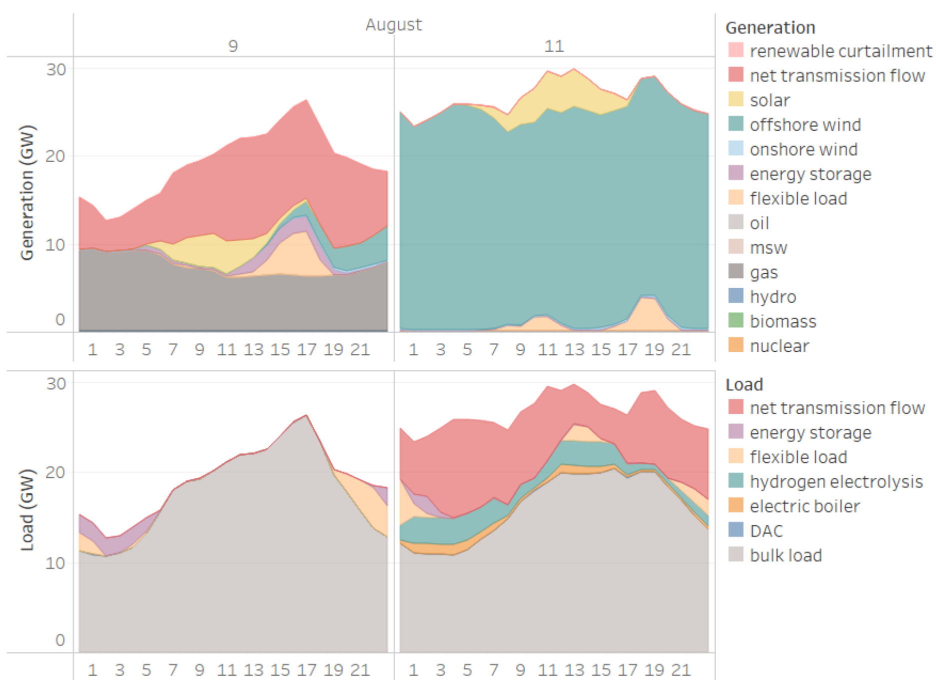

Figure 2.7 Generation and load for a northeastern state in 2050 for (L) a low wind day, and (R) a high wind day.

The form of thermal capacity that pairs best with a high renewables system is gas-fired capacity without carbon capture, due to its low capital cost. Figure 2.8 shows dispatchable capacity in 2020 and 2050. The gas fleet in the *central scenario* is about 600 GW in 2050, somewhat larger than the roughly 500 GW of gas capacity in the U.S. today. This provides the bulk of the dispatchable capacity required by the system in 2050. These plants, while essential for reliability, are operated less frequently as the share of renewable generation grows, reaching an average capacity factor of about 10 percent in 2050. Because there are relatively few operating hours in which to recover fixed costs, plants with low capital cost are preferred. The high capital cost of nuclear plants and gas plants with CCS makes them uneconomic given such low utilization rates. At the same time, nuclear and gas with CCS are not competitive with wind and solar for supplying energy in bulk. To remain within carbon constraints, gas plants without carbon capture either burn natural gas and those emissions are offset elsewhere in the energy system, or they burn zero-carbon fuels such as renewable gas produced from biomass or electricity.

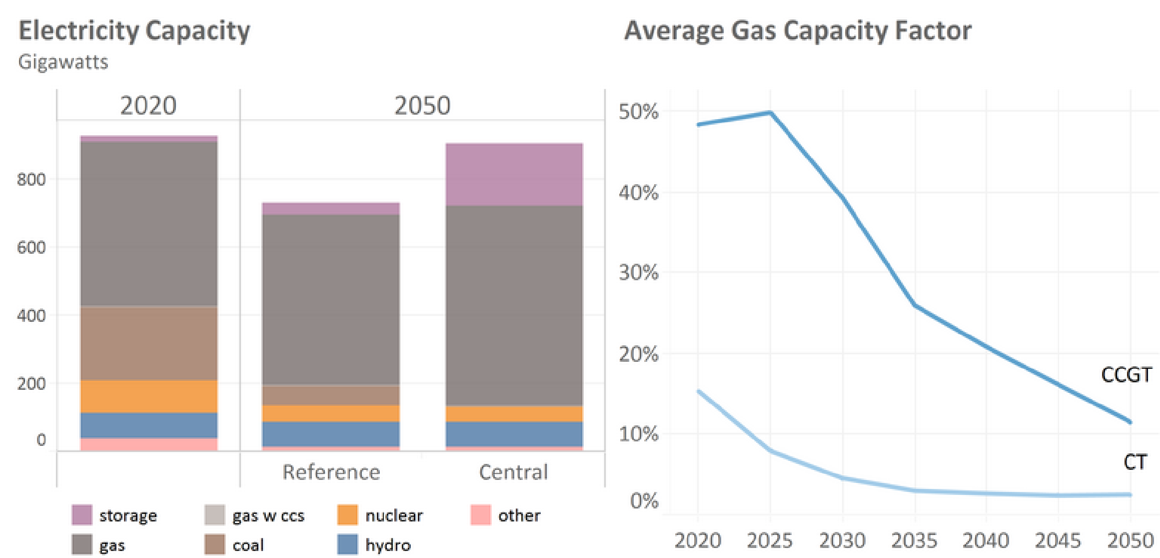

Figure 2.8 The role of gas-fired capacity in a reliable net-zero electricity system.

Non-thermal balancing resources are employed to address the oversupply of renewable energy. Some curtailment of wind and solar is economic, but below 5 percent in all scenarios. Batteries economically time-shift renewable generation from surplus to deficit periods over the period of a day; battery capacity in the *central scenario* is about 200 GW with an average duration of about 7 hours. However, batteries are not economic for balancing on longer time scales and cannot replace thermal generation for reliability. Flexible consumer loads (e.g., EV charging and water heating) are similarly valuable for short-term balancing but not over longer durations. Large, industrial-scale flexible loads, such as electrolysis and dual-fuel industrial boilers, can address energy surpluses lasting periods of days to months, producing useful products from generation that would otherwise be curtailed and support integration of very high levels of renewables.

Transmission enables high renewables electricity systems to take advantage of geographically diverse load and generation profiles. In the *central scenario,* high voltage transmission capacity between different regions increases from 80 GW to 200 GW, a 150 percent increase. Most transmission is built to connect wind-rich and wind-poor regions, generally from the wind belt in the center of the U.S. toward the Southeast and Mid-Atlantic.

2.2.5 Low-Carbon Fuels

Based on current technology forecasts, electricity can meet about 50 percent of final energy demand in a carbon-neutral system. The remaining 50 percent must be met with fuels, especially where the weight or volume of batteries makes electrification difficult, as in aviation; where high process temperatures are needed; in thermal power generation; and in industrial processes and feedstocks that require hydrocarbons. Fuels for these essential applications are the source of residual CO_2 in a system otherwise powered by decarbonized electricity, so different strategies are employed to minimize the need for fuels and to decarbonize fuel supply. Figure 2.9 shows the effect of energy efficiency, including the energy efficiency that results from electrification in the case of electric vehicles and heat pumps. *In the central scenario*, primary energy requirements are reduced by 30 percent from today's level in 2050. Fuel use of all kinds is reduced by 60 percent, with fossil fuels being reduced by 85 percent.

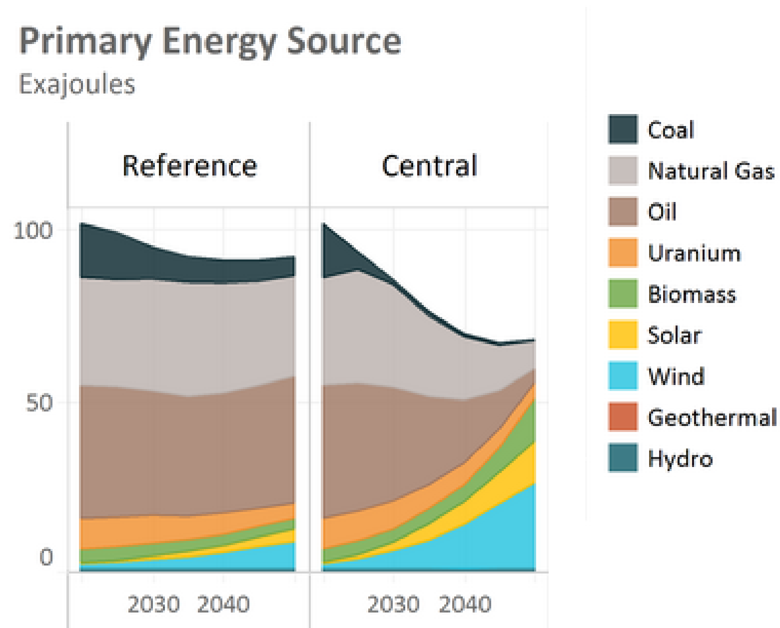

Figure 2.9. Primary energy sources for the *reference* and *central scenarios*.

The remaining fuel demand is met with a combination of "drop-in" carbon-neutral fuels that directly replace fossil fuels without significant changes in the end-use technology (e.g., jet engines), or fuels whose CO_2 is captured post-combustion or offset by negative emissions elsewhere in the energy system, for example by sequestering carbon released in biofuel refining. There are three primary energy sources for carbon-neutral fuels:

- **Biomass.** Biomass is refined using pyrolysis and the Fischer-Tropsch process to synthesize a variety of necessary fuel types; conventional corn ethanol disappears as internal combustion engines are replaced by EVs.
- **Wind and solar electricity.** Hydrogen is produced by electrolysis, and used either directly in end use technologies or combined with carbon in the synthesis of hydrocarbon fuels.
- **Fossil fuels**, especially natural gas, are either used directly in limited quantities with carbon capture or offsetting, or in the production of carbon-neutral fuels, starting with the production of hydrogen by steam methane reforming (SMR) with carbon capture.

Many different types of fuels are needed – fuel for jet engines, diesel engines, steam production, pipeline gas, etc. – and the blends of each will depend on economic and resource considerations, such as relative prices and ecological limits. The fuel blends for the *central scenario* are shown in Figure 2.10.

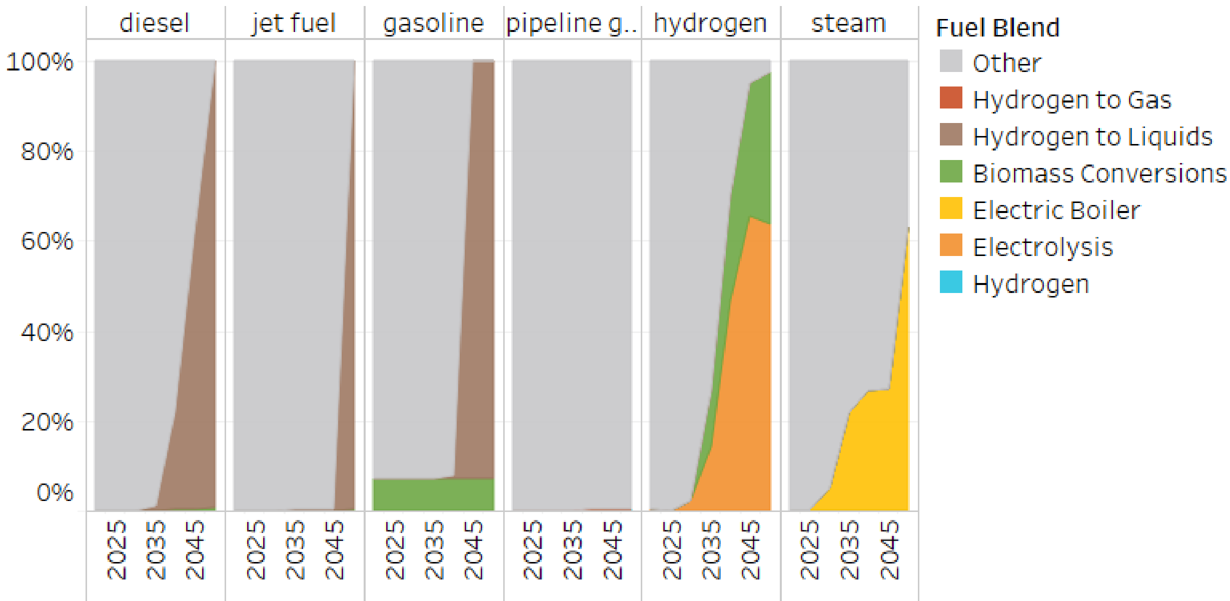

Figure 2.10. Fuel blends for diesel, jet fuel, gasoline, pipeline gas, hydrogen, and steam today and in 2050 *central scenario.*

All three fuel sources have potential resource constraints. For biomass, there is the question of how much biomass feedstock can be produced sustainably. In this analysis, the maximum amount is the resource potential identified in the DOE *Billion Ton Study Update*, which in energy terms is about 21 EJ.[6] In the *central scenario*, about 60 percent of the resource potential is used. For electricity-derived fuels, there is the question of how much land is available for renewable generation and transmission. Some fuel production can be done with overgeneration, but the greater the quantity of electricity-derived fuels required, the more dedicated generation and land is required. For the CCS needed to accompany fossil fuel use, there is a limit on the rate that CO_2 can be injected into geologic formations for sequestration. For this study, an upper limit of 2 Gt CO_2/year was assumed. In the *central scenario*, about 0.3 Gt CO_2/year was sequestered in 2050, and in all cases the maximum rate was less than half of the injection limit.

In addition to these resource limits, there are also cost considerations. Fuels from all these sources have increasing costs with volume, depending on primary energy cost, transport cost, end-use efficiency, and carbon content. Among fossil fuels, natural gas is the last fossil fuel to be replaced in a cost-minimizing system because it is the least expensive on an energy basis and has the lowest carbon content. The way carbon is captured depends on the end use. Post-combustion "end-of-pipe" capture is cost-effective for concentrated, high volume CO_2 streams from sources like cement, while offsetting is used for small and widely dispersed sources for which it is not economic to build carbon capture. Offsetting is accomplished by bioenergy with CCS (BECCS) or direct air capture (DAC). The level of residual fossil fuel use depends in part on relative prices. With high fossil fuel prices, fossil fuels tend to be replaced by drop-in carbon-neutral alternatives; with low fossil fuel prices, emissions offsetting is more cost-effective for some applications.

2.3 Robust Findings Across Scenarios

2.3.1 Alternative Pathways

The *central scenario* is the least-cost carbon-neutral system, based on our assumptions about future costs, with the least constraints on decarbonization options. In the future, resource limitations or societal preferences may place constraints on economically preferred options that require other, higher-cost alternatives to be used. Accordingly, we developed alternative scenarios to explore the impact of potential constraints on technology choices and costs:

Limited land: Biomass supply was limited to 50 percent of the technical potential, and the land area available for onshore wind and utility-scale solar was limited to 50 percent of *central scenario* value. The effect of these constraints was to improve the competitiveness of nuclear, offshore wind, and CCS power generation, plus leading to higher residual fossil fuel use which in turn increased carbon sequestration.

Delayed electrification: Consumer adoption of electrified end-use technologies such as electric vehicles and heat pumps was assumed to be delayed by 15 years relative to the *central scenario*. The effect of this constraint was to require more electricity-derived fuels, biofuels, fossil fuels, and carbon sequestration. It also required more electricity generation to meet the demand for electric fuels, and with that higher land use.

100 percent renewable primary energy: This scenario was constrained to have no remaining fossil fuel or nuclear energy by 2050, including for feedstocks. The effect of this constraint was to require more electricity, solar and wind generating capacity, electricity-derived fuels, biofuels, and land. Gas generation for electric reliability used synthetic carbon-neutral fuels. Perhaps surprisingly, carbon capture technology was still needed in order to provide the carbon for synthesizing hydrocarbon fuels and feedstocks.

Low demand: To explore the effects of aggressive energy conservation, energy service demand in key end-uses was reduced 20-40 percent below *reference scenario* levels. The effect of this constraint was to require less primary and final energy, infrastructure, and land.

Net negative: This scenario was the least-cost cost case that produced net negative emissions of -500 Mt CO_2 in 2050, consistent with a 350 ppm or 1°C global trajectory in 2100 if continued at that level. The result of this constraint was to require greater use of negative emissions technologies and higher carbon sequestration. Perhaps surprisingly, net-negative is a feasible scenario with a relatively small increase in incremental cost, but is more difficult to achieve than net-zero if decarbonization options are limited.

Since future costs may diverge from those assumed in the *central scenario*, we also assessed the sensitivity of our results to changes in the main drivers of those costs, namely renewable technology costs and oil prices.

2.3.2 Cost of Carbon Neutrality

The cost of reaching carbon neutrality in the *central scenario* was $145 billion in 2050, representing 0.4 percent of forecast GDP for that year (Figure 2.11). This is the net energy system cost, which is the difference between the costs of supplying and using energy in the *central scenario* versus that for the *reference scenario*, including fuels used for industrial processes and feedstocks. The net cost is a result of a large swing in gross costs, with roughly $950 billion in spending on efficient and low-carbon technologies such as wind generators and EVs, which enable savings of $800 billion in fossil fuel costs. Put another way, deep decarbonization represents a shift from an energy system that is dominated by variable costs to a system with much higher capital expenditures and much lower variable costs. At 0.4 percent of 2050 GDP, the incremental cost of decarbonization for the *central scenario* is a remarkable decline, given that a few years ago, analysts were calculating a net cost of about 2 percent of GDP for less aggressive emission reductions (80 percent by 2050). Ongoing cost decreases in solar, wind, and EV batteries have driven these lower cost estimates. Sensitivity analysis produced a range of 0.2 percent to 1.2 percent of GDP. Note that our analysis only evaluated the energy costs of the transition to carbon neutrality and did not count the potentially very large economic benefits of avoiding climate change and other energy-related environmental and public health impacts.[ii]

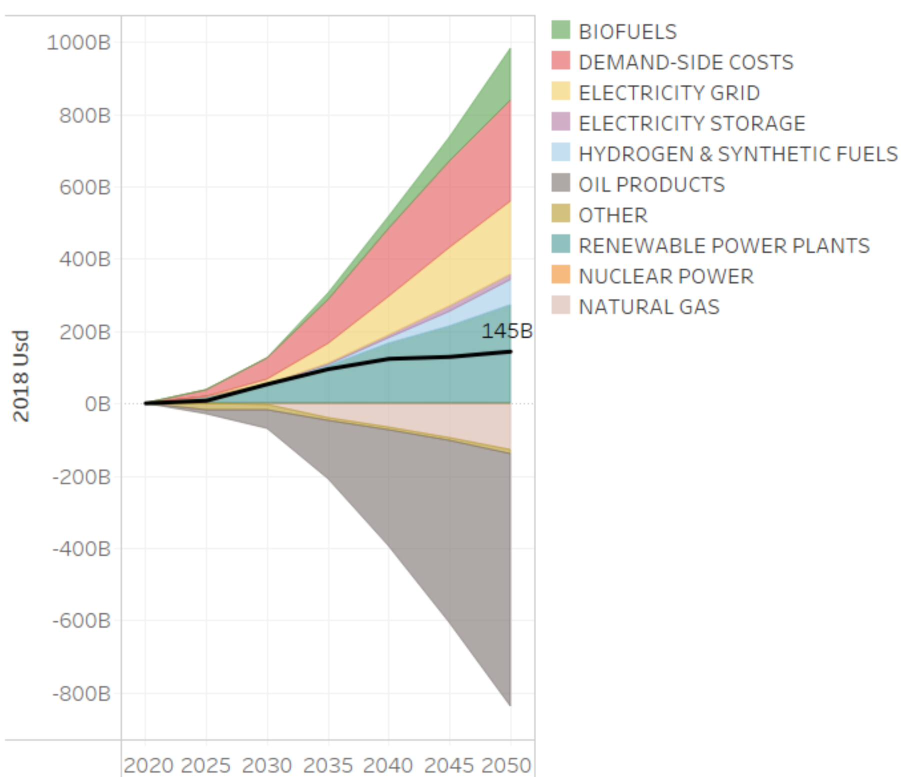

Figure 2.11 Net energy system cost of *central scenario*, 2020-2050 in 2018 USD. The black line shows net cost, and the colored bars show the incremental costs of the *central scenario* relative to the *reference scenario*.

ii See, for example, Risky Business: The Economic Risks of Climate Change in the United States.

For the alternative scenarios, limiting decarbonization options resulted in higher costs than the central scenario. The range of net cost across scenarios was 0.4 percent to 0.9 percent of GDP in 2050, with the 100 percent renewable primary energy case being the highest at 0.9 percent. The net negative case, with a considerably higher emissions reduction ambition, was 0.6 percent.

To put these costs in context, historical U.S. spending on energy has ranged from six percent to 13 percent of GDP during the half-century from 1970 to the present (Figure 2.12). In the reference scenario, this is projected to decline to 3.8 percent in 2050. In the carbon-neutral central scenario, energy spending is also predicted to decline over time, but not as quickly as the reference scenario, reaching 4.2 percent of GDP in 2050. Thus the results are compelling; a decarbonized energy system based on our central scenario will only cost 0.4 percent more than the reference scenario.

In terms of financing decarbonization, incremental capital investment in the central scenario averaged $600 billion per year. This is about ten percent of current U.S. total capital investment of $6 trillion per year in all sectors, a relatively small share that indicates that finance per se is unlikely to present a barrier if policies to limit risk and allow cost recovery are in place. The more likely barriers are political-economic, from opposition to the shift in money flows within the energy economy away from fossil fuels and toward technology, and the effects on fossil fuel extraction industries and the communities that currently depend on them.

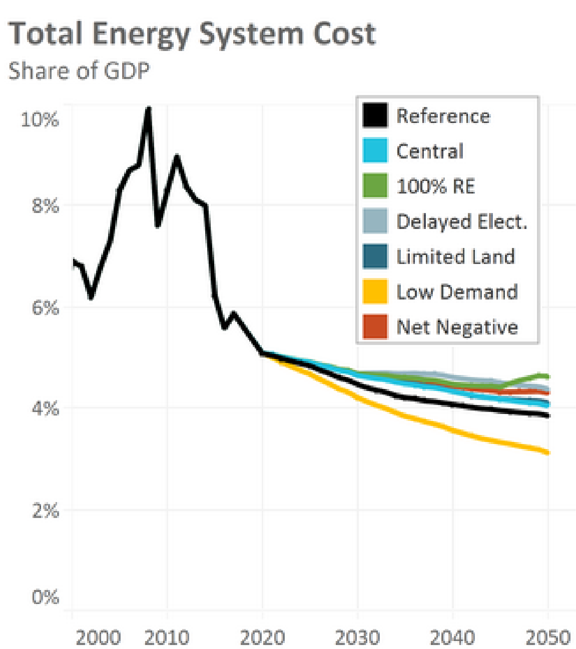

Figure 2.12. Total U.S. spending on energy, historical and modeled.

2.3.3 A High Renewables Electricity System is Robust Across Cases

A common result across the alternative pathways is that the lowest cost approach to decarbonization is by organizing the energy system around deploying high levels of renewable energy. The left-hand panel of Figure 2.13 shows the 2050 generation mix is 90 percent or more wind and solar for all cases except in the limited land case, which despite land constraints that make new nuclear generation economic in some parts of the country with limited wind resources, still has an 80 percent renewable system. As with the *central scenario*, across scenarios the most cost-effective approach to maintaining reliability was a combination of flexible loads, storage, and a large fleet of gas-fired thermal capacity that operates infrequently. The right-hand panel of Figure 2.13 illustrates this is even true in the 100 percent renewable primary energy case, in which the gas-fleet runs even less frequently and burns drop-in zero-carbon fuels, but is still a necessary part of the least-cost supply portfolio.

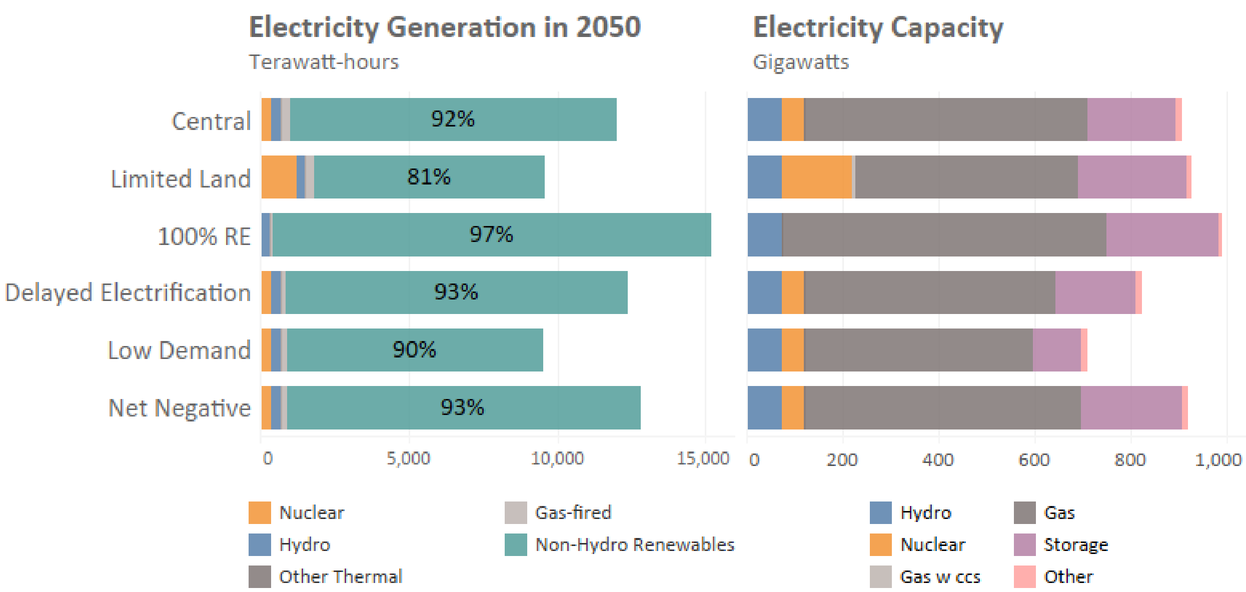

Figure 2.13. Generation and dispatchable capacity in 2050.

2.3.4 The Pathway to Fuel Decarbonization is Varied and Less Certain

While electricity generation mixes were very similar across cases, fuel mixes differed widely as a function of resource constraints and price sensitivities (Figure 2.14). The 100 percent renewable energy case was the only scenario with significant decarbonization of pipeline gas. The delayed electrification case had significantly higher biomass use to supply decarbonized fuels, which because of lower electrification constituted a greater share of final energy demand. The limited land case, having less biofuel and less electric-fuel production capacity, used more fossil fuels with CCUS, including for production of hydrogen and synthetic hydrocarbons; in other words, fossil fuels were used as the feedstocks for carbon-neutral fuels. The net negative case followed the same basic approach as the *central scenario*, but with greater use of biomass and renewable electricity to produce zero-carbon drop-in fuels. The net negative scenario depended more heavily on carbon capture for both fuel production and managing emissions.

Our results demonstrate that there are many technically feasible fuel pathways for carbon neutrality, but the optimal pathway will be uncertain until future fossil fuel price trajectories, levels of electrification, cost and potential of biomass and geologic sequestration, land available for renewable energy and transmission siting, are better known. Fortunately, if electricity decarbonization and electrification are conducted at the scale and pace needed during the 2020s, to stay on the carbon neutral straight line emissions path decarbonized fuels will not be required in bulk until the late 2030s, so there is time to determine optimal strategies.

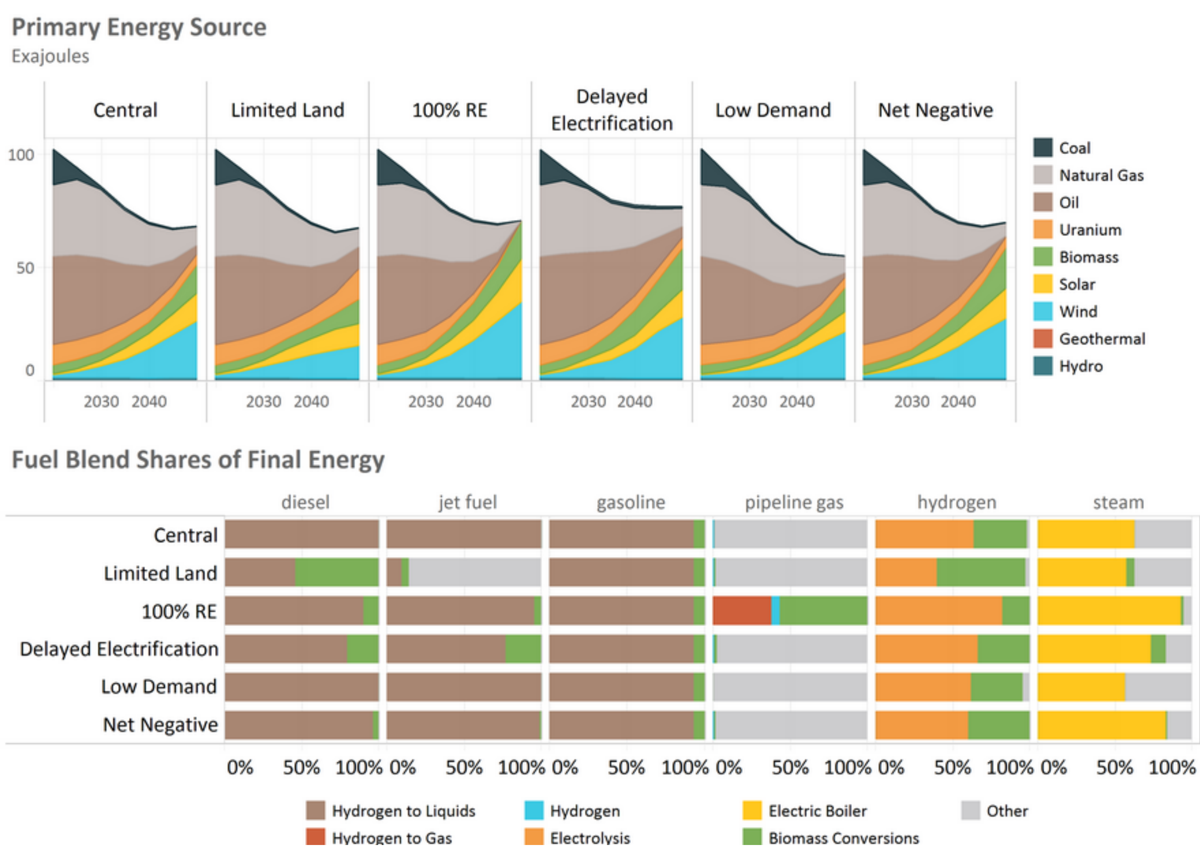

Figure 2.14. Primary energy and fuel blend shares across scenarios.

2.3.5 Carbon Capture Plays a Critical Role in Net-Zero Systems

All carbon neutral and net negative scenarios require carbon capture, which can occur at three points in the fuel lifecycle: in making the fuel, in the exhaust stream from combusting the fuel, or from the air once it is released to the atmosphere (energy & infrastructure capture does not include photosynthetic capture in the land sink or biofuels). Once captured, the CO_2 can be geologically sequestered or used to make zero-carbon fuels (Figure 2.15). Even the 100 percent renewable primary energy case, which uses no fossil fuels, requires about 650 Mt/y of carbon capture in 2050 to capture industrial process emissions (e.g., from cement manufacturing) and to provide the carbon for renewable fuel production. All captured carbon in this case is utilized and none is stored. The *central scenario* captures 800 Mt/y from industrial processes, biofuel refining, and hydrogen production from natural gas. Of this, 40 percent is used to make liquid fuels, and 60 percent is geologically sequestered.

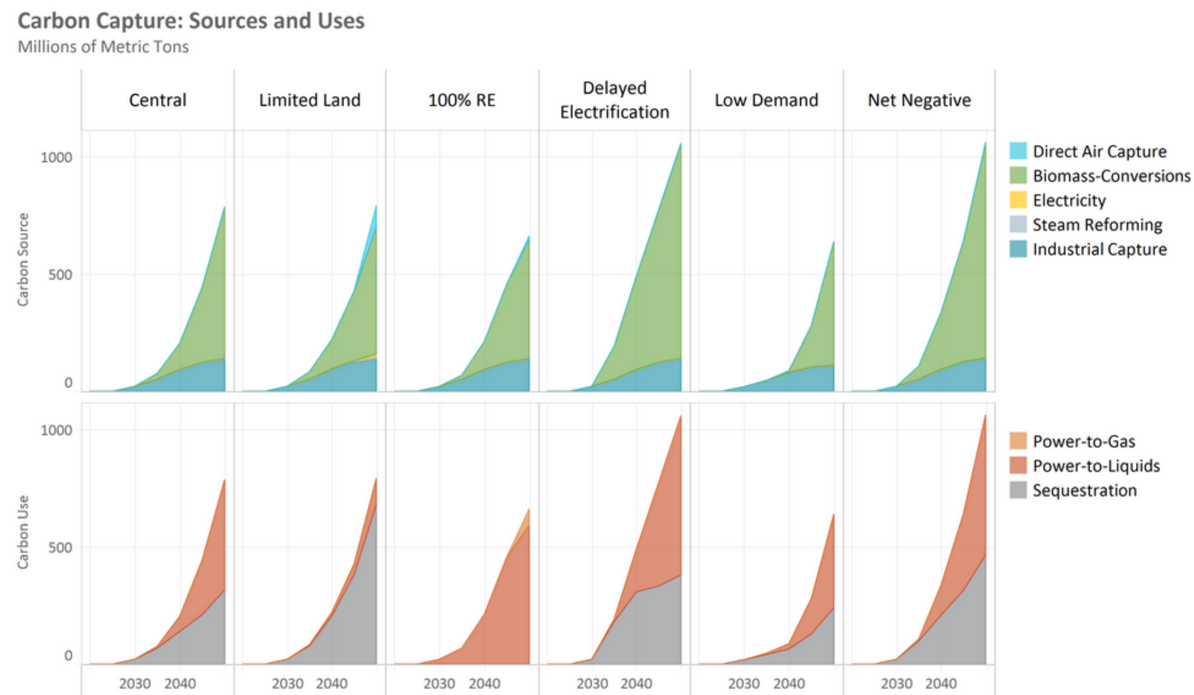

Figure 2.15. Carbon capture, utilization, and sequestration across cases.

BECCS and DAC are used as negative emissions technologies (NETs) to offset uncaptured CO_2 emissions from small and distributed point sources for which CCS and low-carbon fuels are uneconomic. In contrast to some modeling studies, we find that the most economic form of BECCS is not in power plants but in biorefineries, as solar and wind are a lower-cost alternative in electric generation, but biofuels are competitive for fuel production. The delayed electrification case relies heavily on BECCS, utilizing the captured carbon to support synthetic fuel production to support high residual fuel demand. The net negative case has a comparable level of BECCS, but geologically sequesters a greater share of carbon. A low fuel price sensitivity on the *central scenario* captures almost 20 percent more carbon, as it becomes economic to offset more fuel use. In this sensitivity, nearly more than 80 percent of captured carbon is sequestered to support offsetting.

Bioenergy and DAC are most economical when tightly coupled to the energy and industry (E&I) system, where they can be flexibly used for fuels and products (e.g., plastics) or sequestration as circumstances warrant. DAC costs are strongly dependent on energy costs, which can be minimized by flexible operation in locations with high capacity-factor renewable generation. BECCS is resource-limited both in sequestration potential and biomass feedstocks. DAC also faces sequestration injection limits as well as high costs in general, especially where its input energy has not been decarbonized. For these reasons, NETs remain complementary components of a low-cost decarbonization strategy, and it is highly uneconomic to achieve carbon neutrality through a strategy of continuing high levels of gross CO_2 emissions from burning fossil fuels that are offset by NETs.

2.3.6 Potential Tradeoffs

The scale and pace of infrastructure buildout and demands on the land potentially entail competition among social, environmental, and economic priorities. Our scenarios illustrate the effect of these tradeoffs, as limiting technology choices in one area requires compensating changes in other areas to reach the same carbon goal. If consumer adoption of electric end-use technologies is delayed, more decarbonized fuels are required, resulting in higher land requirements for biomass feedstocks and the siting of renewable generation to produce electric fuels. The 100 percent renewable primary energy case has the highest land requirements for these purposes, as well as the highest cost of any scenario. The low demand case has the lowest land requirements and cost but requires a high level of societal commitment to conservation. When siting and biomass were constrained in the low land case, nuclear power, natural gas use, and carbon sequestration all grew substantially, raising different social acceptance issues. Given that such tradeoffs can be anticipated in a transition to carbon neutrality, it is important for the public and decision-makers to engage with the choices and understand their consequences. High-quality analysis is essential for informed decision-making, and supporting it while ensuring that it meets high standards for analytical rigor and clarity of communications needs to be a policy priority.

2.4 From Pathways to Policies

2.4.1 Decarbonization Benchmarks by Decade

The modeling results described here provide a clear set of targets and timelines to guide policy making and implementation. These are summarized in Table 2.1, in which the key outcomes for each sector in each decade are highlighted. The list is not exhaustive, it does not describe the upstream manufacturing and construction changes required to enable these outcomes, and it does not prescribe the policy mechanisms by which the outcomes are to be achieved. It does, however, describe the minimum physical results that must be reached by certain points in time for the U.S. to be on a carbon neutral trajectory.

Table 2.1. Key benchmarks by decade and sector for achieving carbon neutrality in the United States by 2050, with quantitative indicators.

Sector	Indicator	2030	2040	2050
Light duty vehicles	Electric vehicle share	>50% of sales	100% of sales	100% of fleet
Medium duty vehicles	Electric and fuel cell vehicle share	>40% of sales	>80% of sales	
Heavy duty vehicles	Electric and fuel cell vehicle share	>30% of sales	>60% of sales	
Residential buildings	Electric space/water heating share	>50% of sales	100% of sales	-
Commercial buildings	Electric space/water heating share	>50% of sales	100% of sales	-
Electricity generation	Generation to meet new electric loads			>2x current level (~8000 TWh/y)
Electricity emissions	Carbon intensity	60% below current	80% below current	>95% below current
Coal power	Share of total generation	<1% of total generation	all coal retired	all coal retired
Renewable power	Wind and solar capacity	3.5x current (~500 GW)	10x current (~1500 GW)	>2500 GW total capacity
Natural gas power	Capacity	current capacity (~500 GW)	current capacity (~500 GW)	increased capacity (~600 GW)
Nuclear power	Generation	current generation (~800 TWh/y)		
Electricity storage	Capacity (diurnal storage)	>20 GW	>100 GW	
Transmission	Inter-regional capacity			2-3x current (200-300 GW)
Electrolysis	Capacity		>20 GW	>100 GW
Biofuels	Million bbls per day zero-carbon biofuel			>2 MBD
Fossil fuels	Infrastructure to transport fossil fuels	no new oil & gas pipelines		
Carbon capture & storage	CCS capacity large industrial facilities		>250 MMT/year CO_2 sequestered	>500 MMT/year CO_2 sequestered

2.4.2 Key Actions in the Next Ten Years

The key actions over the next decade are robust across different technology pathways and cost assumptions. They form the basis of a common set of near to medium term policy priorities for all proponents of decarbonization, regardless of what long-term pathways are preferred.

Electricity. Electricity must be rapidly decarbonized while generation expands to accommodate new electric end uses. This requires parallel action on several different fronts in this decade.

- **Reduce the carbon intensity of electricity to 60 percent** below its current level by 2030.
- **Ramp up the construction of wind and solar generation** to reach 3.5 times the current capacity by 2030, which means adding on average at least 20 GW of wind and 25 GW of solar (including rooftop) per year.
- **Reinforce the transmission system** to accommodate delivery of renewable generation from areas with high resource quality to distant load centers.
- **Increase storage capacity.** Add at least 20 GW of diurnal storage to help accommodate renewable intermittency, especially solar.
- **Switch from coal to gas in electricity system dispatch.** Reduce coal generation to less than 1 percent of the generation mix.
- **Allow new natural gas power plants to be built to replace retiring plants.** The current capacity of natural gas generation needs to be maintained for reliability.
- **Maintain the existing nuclear fleet** to the extent circumstances allow, in order to limit the rate of new renewable and transmission construction required.
- **Initiate electricity wholesale market reforms** to prepare for a changing mix of electric loads and resources and address emerging issues in operations and cost allocation.

Fuels. Begin a concerted move away from fossil fuels, replacing these with electricity where possible and otherwise with biofuels and electric fuels.

- **Begin large-scale shift from fossil fuels to electricity.** The key fuels policy is replacing fossil fuel end-use technologies in transportation and buildings (see below).
- **Stop developing new infrastructure to transport fossil fuels**, for example oil and gas pipelines, LNG terminals, and coal terminals, as these will rapidly become stranded assets.
- **Pilot and further develop new fuel technologies** that need to be deployed at large scale after 2030, including electrolysis, power to gas, power to liquids, and advanced biofuels.

Transportation. Begin large-scale electrification of transportation, replacing gasoline and diesel use in vehicles of all kinds (personal, commercial, and freight) with low-carbon electricity.

- **Rapidly increase the electric vehicle share** of new light duty vehicle sales (e.g., cars, SUVs, light trucks) to at least 50 percent by 2030.
- **Rapidly increase the electric and fuel cell vehicle share** of new medium duty vehicle sales (e.g., buses, delivery trucks) to at least 40 percent by 2030.
- **Rapidly increase the electric and fuel cell vehicle share** of new heavy duty vehicle sales (e.g., long-haul freight trucks) to at least 30 percent by 2030.

Buildings. Begin large-scale electrification of fossil fuel end uses in buildings, replacing oil and natural gas with electricity.

- **Increase the electric heat pump share of space and water heating** equipment in residential buildings to at least 60 percent of sales.
- **Increase the electric heat pump share of space and water heating** equipment in commercial buildings to at least 60 percent of sales.
- **Adopt best-available efficiency standards** for lighting and appliances in all buildings.
- **Improve residential building shell efficiency** for new construction.

Industry. Electrify industrial end uses where possible, and develop decarbonization strategies for end uses that are difficult to electrify.

- **Begin building carbon capture** on a large pilot or limited commercial scale for large industrial facilities with concentrated CO_2 streams.
- **Begin development of low-carbon feedstocks and processes** for industrial products based on biomass, electric fuels, or carbon capture.

References

1. IPCC. 2018. Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas eamission pathways.
2. Hansen, J., et al. 2017. Young people's burden: Requirement of negative CO2 emissions. Earth Syst. Dynam., 8, 577-616, doi:10.5194/esd-8-577-2017.
3. "Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2018 | US EPA". 2020. US EPA. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018.
4. Williams, J.H., B. Haley, F. Kahrl, J. Moore, A.D. Jones, M.S. Torn, H. McJeon. 2014. Pathways to deep decarbonization in the United States. The U.S. report of the Deep Decarbonization Pathways Project of the Sustainable Development Solutions Network and the Institute for Sustainable Development and International Relations. Revision with technical supplement, Nov 16, 2015.;

   Williams, J.H., B. Haley, R. Jones. 2015. Policy implications of deep decarbonization in the United States. A report of the Deep Decarbonization Pathways Project of the Sustainable Development Solutions Network and the Institute for Sustainable Development and International Relations. Nov 17, 2015.
5. Williams, J.H. et al. 2012. The technology path to deep greenhouse gas emissions cuts by 2050: the pivotal role of electricity. *Science 335.6064*, 53-59;

   Deep Decarbonization Pathways Project. 2015. Pathways to deep decarbonization 2015 report, SDSN and IDDRI;

   The White House. 2016. *United States Mid-Century Strategy for Deep Decarbonization*.
6. U.S. Department of Energy. 2016. "2016 Billion-Ton Report". U.S. Department of Energy. https://www.energy.gov/sites/prod/files/2016/12/f34/2016_billion_ton_report_12.2.16_0.pdf.

3. INDUSTRIAL POLICY, EMPLOYMENT, AND JUST TRANSITION

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3.1 Introduction

This chapter of the Zero Carbon Action Plan focuses on achieving an equitable and just transition as an integral component of the overall U.S. decarbonization project. Of course, this decarbonization project will completely transform the ways that energy is produced and consumed in the United States. It will also initiate major changes more broadly throughout the U.S. economy and society.

The critical considerations that are examined in this chapter include the following. First, investments to build a clean energy economy will be a source of new job creation. But how many jobs are likely to be created? And what policies can be enacted to raise the proportion of good-quality jobs resulting from clean energy investments in terms of wages, benefits and workplace conditions? How can we also ensure that these new job opportunities are fully open to women and people of color? To date, women and communities of color are underrepresented in the existing U.S. energy sector as well as in the areas of employment that will expand through the clean energy investment project.

The contraction of the fossil fuel-dominant energy system will entail job losses. It will also produce hardships for communities whose well-being is currently dependent on the vibrancy of the fossil fuel industries. These negatively impacted workers and communities will require significant transitional support. Just transition policies are certainly justified according to any standard of fairness. But they are also a matter of strategic politics. Without such adjustment assistance programs operating at a major scale, the workers and communities facing retrenchment from the clean energy transition project will, predictably and understandably, fight to defend their communities and livelihoods. This in turn could create unacceptable obstacles in proceeding with effective climate stabilization policies.

The other major focus of this chapter examines the importance of narratives and other forms of public education and on-the-ground programs that will be needed to strengthen support for the clean energy transition. In fact, according to polling evidence, a large majority of the U.S. public already strongly supports a clean energy transition.

Yet, despite this widespread support, it remains the case that, to date, far too little has been accomplished in terms of moving the U.S. economy onto a viable climate stabilization path. It is therefore imperative to strengthen the extent of support around a transformative climate stabilization agenda.

The structure of this chapter is as follows. Following this introduction, Section 2 is titled "Job Creation through Clean Energy Investments". We estimate here that the number of jobs that will be generated between 2020 and 2050 by the *central scenario* developed in Chapter 2 of this plan, through which the U.S. economy will achieve net-zero CO_2 emissions by 2050. We estimate that the full set of clean energy supply investments and energy demand expenditures will generate an average of between about 4.2 – 4.6 million jobs per year between 2020 – 2050, depending on the extent to which the U.S. can reduce its reliance on imports in building its clean energy infrastructure. This level of job creation will equal between 2.4 – 2.6 percent of the projected labor force as of 2035—the midpoint between 2020 – 2050. The range, again, depends on the share of imports required in building out the clean energy economy. However, even with the low-end employment figure, the result will be that through the transition to a clean energy economy—and assuming all else remained equal—the average unemployment rate would fall from, say 5 percent to 2.6 percent, thereby injecting a major long-term boost to overall job opportunities.[i]

Still in Section 2, we then present a range of job quality indicators for the clean energy sectors in the current U.S. economy. It becomes clear that improving job quality standards in these new areas of employment needs to be established as a major priority. As will be discussed in Section 5, two major institutions for achieving higher job quality will be labor unions and effective job training programs. We also discuss in this section the importance of affirmative action programs to ensure that women and people and communities of color have equal access to these job opportunities.

Section 3 focuses on the contraction of the U.S. fossil fuel sectors and what will be needed to establish a just transition for the workers facing job losses. Here we estimate that the extent of job losses that will take place in two phases of the transition, 2020 – 2030 and 2031- 2050 respectively. For both phases, we estimate the number of jobs that will be lost and compare those figures with the number of workers who are likely to voluntarily retire at age 65. When considering these two sets of figures, the analysis shows that the net figure for job displacements – people who will not be retiring, but have lost their jobs and will need to be re-employed – is relatively modest year-to-year. Over 2021 – 2030, the total number of displaced workers will average about 12,000. Between 2031 – 2050, the figure does rise to an average of about 34,000 workers per year

For all of these workers, we propose a just transition policy package that includes five components: pension and reemployment guarantees, along with income, retraining and relocation support. Over 2021 – 2030, we estimate the total costs of the program to be about $1.2 billion per year. For the 2031 – 2050 period, we estimate the total average cost of these just transition policy measures at about $3.8 billion per year.

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i To be clear, we are *not* stating that these job creation figures are cumulative year-by-year—that, for example, the zero carbon program generates 4 million additional jobs in 2020, 8 million in 2021, 12 million in 2022 and so forth. Measuring job creation through clean energy investments in such a cumulative pattern produces figures that are out of scale with the size of the U.S. labor market and the level of annual overall economic activity (GDP). We discuss the distinction between measuring 'jobs-per-year' versus cumulative job years in Section 3.2.2.

Thus, even over the more costly phase of the fossil fuel industry contraction between 2031 – 2050, the total costs of the just transition program will amount to less than one one-hundredth of 1 percent of average U.S. GDP over these years. It is also important to compare this figure of approximately 34,000 fossil fuel industry workers being displaced annually per year over 2031 – 2050 with the average level of increased employment of roughly 4 million jobs that will result through the U.S. clean energy transition.

Section 4 focuses on communities that are presently heavily dependent on fossil fuel-based industries. We first show that fossil fuel production in the U.S., both coal as well as oil and gas, is highly concentrated geographically in a small number of states, and even a small number of communities within these relatively few states. The long-term phase-down in the fossil fuel industry will be felt most acutely in these states and communities. Most of the rest of the country is likely to experience negative effects to a much lesser degree, if at all. Focusing therefore on the heavily impacted communities, we discuss experiences and policy proposals in two main areas—land reclamation and repurposing of what are now sites of fossil fuel production activity. We draw on a range of experiences in the U.S. as well as the successful repurposing initiatives that have been operating for decades in Germany's Ruhr Valley, what had been the country's primary coal-producing region.

Section 5, "Good Quality and Equal Access to Clean Energy Jobs" discusses the role of labor unions and job training programs for raising the job-quality level in the expanding clean energy sectors. It also discusses the importance of effective affirmative action programs to ensure that women and people and communities of color have equal access to these expanding employment opportunities. Evidence shows how important these policy tools have been in different settings and under a variety of circumstances. A review of evidence from surveys of clean energy business managers report that, to a significant degree, firms are facing difficulties in finding well-qualified people to fill their job openings. Providing effective training opportunities is therefore critical for successfully expanding the clean energy sectors at the scale required.

Section 6 is titled "Building Support for Clean Energy Transition through Narratives, Education and Community Engagement." To begin with, as of 2019, over two-thirds of adults think that the Federal Government is doing "too little to reduce the effects of global climate change," and 77 percent think that "developing alternative energy" is a more important priority than "expanding fossil fuels." Yet it is clear that this level of support still needs to be broadened and strengthened. In this section a range of approaches and activities are discussed at the level of individual narratives, educational projects and practical support programs for households and communities. A macro-level narrative will animate this chapter as well as the Zero Carbon Action Plan more generally.

One model of how to advance just transition policies at the state level is currently underway in Colorado. To date, it is focused on the state's coal industry, but the framework could be readily generalized to its much larger oil and gas industry as well. The preliminary draft of the coal transition program was published in August 2020, with the final draft due by the end of 2020.

The program focuses on three areas: the transition for coal workers and coal communities respectively, and the fiscal requirements to support generous support for both the workers and communities that will experience displacement.

The main features of each of these areas include the following[1]:

Workers transition. It develops a package of training, job search, and relocation support services. It also provides temporary income and benefit assistance, including a wage and health differential benefit for most workers.

Community transition. It will assist affected communities with the creation of local transition plans that pivot from resource extraction to new industry sectors that provide living wages and an adequate tax base. It will include investments in local physical and community infrastructure to maintain and improve quality of life and critical services, and a state-wide investment fund focused on making investments in coal transition communities.

Fiscal issues. Commit to continue support for essential services and infrastructure, and support efforts to reinvest in these communities to produce utility-scale renewable energy projects.

Hansen, Bazilian, and Medlock (2019) summarize the approach being developed in the Colorado program as:

> Setting a precedent and model for other labor transitions as it includes specific requirements for utility workforce transition plans to be put in place. In addition, benefits to workers (such as wage differential benefits and training programs) and community grants form two pillars that are essential in recognizing the implications of removing jobs from communities that are dealing with economic malaise.[ii]

As it proceeds, the Colorado just transition project should provide important lessons for how to advance this agenda more broadly throughout the United States.

3.2 Job Creation through Clean Energy Investments

This section estimates the employment effects of advancing the clean energy investment program developed by Jim Williams and Ryan Jones, as summarized in Chapter 2 of this volume. Their model includes seven different U.S. energy system scenarios between 2020 – 2050. The baseline *reference scenario* is based on the Department of Energy's long-term forecast, the Annual Energy Outlook. According to the model specification under this scenario, CO_2 emissions in the United States will decline by only 23 percent between 2020 and 2050, from 5.20 to 4.02 billion tons. Working off of this *reference scenario*, the model then develops six alternative U.S. energy system scenarios between 2020 – 2050. Through each of these alternative scenarios, CO_2 emissions in the U.S. will fall to zero by 2050. In this chapter, we focus on what Williams and Jones term their *central scenario* through which the U.S. achieves zero CO_2 emission in 2050 at the lowest net cost.

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ii Two more general recent studies on just transitions are, Henry, Bazilian and Markusen (2020) "Just Transitions: Histories and Futures in a post-COVID World," and Carley and Konisky (2020) "The Justice and Equity Implications of the Clean Energy Transition." Pollin et al. (2019) presents a detailed just transition program for Colorado that incorporates the state's oil and gas as well as its coal industries.

For estimating the total level spending on both the supply and demand sides of the U.S. energy system, we therefore calculate the difference in spending levels between the *central scenario* and the *reference scenario*. This difference in spending between the *central* and *reference scenarios* represents the net increase in spending required to bring CO_2 emissions in the U.S. economy down from 4 billion tons to zero as of 2050. On average over 2020 – 2050, total net expenditures within the *central scenario* includes $389 billion per year on investments to expand the supply of both clean renewable energy sources, including solar, wind, geothermal, and hydro power, as well as other low- to zero CO_2-emitting technologies, including nuclear power, biomass, and carbon sequestration. It also includes $160 billion per year to purchase a wide range of products that operate through consuming energy or "energy demand expenditures". These include electric vehicles, heating and cooling systems, and refrigeration equipment.[iii] The average overall spending total for both energy supply investments and energy demand expenditures therefore comes to $551 billion per year between 2020 – 2050. This is equal to about 1.7 percent of U.S. GDP at its midpoint between 2020 – 2050, assuming that the U.S. economy grows at an average annual rate of 2.2 percent over this 30-year period.

Working from these budgetary figures, the amount of jobs is estimated that will be created as a result of the spending amounts that the model in Chapter 2 allocates to all categories in the areas of both energy supply and demand.

After estimating the number of jobs that these energy supply and demand expenditures will generate, we then consider indicators of the quality of these jobs. These quality indicators include average compensation levels, health care coverage, retirement plans, and union membership. We also provide data profiling the types of workers who are employed at present in the job areas that will be created by the energy supply and demand expenditures, including evidence on both educational credentials of these workers as well as their racial and gender composition. We then report on the prevalent types of jobs that will be generated by these energy efficiency and clean renewable energy investments.

Before proceeding with presenting job creation estimates, the following section will first briefly describe the methodology used to generate the results.[iv] A fuller discussion of our methodology is provided in Appendix 6.2.[2]

3.2.1 Methodological Issues in Estimating Employment Creation

Our employment estimates are figures are generated directly with data from national surveys of public and private economic enterprises within the U.S. and organized systematically within the official U.S. input-output (I-O) model. The "inputs" within this model are all the employees, materials, land, energy and other products that are utilized in public and private enterprises within the U.S. to create goods and services. The "outputs" are the goods and services themselves that result from these activities that are then made available to households, private businesses and governments as consumers within both domestic and global markets.

iii We provide a full listing of all of the Williams, Jones and Farbes model spending categories in the Appendix.

iv The October 2020 SDSN paper, "Conceptualizing Employment Pathways to Decarbonize the U.S. Economy," presents another methodological perspective on analyzing the employment issues associated with a U.S. clean energy transition project. The approach developed by SDSN is largely complementary to that utilized here.

Within the given structure of the U.S. economy, these figures from the input-output model provide the most accurate evidence available as to what happens within private and public enterprises when they produce the economy's goods and services. In particular, these data enable researchers to observe how many workers were hired to produce a given set of products or services, and what kinds of materials were purchased in the process.

Here is one specific example of how our methodology works. If we invest an additional $1 billion in building electric vehicles, what will be all the activities undertaken to produce these vehicles? How much of the $1 billion will be spent on hiring workers, how much will be spent on non-labor inputs, including materials, energy costs, and maintaining factory buildings, and how much will be left over for business profits? Moreover, when businesses spend on non-labor inputs, what are the employment effects through giving orders to suppliers, such as glass manufacturers or trucking companies?

We also ask this same set of questions about investment projects in renewable energy as well as spending on operations within the non-renewable energy sectors. For example, to produce $1 billion worth of wind energy productive capacity, how many workers will need to be employed, and how much money will need to be spent on non-labor inputs? Through this approach, the analysis is able to provide observations as to the potential job effects of alternative energy investment and spending strategies at a level of detail that is not available through any alternative approach.

3.2.2 Direct, Indirect and Induced Job Creation

Spending money in any area of any economy, including the U.S. economy, will create jobs, since people are needed to produce any good or service that the economy supplies. This is true regardless of whether the spending is done by private businesses, households, or government entities. At the same time, for a given amount of spending within the economy, for example, $1 billion, there are differences in the relative levels of job creation through spending that $1 billion in alternative ways. Again, this is true regardless of whether the spending is done by households, private businesses or public sector enterprises.

There are three sources of job creation associated with any expansion of spending—direct, indirect, and induced effects. For purposes of illustration, consider these categories in terms of investments in manufacturing electric cars or building wind turbines:

- **Direct effects**—the jobs created, for example, by manufacturing electric vehicles or building wind turbines;
- **Indirect effects**—the jobs associated with industries that supply intermediate goods for the electric vehicles or wind turbines, such as glass, steel, and transportation;
- **Induced effects**—the expansion of employment that results when people who are paid in the glass, steel, or transportation industries spend the money they have earned on other products in the economy. These are the multiplier effects within a standard macroeconomic model.

This study reports on all three employment channels – direct, indirect, and induced job creation. It is important to note that estimating induced effects – i.e., multiplier effects – within I-O models is much less reliable than the direct and indirect effects. In addition, induced effects derived from alternative areas of spending within a national economy are likely to be comparable to one another.

Within the categories of direct plus indirect job creation, how is it that spending a given amount of money in one set of activities in the economy could generate more employment than other activities? As a matter of simple arithmetic, there are only three possibilities. These are:

- **Labor Intensity.** When proportionally more money of a given overall amount of funds is spent on hiring people, as opposed to spending on machinery, buildings, energy, land, and other inputs, then spending this given amount of overall funds will create relatively more jobs.
- **Compensation per worker.** If $1 billion in total is spent on employing workers in a given year on a project, and each employee earns $1 million per year working on that project, then only 1,000 jobs are created through spending this $1 billion. However, if, at another enterprise, the average pay is $50,000 per year, then the same $1 billion devoted to employing workers will generate 20,000 jobs.
- **Domestic content.** When a given amount of money is spent in either the areas of energy supply or demand, some of the spending will occur outside of the U.S. economy. Of course, U.S. job creation will increase as the relative share of domestically-produced goods and services rises. Through the input/output model, one can observe the level of job creation at existing domestic content levels; it can also estimate how much overall job creation will increase through assuming an increase in the domestic content share, resulting, for example, from active industrial policies. In what follows, we report job creation levels both with existing domestic content ratios and through assuming that U.S. domestic content is able to increase to 100 percent in the full set of supply and demand activities.

Time Dimension in Measuring Job Creation

Jobs-per-year vs. job years. Any type of spending activity creates employment over a given amount of time. To understand the impact on jobs of a given spending activity, one must therefore incorporate a time dimension into the measurement of employment creation. For example, a program that creates 100 jobs that last for only one year needs to be distinguished from another program that creates 100 jobs that continue for 10 years each. It is important to keep this time dimension in mind in any assessment of the impact on job creation of any clean energy investment activity.

There are two straightforward ways in which one can express such distinctions. One is through measuring *job years*. This measures cumulative job creation of the total number of years that jobs are being generated. Thus, an activity that produces 100 jobs for 1 year would create 100 cumulative *job years*. Similarly, an activity that produces 100 jobs each year for 30 years would generate 3,000 *job years*.

The other way to report the same labor market activity is in terms of jobs-per-year. Through this measure, one is able to show the year-to-year breakdown of the overall level of job creation. Thus, with the 30-year program used in the example, it could be expressed as creating 100 jobs per year, every year, for the 30-year time period.

This jobs-per-year measure is most appropriate for the purposes of this study, in which the focus is measuring the impact on employment opportunities of clean energy investments. The reason that jobs-per-year is a better metric than cumulative *job years* is because the impact of any new investment, whether on clean energy or anything else, will be felt within a given set of labor market conditions at a point in time.

Reporting cumulative job creation figures over multiple years prevents scaling the impact of investments on job markets at a given point in time. For example, if clean energy investments create 5 million jobs in a given year, one can scale that to the size of the U.S. labor market in that year. At present, 143 million people are employed in the U.S. Adding 5 million jobs would therefore amount to an increase in employment of about 3.5 percentage points.

If we then assume that the clean energy investments continue for 10 years at the same scale, that would mean 5 million jobs per year would be created through these investments. That would continue to maintain overall employment in the U.S. at a level that is 3.5 percent greater than it would have been without the injection of clean energy investments (after allowing also for the natural growth of the U.S. labor market). However, if this employment impact is measured in terms of cumulative job creation, the 31 years' worth of investment would, by this measure, amount to over 150 million jobs. It is misleading to compare that cumulative job creation figure to the total of 143 million jobs in the U.S. at any specific point in time (e.g., 2021). In order to scale the cumulative job creation figure of 150 million, the appropriate comparison would be with the cumulative job figures for the whole U.S. economy over 31 years. But this cumulative jobs figure is not a particularly clear or useful way to understand labor market conditions at any given point in time.

Incorporating Labor Productivity Growth over the 31-Year Investment Cycle

The figures we use for the input-output tables are based on the technologies that are prevalent at present for undertaking these clean energy investments. Yet we are estimating job creation through clean energy investments that will occur over a 31-year cycle between 2020 - 2050. The relevant production technologies will certainly change over this 31-year period, so that a different mixture of inputs may be used to produce a given output.

For example, new technologies are likely to emerge, making other technologies obsolete. Certain inputs could also become more scarce, and, as result, firms may substitute other less expensive goods and services to save on costs. The production process overall could also become more efficient, so that fewer inputs are needed to produce a given amount of output. Energy efficiency investments do themselves produce a change in production processes (i.e., a reduction in the use of energy inputs to generate a given level of output). In short, the input-output relationships in any given economy – including its employment effects of clean energy investments – are likely to look different in 2035 or 2050 relative to the present.

Pollin et al. have addressed this issue in detail (e.g., 2015, pp. 133 - 144).[3] For the purposes of the present discussion, a simple assumption is made: that average labor productivity in clean energy investments rises by one percent per year throughout the full 2020 – 2050 period.

3.2.3 Job Creation Estimates

Tables 3.1 – 3.5 report on our job creation estimates generated by the Chapter 2 *central scenario* for reaching a net-zero emissions U.S. economy by 2050. Two overall sets of figures are reported for both the energy supply investments and the energy demand expenditures – first, job creation per $1 million in expenditure, then, job creation given the average annual level of spending incorporated into the Chapter 2 model (i.e., $389 billion per year in net energy supply investments and $163 billion per year in net energy demand expenditures). We first report figures for direct and indirect jobs, along with the totals for these main job categories. We then include figures on induced jobs, and show total job creation when induced jobs are added to figures for direct and indirect jobs.

Further, as noted above, job creation estimates are presented, under two alternative cases: first, that U.S. domestic content shares remain at their existing levels, then, second, that domestic content shares rise to 100 percent for all activities. Examining these two alternative scenarios for domestic content on both supply and demand-based energy-system spending enables us to observe the impact on employment through implementing effective U.S. industrial policies targeted at the emerging clean energy economy.

In Tables 3.1A/3.1B and 3.2A/2B, we present our estimates as to the job creation effects generated by the full range of energy supply projects. These include clean renewables, transmission and storage; fossil fuels; additional supply technologies, including nuclear, carbon sequestration and biomass; and a grouping of difficult to categorize "other" investments.[v] Starting in Table 3.1A with the figures at existing domestic content levels, we see that the extent of direct plus indirect jobs ranges from 2.4 jobs per $1 million in spending for transmission/storage to 8.5 for additional supply technologies. Adding induced jobs brings the range to between 5.1 – 14.2 jobs per $1 million in spending.

Of course, employment per $1 million in spending rises, by assuming that domestic content will rise to 100 percent. Thus, with the transmission/storage investment category, jobs per $1 million rises from 2.4 to 3.0, a 25 percent increase in job creation. The increases in employment in the other supply investment categories range between 10 – 14 percent.

v Our energy supply investment "other" category includes electric boilers, hydrogen blend, industrial CO_2 capital, other boilers, steam production, as well as what are termed "demand response" and "demand-side costs" categories in the Williams, Jones and Farbes model in Chapter 2.

Table 3.1. Job Creation through Energy Supply Investments
Job Creation per $1 million in spending

3.1A) Figures at Existing U.S. Domestic Content Levels

Investment Area	Direct Jobs	Indirect Jobs	Direct Jobs+ Indirect Jobs	Induced Jobs	Direct Jobs + Indirect Jobs + Induced Jobs
Clean renewables	2.8	3.0	5.9	4.4	10.2
Transmission/ storage	1.0	1.4	2.4	2.8	5.1
Additional supply technologies	5.5	2.9	8.5	5.7	14.2
Fossil fuels	1.6	2.7	4.4	4.2	8.5
Other investments	3.3	2.8	6.1	4.7	10.8

3.1B) Figures through Raising U.S. Domestic Content to 100 percent

Investment Area	Direct Jobs	Indirect Jobs	Direct Jobs+ Indirect Jobs	Induced Jobs	Direct Jobs + Indirect Jobs + Induced Jobs
Clean renewables	3.3	3.2	6.5	4.4	10.9
Transmission/ storage	1.0	2.0	3.0	2.8	5.7
Additional supply technologies	6.6	3.1	9.7	5.8	15.5
Fossil fuels	2.0	2.9	4.9	4.3	9.2
Other investments	3.8	3.0	6.8	4.8	11.6

Source: IMPLAN 3.0. Note: These jobs created per $1 million investments figures are based on net *positive* investments only, i.e., *central scenario* investments minus *reference scenario* investments, with net negative investments set to zero.

Based on these proportions, Table 3.2 shows the levels of job creation in the U.S. associated with $389 billion in average annual spending on these energy supply investments between 2020 – 2050. Again we first show our results assuming existing domestic content levels. We then assume domestic content rises to 100 percent. In this case, the individual categories of net investment spending include $164 billion for clean renewables, $48 billion for transmission/storage, and $39 billion for additional supply technologies. In addition, the figure for fossil fuel investments is a net negative $28 billion, reflecting the fact that fossil fuel investments fall in the Chapter 2 *central scenario* relative to their *reference scenario*. The analysis also shows that the largest investment area is the “other” category. This is not surprising, since it is capturing a wide range of technologies within this catch-all grouping.

Within these budgetary allocations, we see first in Table 3.2A, assuming existing domestic content levels, that total direct plus indirect job creation generated in the U.S. by this large-scale expansion in energy supply expenditures will amount to an average of about 946,000 direct jobs and 860,000 indirect jobs per year between 2020 – 2050. This totals to 1.8 million direct and indirect jobs. We also estimate that, as an average between 2020 – 2050, an additional 1.4 million induced jobs will be generated by these investments. This brings the total of direct, indirect and induced jobs generated by net energy supply investments to 3.2 million jobs.

Table 3.2B then shows these same calculations under the assumption that U.S. domestic content rises from existing levels to 100 percent for all activities. With domestic content at 100 percent, direct job creation through supply investments rises to 1.1 million and indirect jobs rise to 942,000, for a total of 2.1 million jobs. With induced jobs, the total rises to 3.5 million jobs after assuming domestic content rises to 100 percent.

Table 3.2 Average Number of Jobs Created Annually through Energy Supply Expenditures Estimates Adjusted for Increasing Labor Productivity (one percent annually), 2020-2050

3.2A) Figures at Existing U.S. Domestic Content Levels

Investment Area	Average Annual Budget Figure	Direct Jobs	Indirect Jobs	Direct Jobs+ Indirect Jobs	Induced Jobs	Direct Jobs + Indirect Jobs + Induced Jobs
Clean renewables	$164.1 billion	372,505	396,385	773,733	575,774	1.3 million
Transmission/ storage	$48.3 billion	36,413	54,071	90,484	106,276	196,493
Additional supply technologies	$39.3 billion	170,166	89,819	260,640	175,410	436,318
Fossil fuels	-$27.5 billion	-50,371	-51,434	-102,376	-104,727	-206,318
Other investments	$164.5 billion	435,372	371,228	806,618	621,294	1.4 million
TOTAL	$388.7 billion	964,085	860,069	1.8 million	1.4 million	3.2 million

3.2B) Figures through Raising U.S. Domestic Content to 100 percent

Investment Area	Average Annual Budget Figure	Direct Jobs	Indirect Jobs	Direct Jobs+ Indirect Jobs	Induced Jobs	Direct Jobs + Indirect Jobs + Induced Jobs
Clean renewables	$164.1 billion	436,402	427,674	864,075	576,911	1.4 million
Transmission/storage	$48.3 billion	37,746	75,726	113,472	106,542	220,014
Additional supply technologies	$39.3 billion	203,899	95,148	299,047	178,706	477,754
Fossil fuels	-$27.5 billion	-54,600	-55,552	-110,152	-106,383	-216,534
Other investments	$164.5 billion	503,014	398,617	901,631	635,986	1.5 million
TOTAL	$388.7 billion	1.1 million	941,612	2.1 million	1.4 million	3.5 million

Sources: IMPLAN 3.0. Budgetary figures from Williams, Jones and Farbes (2020) model in Chapter 2. Note: Investments spending and jobs numbers in this table are based on net investments, allowing for both net *positive* and net *negative* investments.

Tables 3.3 and 3.4 then present comparable estimates for the energy demand expenditures in the Chapter 2 *central scenario*. We have grouped this full set of projects into 10 categories. They are: vehicles, heating/ventilation/air conditioning (HVAC), manufacturing, other commercial and residential spending, construction, appliances, refrigeration, mining, agriculture and lighting.[vi] As Table 3.3A shows, direct plus indirect job creation per $1 million in spending with existing domestic content levels range between 4.4 jobs for vehicles and mining to 17.1 for agriculture. Job creation then rises by about 16 percent for vehicles and mining under the 100 percent domestic content assumption and by 11 percent with agriculture.

vi The “other” commercial and residential category of efficiency investments is taken directly from the Williams, Jones and Farbes model in Chapter 2—or, more precisely, this category combines the “commercial other” and “residential other” categories within the Chapter 2 model.

Table 3.3 Job Creation through Energy Demand Expenditures, by Subsectors and Technology, Job creation per $1 million in spending

3.3A) Figures at Existing U.S. Domestic Content Levels

Investment Area	Direct Jobs	Indirect Jobs	Direct Jobs+ Indirect Jobs	Induced Jobs	Direct Jobs + Indirect Jobs + Induced Jobs
Vehicles	1.1	3.4	4.4	3.5	8.0
HVAC	2.9	3.3	6.2	4.3	10.5
Manufacturing	2.1	3.8	5.8	3.8	9.7
Other commercial and residential	3.4	3.4	6.8	4.6	11.4
Construction	3.8	3.8	7.6	4.4	12.0
Appliances	1.8	3.4	5.3	3.8	9.1
Refrigeration	4.1	3.5	7.5	4.9	12.5
Mining	1.7	2.7	4.4	3.4	7.7
Agriculture	12.7	4.4	17.1	4.3	21.4
Lighting	2.8	3.6	6.4	4.5	11.0

3.3B) Figures through Raising U.S. Domestic Content to 100 percent

Investment Area	Direct Jobs	Indirect Jobs	Direct Jobs+ Indirect Jobs	Induced Jobs	Direct Jobs + Indirect Jobs + Induced Jobs
Vehicles	1.5	3.7	5.2	3.5	8.8
HVAC	3.6	3.5	7.1	4.4	11.5
Manufacturing	2.9	4.3	7.2	4.3	11.5
Other commercial and residential	3.8	3.7	7.4	4.7	12.1
Construction	3.9	4.0	7.9	4.4	12.3
Appliances	2.2	3.7	5.9	3.8	9.8
Refrigeration	4.5	3.7	8.1	5.0	13.1
Mining	2.3	2.8	5.1	3.4	8.5
Agriculture	14.1	4.9	19.0	4.8	23.8
Lighting	3.4	3.8	7.2	4.6	11.9

Source: IMPLAN 3.0. Note: These jobs created per $1 million in spending are based on net *positive* spending figures only, i.e., *central* minus *reference scenario* spending amounts, with net negative spending levels set to zero. Cost figures by technologies are not always available.

Table 3.4 shows the level of job creation through spending an average of nearly $163 billion per year on the full set of these projects between 2020 and 2050. In column 1 of Table 3.4A, we show the spending breakdowns by spending area assuming existing domestic content levels. As we see, of the full $163 billion average annual net spending figure – *central scenario* minus *reference scenario* spending – the largest areas of net expenditures include (with rounding): $80 billion on clean energy vehicles, $32 billion on high-efficiency HVAC systems and $17 billion on manufacturing equipment. These three spending categories therefore account for nearly 80 percent of total net demand expenditures.[vii]

The result of the demand expenditures at this level, and with existing domestic content levels, will be the creation of an average of about 312,000 direct jobs and 214,000 indirect jobs, for an average between 2020 and 2050 of about 530,000 direct plus indirect jobs. Including induced jobs adds another 412,000 jobs per year to the total figure. Assuming existing domestic content levels remain intact, this brings the total net job creation figure for the full set of energy demand expenditures, including induced jobs to about 980,000, as an annual average figure between 2020 – 2050.

In Table 3.4B, when we assume that domestic content rises to 100 percent, direct and indirect job creation through demand expenditures rises to about 630,000. Total job creation rises to 1.1 million when we also include induced jobs. That amounts to about a 12 percent increase in employment on the demand side through moving from existing domestic content levels to 100 percent domestic content.

Table 3.4 Average Number of Jobs Created Annually through Energy Demand Expenditures, by Subsectors and Technology, Figures Adjusted for Increasing Labor Productivity (one percent annually), 2020-2050

3.4A) Figures at Existing U.S. Domestic Content Levels

Investment Area	Average Annual Expenditure	Direct Jobs	Indirect Jobs	Direct Jobs+ Indirect Jobs	Induced Jobs	Direct Jobs + Indirect Jobs + Induced Jobs
Vehicles	$79.8 billion	102,902	-27,674	77,128	121,493	234,874
HVAC	$32.4 billion	84,799	90,711	177,470	115,746	293,449
Manufacturing	$16.9 billion	29,221	52,988	81,748	53,243	135,719
Other commercial and residential	$15.3 billion	42,408	43,236	85,644	57,522	143,166
Construction	$10.9 billion	34,950	34,458	69,253	40,029	109,438
Appliances	$3.1 billion	4,536	8,919	13,648	10,006	23,450
Refrigeration	$2.8 billion	7,126	8,044	15,171	10,093	25,385
Mining	$1.6 billion	2,194	3,544	5,738	4,391	10,095
Agriculture	$542.6 million	5,581	1,934	7,515	1,890	9,404
Lighting	-$739.5 million	-1,500	-2,012	-3,512	-2,532	-6,062
TOTAL	**$162.6 billion**	**312,217**	**214,147**	**529,801**	**411,880**	**978,919**

vii The negative figures in these tables represent cases in which spending in the Chapter 2 William and Jones *central scenario* is less than that in their reference scenario.

3.4B) Figures through Raising U.S. Domestic Content to 100 percent

Investment Area	Average Annual Expenditure	Direct Jobs	Indirect Jobs	Direct Jobs+ Indirect Jobs	Induced Jobs	Direct Jobs + Indirect Jobs + Induced Jobs
Vehicles	$79.8 billion	174,932	-46,385	128,546	127,782	256,328
HVAC	$32.4 billion	97,117	97,578	194,695	117,639	312,333
Manufacturing	$16.9 billion	40,382	60,238	100,620	60,670	161,290
Other commercial and residential	$15.3 billion	47,913	46,534	93,664	58,780	152,753
Construction	$10.9 billion	35,698	36,108	71,806	40,184	111,991
Appliances	$3.1 billion	5,722	9,675	15,397	10,053	25,451
Refrigeration	$2.8 billion	8,058	8,511	16,569	10,326	26,895
Mining	$1.6 billion	2,974	3,708	6,683	4,489	11,171
Agriculture	$542.6 million	6,196	2,153	8,349	2,109	10,459
Lighting	-$739.5 million	-1,874	-2,124	-3,998	-2,588	-6,586
TOTAL	**$162.6 billion**	**417,119**	**215,996**	**632,331**	**429,444**	**1.1 million**

Source: IMPLAN 3.0. Budgetary figures from Williams, Jones and Farbes (2020). Note: Expenditure and jobs numbers in this table are net figures, allowing for both net positive and net negative spending levels based on differences between the *central* and *reference scenarios*.

Table 3.5 brings together our job creation estimates for both the energy supply investments and energy demand expenditures, resulting from spending an average of $551 billion per year from 2020 – 2050. We show total figures for direct plus indirect jobs only, then we also show the total when induced jobs are included. As with Tables 3.1 - 3.4, we first present figures generated by assuming existing domestic content levels, then report our estimates through assuming domestic content rises to 100 percent.

Table 3.5 Average Annual Net Job Creation through Combined Energy Supply and Energy Demand Expenditure Program, 2020 – 2050, Assumption: Current Levels of Domestic Content

	Number of Direct and Indirect Jobs Created		**Number of Direct, Indirect and Induced Jobs Created**	
	Jobs Created at Existing Domestic Content Levels	**Jobs Created at 100% Domestic Content**	**Jobs Created at Existing Domestic Content Levels**	**Jobs Created at 100% Domestic Content**
1) $388.7 billion in net average annual energy supply investments	1.8 million	2.1 million	3.2 million	3.5 million
2) $162.6 billion in net average annual energy efficiency expenditures	529,801	632,331	978,919	1.1 million
3) $551.3 billion in net average annual combined expenditures	2.3 million	2.7 million	4.2 million	4.6 million
4) Total net job creation as share of projected 2035 labor force *(projection is 175 million U.S. workforce in 2035)*	1.3%	1.5%	2.4%	2.6%

Sources: Tables 3.1 – 3.4. U.S. 2035 workforce projection is an extension of the U.S. Bureau of Labor Statistics projection through 2028, which assumes a 0.5 percent average annual labor force growth rate: https://www.bls.gov/news.release/pdf/ecopro.pdf

In row 3 of Table 3.5 the total average direct and indirect job creation between 2020 – 2050 –including jobs generated on both the supply and demand-sides of the energy transformation – is 2.3 million assuming existing domestic content levels, and 2.7 million, assuming domestic content rises to 100 percent.

Through adding induced jobs, the average annual job creation figures then rise, with existing domestic content levels, to 4.2 million, and to 4.6 million through assuming 100 percent domestic content. As seen in Table 3.5, this level of direct and indirect job creation would amount to between about 1.3 – 1.5 percent of the likely total labor force in the U.S. as of 2035. When induced jobs are included in the total, the figure rises to between 2.4 – 2.6 percent of the 2035 labor force. In addition, pushing U.S. domestic content to 100 percent in all of these supply and demand spending areas will produce an average of an additional 400,000 jobs per year between 2020 – 2050 relative to maintaining existing domestic content levels intact.

Indicators of Job Quality

In Table 3.6 - 3.9, we provide some basic measures of job quality for the direct jobs in the core areas that will be generated through both the energy supply investments and energy efficiency expenditures within the Chapter 2 *central scenario*. These basic indicators include: (1) average total compensation (including wages plus benefits); (2) the percentage of workers receiving health insurance coverage through their employer; (3) the percentage having retirement plans through their employers; and (4) the percentage that are union members. These figures are first presented for the energy supply investments in Tables 3.6 and 3.7, then for the energy demand expenditures in Tables 3.8 and 3.9.

Table 3.6 Indicators of Job Quality in Primary Energy Supply Investment Areas: Direct Jobs Only

	1. Clean renewables	**2. Additional supply technologies**	**4. Transmission / Storage**
Average total compensation	$83,000	$76,600	$139,700
Health Insurance coverage, percentage	56.7%	48.0%	72.9%
Retirement Plans, percentage	39.3%	31.7%	61.3%
Union membership, percentage	9.0%	9.1%	22.7%

Source: CPS 2018-2019

Table 3.7 Educational Credentials and Race/Gender Composition of Workers in Primary Energy Supply Investment Areas: Direct Jobs Only

	1. Clean renewables	**2. Additional supply technologies**	**3. Transmission / Storage**
Share with high school degree or less	43.0%	46.1%	31.1%
Share with some college or Associate degree	24.8%	30.1%	29.9%
Share with Bachelor's degree or higher	32.3%	23.8%	39.0%
Racial and Gender Composition of workforce			
Percent People and communities of color	33.7%	34.1%	26.2%
Percent Female	20.5%	19.4%	20.6%

Source: CPS 2018-2019

Energy Supply Investments and Job Quality

The analysis focuses on three core areas of direct job creation through energy supply investments: renewables, other non-renewables, and transmission storage. As the average compensation figures are fairly close in the two energy supply areas, at $83,000 for clean renewables and $77,000 for additional supply technologies. But workers in the transmission/storage areas are earning much higher pay on average, at nearly $140,000.

In terms of the provision of employer-sponsored health care, the workers in the transmission/storage sector are, as with their compensation, better off than workers in the other sectors. Nearly 73 percent of these workers are receiving health care through their employers. By contrast, between 48 – 57 percent of workers in the renewables and additional supply technology sectors are getting employer-based health insurance.

A similar pattern holds with retirement plans, as well as with unionization rates. Over 60 percent of workers in transmission/storage receive pensions from their jobs, while between 32 – 39 percent have employer-based pensions in the two other areas. Nearly 23 percent of workers in transmission/storage are union members, while only about 9 are union members in the other supply side investment areas.

Educational Credentials and Race/Gender Composition

In Table 3.7, we present data on both the educational credentials for workers in the three core energy supply investment categories as well as the race and gender composition of these workers. The analysis focuses here only on the workers who are employed *directly* through these investments.

Educational Credentials

With respect to educational credentials, we categorize all workers according to three educational credential groupings: (1) shares with high school degrees or less; (2) shares with some college or Associate degrees; and (3) shares with Bachelor's degree or higher.

As Table 3.7 shows, we see a similar pattern with the results on compensation and benefits. That is, the workers in transmission/storage have higher credentials, with nearly 40 percent having Bachelor's degrees or higher. In the other three supply-side categories between 43 – 46 percent have high school diplomas or less.

Also, in terms of the share of workers who are people of color, roughly one-third of workers in all of the supply-side investment areas are people of color, with the one exception of the transmission/storage investment area. In this case, the share of workers from communities of color is significantly lower, at 26 percent.

Women are underrepresented across the board—holding only about 20 percent of the jobs in these three core investment areas.

Energy demand expenditures and job quality

Starting with compensation figures, Table 3.8 shows that the averages for the energy demand expenditures range between roughly $70,000 per year for workers in the HVAC and refrigeration categories, rising to an average of $83,000 for workers employed in the clean vehicles category.

Table 3.8 Indicators of Job Quality in Primary Energy Demand Spending Areas: Direct Jobs Only

	1. Vehicles	2. HVAC	3. Refrigeration
Average total compensation	$82,600	$72,500	$69,600
Health Insurance coverage, percentage	73.8%	57.7%	48.3%
Retirement Plans, percentage	49.2%	39.3%	32.7%
Union membership, percentage	13.2%	9.9%	11.7%

Source: CPS 2018-2019

There is significant variation between workers in these three energy demand areas in terms of receiving health insurance through their employers. At the low end, about 48 percent of workers in the refrigeration category receive employer-based health insurance, while nearly 74 percent of workers in the vehicles category receive it.

The range of coverage with respect to private retirement plans is narrower than with health insurance. The low-end figures are with workers in the areas of refrigeration, in which only about 33 percent of workers have employer-based retirement plans. The figure is close to 50 percent for workers employed in the vehicles category. The figures on union coverage are broadly consistent at low levels, ranging between about ten percent for workers in the lighting and HVAC categories up to 13 percent for those in vehicles.

Educational credentials and race/gender composition

In Table 3.9, we present data on both the educational credentials for workers in the three core energy efficiency expenditure categories of vehicles, HVAC, and refrigeration, as well as the race and gender composition of these workers. Again, the analysis focuses here only on the workers who are employed directly through these investments.

Table 3.9 Educational Credentials and Race/Gender Composition of Workers Primary Energy Demand Spending Areas: Direct Jobs Only

	1. Vehicles	2. HVAC	3. Refrigeration
Share with high school degree or less	43.1%	48.6%	53.3%
Share with some college or Associate degree	29.4%	29.2%	27.6%
Share with Bachelor's degree or higher	27.4%	22.2%	19.0%
Racial and Gender Composition of Workforce			
Percent People and communities of color	35.4%	33.2%	36.5%
Percent Female	25.7%	17.3%	13.8%

Source: CPS 2018-2019

Educational credentials

As Table 3.9 shows, the distribution of educational credentials is fairly consistent across the major energy demand spending categories. Thus, the range of workers with high school degrees or less varies from a low of 43 percent for workers employed in the vehicles category to 53 percent in refrigeration. Similarly, the share of workers with Bachelor's degrees or higher ranges from a low of 1 percent in refrigeration to 27 percent in the vehicles category.

Race and gender composition

It is clear from the figures in Table 3.9 that, at present, the jobs created by energy demand expenditures are held mainly by white male workers. At the same time, the share of jobs held by workers from communities of color are somewhat higher than their 28 percent representation throughout the U.S. workforce in general. The range of workers from communities of color is narrow across the energy demand spending categories, between 33 and 37 percent. With respect to gender composition, women are under-represented across all sectors. The share of female employment is between 14 – 26 percent,[viii] even while women make up 46 percent of the U.S. workforce.[4]

viii According to the U.S. Census, 28 percent of U.S.'s labor force was non-White and/or Hispanic/Latino in 2017. The U.S. Department of Local Affairs estimates that 46 percent of U.S.'s labor force is female.

Prevalent Job Types with Clean Energy Investments

In addition to these average results across the various energy supply investment and energy demand expenditure areas, it is important to consider the range of the types of jobs that will be generated in each of the specified areas. To provide a picture of this range of jobs, in the Appendix, we present tables that report on the job categories in all of the investment and expenditure areas. It is difficult to summarize the detailed data on job categories presented in these tables, but the overall point is clear. That is, investing to build a clean energy economy will produce new employment opportunities at all levels of the U.S. economy. New job opportunities will open for, among other occupations, carpenters, machinists, environmental scientists, secretaries, accountants, truck drivers, roofers and agricultural laborers, as well as well as a full range of managerial occupations. It is important to note that this broad range of new opportunities will be available for workers in the U.S. that will have been displaced by the contraction of the fossil fuel industry activities.

3.3 Job Contraction and Just Transition for Workers in Fossil Fuel Industries[5]

The economic transition model developed by Williams and Jones in Chapter 2 describes a detailed pathway for achieving a net-zero U.S. economy by 2050.[ix] Of course, a critical feature of that project will entail a dramatic contraction in the production and consumption of oil, coal, and natural gas as U.S. energy sources. As of 2018, energy supplied by these fossil fuel sources accounted for about 80 percent of all U.S. energy consumption. Moreover, on a net basis, about 96 percent of the fossil fuel energy consumed in the U.S. in 2018 came from U.S. domestic production activity.[6] It therefore follows that the large-scale contraction of the U.S. oil, gas and coal industries will generate major job losses for workers currently employed in these and related industries. The contraction of the U.S. fossil fuel industry will also generate substantial negative impacts on communities which are currently dependent on the fossil fuel economy in terms of jobs, local business activity, and tax revenues to fund schools, health care facilities, infrastructure and other community institutions.

Within the framework of the model in Chapter 2, the rates at which the oil, natural gas and coal industry will contract vary significantly. Table 3.10 summarizes the respective rates of contraction for the three sectors. Specifically, as seen in the Chapter 2 model, the U.S. oil industry contracts by 20 percent between 2020 – 2030 and by 95 percent between 2031 – 2050. The natural gas industry does not contract at all between 2020 – 2030, but declines by 75 percent between 2031 – 2050. Finally, within the Chapter 2 model, the coal industry is phased out entirely and permanently between 2021 – 2030.

ix This section and Section 4 draws substantially from Pollin and Callaci, (2018) and subsequent follow-up projects, including Pollin et al. (2019).

Table 3.10. Assumptions on Contraction Rates for U.S. Fossil Fuel Sectors: Contractions as of 2030 and 2050. Baseline Employment Figures from 2018

	2030	**2050**
Oil	- 20%	- 95%
Natural Gas	No contraction	- 75%
Coal	100%	100%

Source: Williams, Jones and Farbes (2020).

In this section, we first consider these impacts on workers in the fossil fuel industry. We also develop a just transition program to support workers who will be facing displacement as a result of the fossil fuel industry contraction. The next section examines this issue with respect to communities, focusing on communities facing high impacts from the fossil fuel industry contraction. We then consider a range of just transition measures to support these heavily-impacted communities.

3.3.1 Job Losses for Fossil Fuel Industry Workers

In principle, there are 15 industries that would likely be heavily affected by a significant cut in U.S. fossil fuel consumption and production. Of course, the first two would be oil and gas extraction and coal mining themselves. There are also 13 ancillary industries that would be impacted. The first two would be support activities for both oil/gas extraction and coal mining. The 11 additional industries that would be impacted are: gas stations; natural gas distribution; drilling oil and gas wells; wholesale petroleum and petroleum products; fossil fuel electric power generation; pipeline transport; pipeline construction; oil and gas field machinery and equipment manufacturing; other petroleum and coal products manufacturing; and mining machinery and equipment manufacturing.

Table 3.11 lists all of these industries, and the level of direct employment in each of them as of 2018. The total direct employment from all of these industries is at 2.5 million as of 2018, 1.7 percent of the U.S. labor force. The largest source of employment among all of these industries was gas stations, with 765,718 total employment, more than 30 percent of total employment. Oil and gas extraction is the next largest employer, with 636,449 jobs, amounting to another 25 percent of all the fossil fuel industry related jobs. Support activities for oil and gas employ another 129,593, or 15 percent of the total for all fossil fuel-based industries. These largest 3 employers therefore account for around 70 percent of all the jobs tied to fossil fuels.

Table 3.11 Number of Workers in U.S. Employed in Fossil Fuel-Based Industries, 2018

Industry	**2018 Employment Levels**
Gas Stations	765,718
Oil and Gas Extraction	636,449
Support Activities for Oil/Gas	369,646
Natural Gas Distribution	129,593
Drilling Oil and Gas Wells	117,529
Wholesale -Petroleum and petroleum products	114,266
Fossil Fuel Electric Power Generation	98,604
Petroleum Refining	72,495
Coal Mining	55,988
Pipeline Transport	54,285
Support Activities for Coal	38,368
Pipeline Construction	36,690
Oil and Gas Field Machinery and Equipment Manufacturing	29,891
All other petroleum and coal products manufacturing	5,802
Mining Machinery and Equipment Manufacturing	5,133
Fossil Fuel Industry Total	2,530,459
Total Fossil Fuel Employment as Share of U.S. Employment *(U.S. 2018 employment = 148,891,000)*	1.7%

Sources: IMPLAN, 3.0, U.S. Department of Labor.

Among the other industries listed, the total direct employment in coal mining is at about 56,000 as of 2018. Total coal mining employment therefore amounted to only 0.04 percent of all employment in the U.S. in 2018. Even when we add another 38,368 for coal industry support activities, the total still amounts to less than 1/10th of one percent of overall U.S. employment. These figures offer valuable perspective, conveying that the resources that will be required to mount a just transition for these coal industry-related workers should be negligible relative to the size of the overall U.S. labor force.

Treatment of Indirect and Induced Employment Effects

We should note that the ancillary fossil fuel-based industries listed in Table 3.11 approximately match up with the industries in which *indirect employment* occurs resulting through fossil fuel sector production, as defined in the input-output tables, and as we have describe above. In estimating the number of workers who would require some form of support through a just transition program, it is more accurate to focus on the direct employment figures for these 13 ancillary fossil fuel industries as opposed to utilizing the indirect employment data from the input-output tables.

For our purposes of developing a just transition program, we are able to incorporate important details on employment conditions in these 13 ancillary industries by working with the available employment data on the specific industries as opposed to relying on a single generic category of indirect employment for the oil/gas and coal industries. At the same time, for the purposes of drawing comparisons with the figures presented above on employment creation through clean energy investments, it is useful to keep in mind that the figures reported here on ancillary employment relative to the oil/gas and coal industries are the equivalent of the indirect employment figures reported in the clean energy industries.

In drawing out the comparison between employment impacts of clean energy investments versus employment losses through the fossil fuel industry contraction, one should also consider the relative size of the induced employment effects of the fossil fuel industry contraction, as has been described in the employment effect above. As noted above, induced employment effects refer to the expansion of employment that results when people in any given industry – such as clean energy or fossil fuels – spend money to buy goods and services. This increases overall demand in the economy, which means more people are hired into jobs to meet this increased demand. It follows that the loss of incomes through a contraction of employment will create a negative induced employment effect. People will have less money to spend, overall demand for goods and services will contract, and therefore the demand for workers will decline correspondingly. However, because of the way we propose to implement a just transition program for fossil fuel-related industry workers throughout the U.S., there will be no loss of income for fossil fuel-dependent workers in the country, even as the industry itself contracts. It follows that implementing the just transition program will mean that there will also be no induced employment losses in the U.S. labor market even as the fossil fuel industry itself contracts. This will become clear after we describe the features of the proposed just transition program. We therefore return to this issue briefly at the end of this just transition section

Characteristics of Fossil Fuel and Ancillary Industry Jobs

Table 3.12 provides basic figures on the characteristics of the jobs in fossil fuel-based industries. As the table shows, on average, these are relatively high-quality jobs. The average overall compensation level is $109,000. This figure is significantly higher than what was seen above for most of the main supply- and demand-side areas within the clean energy project. With the exception of transmission/storage, average compensation in these other clean energy activities ranged between $70,000 and $83,000.

Workers in these industries are also relatively well off in terms of the benefits they receive from their jobs. Over 75 percent of them receive health insurance from their jobs. This contrasts with the figures we saw above for the clean energy areas, where, again, with the exception of transmission/storage, the share of workers receiving health insurance from their employers ranged between 32 – 57 percent. Nearly 50 percent of workers in the fossil fuel-based sectors also receive pension retirement benefits. Union membership is at 8.8 percent. This is, of course, a low figure, but it is still somewhat higher than the average for the entire U.S. private sector, at only 6.2 percent.

Table 3.12 Characteristics of Workers Employed in Fossil Fuel-Based Sectors in U.S. 2021-2030

	Fossil Fuel-Based industries
Average total compensation	$109,400
Health insurance coverage	75.4%
Retirement benefits	48.6%
Union membership coverage	8.8%
Educational credentials	
Share with high school degree or less	40.0%
Share with some college or Associate degree	27.2%
Share with Bachelor's degree or higher	32.8%
Racial and gender composition of workforce	
Percent People and communities of color	29.2%
Percent Female workers	16.1%

Source: IMPLAN 3.0; CPS 2018-2019

Table 3.12 also reports figures on educational credential levels for workers in each of the 13 industries, as well the percentages of female workers and workers from communities of color. The jobs are distributed fairly evenly with respect to educational credentials, with 40 percent of workers having high school degrees or less, 27 percent having some college and 33 percent with Bachelor's degrees or higher. The share of female workers is quite low at 16 percent. People of color make up nearly 30 percent of the workforce. This is basically the same percentage of people of color in the U.S. overall.

We can gain further detailed information on the composition of the workforce in the fossil fuel-based industries in Table 3.13, in which all the job categories are listed in which 5 percent or more of the workforce is employed. The table shows the highest percentage of jobs, at 14.6 percent, are in various forms of management. Jobs in extraction is the next largest category of employment, at 14.3 percent of all jobs. The representative occupations in these jobs include earth drillers, oil and gas roustabouts, and derrick operators. Generally speaking, as with the areas of employment in clean energy, we see that employment in fossil fuels engages a wide range of workers. Some of them will have skills specific to the industry and will therefore face difficulties moving into new employment areas. The majority of the workers will have jobs that should be transferable to new employment opportunities, in the clean energy economy or elsewhere. More generally, any just transition program to support displaced workers in the U.S. fossil fuel related industries will need to be focused on the specific background and skills of each of the impacted workers. We now turn to considering the specific dimensions and features of such a just transition program.

Table 3.13 Prevalent Job Types in U.S. 's Fossil Fuel-Based Sectors, 2021-2030 (Job Categories with 5 percent or more of employment)

Fossil Fuel-Based Sectors

Job Category	Percentage of Direct Jobs Lost	Representative Occupations
Management	14.6%	Financial managers; marketing managers; financial chief executives
Extraction	14.3%	Earth drillers; oil and gas roustabouts, derrick operators
Transportation and material moving	10.0%	Crane operators, industrial truck operators, pumping station operators
Construction	9.2%	Carpenters, pipelayers, construction equipment operators
Installation and maintenance	9.2%	Maintenance and repair workers; first-line supervisors, industrial machinery mechanics
Architecture and engineering	8.5%	Electrical engineers; mining and geological engineers; engineering technicians
Production	7.7%	Power plant operators, inspectors, welding workers
Office and administrative support	7.6%	Bookkeeping clerks, customer service representatives; secretaries

Source: IMPLAN 3.0; CPS 2018-2019

Estimating Annual Job Losses through Fossil Fuel Contraction

For designing effective just transition initiatives, the most relevant metric will be the rate at which workers are likely to be losing their jobs through the fossil fuel industry contraction. Working within the Chapter 2 model, these rates will differ significantly in the 13 fossil fuel-based industries. This is because the rates at which the oil, natural gas, and coal industries are projected to decline themselves differ significantly in the model.

Based on the varying rates of contraction in oil, natural gas, and coal, as shown in Table 3.10, we estimate in Table 3.14 the total number of jobs that will be lost in the various individual industries. We show these figures separately for the 2020 – 2030 and 2031 – 2050 periods. For both periods, the 10 industries are listed that will experience the most significant job losses. In both periods the largest number of job losses will be in oil and gas extraction. But the figure is relatively small for 2020 – 2030, at 63,645 relative to the 2031 – 2050 period, at 477,337. This disparity is due to the fact that in the 2020 – 2030 period, natural gas does not contract at all, while oil declines by only 20 percent. By contrast, in the 2031 – 2050 period, oil declines to only 5 percent of its 2019 level while natural gas falls by 75 percent. The analysis also shows that all 55,998 jobs in the coal mining sector as of 2018 will be lost by the end of the 2020 – 2030 period.

Table 3.14 Total Job Losses in Major Fossil Fuel-Based Industries, 2021 – 2030 and 2031 – 2050

A) 2021 – 2030 Job Losses

Oil and gas extraction	-63,645
Coal mining	-55,988
Fossil fuel electric power generation	-49,302
Support activities for coal mining	-38,368
Support activities for oil and gas operations	-36,965
Wholesale: Petroleum and petroleum products	-22,853
Petroleum refineries	-14,499
Drilling oil and gas wells	-11,753
Mining machinery and equipment manufacturing	-5,133
All other petroleum and coal products manufacturing	-3,481
Oil and Gas Field Machinery and Equipment Manufacturing	-2,989

B) 2031 – 2050 Job Losses

Oil and gas extraction	-477,337
Gas stations	-382,859
Support activities for oil and gas operations	-277,235
Natural gas distribution	-97,195
Drilling oil and gas wells	-88,147
Wholesale: Petroleum and petroleum products	-85,699
Petroleum refineries	-54,372
Pipeline transportation	-40,714
Fossil fuel electric power generation	-39,441
Pipeline construction	-27,518
Oil and Gas Field Machinery and Equipment Manufacturing	-22,419
All other petroleum and coal products manufacturing	-2,176

These Table 3.14 figures are useful as a first indicator of what will be entailed in designing effective just transition policies. However, by themselves, they do not convey the actual patterns in which workers are likely to experience job losses. To estimate this pattern more accurately, two further considerations need to be incorporated. These are: (1) whether the rate of contraction for any given industry will be steady or episodic; and (2) the rates at which older workers will move into retirement. Of course, workers moving into retirement will not require assistance in finding new jobs. However, it will be critical that the pension funds accrued by these older workers will be available to them in full as they move into retirement. We consider these issues in turn.

Steady versus Episodic Industry Contraction

The scope and cost of any set of just transition policies will depend heavily on whether the contraction is steady or episodic. Under a pattern of steady contraction, there will be uniform annual employment losses over both the 2020 – 2030 and 2031 – 2050 periods, with the steady rates determined by the overall level of industry contraction within the given time period. But it is not realistic to assume that the pattern of industry contraction will necessarily proceed at a steady rate. An alternative pattern would entail relatively large episodes of employment contraction, followed by periods in which no further employment losses are experienced. This type of pattern would occur if, for example, one or more relatively large firms were to undergo large-scale cutbacks at one point in time as the industry overall contracts, or even for such firms to shut down altogether.

The costs of a just transition will be much lower if the transition is able to proceed smoothly rather than through a series of episodes. One reason is that, under a smooth transition, the proportion of workers who will retire voluntarily in any given year will be predictable. This will enable the transition process to avoid having to provide support for a much larger share of workers. The share of workers requiring support would rise if several large businesses were to shut down abruptly and lay off their full work force at once, including both younger as well as older workers. Similarly, it will be easier to find new jobs for displaced workers if the pool of displaced workers at any given time is smaller.

For the purposes of our calculations, we proceed by assuming that the U.S. will successfully implement a relatively smooth contraction of its fossil fuel industries. This indeed would be one important feature of a well-designed and effectively implemented just transition program. As a practical matter, a relatively smooth transition should be workable as long as policymakers remain focused on that goal.

Estimating Attrition by Retirement and Job Displacement Rates

In Tables 3.15 and 3.16 respectively, we show figures on annual employment reductions in the U.S. fossil fuel-based industries over two periods, 2021 – 2030, and 2031 – 2050, that will result through a smooth contraction at the rates described in Table 3.10. That is, coal is phased-out entirely by 2030, while oil declines by 20 percent and natural gas remains intact over this initial period. Then, from 2031 – 2050, oil falls to 5 percent and natural gas falls to 25 percent of 2020 production levels.

We also then estimate the proportion of workers who will move into voluntary retirement at age 65, both by 2030 and by 2050. Once the share of workers who will move into voluntary retirement at age 65 is known, we can then estimate the number of workers who will be displaced through the industry-wide contraction.

Because the rates at which the coal industry is phased out in the Chapter 2 model is much faster than that for oil and gas, we report in Table 3.15 separate figures on contraction rates for the two industries between 2021 – 2030. Table 3.16 then reports figures on contraction rates for the oil and gas industry only, since coal will have been shut down as of 2030.

2021 – 2030 contraction

We begin in Table 3.15 with the total fossil fuel-based industry workforce of 2.5 million workers. Based on the respective contraction rates for the oil, natural gas and coal industries over 2020 – 2030, we estimate that total job losses will be about 305,000 workers over 2021 – 2030. Assuming a smooth pace of contraction, this amounts to an average rate of job losses of 30,500 per year.

Table 3.15 Attrition by Retirement and Job Displacement for Fossil Fuel Sector Workers in U.S., 2021-2030

	All Fossil Fuels	Coal Mining and Related Ancillary Industries	Oil and Gas Extraction and Related Ancillary Industries
1) Total workforce as of 2018	2,530,459	151,693	2,378,766
2) Job losses over 10-year transition, 2021-2030	304,977	151,693	153,284
3) Average annual job loss over 10-year production decline *(= row 2/10)*	30,498	15,169	15,328
4) Number of workers reaching 65 over 2021-2030 (=row 1 x % of workers 54 and over in 2019)	422,436* *(16.7% of all workers)*	38,530 *(25.4% of all workers)*	383,906* *(23.8% of all workers)*
5) Number of workers per year reaching 65 during 10-year transition period (=row 4/10)	42,244	3,853	38,391
6) Number of workers per year retiring voluntarily (80% of 65+ workers)	33,795	3,082	30,713
7) Number of workers requiring re-employment (= row 3 – row 6)	12,087	12,087	0

Source: The 80 percent retirement rate for workers over 65 derived from U.S. Bureau of Labor Statistics: https://www.bls.gov/cps/cpsaat03.htm. According to these BLS data, 20 percent of 65+ year-olds remain in the workforce. Note: *This figure does not include gas station industry workers who are 54 years and older in 2019. This is because it is assumed that the gas station sector will begin to contract until 2031.

As row 2 of the table shows, there will be a roughly equal number of job losses between 2021 – 2030 in coal, at 151,691 and oil/gas, at 153,284. But the big difference between the job losses for coal versus those for oil/gas is that the coal figure represents 100 percent of the industry's entire current workforce, while the oil/gas figure amounts to only 6.4 percent of its current workforce. As a result, with oil/gas, our estimate that nearly 31,000 workers will voluntarily retire every year from their industry jobs once they turn 65 is more than twice as large as the roughly 15,000 job losses per year. This means that, for the oil/gas industry, with voluntary retirements being roughly twice as large as the number of job losses within the industry, the total number of workers that will face displacement and requiring re-employment will be zero. However, all oil/gas industry workers that move into retirement will need to have their pensions fully guaranteed.

By contrast, with the coal industry, it is estimated that 3,082 workers per year will retire voluntarily at age 65 between 2021 – 2030. But with average annual job losses in coal at 15,169, this then means that 12,087 workers will experience displacement per year—i.e. their coal industry jobs will be lost and they will not be choosing to voluntarily retire. All of these roughly 12,000 workers per year will need to receive the full package of just transition support, including guaranteed re-employment, along with income, retraining, and relocation support. All of these workers, along with those who had voluntarily retired, will need to have their pension accounts fully guaranteed. We describe the details of the program below.

2031 – 2050 contraction

In Table 3.16, we now perform the same set of calculations for the contraction process over 2031 – 2050. In this case, the challenge of mounting a just transition will be more substantial since, by 2050, the oil industry will have been reduced to 5 percent of its 2018 employment level and the natural gas industry will have declined by 75 percent relative to 2018. Coal, again, will have been totally phased out by 2030. Table 3.16 shows the impact of the oil/coal contraction over 2031 – 2050.

Table 3.16 Attrition by Retirement and Job Displacement for Fossil Fuel Sector Workers in U.S., 2031-2050

	Oil and Gas Extraction and Related Ancillary Industries*
1) Total workforce as of 2030	2,225,482
2) Job losses over 20-year transition, 2031-2050	1,595,110
3) Average annual job loss over 20-year production decline *(= row 2/20)*	79,756
4) Number of workers reaching 65 over 2031-2050 (=row 1 x % of workers between 34 and 55 years in 2019)**	1,138,707 *(45% of all workers)*
5) Number of workers per year reaching 65 during 20-year transition period (=row 4/20)	56,935
6) Number of workers per year retiring voluntarily	45,548 *(80% of 65+ workers)*
7) Number of workers requiring re-employment (= row 3 – row 6)	34,207

Source: The 80 percent retirement rate for workers over 65 derived from U.S. Bureau of Labor Statistics: https://www.bls.gov/cps/cpsaat03.htm. According to these BLS data, 20 percent of 65+ year-olds remain in the workforce. Note: *As indicated in Table 3.15, coal mining and related ancillary industries will have 0 employment as of 2030. **This is an underestimate of the percent of workers reaching retirement age which assumes that all workers ages 55 and older as of 2019 will have retired and been replaced by young workers in industries, such as gas stations, that are not contracting during 2021-2030. However, such industries may, in fact, hire workers to replace retiring workers during 2021-2030 that are not young. If this occurs, then the percent of workers reaching retirement age during 2031-2050 would be larger than the 45 percent figures used.

As seen in Table 3.16, about 2.2 million workers will remain employed in the oil and natural gas industries as of 2030, after about 150,000 jobs will have been lost between 2021 - 2030. A bit less than 1.6 million jobs will then be lost over the 20-year transition from 2031 – 2050. This amounts to an annual rate of employment decline of about 80,000 jobs per year. At the same time, we estimate that about 57,000 workers will turn 65 each year during this 20-year transition period. With an 80 percent voluntary retirement rate among workers turning 65, this then means that about 45,500 workers over 65 will choose retirement. The net effect over 2031 – 2050 will be that 34,200 workers per year will become displaced. These 34,000 workers per year will require a full set of just transition support policies, including re-employment, retraining, and relocation support. This will be in addition to the pension guarantees that will have been put in place during the first 2021 – 2030 contraction phase.

3.3.2 Features of Just Transition Program

We describe here a just transition program for workers in the U.S. fossil fuel-based industries that includes five components:

- **Pension guarantees.** This form of support will be provided for all workers, those moving into retirement as well as those with ongoing accounts through their employers.
- **Employment guarantees.** These would be jobs provided through clean energy investments as well as public-sector employment more generally.
- **Wage insurance.** Displaced workers will be guaranteed three years of compensation at their new jobs that will at least equal their pay levels in their fossil fuel-based industry jobs.
- **Retraining support.** This would include two years of retraining, as needed for all displaced workers.
- **Relocation support.** Workers will be guaranteed a one-time payment of $75,000 to relocate, as needed. This assumes one-half of all displaced workers will require this support.

Table 3.17 lists this full set of policy proposals, along with proposed budgetary outlays per workers for each measure. Table 3.18 then shows our overall budget estimates for the income, retraining, and relocation support programs.

Table 3.17 Policy Package for Displaced Workers in U.S.

Fossil Fuel-Based Industries

Pension guarantees for workers (65+) voluntarily retiring	**Legal pension guarantees**
Employment guarantee	Jobs provided through clean energy and public infrastructure investment expansions
Wage insurance	Displaced workers guaranteed 3 years of total compensation at levels in fossil fuel-based jobs
Retraining support	2 years of retraining, as needed ($4,000 in tuition and fees, $2,000 in other expenses)
Relocation support	$75,000 for one-half of displaced workers

Source: American Association of Community Colleges, "DataPoints: Tuition and Fees," 6/18/2020, see: https://www.aacc.nche.edu/2020/06/18/datapoints-tuition-and-fees/.

Table 3.18 Total and Annual Average Costs for Just Transition Support for Displaced Fossil Fuel-Based Workers

A. Years: 2021-2030

Year	**Income support** *(3 years of support for 12,087 coal workers/ year)*	**Retraining support** *(2 years of support for 12,087 coal workers/ year)*	**Relocation support** *(1 year of support for 12,087 coal workers/ year)*	**Total** (= Cols. 1+2+3)
Total Costs	$11.9 billion	$1.5 billion	$4.5 billion	$17.9 billion
Average Annual Costs	$991.1 million *(12 years of support)*	$131.9 million *(11 years of support)*	$453.3 million *(10 years of support)*	$1.5 billion *(12 years of support)*

B. Time Period: 2031-2052

Year	**Income support** *(3 years of support for 34,207 oil and gas workers/year)*	**Retraining support** *(2 years of support for 34,207 oil and gas /year)*	**Relocation support** *(1 year of support for 34,207 oil and gas/ year)*	**Total** (= Cols. 1+2+3)
Total Costs	$49.1 billion	$8.2 billion	25.7 billion	$82.9 billion
Average Annual Costs	$2.2 billion *(22 years of support)*	$0.4 billion *(21 years of support*	$1.3 billion *(20 years of support)*	$3.8 billion *(22 years of support)*

Note: Appendix 6.4 presents detailed annual calculations.

Before reviewing these cost estimates, we should explain why we are assuming that the pension fund guarantee program should be able to operate on a modest budget, covering only administrative costs, under the auspices, for example, of the federal Pension Benefit Guarantee Corporation (PBGC). As the agency tasked with enforcing the pension guarantees for fossil fuel-based workers, the PBGC could enact regulations to prohibit fossil fuel-based companies from paying dividends or financing share buybacks until their pension funds have been brought to full funding and then maintained at that level. As needed, the PBGC could also consider placing liens on company assets when pension funds are underfunded. Through such measures, the pension funds for most of the affected workers can be protected through a regulatory intervention alone, without the government having to provide financial infusions to sustain the funds.

At the same time, it will be likely that one or more of the firms will experience serious financial crises in the future. Within the context of the Chapter 2 model, this will most immediately be the case for the coal companies, with phase downs for oil and natural gas occurring more gradually over 2031 – 2050. In fact, some coal companies operating throughout the U.S. do now already face critical conditions with their pension funds, due to cutbacks in U.S. coal demand. In addressing the ongoing crisis with coal industry pensions, the Obama administration had proposed in 2015 a measure to support the pensions, under its “Power Plus” program that aimed broadly to support coal communities and workers.[7]

This proposal was blocked in the U.S. Congress by the Republican majority. But the broader point is that the equivalent of such a measure will need to be included as a centerpiece for the U.S. just transition program. The costs of this intervention could nevertheless be minimized to the extent that the PBGC operates effectively as a regulator during the fossil fuel industry phase down.

For estimating the costs of the income, retraining, and relocation support programs, as shown in Table 3.17, the overall set of policies will run for two years beyond 2050, to 2052. This is because displaced workers will be receiving 3 years of income support and two years of retraining support, including those workers who are displaced in 2050 itself.

As seen in Table 3.18, total costs for 2021 will be $17.9 billion for 2021 – 2030 and $82.9 billion for 2031 – 2050. The full 2021 – 2050 costs will therefore be just over $100 billion. The average costs will amount to $1.5 billion per year over 2021 – 2030, including $991 million for income support, $132 million for retraining, and $453 million for relocation support. For 2031 – 2050, we estimate overall average costs to be $3.8 billion per year, with $2.2 billion in income support, $0.4 billion for retraining and $1.3 billion for relocation support. Appendix 6.4 presents the full set of calculations whose results we summarize in Table 3.18. Overall, even during the high-cost period of 2031 – 2050, the $3.8 billion per year amount to less than one one-hundredth of 1 percent of average U.S. GDP over 2031 – 2050, assuming the U.S. economy grows at 2.2 percent per year between the most recent actual data of 2019 and 2050.[x]

3.4 Just Transition for Fossil Fuel-Dependent Communities

Communities that are dependent on the fossil fuel industry will face formidable challenges adjusting to the decline of the industry. This will be true even if all workforce reductions can be managed through a combination of attrition by retirement along with job guarantees for younger workers facing layoffs, and if all pension fund obligations to retired fossil fuel workers are honored in full. It is therefore imperative that effective community support programs be included as a major element of an overall just transition program for U.S. fossil fuel workers.

In seeking to develop such a program, it is first necessary to recognize the extent to which fossil fuel production in the U.S. is concentrated geographically. Five states –Kentucky, Montana, Pennsylvania, West Virginia, and Wyoming – account for nearly 70 percent of all U.S. coal production. But even within these five states, coal industry jobs represent a low percentage of overall statewide employment. In fact, as seen in Table 3.19 only five states employ more than 4,000 people total in the coal industry – West Virginia, Kentucky, Pennsylvania, Wyoming, and Alabama. West Virginia has the highest share of coal employment, with the 14,146 coal industry workers representing 2.6 percent of the overall statewide workforce. In Wyoming, the 5,294 coal industry workers represented 2.5 percent of the state's overall workforce. As the table shows, these are the only two states in which coal industry jobs exceed one percent of overall statewide employment.

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x Average U.S. GDP between 2031 and 2050 will be $35.3 trillion, assuming the U.S. economy grows at an average annual rate of 2.2 percent between 2019 and 2050.

Table 3.19 U.S. Coal Employment in States with 3,000 or More Employees, 2019

	Coal Employment	**Total State Employment**	**Coal as share of total Employment (%)**
West Virginia	14,136	553,604	2.6%
Kentucky	6,849	1,606,009	0.4%
Pennsylvania	5,568	5,248,989	0.1%
Wyoming	5,294	211,524	2.5%
Alabama	3,133	1,622,325	0.2%

Source. Quarterly Census of Employment and Wages from Bureau of Labor Statistics; https://www.bls.gov/cew/. Figures are for private employment.

In fact, coal production is further concentrated by county within these heavily-producing states. Four counties produce 52 percent of Kentucky's coal output, a single county produces 58 percent of Montana's output, two counties produce 77 percent of Pennsylvania's output, six counties produce two-thirds of West Virginia's output, and Campbell County alone in Wyoming itself produces 89 percent of that state's output.

The level of geographic concentration for U.S. oil and gas production is roughly equivalent to that for coal. The top three states in oil production – Texas, North Dakota, and New Mexico along with offshore federal waters – account for 76 percent of all U.S. production, with Texas by itself accounting for 41 percent. With natural gas, the top five producing states – Texas, Pennsylvania, Louisiana, Oklahoma and Ohio – account for 62 percent of total production, with Texas alone producing 22 percent.[8]

Table 3.20 lists the 7 states in which oil and gas employment reaches 15,000 or higher – Texas, Oklahoma, Louisiana, Colorado, New Mexico, North Dakota, and Pennsylvania. In terms of employment, as seen in Table 3.10, Texas has the largest number of employees, at 234,022, while Wyoming has the highest proportion, at 5.9 percent of total employment. In addition to Texas and Wyoming, seven other states have employment levels in oil and gas exceeding 1 percent of total statewide employment. These are Oklahoma, Louisiana, Colorado, New Mexico, North Dakota, Alaska, and West Virginia.

Table 3.20 U.S. Oil and Gas Extraction Employment in States with 15,000 or more Employees. 2019

	Oil and Gas		**Oil and Gas**
	Extraction Employment	Total State Employment	Share of Total Employment (%)
Texas	234,022	10,691,618	2.2%
Oklahoma	45,587	1,295,884	3.5%
Louisiana	33,563	1,611,229	2.1%
Colorado	24,070	2,308,090	1.0%
New Mexico	21,799	657,218	3.3%
North Dakota	19,311	351,482	5.4%
Pennsylvania	17,546	5,248,989	0.3%

Source. Quarterly Census of Employment and Wages from Bureau of Labor Statistics. https://data.bls.gov/cew/apps/data_views/data_views.htm#tab=About

The impact of a long-term phase-down in the fossil fuel industry will of course be felt most acutely in these states and counties where production is highly concentrated. Most of the rest of the country is likely to experience negative effects to a much lesser degree, if at all.

Large cities tied to the fossil fuel industry, such as Houston and Dallas, will unavoidably face big adjustments, similar to those experienced by major manufacturing cities such as Detroit and Pittsburgh over the past three decades. But smaller communities that are less diversified will experience still greater losses. Midland Texas, a city of 145,000 residents, had been relying on both traditional oil and gas extraction as well as more recent shale oil projects to generate about two-thirds of the city's overall economic activity.[9] As a result, Midland and its sister city Odessa boomed when oil prices were rising and the shale oil extraction industry were growing. For example, real earnings for fossil fuel workers in the area rose by an average of 22 percent between 2006 – 2014, due especially to the growth in shale oil extraction.[10] But the area then experienced a loss of about 13,000 jobs in 2015 – 7.5 percent[xi] of the area's overall workforce – when oil prices fell that year.[11] More recently, between January – April 2020, the area experienced nearly 37,000 job losses – over 18 percent of the area's total workforce – as global oil prices fell by over 70 percent. Without an effective transition program, this pattern of sharp decline will persist in this and similarly oil and gas dependent communities.[12]

The situation is, again, still worse for coal-dependent communities. For example, in Boone County, West Virginia, in 2009, 52 percent of all jobs were with the region's coal industry.[13] By 2019, that figure had fallen to 23 percent. In total, the coal industry employed about 3,600 people in Boone County in 2009. That figure fell to 737 as of 2019.[14] In 2019, reflecting this pattern of employment decline, county employees were asked to take 20 percent pay cuts.[15] Again, in the absence of a well-functioning transition program, this pattern will only become more severe in Boone County and similarly coal-dependent communities.

Experiences with Community Transition Projects

The U.S. can advance viable readjustment programs that are capable, at least, of significantly softening the blows to be faced by Midlands, Boone County, and many similarly-situated communities. The fact that U.S. fossil fuel production is so highly concentrated should make the task less difficult to accomplish, since there will be only a relatively small number of heavily impacted communities.

In addition, critically, the decline of the fossil fuel industry will be occurring in conjunction with the rapid expansion of the clean energy economy. This should provide a basic supportive foundation for advancing effective community transition policies, in ways similar to what has already been discussed in terms of providing job opportunities for younger displaced fossil fuel industry workers.

Within this broader clean energy investment program, policies can be designed so that regions and communities that are heavily dependent on fossil fuel industries will receive disproportionate support to advance regionally appropriate clean energy projects. For example, in a 2019 report, the Reclaiming Appalachia Coalition proposed projects in three areas for their region: solid waste, recycling, and sustainable management materials; technology; and recreation and ecotourism.[16]

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xi According to BLS figures, the Midland-Odessa Combined Statistical Area had 173,000 employed persons in January 2015, and 160,000 employed persons in January 2015. The decline of 13,000 is therefore a loss of 7.5 percent.

The Appalachian region could also receive extra support for upgrading the energy efficiency of their building stock and electrical grid transmission system. As another example, Texas and Wyoming could receive support to build wind energy production projects in their respective high-wind areas. One major project area for all fossil fuel dependent regions is, straightforwardly, to reclaim the land that has been damaged through mining and extraction operations.

Previous federal programs can serve as useful models on how to leverage this wave of clean energy investments to also support fossil-fuel dependent communities facing transition. There are both positive and negative lessons on which to build.

Reclamation

Reclamation of abandoned coal mines as well as oil and gas production sites is one major category of community reinvestment that should be pursued as the fossil fuel industry contracts. Moreover, the Federal Government already has extensive experience financing and managing reclamation projects, beginning with the passage of the Abandoned Mine Land (AML) program in 1977, as one part of the broader Surface Mine Control and Reclamation Act. The program has been funded through fees charged to U.S. mining companies, with the fees having been set as a percentage of market prices for coal. In the early years of the program, the fees amounted to about 1.6 percent of the average price of a ton of surface coal and 0.7 percent of underground coal. However, the fee rates have declined sharply over time, to less than half their initial value as of 2013. Since its inception, the program has generated around $9 billion in total fees.

As of the most recent Department of Interior figures, the program had reclaimed over $5.9 billion worth of damaged sites spanning roughly 800,000 acres.[17] But a 2015 study by Dixon and Bilbrey estimates that at least an additional $9.4 billion will be needed to remediate the approximately 6 million acres of land and waters that remain damaged through mining and abandonment.[18] In 2016, the Obama administration had proposed a Power Plus Plan through which $1 billion from the existing pool of AML funds would be disbursed, with about 1/3 of these funds targeted for the Central Appalachian states. These funds would have represented significant support. But this $1 billion budget would still have represented only about 10 percent of the nearly $10 billion Dixon and Bilbrey estimate will be needed to adequately remediate the roughly 6 million acres that remain damaged.

The Obama program was never enacted once Donald Trump assumed the presidency in January 2017. But the reclamation of the abandoned coal mines still needs to be accomplished.[19] Otherwise, the damaged 6 million acres will continue to face severe problems, including, as Dixon and Bilbery write, “landslides, the collapse of exposed highwalls, mine fires, subsidence caused by the deterioration of underground mines, water problems caused by abandoned mine pollution, and more”.[20] Dixon and Bilbery further argue that “these problems continue to markedly impede local economic development and threaten the livelihoods of citizens”.[21]

There are no comparable federal reclamation projects for abandoned oil and gas extraction production sites. However, in June 2020, the U.S. Congress began considering legislation to plug so-called orphaned[xii] oil and gas wells.[22]

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xii To be more precise, the term “orphan well” is an legal term that can be used for regulatory purposes by relevant federal or state-level regulators. Related terms are “marginal,” “inactive” and “idle” wells. Biven (forthcoming 2020) reviews these issues in detail.

Orphaned wells are abandoned oil and gas wells for which no viable responsible party can be located. Idle oil and gas wells emit pollutants into the air, including hydrogen sulfide and organic compounds that contribute to ground-level ozone.

The one-time owners of these wells earn revenues during the wells' productive lives. They then frequently file bankruptcy to shield assets from creditors and then "orphan" the wells. At that point, the costs and responsibility to decommission and plug the wells becomes a matter of public policy intervention.

The policy measure that was introduced into the House of Representatives in June 2020 was included in the $1.5 trillion Moving Forward Act.[23] This bill included $2 billion to support well-plugging programs. But this budgetary figure assumes that there are only about 57,000 orphaned wells around the country and that the average clean-up cost would be $24,000. By contrast, in 2018, the U.S. Environmental Protection Agency estimated the number of orphaned onshore wells to be between 2.3 and 3 million – that is, more than 30 times the number of wells estimated in the House bill.[24] The total number of orphaned wells has been increasing due to the recent global oil price collapse, and will increase further, of course, as the clean energy transition proceeds.[25] Moreover, a recent report on the costs of plugging orphaned wells in Ohio put this figure at $110,000, more than 4 times the amount included in the House bill. In short, plugging orphaned oil and gas wells should be recognized as a major reclamation project. It can also generate thousands of long-term jobs for former oil and gas field workers.

At the same time, while recognizing the imperative of reclamation projects, it is also important to not overstate their potential as an engine of long-run community development. For one thing, beyond the clean-up work itself, even when such projects are substantial, one cannot expect that a broader set of community-based development projects will inevitably emerge as spillover effects tied to the reclamation projects. In addition, reclamation projects are generally highly capital intensive. As such, on their own, they are not likely to produce large numbers of new job opportunities for workers laid off through declining fossil fuel production. It is therefore critical to also examine experiences and prospects for repurposing beyond reclamation in the current fossil fuel-dependent communities.

Repurposing

One important example of a federal government-directed repurposing project was the Worker and Community Transition program that operated through the Department of Energy from 1994 – 2004. Its mission was "to minimize the impacts on workers and communities caused by changing Department of Energy missions." This program, along with related initiatives, was targeted at 13 communities which had been heavily dependent on federal-government operated nuclear power and weapons facilities but subsequently faced retrenchment due to nuclear decommissioning.

The conditions faced by the nuclear power-dependent communities and the aims of the repurposing program for them have useful parallels with the challenges that will be faced by many fossil fuel dependent communities. To begin with, for security reasons, the nuclear facilities were located in rural areas. Most fossil fuel extraction sites are also in rural areas, as determined by the location of the fossil fuel deposits. As a result, in most cases, with both the nuclear weapons facilities and the fossil fuel production sites, the surrounding communities and economies became heavily dependent on these single activities.

Finally, both with the nuclear and fossil fuel-dependent communities, the opportunities are limited to directly repurpose much of the physical infrastructure in place[xiii], since that infrastructure was built to meet the specific needs of each of the industries.[26]

Operating with such constraints, the Worker and Community Transition program provided grants as well as other forms of assistance in order to promote diversification for these 13 nuclear energy-dependent communities and to maintain jobs or create new employment opportunities. The program targeted sites where job losses exceeded 100 workers in a single year. It encouraged voluntary separations, assisted workers in securing new employment, and provided basic benefits for a reasonable transition period. The program also provided local impact assistance and worked with local economic development planners to identify public and private funding and assist in creating new economic activities and replacement employment. Annual appropriations for the program totaled around $200 million in its initial years but became much smaller—in the range of $20 million – in the final years of operation.

Lynch and Kirshenberg, writing in the *Bulletin of the Energy Communities Alliance*, provide a generally favorable assessment of the program.[27] They conclude as follows:

> Surprisingly, the 13 communities, as a general rule have performed a remarkable role in attracting new replacement jobs and in cushioning the impact of the cutbacks at the Energy-weapons complex across the country … The community and worker adjustments to the 1992 – 2000 DOE site cutbacks have been strong and responsive, especially when compared with any other industrial adjustment programs during the same decade..[28]

The experience in Piketon, Ohio provides a good case study of how this program has operated in one community. Piketon had been the home of a plant producing weapons-grade uranium that closed in 2001. The workers in the plant were represented by the Oil Chemical and Atomic Workers union (OCAW) which merged in 1999 with the United Steel Workers. The union leadership was active in planning the plant's repurposing project. The closure could have been economically devastating for the region, but the Federal Government provided funding to clean up the 3,000 acre complex[xiv]. The clean-up operation began in 2002, and is scheduled to take 40 years to complete.[29] Currently 1,900 workers are employed decontaminating the site at a cost of $300-$400 million a year. The contractor hired to clean up the site employs union workers and the president of the USW local union is enthusiastic about the long-term prospects for the project and the site.[30]

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xiii With respect to repurposing the infrastructure around the nuclear sites, Lowrie et al. (1999) write that "much of federal investment leaves behind little usable on-site infrastructure to provide long-term economic benefits to a region. For instance, there are odd-shaped buildings, unusable waste management systems, and roads and railroads with inefficient locations. It is hard to convert resources for arms production to civilian uses because the technologies are significantly different and the workers skills are unique," (pp. 120 – 121).

xiv In May 2016 Congress legislated to maintain funding for the site.

Despite the positive achievements with projects such as Piketon, Lynch and Kirshenberg also note more generally that "The most serious problem facing the energy-impacted communities…was the lack of a basic regional economic development and industrial diversification capacity for most of the regions affected by the cutbacks…" A separate study by Lowrie et al. reaches the same conclusion.[31] They write:

> The community transition efforts thus far are inadequate, and the cleanup funds being distributed to the sites have become a substitute for adjustment to a post-Department of Energy world. Continued dependence on cleanup jobs at the sites rather than transitioning to a non-DOE economy will exact a toll on long-term economic sustainability (p. 121).

To address this problem directly, community assistance initiatives could encourage the formation of new clean energy businesses in the affected areas. One example of a successful diversification program was the repurposing of a nuclear test site in Nevada to what is now a solar proving ground. More than 25 miles of the former nuclear site are now used to demonstrate concentrated solar power technologies and help bring them to commercialization.[32]

Another important set of examples with community transition has been the integration of clean renewable energy sources – primarily wind and solar power – into Alaska's longstanding and extensive energy microgrid infrastructure. A microgrid is a localized power grid. Some are connected to larger traditional power grids, and can disconnect to operate autonomously, though not all have that capacity. Others, like most of the microgrids in Alaska, operate on their own, with no connection to a larger transmission system. More than 200 microgrid systems are operating in Alaska, mostly in the state's geographically remote areas, where it is difficult and expensive to connect to the closest available larger power grid.

Since the 1960s, these grids have been heavily reliant on diesel generators. But since around 2005, renewable energy has become an increasingly significant alternative to diesel fuel. As of 2015, the Alaska Center for Energy and Power described this development as follows:

> Over the past decade, investment in renewable energy generation has increased dramatically to meet a desire for energy independence and reduce the cost of delivered power. Today, more than 70 of Alaska's microgrids, which represent approximately 12 percent of renewably powered microgrids in the world, incorporate grid-scale renewable generation[xv], including small hydro, wind, geothermal, solar and biomass.[33]

The initial motivation for the transition from diesel to renewable energy was cost. Delivering diesel to Alaska's more remote areas can be extremely expensive, up to $1 per kilowatt hour of electricity. With wind and especially solar costs having fallen significantly over the past decade, they are capable of delivering electricity to the microgrids at significant cost savings.[xvi] But more generally, the development of renewable energy-powered microgrids in Alaska provides an innovative model for repurposing former fossil fuel based energy operations.

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xv For more detailed analyses of various aspects of the renewable energy transition in Alaska's microgrids, see the special November 2017 issue of the *Journal of Renewable and Sustainable Energy*, "Technology and Cost Reviews for Renewable Energy in Alaska: Sharing Our Experience and Know-How".

xvi Erin Whitney, the editor of the special issue of the *Journal of Renewable and Sustainable Energy*, writes in her preface that "the driving factor for renewable energy implementation in remote grids in Alaska is the reduction in the cost of energy" (see Whitney (2017)).

Among other features of this energy transition in Alaska is that the publicly-funded Alaska Network for Energy Education and Employment (ANEE) is providing training programs to enable local community residents to manage the renewable-based microgrid operations themselves.[34]

There are also important cases of successful repurposing projects in other countries. Most prominent has been the experience in Germany's Ruhr Valley, which has been the traditional home for its coal, steel and chemical industries. Since the 1990s, the region has advanced industrial policies to develop new clean energy industries.[xvii] As one important example of this repurposing project in the Ruhr region, RAG AG, a German coal-mining firm, is in the process of converting its Prosper-Haniel coal mine into a 200 megawatt pumped-storage hydroelectric reservoir that acts like a giant battery. The capacity is enough to power more than 400,000 homes in North-Rhine Westphalia.[xviii] In addition to hydroelectric power storage, the company is also erecting wind turbines on the top of tall waste heaps and installing solar panels on the slopes. Other firms in the region have branched into producing wind and water turbines. This regional transition project has succeeded through mobilizing the support of the large coal, steel and chemical companies and their suppliers, along with universities, trade unions and government support at all levels.

U.S. Defense Industry Conversion

With respect to the U.S. challenge specifically, it is important to keep in mind that the extent of the overall community displacement that will result through the clean energy transition will be no greater than what the U.S. experienced after the end of the Cold War. Between 1987 and 1996, 1.4 million jobs were lost overall in the defense and aerospace industries, a 40 percent decline.[35] San Diego and Philadelphia both lost around 50,000 jobs over this period[xix], representing declines in both cases of about 6 percent of their respective workforces.[36]

The Federal Government did advance substantial transition programs during this period, in particular through the Defense Reinvestment and Conversion Initiative. The total funding for the program amounted to more than $16.5 billion over the years 1993 to 1997 (i.e., about $4 billion per year). A 1999 study by Powers and Markusen found that these programs were adequate in terms of overall funding levels, at about $12,000 per displaced worker. Still, Powers and Markusen concluded that the program did not succeed in terms of supporting the well-being of the individual workers and their communities. This was because the transition policies were primarily focused on providing support for the defense industry contractors, through promoting mergers and the expansion of foreign weapons markets. The laid off workers often did not find the assistance necessary to make satisfactory job and career changes.

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xvii The general descriptions in this paragraph is based on Galgoczi (2014) and Dohmen and Schmid (2011) (see Bibliography).

xviii See, for example, Chow (2017) (see Bibliography).

xix Employment in Philadelphia in 1987 was 772,300, so employment loss was 6.5 percent Employment in San Diego that year was 851,000, so employment loss was 5.9 percent; BLS, Employment, Hours and Earnings—State and Metro Area, from the Current Employment Statistics, data can be queried via http://www.bls.gov/data/#employment (see "Databases, Tables & Calculators By Subject").

It is not realistic to expect that transitional programs will, in all cases, lead to developing new economic bases that support a region's previous level of population and community income. In some cases, the role of community assistance will be to enable communities, moving forward, to shrink to a size that a new economic base can support. Moreover, the Cold War conversion experience makes clear that mounting a federal transition program, even if it is well-funded, is not a solution in itself. As seen in some cases with repurposing nuclear waste sites and in the experiences in Germany's Ruhr Valley, the central challenge will be to effectively integrate transition programs with the coming wave of public and private investments in energy efficiency and clean renewable energy and the millions of new job opportunities generated by these investments.

3.5 Good Quality and Equal Access for Clean Energy Jobs

What is clear from the evidence we have reviewed is that large-scale job creation will certainly result in all regions of the U.S. economy through clean energy expenditures on both the supply and demand sides of this nationwide project, with budgetary levels in the range of about $500 billion per year on average between 2021 – 2030. But it is also clear that these will not necessarily all be good-quality jobs or that these newly-created jobs will be broadly accessible to all population cohorts within the overall U.S. labor force. As we have seen, average compensation varies widely in the various clean energy activities, from roughly $70,000 - $140,000, depending on the sector. Representation by women and people of color is also generally low, as is union membership.

It is critical that the large-scale expansion of employment opportunities that will result through clean energy investments actively address these concerns, to maximize the extent to which the jobs that are created will be good-quality jobs, and that these newly-created jobs are widely accessible to all population groups. This includes the workers who will have become displaced by the contraction of the U.S. fossil fuel industry. It also includes women and people of color, groups that, as we have seen, are now underrepresented in the main areas of clean energy employment.

To advance these two critical goals – an abundance of good quality jobs in the clean energy economy and wide access to these newly-created jobs – we consider now the role of three major tools for achieving these critical goals (i.e., labor unions, job training programs, and affirmative action policies).

3.5.1 Labor Unions and Labor Standards[xx]

The important role that can be played by unions in supporting high-quality employment in the clean energy economy becomes clear in comparing the respective recent experiences in the solar energy installation sectors in California and Arizona. The California sector operates within a framework of relatively strong unions and labor laws while these are both relatively weak in Arizona. A 2014 study by University of Utah economist Peter Phillips describes how these distinct institutional settings play out within the respective state-level solar installation labor markets. Phillips writes:

> Jobs building utility-scale solar electricity generating facilities are not inevitably good jobs paying decent wages and benefits and providing career training within construction. Under some labor market conditions, many solar farm jobs can be bad jobs paying low wages, with limited benefits or none at all, working for temporary labor agencies with no prospect for training, job rotation, or career development.
>
> In California, this low-road approach to utility-scale solar construction is uncommon for several reasons. First, when any federal funds are involved, the project is governed by federal prevailing wage regulations mandating that, for each occupation on the project, the wage in the local area that prevails for that occupation, based on Davis-Bacon surveys, must be paid.
>
> All states are covered by the federal Davis-Bacon Act, but in some states, such as Arizona, for some construction crafts, nonunion rates prevail in many counties, meaning that prevailing wage jobs can be paid low wages with limited benefits. In California, union strength has meant that in most cases on prevailing wage solar projects, workers will get paid good wages with good benefits. State right-to-work laws play a role in determining union strength. By undercutting union strength, Arizona's right-to-work law plays a role in determining the low-road practices found on some solar farm construction in that state. In contrast, California's resistance to right-to-work regulations reinforces federal Davis-Bacon wage mandates, thereby helping lead California's solar farm work along a high-road approach to construction.

3.5.2 Worker Training

In addition to the support for good clean energy industry jobs provided by unions and labor standards, it will also be critical that workers have access to high-quality training programs that will enable them to enter their new jobs with the skills they need to succeed. Without high-quality and accessible training opportunities, the likelihood increases that labor force quality standards will become compromised. The importance of providing high-quality training programs for workers entering the clean energy economy are reflected in a 2018 survey conducted jointly by the National Association of State Energy Officials (NASEO) and the Energy Futures Initiative (EFI), in which, among other questions, employers in clean energy sectors were asked whether they faced difficulties in hiring new workers. This survey found that a high proportion of clean energy employers are facing significant challenges in finding qualified people to hire.

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xx In our discussion, the term "union" refers only to the traditional definition of unions, i.e., an organization that has been certified under the provisions of the National Labor Relations Act to represent employees. For example, the Current Population Survey which provides the micro-data on job characteristics in this section, only asks about formal union membership. However, other labor organizations such as worker centers and worker collectives could also serve the same purpose as traditional unions. Worker centers frequently represent low-wage and immigrant workers and aim to achieve similar objectives as traditional unions—they are institutions through which workers and their communities can advocate collectively for their interests. For examples of such organizations, see: https://aflcio.org/what-unions-do/social-economic-justice/worker-centers, and https://www.epi.org/publication/bp159/.

We present the main results of this survey in Tables 3.21 and 3.22. We show the survey results in the three largest areas of clean energy employment to date in the U.S. – i.e., energy efficiency, in which 2018 employment was at 2.3 million; solar electricity, with 242,343 people employed; and wind electricity, with 111,166 people employed. We present figures for each clean energy sector broken out according to sub-sectors, including construction; professional/business services; manufacturing; wholesale trade, distribution and transport; utilities; and other services.

Table 3.21 Firms that Reported Hiring Difficulties in Solar, Wind, and Energy Efficiency Sectors

3.21A) Energy Efficiency; 2018 Employment = 2.3 million

		Firms Reporting Hiring Difficulties		
	2018 Employment Level	**Somewhat difficult**	**Very Difficult**	**All firms reporting difficulties**
Construction	1.30 million	32%	52%	84%
Professional/business services	484,481	21%	61%	82%
Manufacturing	321,581	14%	58%	72%
Wholesale trade, distribution, transport	180,339	24%	48%	72%
Other Services	42,881	40%	36%	76%

Source: *The 2019 U.S. Energy & Employment Report*, https://www.usenergyjobs.org/

3.21B) Solar Electric Power; 2018 Employment 242,343

		Firms Reporting Hiring Difficulties		
	2018 Employment Level	**Somewhat difficult**	**Very Difficult**	**All firms reporting difficulties**
Construction	177,320	54%	31%	85%
Professional/business Services	48,142	57%	16%	73%
Manufacturing	46,539	60%	18%	78%
Other services	32,937	54%	23%	77%
Wholesale trade, distribution, transport	26,759	73%	6%	79%
Utilities	3,295	31%	31%	62%

Source: The 2019 U.S. Energy & Employment Report, https://www.usenergyjobs.org/

3.21C) Wind Electric Power; 2018 Employment 111,166

		Firms Reporting Hiring Difficulties		
	2018 Employment Level	**Somewhat difficult**	**Very Difficult**	**All firms reporting difficulties**
Construction	36,706	58%	28%	86%
Professional/business services	27,058	66%	15%	81%
Manufacturing	26,490	53%	26%	79%
Wholesale trade, distribution, transport	11,783	77%	8%	85%
Utilities	6,231	50%	33%	83%
Other services	2,898	40%	33%	73%

Source: *The 2019 U.S. Energy & Employment Report*, https://www.usenergyjobs.org/

Table 3.22 Summary Figures: All Firms Reporting Hiring Difficulties in Energy Efficiency, Solar Electricity and Wind Electricity Sectors

	Energy Efficiency	**Solar Electricity**	**Wind Electricity**
Construction	84%	85%	86%
Professional/business services	82%	73%	81%
Manufacturing	72%	78%	79%
Wholesale trade, distribution, transport	72%	77%	85%
Utilities	---	79%	83%
Other services	76%	62%	73%

Source: *The 2019 U.S. Energy & Employment Report*, https://www.usenergyjobs.org/

In the energy efficiency sector, the largest source of employment by far is in construction, with 1.3 million out of the total employment of 2.3 million (i.e., 56 percent of total energy efficiency investment). As seen in Table 3.21A that fully 84 percent of employers reported difficulties in hiring workers, with 52 percent finding it "very difficult" to hire qualified workers.

The results are only moderately lower in the other sub-sectors within energy efficiency. Thus, manufacturing firms reported the lowest level of hiring difficulties, at 72 percent. We see in Tables 3.21 B and C, as well as in the summary Table 3.24, these patterns are similar in the solar and wind electricity sectors and sub-sectors as well.

The survey further found that "lack of experience, training or technical skills" was the most important reason that employers were facing difficulties in hiring workers. The other, less significant factors were location and a relatively small applicant pool.

The study's conclusion from these survey results is that "The need for technical training and certifications was also frequently cited, implying the need for expanded investments in workforce training and closer coordination between employers and the workforce training system".[37]

It is clear therefore that high-quality and accessible workforce training programs need to be included as an important component of the overall clean energy investment project in the U.S. Some crucial features of what would constitute such programs have been well described in recent research by Ellen Scully-Russ.[38]

Scully-Russ provides case study evidence on two successful clean energy training programs that operated in Vermont and Oregon respectively. The two programs were the Vermont Growing Renewable Energy/Efficiency Employment Network (Vermont GREEN) and Renewable Northwest (ReNW). Both programs received grants in 2010 of approximately $5 million from the U.S. Department of Labor to develop innovative training programs to support the development of green enterprises as well as raise job quality standards more generally in their respective regions. Paraphrasing Scully-Russ, the main features of these two program were as follows:

Vermont GREEN

Vermont GREEN supported the extensive, state-sponsored weatherization program. Homeowners living in low-income neighborhoods could apply for state funds to weatherize their homes. In turn, the state required homeowners to hire local contractors, who themselves had to hire local residents to perform this weatherization work. The state paid for the training and certification, while Vermont GREEN recruited the trainees and provided wraparound support services to ensure trainees succeed in the program and are placed in weatherization jobs.

Vermont GREEN worked with a network of community action agencies to offer extensive career counseling. Counselors help residents assess their interests and training needs, access relevant federal- and state-funded green training programs, and secure a job.

Vermont GREEN offered customized training services to meet the specific needs of green regional employers and union apprenticeship programs. Vermont GREEN paid for a portion of this training and leveraged this investment to help employers tap other public and private resources to pay for training. All customized training was required to result in an industry-recognized certificate. Vermont GREEN also worked to integrate a wide variety of resources to deliver workforce development programs throughout the state. The aim here was to help ensure that the effort was sustained beyond the grant period.

ReNW

ReNW also developed a three-pronged strategy, including the following:

Economic development strategy. To cultivate new markets in the renewable electricity industry for the area's small and mid-sized manufacturers, ReNW worked with providers to determine their needs for equipment and component parts, build a local supply chain, and upgrade the manufacturing workforce and production system.

Workforce development strategy. ReNW engaged regional Workforce Investment Boards (WIB) to recruit workers and refer them to jobs and/or training and certification programs. Area education providers provide the training either through degree-granting programs or customized training offered to individual employers.

Job placement strategy. ReNW counselors worked with green employers to place workers in green jobs. At least 13 employers in the ReNW network agreed to provide workers referred by ReNW counselors first consideration for all open positions.

In Scully-Russ's overall assessment, these two programs were both broadly successful in providing good-quality training experiences for both newly-hired workers as well as incumbent employees who needed to acquire new skills. However, she found that these programs were only partially successful in establishing that the clean energy sector jobs were consistently good-quality jobs (i.e., full-time positions at decent pay and benefits). She also found that while these programs did exert a positive impact on general labor market conditions in their respective regions, this impact overall was limited.

Scully-Russ concludes the case study with a more general set of "lessons learned" and "challenges/barriers." These include the following:

Lessons Learned

- Policy leaders and workforce practitioners can raise equity standards generally through leveraging public investments to move green employers to adopt a work system based on high quality and skill standards.
- Policy leaders and workforce practitioners can leverage public investments in the green economy to also enhance new workforce and certificate programs, both for the green economy specifically and more generally.
- Responsive and effective economic and workforce development strategies in the green sector must emerge from within local relationships and conditions.

Challenges/Barriers

- Local programs need to work effectively among each other, and within the specific context of existing labor market institutions.

New incentives and regulation requiring public agencies to work together in servicing industries, like the green sector, targeted for economic development may be required if the investments are to result in improvements to the public system.

- Traditional workforce planning, development strategies, and methods are ineffective in responding to the needs of emerging sectors and occupations and therefore thwart their development.

Workforce development plans that drive the preparation of the workforce are often based on analysis of a small number of supply and demand variables that do not account for the dynamic changes taking place in new and emerging industries. In addition, the conventional process is linear, sequential, and protracted; employers hand off an analysis of needs to educators who are then expected to respond with education and training to prepare the workforce.

In the cases of Vermont GREEN and ReNW, the parties departed from these conventions by accounting for more factors in the program development process and engaging in a highly interactive planning process. However, participants still expressed reservations that training investments were premature, jobs were not yet solidified, and needs were not well understood. It was broadly understood that that workforce development in this context was risky because there was little certainty that training would match the jobs as they emerged and that jobs would be there to employ trainees. New methods to synchronize the supply and demand in the labor market and to anticipate future needs in an ambiguous and uncertain context are therefore required.

How Much to Spend on Worker Training?

It is critical to consider the overall level of spending that needs to be committed to clean economy training programs throughout the U.S. Of course, these overall budgetary issues are complementary to the critical issues highlighted by Scully-Russ with respect to the design of individual programs and their local and regional impacts.

The U.S. government has recently operated an economy-wide clean energy job training program. This was the Energy Efficiency and Renewable Energy Training Program, which was initially one component of the 2007 Energy Independence and Security Act. The program was then funded as part of the 2009 American Recovery and Reinvestment Act – the Obama stimulus program. Over 2009 – 13, the funding allocated specifically for job training programs averaged $75 million per year.

The program supported the following: national training grants that were geographically distributed; state training grants; demonstration grants that prioritized for low-income population, termed the 'pathways out of poverty' demonstration program; and research on training needs and labor markets. The specific types of training programs included in this measure were: occupational skills training; safety and health training; basic skills and job readiness training; college training programs; internship programs; apprenticeship programs and skill upgrading and retraining. The funding allocations included at least 60 percent for the various training programs themselves, 20 percent for the 'pathways out of poverty' measures, and no more than 20 percent for labor market research.

Assessments of this program were mixed. A 2012 report from the U.S. Department of Labor[xxi] found that the program had been only partially successful in placing workers into jobs in clean energy sectors.[39] A 2013 study by an outside consulting group, IMPAQ International, reported that, according to the majority of program administrators, funding to support the programs was not available for a sufficiently long time to have been effective.[xxii] Two more recent studies, by Mundaca and Richter (2015) and Hughes (2018) respectively, supported the basic findings by the Department of Labor and IMPAQ International.[40]

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xxi The DOL study found, in particular, that "the impact of the Recovery Act Green Jobs training program has been limited in terms of reported employment outcomes…entered employment and retention results are far lower than planned" (p. 29; see BPA and SPRA (1994)).

xxii See also Bradley, Congressional Research Service (2013) and U.S. Government Accountability Office (2013) (both in the Bibliography), which were also mixed in their assessments.

It is clear that worker training programs do need to be revived at a major scale, in order to operate at a quality level sufficient to both support the clean energy investment agenda and to expand opportunities for workers to move into these new employment areas. Given that we are proposing that annual clean energy investments expand roughly 10-fold relative to the levels of 2010 – from around $50 billion to $500 billion per year – it would suggest, at least as an initial reference point, that worker training programs increase equivalently. This would imply an annual budget for worker training in the range of $750 million per year. More generally, it would imply a spending level at roughly 1.25 percent of overall annual clean energy investment spending in the U.S.

In practice, there is likely to be overlap between worker training programs and the separate programs tied to both community and worker adjustment. Nevertheless, for the purpose of not underestimating costs of important programs aimed at assisting workers and communities, we assume that the budget for clean energy worker training programs should be treated as distinct from and in addition to those for both community and workers adjustment.

Affirmative Action

As described above, women and people and communities of color are currently underrepresented in the range of job areas that make up the emerging U.S. clean energy economy. The composition of the current U.S. clean energy workforce is, first, predominantly male within all racial categories. But male non-whites still have far fewer positions in the sectors where the job quality is relatively high, such as Transmission and Storage.

This current imbalance of job opportunities for women and communities of color is driven, in particular, by the long-standing pattern of gender and racial discrimination in the U.S. construction industry. Currently, women make up only 3.5 percent of construction workers, even while women represent 47 percent of all employed workers. Similarly, Black workers make up 13 percent of all employed workers throughout the U.S. economy, but hold only eight percent of construction industry jobs.[xxiii] This is especially significant because a disproportionate share of overall employment creation through both energy supply and demand expenditures will be in construction. For example, construction employment accounts for 28 percent of the jobs created in the primary areas of clean renewable supply investments, including solar and wind energy; and 22 percent in the additional non-fossil fuel investment areas (i.e., nuclear, biomass and carbon sequestration).

To achieve an equitable representation of women and communities of color in the newly created clean energy economy jobs, it will be necessary to implement employment policies that both prohibit discriminatory behavior and require employers to develop positive affirmative action plans, especially in the construction industry. One of the most prominent examples of affirmative action policies is set out in federal policy through Executive Order 11246. EO11246 requires employers with large federal contracts or employers who receive significant federal assistance to work toward employment equity (i.e., “employment utilization goals”) with regard to nonwhite and women workers. These requirements typically entail employers providing written affirmative action plans. The equity standards generally aim for employment shares for women and non-whites that reflect their overall shares within the given local labor market.[xxiv]

xxiii Authors’ analysis of Current Population Survey basic monthly microdata, 2019.

xxiv The construction industry has proved to be a particularly challenging sector with respect to diversifying their workforce. EO11246 regulations has responded to this challenge by modifying the requirements for the construction industry. EO11246 sets a low utilization goal of 6.9 percent for women and federal construction

Employers who fail to meet these equity standards risk cancelation of their contracts, disqualification from bidding on future federal contracts, as well as legal action by the Equal Employment Opportunity Commission (EEOC).

The relevant research literature finds that this type of federal affirmative action policies has been effective, in particular, in raising employment opportunities for Black men. The evidence is more mixed for women.[xxv] Two factors have been critical in achieving successful results with these programs: (1) a high level of enforcement activity by the Office of Federal Contract Compliance Program (OFCCP); and (2) an expansion of job opportunities in the relevant labor market segments. In other words, not surprisingly, affirmative action policies are more successful: (1) when they are being effectively enforced; and (2) when employers are able to diversify their workforces through adding women and people of color as opposed to having these underrepresented groups replace existing cohorts of white male workers.[xxvi]

The experience with the Obama Administration's implementation of its 2009 economic stimulus program, aiming to counteract the 2007 – 2009 Great Recession, is instructive. The infrastructure spending program within the broader policy initiative – the American Recovery and Reinvestment Act – included a large expansion of federally-supported construction contracts. To ensure compliance by employers with the federal affirmative action standards, the Obama Administration expanded the budget and staffing for affirmative action enforcement at the Office of Federal Contract Compliance and increased the agency's focus on the construction industry. This combination of policy initiatives did achieve a measurable improvement in the diversity of the construction industry workforce.[41]

3.6 Building Support for Clean Energy Transition Through Narratives, Education and Community Engagement

To successfully advance a transition to a net-zero emissions economy over the next 30 years, it will be critical that this project be widespread and have deep support throughout U.S. society. At present, the level of support does already appear strong – a November 2019 Pew Research poll reported that 67 percent of U.S. adults think that the Federal Government is doing "too little to reduce the effects of global climate change," and 77 percent think that "developing alternative energy" is a more important priority than "expanding fossil fuels". In addition, 89 percent of adults "say that they make an effort to live in ways that protect the environment," though only 25 percent report that they do so "all of the time".[42]

contractors are not required to produce written affirmative action plans but instead to make good faith efforts, as defined by the OFCCP, the agency that monitors contractor compliance.

xxv See for example Leonard (1984a) and (1984b); and Rodgers and Spriggs (1996) (in Bibliography).

xxvi To further strengthen such affirmative action initiatives, in particular in behalf of female workers, one specific initiative would be to increase support for the U.S. Department of Labor's Women in Apprenticeship and Non-Traditional Occupations program (WANTO; see: https://www.dol.gov/agencies/wb/grants/wanto-grants). This grant program funds organizations that 1) offer women pre-apprenticeship and training programs for the skills they need to succeed in occupations in which women are presently underrepresented; 2) provide training for employers, unions and workers in how to remove workplace barriers that cause women to leave such occupations; and 3) provide wrap-around support services such as mentoring services and childcare support.

Despite this widespread support, it remains the case that to date, far too little has been accomplished in terms of moving the U.S. economy onto a viable climate stabilization path. It is therefore imperative to strengthen the extent of support around a transformative climate stabilization agenda. This will entail creating effective narratives as to how the clean energy transition can proceed and communicating these narratives widely.

Toward this end, it is critical that the perspectives of a wide range of people, at all levels of society, be transmitted widely. Individual stories can help people to understand the problem and provide inspiration in terms of solutions and best practices. The organization Our Climate Voices is one important resource that brings together the perspectives of people throughout the society. Our Climate Voices describes its work as follows:

> Our mission is to humanize the climate disaster through storytelling, contribute to a shift in the climate change dialogue that puts the voices of those most impacted at the forefront of the conversation, and to connect people with ways to support the community-based climate solution-making work that frontline and vulnerable communities are already doing to combat climate change impacts.
>
> We believe that storytelling is an underutilized and vital tool in the fight for climate justice. First-hand narratives connect with people on an emotional level and raise the issue of climate change in people's hearts and minds. Stories are more memorable than facts and figures.
>
> We believe in the importance of listening to and learning from one another. Our Climate Voices storytellers provide a window into the daily ways that climate change affects us all. This global disaster is urgent and each of our communities is impacted. Our storytellers have insight and wisdom into how to envision a more equitable and sustainable world. Effective climate justice work strengthens not only environmental health, but also human livelihood.[43]

One dimension of the storytelling challenge is to strike the most effective balance between hope and fear. In recent years, both climate change activists and climate change deniers have often told stories that have been dominated by fear. Activists have focused on the threat of global ecological catastrophe, while deniers warn that America could 'return to the Stone Age' if radical environmentalists succeed in implementing their agenda. Unfortunately, as neuroscientists have shown[xxvii], intense threat perceptions impair humans' capacity for cognition, creativity, and collaboration – all of which are urgently needed to address this complex challenge.[44] Stories that conjure images of overwhelming threats – whether to the global environment or the U.S. economy – tend to polarize and paralyze their audiences. Conversely, unrealistically optimistic stories about the prospects for rapid decarbonization may result in disillusionment or cynicism if these promises cannot be met. Vivid narratives are essential for catalyzing effective action, but these narratives must be rooted in a realistic appraisal of the technological, economic, and political possibilities.[xxviii]

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xxvii See, for example, Landau-Wells and Saxe (2020).

xxviii This paragraph follows closely and quotes directly from a 7/3/20 private correspondence between Robert Pollin and Professor Mark Levinger of George Washington University.

Three organizations in Alaska provide effective case studies of how to offer education and support that will help individual people and communities to become engaged with the clean energy transformation project. Alaska Heat Smart focuses specifically on providing information and consulting services to help homeowners purchase heat pumps and install them in their homes.[45] They work especially in support of low-income families, informing homeowners that they can save between 40 – 70 percent over oil or electric heat through installing a heat pump, while also reducing the household's carbon footprint. At a very practical level, Alaska Heat Smart assists families in obtaining bids from contractors and in identifying financing options for heat pump installations. Renewable Juneau often works in conjunction with Heat Smart Alaska on converting homes to efficient heat pumps.[46] It also provides educational materials and support in making electric vehicle purchases. Renewable Juneau is also active more broadly in supporting policies that advance renewable energy in their region. The Renewable Energy Alaska Project operates a range of educational projects throughout the state.[47] These include the Alaska Network for Energy Education and Employment, which aims to support individual Alaskans in finding high-quality clean energy learning, training, and job opportunities. They also advocate in support of developing "green bank" funding programs that will lower the risks and costs of financing clean energy investments in the state.

At the level of individual and household behavior, the work of David Finnegan in creating Green Actioneers provides another valuable case study for advancing new modes of thinking in behalf of the clean energy transition project. In his Green Actioneers Workbook and website, Finnegan specifies 100 practical actions that families and individuals can take to "go green," starting with an energy audit for their homes. Finnegan writes that the book and website provide:

> Guidelines to improve the quality of the soil in their yards and throughout their communities, to improve the quality of their water and air, to attract beneficial insects not kill them with pesticides, to use much less electricity and water, to use EnergyStar appliances, to grow their own food in rooftop and porch gardens as well as their yards using natural fertilizers, to filter their own water, to take public transportation or drive electric, to install solar arrays backed up by wind energy RECs, to compost, to use natural cleansers and dispose of chemicals wisely, to reduce their use of plastic and shift from plastic to glass for food storage, and from paper to cloth for clean-ups, to seal their building "envelope" to reuse their own belongings, to repurpose fabric and recycle or reuse everything they can, to shop in thrift stores, to plant trees, to eat less meat, to avoid fast food and bring their lunch from home, to avoid flying and work from home if possible, among over 100 "Green Actions."

Finnegan also writes that his list of Green Actions will grow through communications he will develop with consumers.[xxix]

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xxix The quotes from Finnegan and the overall description of his project are taken from private correspondence on 3/9/20 and 4/3/20 with Robert Pollin.

In addition to the critical interventions at the level of individual narratives, educational projects and highly practical support programs, it is equally important to be able to project a credible macro-level narrative capable of bringing together these micro-level initiatives. By way of summary, the macro-level narrative that animates this chapter on Equitable and Just Transition, as well as the Zero Carbon Action Plan more generally, includes the following themes:

- Driving U.S. and global CO_2 emissions to net-zero by 2050 is an ecological imperative.
- Undertaking the myriad of investments that can create a clean energy economy should create large scale expansion of job opportunities as well as new business opportunities.
- If managed effectively, building a clean energy economy will not entail increased costs for consumers. This is because, on average, the costs of delivering energy through clean renewable sources is already at cost parity with fossil fuels, and those costs are on a long-term downward trajectory. Moreover, by definition, raising efficiency standards in buildings, transportation systems and industrial machinery will entail energy savings and lower energy costs.
- Building a clean energy economy can serve as a framework for advancing greater social equality.
- Creating a clean energy economy will create losers. As we have focused in this chapter, this includes workers and communities whose livelihoods are presently dependent on the fossil fuel-based economy. Providing a just transition for these workers and communities must be a central focus of the overall clean energy transition project.
- The other major group that will be losers in the clean energy transition are, of course, the companies, public and private, which now own and manage the world's fossil fuel energy assets. This chapter has not focused on a transition program for the fossil fuel companies and their owners.[xxx] The broad point is nevertheless clear enough: the fossil fuel industry will have to experience near-total demise over the next three decades. There is no choice in the matter if we take seriously, as we must, the research produced by climate scientists.

xxx See, for example, Pollin (2015) (in Bibliography).

References

1. Colorado Just Transition Advisory Committee. 2020. "Draft Colorado Just Transition Plan". Denver, CO: Colorado Department of Labor and Employment.
2. Sustainable Development Solutions Network. 2020. *Conceptualizing Employment Pathways to Decarbonize the U.S. Economy*. New York: Sustainable Development Solutions Network (SDSN).
3. Pollin, Robert, Heidi Garrett-Peltier, James Heintz, and Shouvik Chakraborty. 2015. Global Green Growth: Clean Energy Industrial Investments and Expanding Job Opportunities, United Nations Industrial Development Organization and Global Green Growth Institute, http://gggi.org/wpcontent/uploads/2015/06/GGGI-VOLI_WEB.pdf. pp. 133-44
4. "U.S. Census Bureau | Usagov". 2020. *Usa.Gov*. https://www.usa.gov/federal-agencies/u-s-census-bureau.
5. Pollin, Robert, and Brian Callaci. 2018. "The Economics Of Just Transition: A Framework For Supporting Fossil Fuel–Dependent Workers And Communities In The United States". *Labor Studies Journal* 44 (2): 93-138. doi:10.1177/0160449x18787051.;

   Pollin, Robert. 2019. "Green Economics And Decent Work: A Viable Unified Framework". *Development And Change* 51 (2): 711-726. doi:10.1111/dech.12559.
6. "Fossil Fuels Continue To Account For The Largest Share Of U.S. Energy". 2019. *Eia.Gov*. https://www.eia.gov/todayinenergy/detail.php?id=41353.
7. The Obama White House. 2015. "FACT SHEET: The Partnerships For Opportunity And Workforce And Economic Revitalization (POWER) Initiative". https://obamawhitehouse.archives.gov/the-press-office/2015/03/27/fact-sheet-partnerships-opportunity-and-workforce-and-economic-revitaliz.
8. "Crude Oil Production". 2020. *Eia.Gov*. https://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm.; "Natural Gas Dry Production (Annual Supply & Disposition)". 2020. *Eia.Gov*. https://www.eia.gov/dnav/ng/ng_sum_snd_a_EPG0_FPD_Mmcf_a.htm.https://www.eia.gov/dnav/ng/ng_sum_snd_a_EPG0_FPD_Mmcf_a.htm
9. Simon, Ruth. 2016. "Oil Bust Forces West Texas To Adjust". *The Wall Street Journal*, 2016. https://www.wsj.com/articles/oil-bust-forces-west-texas-to-adjust-1456950453.
10. Federal Reserve Bank of Dallas. 2018. "At The Heart Of Texas: Cities' Industry Clusters Drive Growth". A Special Report Of The Federal Reserve Bank Of Dallas, Second Edition. Dallas, TX: Federal Reserve Bank of Dallas. https://www.dallasfed.org/research/heart/~/media/Documents/research/heart/heartoftexas.pdf.
11. "BLS Data Finder". 2020. *Beta.Bls.Gov*. http://beta.bls.gov/dataQuery/find?st=240&r=20&fq=areaT:%5BCombined+areas%5D&more=0.
12. The 2020 employment figures for the area are from: "BLS Data Finder Midland-Odessa, TX Combined Statistical Area". 2020. *Beta.Bls.Gov*. https://beta.bls.gov/dataQuery/find?st=0&r=20&q=midland-odessa&fq=areaT:[Combined+areas]&more=0&fq=survey:[la].
13. "One-Screen Data Search". 2020. *Data.Bls.Gov*. https://data.bls.gov/PDQWeb/en.
14. "One-Screen Data Search".
15. MetroNews. 2020. "Boone County Commission Asking For 20% Spending Cut", 2020. https://wvmetronews.com/2019/08/28/boone-county-commission-asking-for-20-percent-spending-cut/.
16. Appalachian Citizens' Law Center, Appalachian Voices, Coalfield Development Corporation, Rural Action and Downstream Strategies. 2020. "A New Horizon: Innovative Reclamation For A Just Transition". Reclaiming Appalachia Coalition. https://reclaimingappalachia.org/new-2019-report-a-new-horizon/.
17. "OSMRE Reclaiming Abandoned Mine Lands". 2020. *Osmre.Gov*. https://www.osmre.gov/programs/aml.shtm.
18. Dixon, Eric L., and Kendall Bilbrey. 2015. "Abandoned Mine Land Program: A Policy Analysis For Central Appalachia And The Nation". Whitesburg, KY: Appalachian Citizens' Law Center; Knoxville, TN: The Alliance for Appalachia. p. 13. https://appalachiancitizenslaw.files.wordpress.com/2015/07/abandoned-mine-reclamation-policy-analysis.pdf.
19. Higdon, James. 2020. "The Obama Idea To Save Coal Country". *POLITICO Magazine*. https://www.politico.com/magazine/story/2017/03/the-obama-administration-idea-to-save-coal-country-214885.
20. Dixon and Bilbrey, "Abandoned Mine Land Program".
21. Dixon and Bilbrey, "Abandoned Mine Land Program".

22. Olalde, Mark. 2020. "Support Grows For Taxpayer-Funded Oil Well Cleanup As An Economic Stimulus". *Energy News Network*. https://energynews.us/2020/06/23/national/support-grows-for-taxpayer-funded-oil-well-cleanup-as-an-economic-stimulus.

23. Furst, J. and Howard, A. 2020. "The Moving America Forward Act: If Passed, Will Result In Increased Opportunities For Infrastructure Work And Contracting With The Federal Government". 2020. *JD Supra*. https://www.jdsupra.com/legalnews/the-moving-america-forward-act-if-66813/.

24. "Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2016". 2020. *US EPA*. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016.

25. Schleifstein, Mark. 2020. "Number Of "Orphaned" Wells Increased By 50 Percent, Could Cost State Millions: Audit". *The Times-Picayune*, The New Orleans Advocate, 2020. https://www.nola.com/news/business/article_313d8dd2-7a9d-11ea-b4a4-e7675d1484f7.html#:~:text=Mark%20Schleifstein,-Author%20email&text=The%20Louisiana%20agency%20overseeing%20oil,the%20Louisiana%20Legislative%20Auditor's%20Office.

26. Greenberg, Michael, Karen Lowrie, Henry Mayer, K. Tyler Miller, and Laura Solitare. 2001. *The Environmentalist* 21 (2): 129-143. doi:10.1023/a:1010684411938..

27. Lynch, John, Kirshenberg, Seth. 2000. Economic Transition by the Energy-Impacted Communities. Sacramento: California Energy Commission.

28. Lynch and Kirshenberg, Economic Transition.

29. "Senate Passes Portman Priority To Fund Cleanup Of Portsmouth Gaseous Diffusion Plant". 2020. *Senator Rob Portman*. https://www.portman.senate.gov/newsroom/press-releases/senate-passes-portman-priority-fund-cleanup-portsmouth-gaseous-diffusion.

30. Hendren, Sam. 2020. "Slow Paced Clean Up Of Cold War Era Atomic Plant Frustrates Piketon Area Residents". *Radio.Wosu.Org*. https://radio.wosu.org/post/slow-paced-clean-cold-war-era-atomic-plant-frustrates-piketon-area-residents#stream/0.

31. Lowrie, Karen, Michael Greenberg, and Michael Frisch. 1999. "Economic Fallout," Forum for Applied Research and Public Policy, 14(2).

32. U.S. Department of Energy."U.S. Departments of Energy and Interior Announce Site for Solar Energy Demonstration Projects in the Nevada Desert," Press release, 7/8/10, http://energy.gov/ articles/us-departments-energy-and-interior-announce-site-solar-energy-demonstration-projects-nevada.

33. Alaska Center for Energy and Power. 2020. "Microgrids". Fairbanks, AK: University of Alaska Fairbanks. Accessed September 3. http://acep.uaf.edu/media/158027/Microgrids-6-26-15.pdf.;

Whitney, Erin. 2017. "Preface: Technology And Cost Reviews For Renewable Energy In Alaska: Sharing Our Experience And Know-How". *Journal Of Renewable And Sustainable Energy* 9 (6): 061501. doi:10.1063/1.5017516.

34. "Alaska Network For Energy Education And Employment | REAP". 2020. *Alaskarenewableenergy.Org*. https://alaskarenewableenergy.org/initiatives/alaska-network-for-energy-education-and-employment/.

35. Powers, Laura, and Ann Markusen. 1999. "A Just Transition? Lessons From Defense Worker Adjustment In The 1990S". Washington D.C.: Economic Policy Institute. https://www.epi.org/publication/technicalpapers_justtransition/.

36. Berkeley Planning Associates and Social Policy Research Associates. 1994. "Evaluation Of The Defense Conversion Adjustment Demonstration: Interim Report On Implementation". Research And Evaluation Report Series. Office of Policy and Research, U.S. Department of Labor, Employment and Training. https://wdr.doleta.gov/opr/FULLTEXT/1994_12_NEW.pdf.;

"Databases, Tables & Calculators By Subject". 2020. *Bls.Gov*. https://www.bls.gov/data/#employment.https://wdr.doleta.gov/opr/FULLTEXT/1994_12_NEW.pdf, pp. 4-3, 4-5

37. NASEO and EFI. 2019. "The 2019 U.S. Energy And Employment Report". Arlington, VA: National Association of State Energy Officials; Washington D.C.: Energy Futures Initiative. http://www.naseo.org/data/sites/1/documents/publications/USEER-2019-US-Energy-Employment-Report1.pdf.

38. Scully-Russ, Ellen. 2018. "The Dual Promise of Green Jobs: Sustainability and Economic Equity." In *The Palgrave Handbook of Sustainability: Case Studies and Practical Solutions*, edited by Robert Brinkmann and Sandra J. Garren, 503–21. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-71389-2_27.

39. Berkeley Planning Associates and Social Policy Research Associates, "Evaluation Of The Defense Conversion Adjustment Demonstration: Interim Report On Implementation".

40. Mundaca, Luis, and Jessika Luth Richter. 2015. "Assessing 'Green Energy Economy' Stimulus Packages: Evidence From The U.S. Programs Targeting Renewable Energy". *Renewable And Sustainable Energy Reviews* 42: 1174-1186. doi:10.1016/j.rser.2014.10.060.;

Hughes, Erik-Logan. 2018. "Where Did The Green Jobs Go? A Case Study Of The Boston Metropolitan Region". Master in City Planning, Massachusetts Institute of Technology.

41. Wicks-Lim, Jeannette. 2013. "A Stimulus for Affirmative Action? The Impact of the American Recovery and Reinvestment Act on Women and Minority Workers in Construction," In *Capitalism on Trial: Explorations in the Tradition of Thomas E. Weisskopf*, edited by Jeannette Wicks-Lim and Robert Pollin (Northampton, MA: Edward Elgar Publishing, Inc.).

42. "U.S. Public Views On Climate And Energy". 2020. *Pew Research Center Science & Society*. https://www.pewresearch.org/science/2019/11/25/u-s-public-views-on-climate-and-energy/.

43. "What We Do — Our Climate Voices". 2020. *Our Climate Voices*. https://www.ourclimatevoices.org/what-we-do.

44. Landau-Wells, Marika, and Rebecca Saxe. 2020. "Political Preferences And Threat Perception: Opportunities For Neuroimaging And Developmental Research". *Current Opinion In Behavioral Sciences* 34: 58-63. doi:10.1016/j.cobeha.2019.12.002.;

Fernandes, Orlando, Liana C. L. Portugal, Rita C. S. Alves, Rafaela R. Campagnoli, Izabela Mocaiber, Isabel P. A. David, Fátima C. S. Erthal, Eliane Volchan, Leticia de Oliveira, and Mirtes G. Pereira. 2013. "How You Perceive Threat Determines Your Behavior". *Frontiers In Human Neuroscience* 7. doi:10.3389/fnhum.2013.00632.

45. 2020. *Akheatsmart.Org*. https://akheatsmart.org.

46. "Renewable Juneau". 2020. *Renewable Juneau*. https://renewablejuneau.org/.

47. "Home | REAP". 2020. *Alaskarenewableenergy.Org*. https://alaskarenewableenergy.org/.

4. APPROACHES FOR ALL LEVELS OF GOVERNMENT

4.1 Federal Legislative and Administrative Framework

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Achieving net-zero carbon emissions by 2050 will necessitate significant changes to most of America's physical assets, from its power generation and transmission infrastructure to its buildings, vehicles, factories, forests and farms. These broad changes will need to address all four pillars of deep decarbonization – electricity decarbonization, energy efficiency and conservation, electrification of transportation and buildings, and carbon capture – supplemented by significant reductions in emissions of non-CO_2 pollutants. Such comprehensive change will necessitate the coordinated action of most of the departments of the Federal Government, from the Environmental Protection Agency (EPA) and Department of Energy (DOE) to Department of Defense (DOD), Department of Housing and Urban Development (HUD), the General Services Administration (GSA), and other federal agencies, including the Departments of Transportation, Commerce, Agriculture, Interior, Education, and Justice over a 30-year period. In addition, the states, territories, and local and tribal governments will play essential roles. Launching and implementing this comprehensive, coordinated action over three decades will require the establishment of clear and enforceable goals and subgoals; reporting and accountability, including processes for feedback loops and course corrections; and an organizational structure that can manage and drive this sprawling endeavor. Moreover, the process must be protected from backsliding.[i]

4.1.1 Overall Approach

Change Strategy

Congress should adopt a Zero Carbon Action Plan committing the nation to net-zero or net-negative anthropogenic GHG emissions by no later than 2050. The Federal Government also needs to set short- and long-term goals to guide and motivate the decarbonization efforts of governments, private actors, nongovernmental organizations, and citizens. Clear and effective implementation mechanisms for implementing and tracking these goals are also needed.

i Many but not all of the recommendations in this section are taken from Legal Pathways to Deep Decarbonization in the United States (Michael B. Gerrard & John C. Dernbach eds. 2019).

Goals

- Congress should establish a binding national goal of achieving net-zero or net-negative anthropogenic GHG emissions by 2050.
- Congress should also establish intermediate and sector-specific emissions reduction goals that further and are consistent with the goals for 2030, 2040, and 2050 that are set out in Chapter 2.
- The goals should be adopted and implemented to fully engage not only the federal government but also state, territorial, tribal, and local governments as well as all sectors of society to participate in their achievement.

Relationship Among Levels of Government

The federal government; state, territorial, and tribal governments; and local governments all have significant roles to play in reducing GHG emissions. The Federal Government has clear strengths in a number of dimensions, such as its ability to fund research, development, and deployment. The Federal Government has the ability to act at a larger scale – involving all states and municipalities – than any state or local government. The Federal Government also has clear and exclusive responsibility on certain matters, such as its ability to conduct foreign policy.

State, territorial, and tribal governments have long been leaders on climate change, clean energy policy, and efforts to prepare for climate impacts. Some states have also adopted significant economy-wide greenhouse gas targets, regional cap and trade programs, and aggressive renewable portfolio standards. State governments also hold authority over retail electricity regulation, siting of new generation, transportation planning, and other critical components of a decarbonization agenda. States are playing a critical role in electrification of transportation and are beginning to explore new approaches for building sector electrification. States have also often led on many aspects of energy efficiency, including building codes, utility programs, and other initiatives.

Local governments have authority over zoning and land use, as well as authority to operate mass transit systems, and often have authority over building codes and standards. These roles are all important in energy use and efficiency in major sectors as described later in this plan.

But where there is significant overlap between federal authority on the one hand, and state and local authority on the other, certain general principles should guide the allocation of their respective authorities. They are as follows:

In general, the Federal Government should:

- Set ambitious national goals for reducing GHG emissions.
- Establish and strengthen national standards for reducing emissions where national standards are appropriate.
- Provide financial and technical support to state, territorial, trrbal, and local governments.
- Establish, where appropriate, trading and other market-based systems to reduce costs, with provisions to ensure that this does not adversely affect low-income and marginalized communities.

In general, state, territorial, and tribal governments governments should:

- Continue to make progress using their legal authority on greenhouse gas emission reduction programs, renewable energy portfolio standards, energy efficiency standards, and other legal tools.
- Take a leading role in implementing national goals and standards.
- Be specifically authorized or allowed to adopt more stringent goals and standards.

Authority and Process for Achievement of Goals

- The Administration should establish a White House Office on Climate Change to coordinate federal agency implementation of the Zero Carbon Action Plan, including climate change mitigation and adaptation activities; and to the extent authorized by law, direct the development of plans, establish program metrics, track progress, and otherwise oversee those activities.

Congress should:

- In addition to the actions recommended below, and without delaying their implementation, require the Administration to create a specific enforceable national plan by January 2022 to ensure that the country is on the path toward carbon neutrality, with long-term policies containing near term milestones that can be accomplished within the Administration's term. The plan shall equitably apportion the environmental, job creation, and other benefits of the transition in terms of geography and ethnicity.
- Require each Administration to update the plan every two years, including near term milestones to be accomplished.
- Require the Administration to report annually to Congress on the progress toward carbon neutrality, including specific reporting criteria; and that a website be established to provide information to the public, businesses, and the press regarding the overall plan and progress, the projects undertaken by each federal agency, links to state websites, funding that is available, and the like.
- Adopt an initial set of fully funded, no-regrets federal policies to be launched while the national plan is under development. No-regret strategies are justifiable based on their social, economic, and environmental benefits, wholly apart from any contribution they make to reducing greenhouse gas emissions.
- Assess the public and private funding needed to implement the plan, and demonstrate how sufficient funding will be available.

Powers and Duties of Federal Agencies:

- Congress should direct each federal agency to exercise its existing powers and duties to contribute to the fullest possible extent to the achievement of the Zero Carbon Action Plan, including national climate change goals and specific emission reduction targets.

Congress should also amend the powers and duties of federal agencies so that they can better contribute to the achievement of these goals without any substantial legal question about their legal authority to do so. To use just one federal agency, the Federal Energy Regulatory Commission (FERC), as an example:

- Congress should direct FERC to encourage states to modify electricity markets to provide incentives to maintain capacity fired with gaseous fuels to the extent necessary for grid balancing, but without also providing incentives to make significant use of gas capacity.
- Congress should change the mandate of FERC to include oversight of competitive markets with decarbonization as a central goal.
- Congress should also direct FERC to ensure that renewable power generation gets credited with a clean energy “attribute” value so that it has a strengthened position in the “day ahead” electricity auctions managed by the independent system operators (ISOs).
- Congress should prohibit FERC from approving any new liquefied natural gas (LNG) export facilities, and prohibit any new natural gas pipelines except in extraordinary circumstances.

Congress should require that, in considering permits, licenses, and other administrative approvals and decisions, all federal agencies shall consider whether such approvals or decisions are inconsistent with or will interfere with the attainment of national greenhouse gas emissions reduction goals. Where such decisions are inconsistent with or will interfere with the attainment of any of these goals, the agency must provide a detailed justification and identify alternatives or other GHG mitigation measures that will be implemented.

Presidential Action if Congress Fails to Act

- If Congress fails to act, the President should use all lawful means within his executive authority to drive decarbonization to net-zero or net-negative anthropogenic greenhouse gas emissions by 2050.

Cross-cutting Recommendations

Research, Development, Demonstration and Deployment (RDD&D)

- Congress should triple funding for deep decarbonization research, development, demonstration and deployment from current levels. The principal focal points of this enhanced effort should include elimination of technological and cost barriers to accelerated decarbonization.[1]
- The Federal Government should accelerate, intensify, and fully fund research and development for zero-greenhouse-gas emitting technologies, energy efficiency technologies, and carbon removal technologies.
- Congress should fund additional research, technology, and development on a range of distribution network and smart grid developments, including energy storage.
- The Federal Government should ramp up spending on building-related RDD&D, including development of carbon neutral fuels appropriate for buildings, to 5 percent of national RDD&D budget, from its current low of 0.1 percent.
- As an example of the kind of new area where RDD&D needs to be developed, Congress should establish and finance ARPA-Land (Advanced Research Projects Agency), a new research agency under the United States Department of Agriculture (USDA) to bolster public and private research funding into technologies, practices and policy measures that can reduce GHG emissions across a range of land-based activities – from monitoring soil carbon storage to next generation biofuels.

Social Cost of Carbon

- The Federal Government should establish a scientifically based Social Cost of Carbon (SCC) consistent with the Paris Climate Agreement objective of stabilizing greenhouse gases in order to limit global warming to 1.5°C, including decarbonization of the energy system by 2050.
- The Federal Government should use the SCC to guide the development of: regulations, cost-benefit analyses, public procurements, clean-energy subsidies, carbon taxes, feed-in tariffs and auctions, and and other policies.

Carbon Pricing

- It is important that our market economy has a price signal instilled to reduce carbon. We define "carbon pricing" to embrace a large number of various policy instruments, including but not limited to a carbon tax, cap-and-trade mechanisms, fuel pricing, subsidies, feed-in tariffs, tradable credits, and the like. Carbon pricing in its various forms should be an important part of the national effort to reduce greenhouse gas emissions.
- Congress should use carbon-based border adjustments to address leakage concerns as part of setting a price on CO_2 and other GHGs.

Procurement

- The Federal Government should use its procurement power to accelerate the development of markets and technologies for low-emission and negative-emission building materials, products, and services, as well as pavements.

Climate Regulation

- The Federal Government should reinstate and strengthen climate change regulations that have been rescinded or weakened under the Trump Administration.

Subsidies

- The Federal Government should eliminate monetary fossil fuel subsidies (except direct payments to low-income households).

Other Federal Recommendations

- The Federal Government should design and implement climate laws, policies and programs based on behavioral science to reduce household emissions.
- The Federal Government should design and implement climate laws, policies and programs to leverage domestic and international private sector action.
- In all actions taken to reduce greenhouse gas emissions, the Federal Government should:
  - Foster a just transition for those individuals and communities dependent on the carbon economy. The Federal Government should also ensure that all displaced workers receive pension and re-employment guarantees, as well as generous income, retraining and relocation support.
  - Maximize environmental, economic, and social co-benefits.

4.1.2 Pillar I: Electricity Decarbonization

Change Strategy

Less than a decade ago, it appeared that there may be as many as four ways to decarbonize the electric sector: large-scale use of renewable electricity, large-scale use of nuclear power, large-scale use of carbon capture and storage, or a mixture of these. It has since become clear that variable renewable energy (VRE) is the least-cost form of primary electricity in a decarbonized energy system, per the results of the modeling work discussed in Chapter 2. Transitioning to renewable energy resources is the largest single effort required to efficiently, economically, and cost-effectively mitigate anthropogenic greenhouse gas emissions according to both the International Energy Agency (IEA) and the International Monetary Fund (IMF). These technologies are widely used and their costs are declining, including costs associated with storage of electricity. As a result, this plan's change strategy for electricity decarbonization focuses on renewable electricity. Relying on available technologies at current costs of VRE and utilizing various means of energy efficiency as described in pillar 2, the goals set forth below are feasible, affordable and beneficial to the overall health and resilience of the U.S. economy and workforce.

Goals

Congress should adopt goals for the electricity sector for 2030 based on Chapter 2:

- Solar and wind capacity should be 3.5 times greater than at present.
- Coal generation should be less than 1 percent of total generation.
- More than 20 GW of battery storage should be available.
- Gas generating capacity should be maintained at the current level with declining usage as VRE scales up.
- The existing nuclear fleet should be maintained to the extent feasible and to an extent it can be done safely and cost effectively – recognizing the value of the zero-carbon power generated.

Recommendations for Congress

Congress should:

- Adopt a national clean energy standard for electricity and incentives to promote the infrastructure investments required to meet the targets established; these should rise over time to 100 percent zero-carbon electricity.
    - The standard should be based on carbon emissions.
    - The standard should also reduce emissions compared to the present by at least 60 percent by 2030, 80 percent by 2040, and >95 percent by 2050.
    - Each state should be required to achieve zero-carbon electricity production, but the required pace of achieving zero-carbon should depend on its resource mix and legacy generation facilities.
    - EPA should set the timetables for meeting the target for each state. Trading among states would be permitted.
    - Require sufficient storage capacity coupled with demand response to accommodate intermittent renewables as part of the national clean energy standard.
    - Consider nuclear power as clean energy for purposes of the national clean energy standard.
- Call for a program for the large-scale construction of offshore and onshore wind, utility-scale solar, distributed solar, and associated transmission and storage to lead to a rapid expansion of zero emissions electricity. A national clean energy standard, state zero-carbon goals, and a price on carbon should go a long way toward inducing the private sector to undertake this construction. Should this fall short, the Federal Government should, using its own funds, contract for and oversee the necessary construction. If the Federal Government does this, it should recoup its expenses from electricity sales.
- Mandate the phasing out of all coal-fired power plants by 2030.
- Make adequate provision for displaced workers as part of that phase out. For example:
    - Congress should use grants, technical assistance, and peer learning to induce more companies to reposition themselves from carbon to non-carbon energy markets, retraining and retaining more of their existing workers, and reducing job loss in communities currently dependent on carbon jobs.

  - Congress should enact and fund the RECLAIM Act of 2019 (H.R. 2156) (also known as "Power Plus") to provide $1 billion over five years to restore abandoned coal mines to something like their natural state and to plug abandoned oil and gas wells, employing workers displaced by the phase out of coal, oil, and gas, while also scaling up economic diversification efforts in coal, oil, and gas country.
  - Congress should adopt "carbon adjustment assistance" for workers dislocated by trade, and move toward an overall "active labor market system" through which society as a whole covers more of the costs to workers and their families of all economic transitions.

- Adopt a low-carbon fuel (aka clean fuel) standard for transportation fuels to support and accelerate the transition to electricity, hydrogen and biofuels. It should be based on a carbon intensity metric, and the target should be at least 15 percent lower than in 2020.
- Reform the process for approval of interstate transmission lines to facilitate long-distance transmission of electricity from renewable sources.
- Continue the production tax credit and the investment tax credit for renewables.
- Adopt the Master Limited Partnerships Parity Act to extend favorable tax treatment to financing arrangements known as "master limited partnerships" and "yieldcos," a benefit already available to investors in fossil fuel development, to also include investments in renewable power demand reduction projects. In adopting the Master Limited Partnerships Parity Act, Congress should also extend favorable tax treatment for certain financing arrangements to include investments in energy storage.

Other Federal Recommendations

- The Federal Government should adopt expedited approval procedures for leasing for offshore wind and onshore wind and solar and not unduly delay the National Environmental Policy Act (NEPA) and Endangered Species Act (ESA) processes.
- The FERC should adopt policies that encourage rather than discourage the development of renewable energy resources.
- In the absence of a federal carbon price, FERC should approve applications by regional transmission organizations (RTOs), independent system operators (ISOs), and state public utility commissions for carbon adders on wholesale electricity rates.
- The Federal Government should impose a moratorium on leasing of federal onshore and offshore lands for fossil fuel extraction, and a moratorium (subject to project-specific review) on the construction of fossil fuel infrastructure.
- The EPA should strengthen the regulation of air pollution from coal-fired power plants using existing authority under the Clean Air Act.
- The Securities and Exchange Commission should require and enforce greater disclosure:

  - of investments in coal and other fossil fuels;
  - of corporate and financial institutions' exposure to losses due to the energy transition;
  - of physical risks of climate change; and
  - of broader Environmental/Social/Governance impacts.

4.1.3 Pillar 2: Energy Efficiency and Conservation

Change Strategy

Energy efficiency and conservation measures are well established, widely available, have a long history of reducing costs, and make energy services more affordable to families and businesses. These measures also support the first pillar of decarbonization because they reduce the required buildout of renewable electricity from about four terrawatts (without high use of energy efficiency) to three terrawatts (with high use of energy efficiency). These measures also support the third pillar of decarbonization (electrification of transportation and buildings) because they reduce emissions in the short and medium terms. In addition, these measures offer one of the largest job multipliers in the decarbonization technology toolkit.

Recommendations for Congress

Congress should:

- Amend the Energy Policy and Conservation Act in order to broaden the DOE's authority to establish energy efficiency standards for new products; authorize DOE to adopt energy efficiency standards with multiple efficiency metrics; give DOE discretion to establish shorter compliance lead times for energy efficiency standards; require establishment of standards for sectors that are not currently covered (such as computers and displays); and give DOE binding deadlines for adopting and strengthening standards.
- Amend the Energy and Policy Conservation Act (EPCA) to remove federal preemption of state standards applying to appliances for which DOE has missed its deadlines, to allow the standards to be fuel neutral, and to require DOE to establish an overall reduction goal across each six-year cycle that is consistent with the national carbon goals.

Other Federal Recommendations

The Federal Government should provide incentives for building retrofits, including but not limited to multi-family affordable housing and senior housing, for resilience, electrification, and efficiency, including low-interest loans and favorable tax treatment.

Metropolitan Travel

The Federal Government should:

- Shift federal funds (including stimulus packages) away from the funding of new highway capacity and lane expansions. Focus on support for multimodal integration, micro-mobility infrastructure, transit-oriented development, and for improved bike/pedestrians/transit. Funding should be allocated for public-private partnerships, with an increased focus on under-resourced and minority communities.
- Empower and support state and local governments to create pricing systems that discourage single occupant vehicles and single passenger services and encourage more intensive use of vehicles (e.g., incentives for multiple occupants in ride-hailing services, personally owned vehicles, and transit). Pricing can include road user charges, congestion pricing, and making "free parking" at work taxable income.

Vehicle Automation

The Federal Government should:

- Modify road pricing, curb management, vehicle registration fees, and more to encourage pooling and right-sizing of vehicles.
- Encourage electrification by creating incentives for compliance with zero-emissions vehicle (ZEV) mandates and fuel economy rules.
- Support and encourage telecommunication as a substitute for passenger travel and local goods delivery.
- Expand broadband, especially for rural areas via infrastructure spending (as part of infrastructure and stimulus bills).

Public Transit

The Federal Government should:

- Modify public finance rules to encourage integration and coordination with pooled mobility services, with initial focus on mobility disadvantaged travelers.
- Subsidize rural on-demand transit service for small cities and denser rural areas.

Aviation

- The Federal Government should continue to incentivize aircraft design and low-carbon fuels to achieve 2 percent carbon intensity improvements per year.

New Buildings

- Congress should require that, starting in 2025, new buildings generally will not burn fossil fuels onsite, will be highly energy efficient, and will be constructed using low-carbon techniques and materials. This should be accomplished through a model National Energy Code for Buildings (NECB). The NECB should also ensure that replacement equipment and appliances in existing buildings will be energy efficient and largely electrified.
- Congress should direct the adoption of the NECB to be cognizant of geographic differences.
- Congress should provide incentives to states to help them make their latest residential and commercial energy codes consistent with national carbon reduction goals and to help them vigorously enforce these codes. Congress should require DOE to develop the model NECB to be consistent with national carbon reduction goals and be updated every three years. In addition, Congress should give DOE the authority to directly enforce those codes in states that do not adopt or enforce adequate codes.
- The Federal Government should place requirements on testing and eliminating refrigerant leaks and methane leaks in buildings.
- The Federal Government should support the development of local manufacturing for advanced building products in the rust belt and in areas that are likely to lose jobs in the energy/carbon transition, making long-term commitments for support.
- Federal agencies, including the General Services Administration, Department of Defense, and U.S. Postal Service, should lead by example in the decarbonization of buildings on federally-owned properties.

- Congress should require (and adequately fund) aggressive per square foot energy and carbon emissions reductions across the federal building portfolio, such as 20 percent aggregate energy reductions and 60 percent aggregate carbon reductions by 2030, and 30 percent and 90 percent aggregate reductions respectively by 2035.
- Congress should fund a program to help states and localities to achieve similarly deep reductions across their portfolios, perhaps on a slightly slower timeline, with federal seed funding.
- Congress should also fund a program to assist sub-regional governments in adopting and enforcing energy and carbon codes and in developing and enforcing codes that go beyond the nationally mandated minimums.

Materials

- Congress should amend the Resource Conservation and Recovery Act (RCRA), articulating and codifying Sustainable Materials Management (SMM) as the new framework for solid waste/materials management, keeping associated delegated authorities intact. SMM includes, but is not limited to, extended producer responsibility, increased diversion rates of specified materials from landfills, bans of certain single-use materials, and other means of reducing the amount of waste requiring disposal as much as possible.

Food and Land Use

Guidelines and information:

- The Federal Government should consider incorporating sustainability, including carbon footprint, in its dietary guidelines.
- The Federal Government should prioritize climate change in procurement contracts.
- Congress should adopt legislation prioritizing low-carbon agricultural products, including local agriculture products, for all government bodies.
- The Federal Government should develop certification programs for carbon-neutral food products.
- The Federal Government should encourage and support dietary interventions such as pricing strategies and product placement at retailers; menu labeling and healthy default choices in restaurants; adding more vegetables and fruits to the Supplemental Nutrition Assistance Program (SNAP); and providing plant-based meat alternatives in workplaces and schools.

Food waste policies:

- The Federal Government should establish policies for reducing post-harvest food losses by 50 percent by 2050 compared to 2010 levels, and reducing household-level food waste from 30 percent to 15 percent by 2050.

4.1.4 Pillar 3: Electrification of Transportation and Buildings

Change Strategy

Reducing greenhouse gas emissions from transportation and buildings through use of greater energy efficiency and conservation is necessary but insufficient. For deep reductions, it is imperative to change the energy source for transportation and buildings to electricity. For light-duty and heavy-duty vehicles, this can be accomplished largely by ensuring that new vehicles are powered by electricity and, to some extent, encouraging existing vehicles to be retired early. Separate strategies are needed for new and existing buildings. The U.S. population may grow by tens of millions of people by 2050, which means a substantial increase in new housing and commercial building stock. To prevent additional GHG emissions from this new housing stock, these buildings need to be electrified as they are built. For existing buildings a variety of renovation strategies need to be employed on a large scale.

Goals

Congress should adopt goals for electrification that include the following benchmarks from Chapter 2 for 2030:

- More than 50 percent of sales of light duty vehicles should be electric vehicles.
- More than 50 percent of new building sales should be buildings that have heat pumps.
- No new oil and gas transport facilities should be authorized or constructed.

Recommendations

- The Federal Government should tighten GHG emission standards under the Clean Air Act and fuel economy standards under the Energy Policy and Conservation Act to compel a reduction in fossil fuel use and eventual phasing out of internal combustion engines for new passenger vehicles, with substitution by electric vehicles. For heavy duty vehicles, the Federal Government should continue to tighten GHG standards, in part to accelerate electrification of trucks (including H_2 fuel cells) and low-carbon biofuels for long-haul trucks.
- The Federal Government should engage in a massive infrastructure program to partner with industry and state and local governments and electric utilities to construct EVe charging stations.
- The Federal Government should direct biofuels use from LDV to long-haul trucks, aviation, and ocean shipping, and strengthen requirements to reduce their carbon intensity and assure production is more sustainable.

Vehicles
Congress should establish:

- National LDV ZEV mandate at a minimum of 30 percent of new sales by 2030 and 100 percent of new sales by 2040.
- National medium duty vehicle (MDV) and HDV ZEV mandate at a minimum of 20 percent of new sales by 2030 and 80 percent of new sales by 2050.

- National bus ZEV mandate of 100 percent urban bus purchases by 2035.
- A requirement for annual improvements of about five percent in both energy efficiency and carbon dioxide emissions per year in cars and trucks and feebates for new LDVs (providing ongoing incentives to EV buyers).
- Fleet car and truck ZEV purchase requirements (including for Federal Government).
- Incentives for TNCs (e.g., Uber, Lyft), transit agencies, and medium- and heavy-duty truck fleets to purchase and use electric vehicles.

Fuels

Congress should:

- Establish a national Low-Carbon Fuel Standard (LCFS) for gasoline, diesel, and jet fuel, with 20 percent reduction in carbon intensity by 2030 and 80 percent by 2050, and allow states to adopt stronger standards.
- Establish incentives and subsidies for charging and H_2 infrastructure, with focus on truck stations for H_2, until at least 2030.
- Accelerate vehicle turnover (e.g., "scrap and replace") for low-income buyers.
- Use LCFS and other pricing and regulatory policies to accelerate use of low-carbon biofuels in aviation.
- Use revenue from cap and trade for incentives for electric cars and trucks and mobility programs that reduce vehicle use, as well as RDD&D for low-carbon technologies and fuels, including biofuels for aviation.
- Reform transportation finance to support partnerships between transit operators and mobility service companies, with a particular focus on increasing service to low-income and other disadvantaged riders.
- Increase funding of transport operators serving dense cities.
- Increase funding for micro mobility (shared bikes and scooters) and public and private microtransit, especially in suburban areas and small cities where transit is sparse.
- Convert the gasoline tax financing system to a mileage-based system that incorporates environmental and climate priorities.

Stimulus package

Congress should:

- Provide greater funding for electric car and truck purchase incentives, possibly linked to a feebate and/or to restrictions on the income of people receiving it.
- Provide targeted incentives for commercial drivers/operators to purchase or use electric vehicles.
- Establish a federal job stimulus program to build electric grid redundancy/resiliency and large numbers of EV charging stations and H_2 refueling stations.

Existing Buildings

- Congress should require each state to create a census of its building stock at a minimum of every five years, including annual benchmarking of energy use and carbon emissions from all buildings greater than 25,000 square feet, and a representative sampling of such information for smaller buildings, no later than 2025.
- Congress should also create a program to manage and enforce building decarbonization at the federal level and provide funding and general resources to states to develop and maintain such programs.
- The Federal Government should create systems to collect and manage this building level data, make it broadly accessible to researchers, and provide annual reports on the progress of the nation's existing buildings.
- The Federal Government should develop an energy code supplement tailored to existing buildings, and require states to adopt it, targeted to achieving the maximum reasonable reductions at time of equipment replacement.
- The Federal Government should provide funding to cities, states, territories, and tribes to adopt and enforce these building requirements, and provide additional funding for cities and states that go beyond the minimum.
- The Federal Government should use all of the financial instruments at its disposal to encourage energy/carbon improvements in the building sector, including Fannie Mae policies, tax incentives, low cost loans, depreciation schedules, and Property Assessed Clean Energy (PACE) financing.
- The Federal Government should fund a national program to promote electrification in buildings where it would reduce bills for heating and hot water.
- The Federal Government should provide generous subsidies for affordable and low-income housing energy efficiency and electrification retrofits.

4.1.5 Pillar 4: Carbon Capture

Change Strategy

An all-hands-on-deck approach to reducing U.S. greenhouse gas emissions requires the serious consideration of all possible technologies to do so, including approaches and technologies that are just beginning to be demonstrated as well as technologies that are not even imagined at present. Removing CO_2 from combustion processes as it is produced and removing CO_2 from the atmosphere are both essential. The latter is particularly important because it is increasingly clear that the U.S. and other countries need to have net-negative emissions, not just zero emissions. The change strategy employed here is designed to foster a high level of technological innovation and reduced costs, so that these technologies can be deployed at scale as rapidly as possible.

Recommendations for Congress

Congress should adopt the following goals and strategies, and appropriate implementing mechanisms, for carbon capture:

- For RDD&D, carbon capture and negative emissions technologies should be brought to scale at much lower costs as soon as possible
- For carbon sequestration, Congress should mandate the development of a strategy to achieve a national reforestation goal by 2050.

Other Federal Recommendations

- The Federal Government should provide appropriate financial mechanisms and a legal structure that will attract private investment.
- The Federal Government should direct emissions reductions as well as carbon capture and utilization in a broad range of high-heat-generation industrial activities through a combination of incentives, research and development, procurement mandates, and regulatory requirements.
- The Federal Government should make the 45Q tax credit more generous for CO_2 removal and sequestration technologies.
- Congress should make negative emissions technologies eligible to participate in a national clean energy standard.
- The Federal Government should progressively reform agricultural subsidy and crop insurance programs, as well as triple the number of USDA extension agents, to incentivize and facilitate agricultural best practices that enhance soil carbon storage. The Federal Government should also reform the renewable fuel standard to spur the development, scale-up and adoption of low-GHG biofuels.
- Congress should amend the “organic legislation” for each federal public land system to mandate consideration and implementation of climate mitigation, adaptation, and resilience in management plans.
- Congress should adopt the following to meet the reforestation goal:
    - Carbon price to incentivize reforestation on private land.
    - Incentive programs (e.g., tax breaks, cost-sharing for planting costs), such as:
        - Reforestation tax incentives akin to the Investment Tax Credit (ITC) for solar, the Production Tax Credit (PTC) for wind, and 45Q tax credit for carbon capture, utilization, and storage.
        - Conservation easement tax deductions.

4.1.6 Significant Reductions in Emissions of Non-Carbon Dioxide Pollutants

Change Strategy

Although non-CO_2 pollutants are not directly included in the modeling framework described in Chapter 2, they are a significant contribution to U.S. GHG emissions. Many of the pollutants included in this framework, moreover, are byproducts of the combustion, transportation, or production of fossil fuels, particularly black carbon, nitrous oxide, and methane. Policies specifically directed at these pollutants are intended to reinforce other recommended policies. More generally, reducing these pollutants – whether they are derived from fossil fuels or not – will provide an extra measure of insurance that the level of emissions reductions sought for the four pillars presented in this chapter will actually be achieved.

Recommendations for Congress

- Congress should amend the Energy Policy and Conservation Act to apply full life-cycle climate performance accounting to regulated appliances as a way to reduce the use and emission of fluorinated compounds.

Other Federal Recommendations

- The Federal Government should strengthen controls over leakage, venting, and flaring of methane throughout its life cycle. The controls that were imposed during the Obama Administration and revoked or weakened during the Trump Administration, including those for landfill methane, should be reinstated.
- The Federal Government should require the shift from diesel engines to electric trucks as soon as possible, thus eliminating particulate matter emissions.
- To reduce black carbon and other emissions, EPA should prioritize regulations that accelerate fleet turnover and otherwise take older and dirtier engines and vehicles off the road.
- The Federal Government should update and amend its green purchasing program requirements to eliminate purchases of equipment containing hydrofluorocarbons (HFCs) where other low-global-warming-potential and more energy efficient alternatives are available.

4.1.7 Foreign Policy

Change Strategy

In terms of direct physical reductions in GHG emissions, foreign policy is not a pillar of domestic decarbonization in the same sense as the four pillars outlined in this chapter. It is, however, an absolutely essential component of any overall federal strategy to reduce GHG emissions. While climate change is widely understood as a global problem, the U.S. has among the highest per-capita emissions of any country in the world and produces 13 percent of global GHG emissions. A strong U.S. foreign policy on climate change involves a great many different kinds of approaches to make rapid global progress on deep decarbonization. The critical components are (1) a serious domestic effort to reduce GHG emissions that demonstrate the credibility of U.S. foreign policy actions on climate change, and (2) a willingness to engage in genuine and constructive ways with other countries and the international community.

Recommendations

- The Federal Government should quickly rejoin the Paris Climate Agreement and set a new, stronger Nationally Determined Contribution for U.S. greenhouse gas emissions.
- The Federal Government should refrain from using trade mechanisms to disadvantage renewable energy in the U.S. and other countries.
- The Federal Government should quickly ratify the Kigali Amendment, either through existing authority under the Clean Air Act or through formal advice and consent of the U.S. Senate.

- The U.S. should begin to re-establish foreign policy leadership by:
  - Supporting global “Zero-by-2050” commitments, and aligning its policies with other national mid-century transition strategies, particularly that in the particularly those in Europe.
  - Actively participating in technology partnerships with key global industry groups, including aviation, shipping, global grid interconnections, hydrogen, and international markets for renewable energy, etc.
  - Providing financing for low-income countries to ensure the global engagement envisioned by the Paris Climate Agreement.
  - Establishing border taxation and regulation for trade in carbon-intensive fuels and products.
  - Actively participating in transnational processes for sub-national actors and firms so that best practices can be identified (akin to ICLEI and C40 but with much more active systems for policy review and learning).
  - Negotiating mainstream circular economy objectives in free trade agreements; bilateral, regional, and multilateral processes and agreements; and in U.S. external policy funding instruments (such as that for the EU).

References

1. Columbia University SIPA Center on Global Energy Policy, Energizing America: A Roadmap to Launch a National Energy Innovation Mission 43-50 (2020), https://www.energypolicy.columbia.edu/sites/default/files/file-uploads/EnergizingAmerica_FINAL_DIGITAL.pdf.

4.2 States and Cities for Climate Action

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4.2.1 Introduction

States and cities play an essential role in implementing and innovating decarbonization. Notably, states and cities are already innovating in regard to the Four Pillars of Decarbonization: electricity decarbonization, energy efficiency, electrification, and carbon capture. As the U.S. society undergoes significant transitions in regard to infrastructure, energy economy, jobs, land use, and policy, collaboration and coherence across scales of governance are essential. States and cities are key to the development of decarbonization infrastructure and the implementation of effective policies.

States and cities are also important agents in the mobilization of multiple actors across both the public and private sectors. They have direct contact with key stakeholders for the new energy system, as described in Chapter 2. Key stakeholders include, but are not limited to: federal, state and municipal government agencies, local communities, non-governmental organizations (NGOs), National Labs, policymakers, urban planners, public and private companies, and the scientific community.

Mitigation and adaptation strategies are widely used to frame subnational climate change efforts, and they are often closely integrated. For example, green roofs can both serve as a mitigation strategy to reduce energy use and greenhouse gas emissions, but also serve to cool building inhabitants, and are therefore an adaptation measure as well. Another example is upgrading the insulation of houses and weatherizing for extreme events which also often reduces energy needs and emissions. Actions that reduce greenhouse gas emissions while increasing resilience are win-win. Mitigation and adaptation measures should be made in the context of current resources and technical means of the city or state, community needs, and the Sustainable Development Goals (SDGs).

Disaster risk management is a critical domain at the intersection of mitigation and adaptation. In coastal areas, for example, there is a dual threat of gradual sea level rise and the increasing intensity of more sudden disasters such as extreme precipitation events, hurricanes, and accompanying storm surge. New building stock that is built via circular/regenerative methods, also described in the Buildings chapter, is more likely to both produce zero-to-low emissions (mitigation) and can be designed to be more resilient to future natural disasters (adaptation). Disaster risk management is often coordinated haphazardly across multiple tiers of government and among peer jurisdictions; further case studies and models of how to more successfully link these efforts within a region are urgently needed.

Measures to accomplish deep decarbonization need, at a minimum, to ensure that underserved communities are not disproportionately burdened, but they also offer the opportunity to address long-standing social inequities. Equity[i] fosters human well-being, social capital, and sustainable social and economic development, all of which increase a city or state's capacity to respond to climate change. Policies should include equity and environmental justice as primary goals.

4.2.2 Status of States and Cities

The U.S. federal system allows state and city governments to set policies and targets, design laws and standards, implement financial mechanisms to develop and support markets (e.g., green bonds), and enforce regulatory compliance.[1] The majority of regulatory and siting decisions for utilities, transportation planning, building codes, and other important aspects of energy and transportation decision-making take place at the state and regional levels. Many states and cities have been early adopters of climate action. The U.S. Climate Alliance is one of the best examples of bold state action, with a coalition of 25 states committed to climate action and development of sustainable and scalable policies to enable the green transition.

This sub-national U.S. effort is bolstered by a proliferation of trans-national city networks sharing best practices on climate action, such as C40, ICLEI, and 100 Resilient Cities. Knowledge providers such as the Urban Climate Change Research Network (UCCRN) also play a significant role.[2]

Since cities are a key source of emissions, and global urbanization processes will only increase that trend unless substantial local action is taken.[3] Already, cities emit 70 percent or more of the world's emissions.[4] The bulk of the country's consumption-related carbon emissions can be concentrated in just a few cities; the populations of Chicago, New York and Los Angeles combined account for nearly ten percent of U.S. consumption-related carbon emissions.[5] For U.S. cities, there is a lower household carbon footprint (HCF) in urban core cities (40 tCO_2e) and higher carbon footprints in outlying suburbs (50 tCO_2e), with a range from 25 to >80 tCO_2e in the 50 largest metropolitan areas.[6]

U.S. cities have significant power to take climate action due to their ownership of key assets, their ability to set and control budgets for city functions, and the ability to set their own vision and policy.[7] However, while cities and states are both empowered to undertake many roles in regard to climate action, they do have limited agency in regard to resources and overarching jurisdiction. These limitations can be overcome by a coherent set of policies across city, state, and federal levels.

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i Racial equity is the condition when race no longer predicts a person's quality of life outcomes in U.S. communities. For example, the City of Austin recognizes that race is the primary determinant of social equity; the City recognizes historical and structural disparities and a need for alleviation of these wrongs by critically transforming its institutions and creating a culture of equity.

State Renewable Portfolio Standards

Analysis of U.S. Renewable Portfolio Standards (RPS) in 2013 found economic benefits of an average of $2.2 billion from reduced GHG emissions, and another $5.2 billion in benefits from reductions in air pollutants.[8]

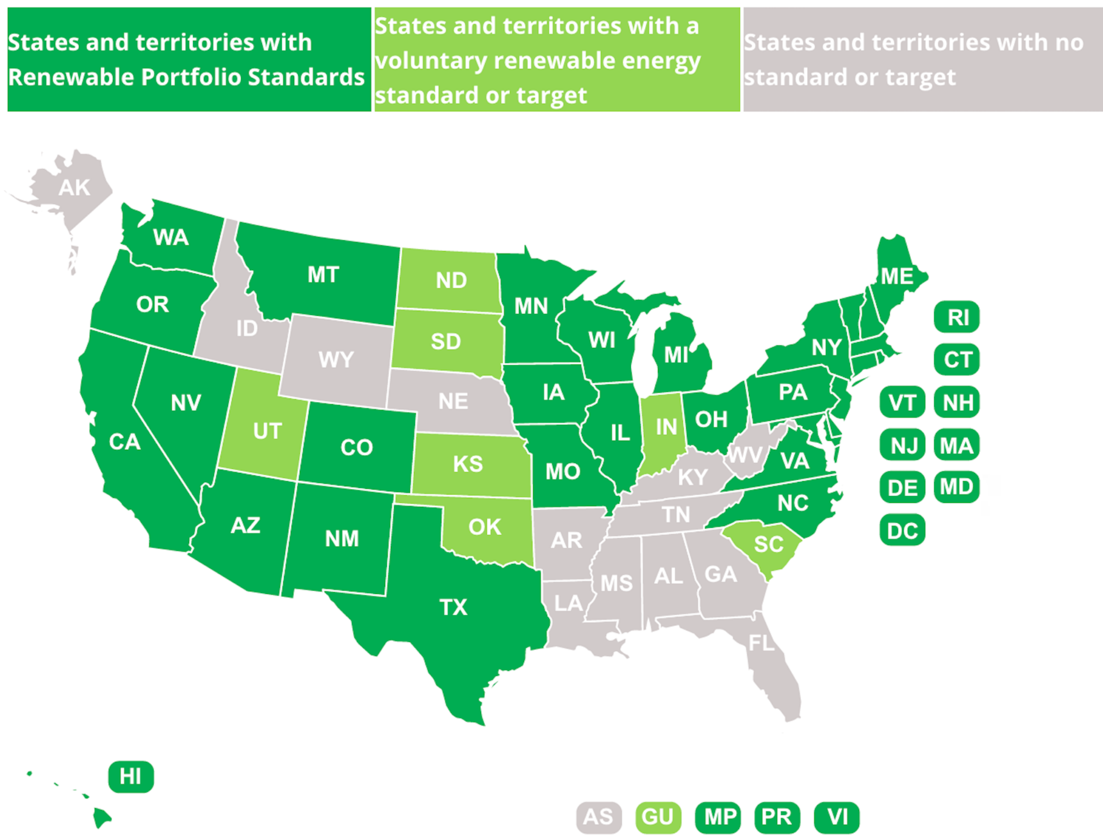


Figure 4.2.1. Renewable Portfolio Standards by state and territory ("State Renewable Portfolio Standards", 2020).

City Climate Action Plans and Legislation

Many U.S. cities have chosen to accelerate their commitment to climate action, adopting the emission goals and guidelines of the Paris Climate Agreement.[9] Following the "We Are Still In" pledges of several C40 Cities and their implementation of climate action goals, mayors of hundreds of cities across the country have followed suit. While cities are committed to upholding the goals of the Paris Climate Agreement, every city has a different approach that works for the specific culture, landscape, and economy of that municipality (see Table 4.2.1).

Table 4.2.1. Climate action plans for selected cities.

City	State	Climate Action Plan
Boston	Massachusetts	City of Boston Climate Action Plan 2019 Update
Boulder	Colorado	City of Boulder Climate Commitment
Dallas	Texas	Comprehensive Environmental & Climate Action Plan
Denver	Colorado	80x50 Climate Action Plan
Los Angeles	California	L.A.'s Green New Deal
Miami	Florida	City of Miami Climate Action Plan
Minneapolis	Minnesota	Minneapolis Climate Action Plan
New Orleans	Louisiana	Climate Action for a Resilient New Orleans
New York City	New York	New York City's Roadmap to 80 x 50
Phoenix	Arizona	2015-2016 Sustainability Report
Portland	Oregon	Local Strategies to Address Climate Change
San Francisco	California	San Francisco Climate Action Strategy 2013 Update
San Jose	California	Climate Smart San Jose
Seattle	Washington	Seattle Climate Action
St. Louis	Missouri	Climate Action & Adaptation Plan Report
Washington D.C.	n/a	Climate Ready D.C.

Case Study - Implementation of Climate Action in California

In 2006, California passed its landmark climate legislation, the Global Warming Act, or Assembly Bill (AB) 32. AB 32 set a total limit for statewide GHG emissions, requiring California to reduce its GHG emissions to 1990 levels, equivalent to 431 MMtCO_2e, by 2020.[10] It further mandated the state to address climate change through a long-term transition to a low-carbon and sustainable energy economy, by emphasizing the expansion of renewable energy, clean transportation and energy conservation, as well as energy efficiency improvements, and waste reduction.[11] Accordingly, AB32 focused on four primary energy efficiency programs: renewable portfolio standard, advanced clean cars, low-carbon fuel standard, and carbon cap and trade. While the bill allowed the state to choose from a wide range of possible approaches to achieve these goals, it excluded the implementation of a carbon tax.[12] The California Air Resource Board (CARB) was put in charge as the lead agency to adopt regulations, and the Climate Action Team was formed, encompassing 18 state agencies, to support CARB's efforts.[ii]

ii California Environmental Protection Agency; Governor's Office of Planning and Research; California Air Resources Board; Business, Consumer Services, and Housing Agency; Government Operations Agency; California Natural Resources Agency; California Department of Public Health; Office of Emergency Services; California Transportation Agency; California Energy Commission; California Public Utilities Commission; California Department of Food and Agriculture; Department of Forestry and Fire Protection; Department of Fish and Wildlife; Department of Transportation; Department of Water Resources; Department of Resources Recycling and Recovery; State Water Resources Control Board

Within ten years (2006-2016) California's emissions dropped by around 56 MMTCO_2e, allowing California to achieve its 2020 goal earlier than mandated.[13] Most of the reduction of GHG emissions occurred through the electricity sector switching to renewable energy sources. In 2017, 52 percent of California's in-state and imported electricity was generated by renewable energy and zero GHG resources (small and large scale hydropower, solar, wind and nuclear).[14] In contrast, California's biggest contributor to GHG emissions, the transportation sector, has experienced increasing emissions since 2013, although the rate of emissions growth has declined.[15]

According to CARB, this shift in the electricity sector is partly driven by California's Renewable Portfolio Standard (RPS), the Senate Bill (SB) 1368 power plant emissions standard, and the Cap and Trade Program.[16] However, there have been speculations on the program's efficiency in reducing California's GHGs. There has been an oversupply of compliance instruments on the market compared to emissions subject to the Cap and Trade Program for years. This condition, referred to as overallocation, is projected to last until the mid-2020s.[17]

Policymakers tend to promote the Cap and Trade Program as a tool that reduces emissions in an economically feasible manner and strengthens program links of jurisdictions.[18] However, the California Legislative Analyst's Office points out that the state's emissions were below the cap early on in the program (2013 - 2015), indicating that it likely did not have much of an effect, if any.[19] Instead, according to Michael Wara, Associate Professor at Stanford Law School, the biggest impact ascribable to policy generated from reducing emissions has been regulatory programs based on institutional experience.[20]

By setting stringent emission targets and taking a holistic, multi-sector approach, California has been able to progressively reduce its GHG emissions and lower the costs of solar and wind electricity while maintaining a growing economy.[21] California's rich economy creates a unique opportunity to put policy strategies to the test. The state's openness to policy innovation provided context to enable other U.S. states and jurisdictions to adopt successful policies and standards established by California. However, to continue this momentum, it is imperative to close the gap between California's ambitious decarbonization goals and the current implementation level.

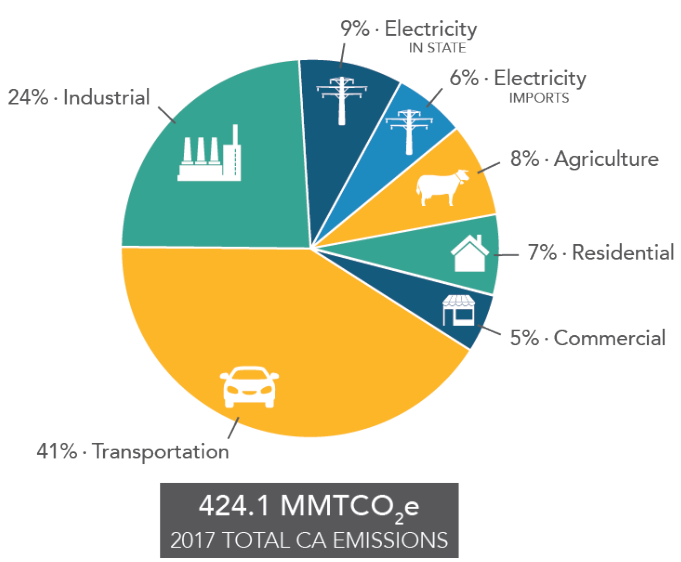


Figure 4.2.2. California's 2017 emissions by economic sector ("GHG Current California Emission Data", 2020).

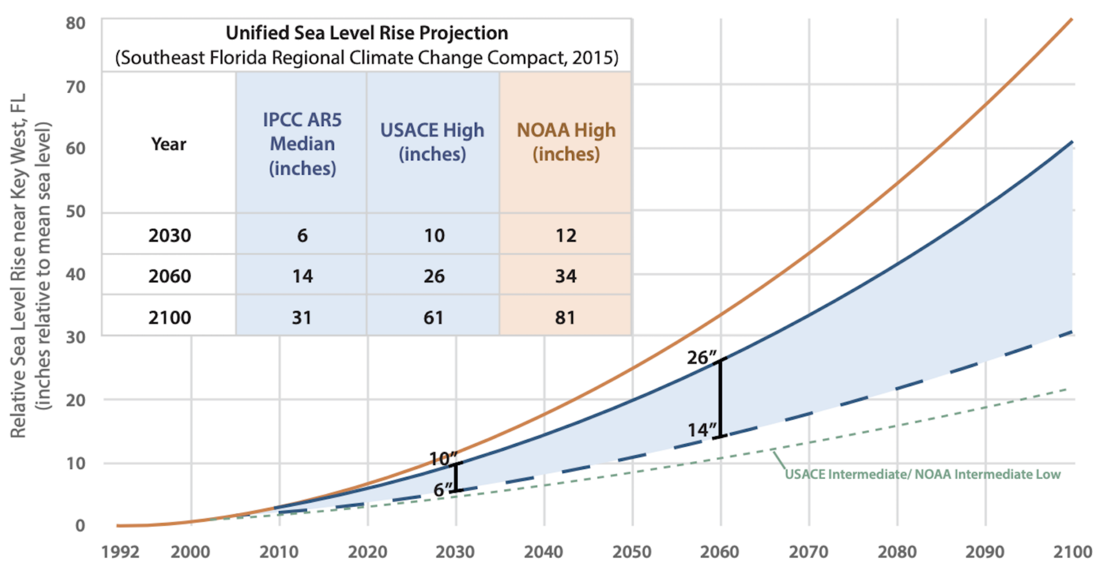
Case Study - Oakland Park and Wilton Manors, Florida 2019 Joint Climate Action Plan

Municipalities are increasingly establishing their own climate action and resilience plans. A further development, still in early stages, is for local municipalities to coordinate their climate planning efforts as opposed to operating independently. For example, Oakland Park and Wilton Manors – two neighboring cities in the Miami metropolitan area – jointly released a 2019 Climate Action Plan.[22] The mayors of the two cities wrote:

> "We encourage other cities and communities to follow our lead and form collaborative relationships to fight the [climate-related] challenges that would otherwise be tough to do independently… To our knowledge this is the first time two local jurisdictions have joined forces [to write a climate action plan]."[23]

The Oakland Park/Wilton Manors Climate Action Plan stems from the growing recognition that a piecemeal approach to climate action – with each municipality only considering adaptation and mitigation within its own jurisdictional boundaries – is outdated. With southern Florida at an increasingly high risk of flooding due to sea level rise (see Figure 4.2.3), among other climate-related concerns, these two cities are reckoning with a changing reality that urgently necessitates new governance approaches.

This new reality is clearly a motivation, as stated in the Plan's Executive Summary: "With contiguous borders and waterways as well as adjacent water and sewer systems, *city boundaries are irrelevant and artificial for the purposes of climate action*" (p. 4; emphasis added). Good climate governance, for them, means greater regional coordination.



Year	IPCC AR5 Median (inches)	USACE High (inches)	NOAA High (inches)
2030	6	10	12
2060	14	26	34
2100	31	61	81

Figure 4.2.3. Sea level rise projections near Key West, FL utilizing regional adaptations of three global curves (Cities of Oakland Park and Wilton Manors, 2019).

The Plan considers transportation, water, energy, and emergency management systems from a joint perspective – encouraging the two cities to remain in conversation with each other to achieve shared goals, while simultaneously recognizing that approaches may differ slightly between them. The many goals listed in the plan prioritize equity and resilience, encourage coordination with higher levels of government, and stress the need for public participation in policy development.

The plan lays out lofty goals, but is light on next steps and milestones. It remains to be seen whether the two cities will be able to maintain their initial level of commitment to regional coordination. Still, if successful, this pilot may well lay the groundwork for other regional municipalities or greater metropolitan areas. Furthermore, states and the Federal Government would do well to champion and even finance such initiatives within and across jurisdictional borders.[24]

Decarbonization Transition and Regional Collaboration

The U.S. is a large country with a vast geography and regional variations in population, climate, culture, and energy demand. Focusing at the state and city levels enables experts to identify best practices and methods that work specifically for that region's resources, existing infrastructure, and economic opportunities.

Low-carbon emission strategy reports have been created for the Midwest and Southwest regions of the U.S., outlining unique critical issues and opportunities for each region.[25] [26] The Midwest focused report shows the region has ample opportunity for carbon capture and storage and to continue as a leader in the production of biofuels, while the Southeast has an abundance of sun exposure and, as a result, renewable energy installations. In addition to regions aligning with the strengths and opportunities the geography provides, collaboration between regions enables the sharing of resources and aid where another region is lacking. For example, the Southeast relying heavily on solar for electricity generation brings challenges to deliver clean energy during hours when the sun is not shining. These challenges are addressed by sharing resources with the Midwest and importing onshore wind from the lower-Midwest when solar energy is lacking.

With a focus on electrification, modernizing the grid and allowing the sharing and transmission of renewable resources within and between regions is crucial. In addition, this modernization of the grid along with the transition from coal to clean energy, and electrifying transportation provides opportunity to grow new industries and create jobs for Americans.

4.2.3 Policy Playbook

Ambitious state and local policy remains essential because federal interventions have their limits. For instance, state and local zoning decisions will drive the smart growth and urban densification policies that are critical for cost-effectively reducing transportation-related emissions and maintaining our terrestrial carbon sink. In the realm of energy policy, states have led the charge on energy efficiency standards, and federal policy has followed suit. Appliance standards were first established in California in 1974, followed quickly by Florida, New York, and Massachusetts. In 1978, federal standards were proposed, though national efficiency standards did not become mandatory until 1987, when the National Appliance Energy Conservation Act was enacted.[27]

State governments are responsible for power generation and within-state distribution – and play a role in coordinating regional grids. State government instruments include public investments, regulation of the utility sector, tax and other incentives for industrial location, land siting and right-of-way, building codes, design and retrofitting of state buildings and transportation fleet, public transportation policies, state building codes, public infrastructure (e.g., charging stations on state roads).

Local governments, like state governments, have often been leaders on climate and sustainability. Local governments also have jurisdiction over urban land use, building codes, roads, transit, and much more. Recent research shows that U.S. cities have stronger powers to set their own vision and enforce policy than non-U.S. cities (around ten percent higher than the average).[28] Compared with other countries, U.S. mayoral powers are particularly strong in relation to finance (about 30 percent higher than the international average), water (~ 20 percent higher), outdoor lighting (~ 15 percent higher), buildings (~ 10 percent higher), and energy supply (~ 10 percent higher).[iii]

Renewable energy procurement strategies available to cities vary based upon the city's electricity provider and the state's regulatory environment. Renewable energy purchase options include: onsite solar projects at municipal facilities, utility programs, physical power purchase agreements (PPAs), virtual power purchase agreements (VPPAs), community solar programs, and renewable energy certificates.

Twenty-five of the 100 largest cities in the U.S. are participating in the Bloomberg American Cities Climate Challenge (ACCC). The challenge was launched in 2018 to help cities establish high-impact policies to reduce emissions from electricity, buildings, and transportation. ACCC recently released a playbook highlighting activities already underway – ranging from foundational actions such as strengthening enforcement of building energy codes to providing commuter incentives to reduce driving – as well as more ambitious actions such as achieving ubiquitous EV charging infrastructure.[29]

Electrical utilities and renewable energy standards

According to the U.S. Energy Information Administration, in 2019 about 32 percent of U.S. energy-related carbon emissions were from the electric power sector. Because wind and solar electricity are currently the lowest-cost carbon-free energy technologies, deploying them in the electricity sector would result in a major decarbonization thrust. Over 70 percent of the U.S. coal fleet is now more expensive to operate than it would be to build and operate new solar and wind energy.[30] By 2025, this will be true for nearly the entire U.S. coal system.[31] States have long led the way in promoting renewable electricity generation by enacting various RPS, which require that a certain percentage of a utility's electric generation must come from renewable sources.

According to Lawrence Berkeley National Laboratory, in 2019 RPS policies existed in 29 states and the District of Columbia (Figure 4.2.4)[32] and covered 56 percent of total U.S. retail electricity sales.[33] According to the National Council of State Legislatures, "Roughly half of the growth in U.S. renewable energy generation since 2000 can be attributed to state renewable energy requirements."[34] In the last 5 years, many ambitious state goals have been enacted, and 2019 was a particularly active year. In addition, a number of states have experimented with different carbon pricing methods, a key area of climate policy experimentation.

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iii Comparison between C40 cities in the U.S. and non-U.S. C40 cities; 1 in 5 U.S. city dwellers lives in a C40 city.

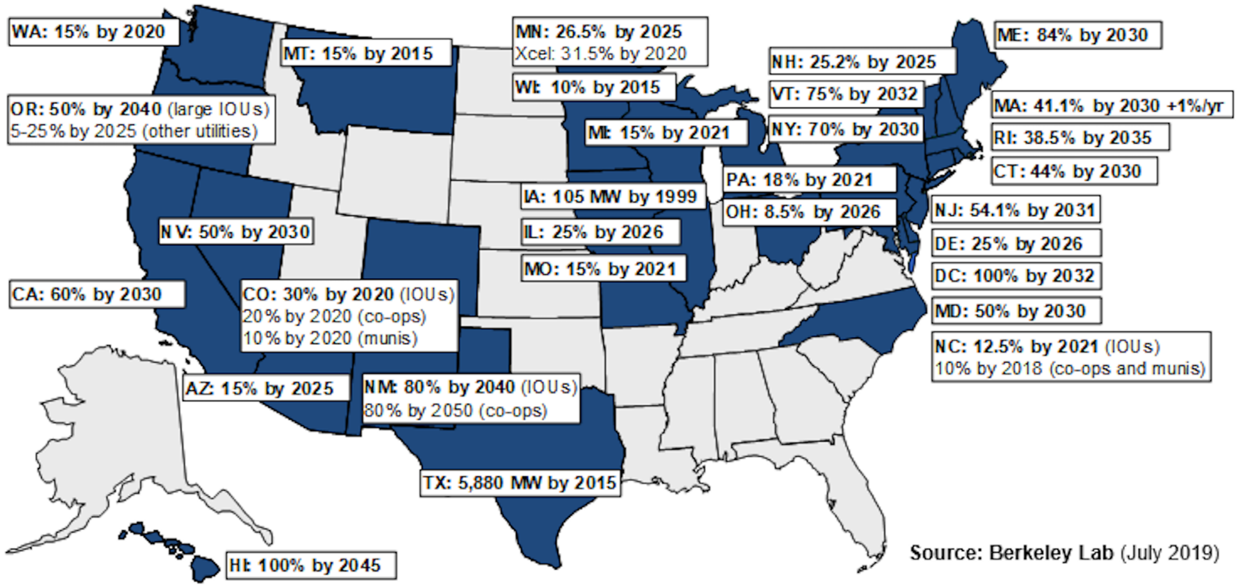

Figure 4.2.4. U.S. map showing state RPS requirements and timelines (Barbose, 2019).

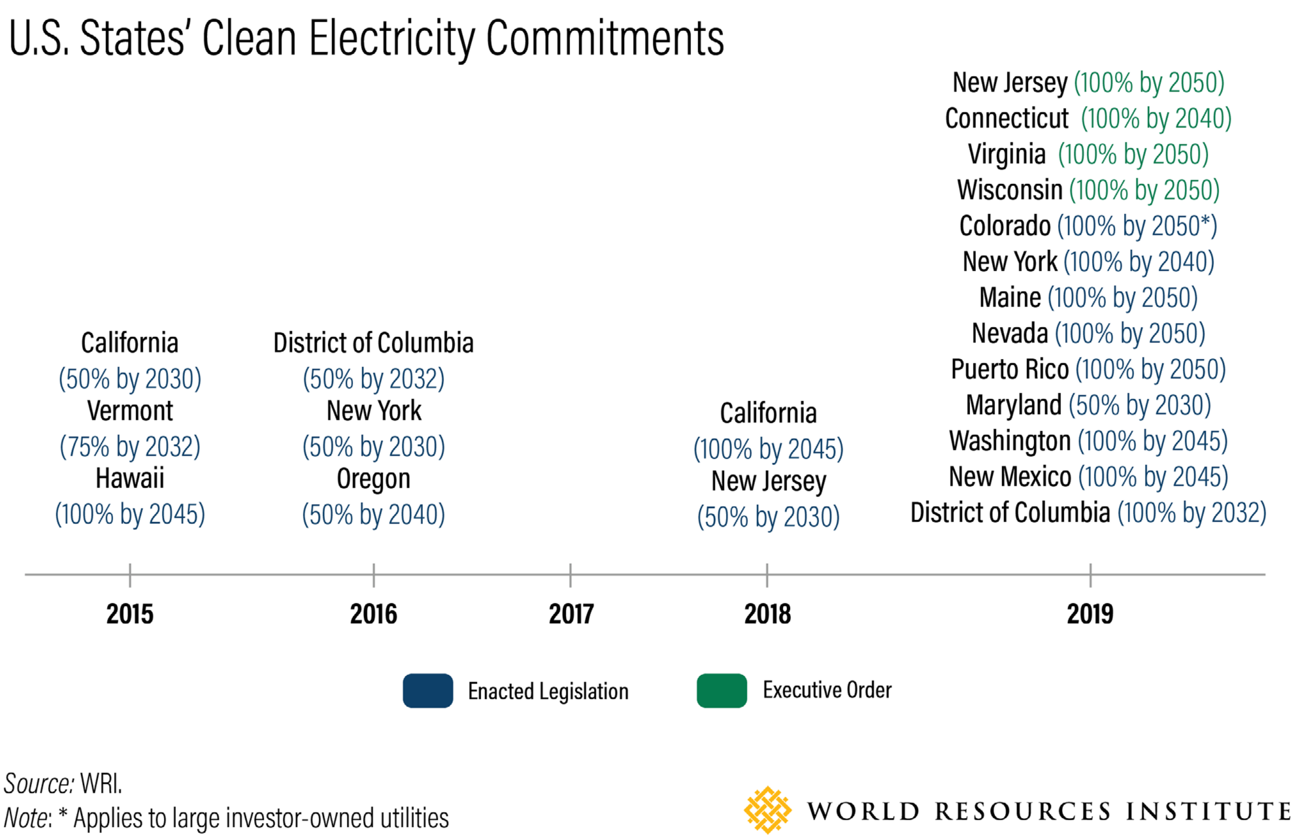

Figure 4.2.5. Recent clean energy commitments by U.S. states (2019 Was a Watershed Year, 2019).

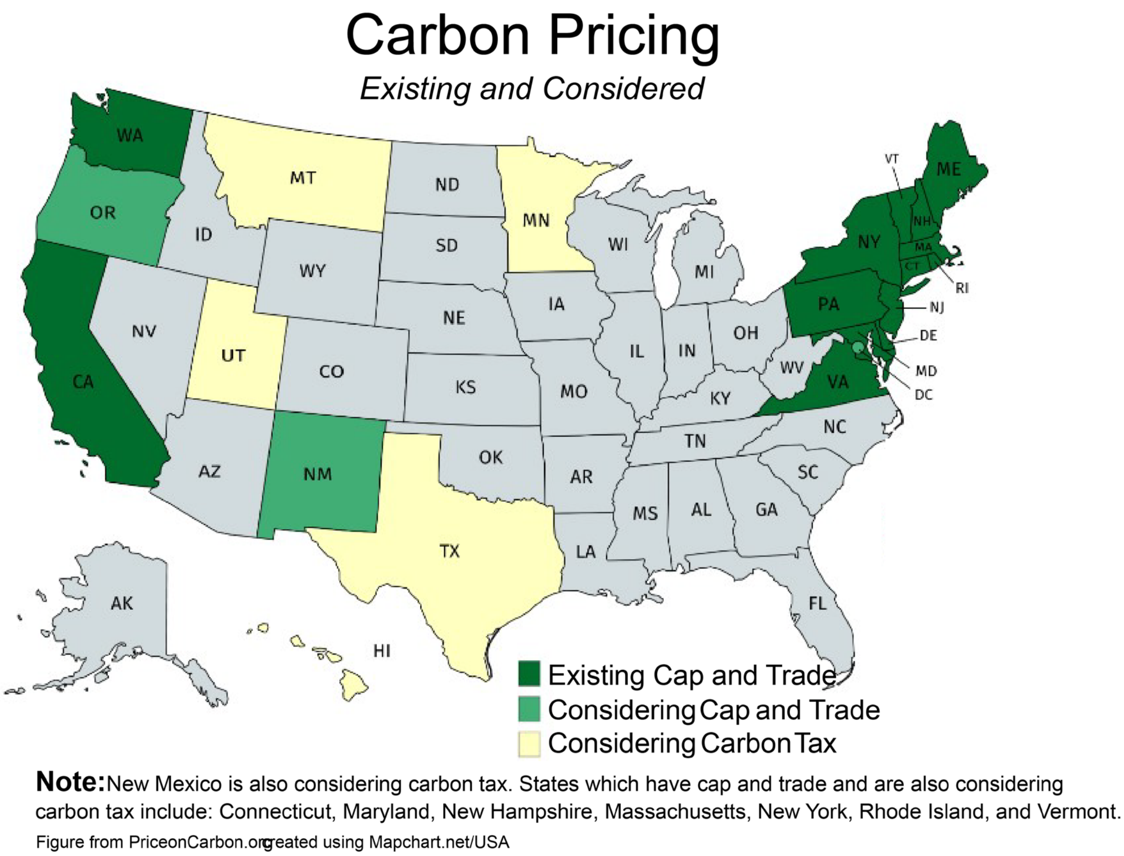

Figure 4.2.6. Carbon pricing methods existing and under consideration in U.S. states ("State Actions", 2020).

Case Study - Colorado's Renewable Energy Portfolio

As the state of Colorado has excellent wind and solar resources, it is not surprising that in 2004, Colorado voters passed the first citizens' ballot measure to provide a statewide renewable energy portfolio standard. This required that three percent of retail electricity sales come from renewable sources in 2007, increasing to ten percent by 2015. The state legislature has increased the goals three times since 2004, the most recent requirement being 30 percent renewable energy for investor-owned utilities by 2020. (Xcel Energy, the state's largest utility, reports that 28 percent of its electricity is from renewable sources at the time of this writing.)

In 2019, Colorado Governor Jared Polis signed 11 new clean energy bills passed by the state legislature.[35] These cover carbon emissions, renewable energy, electric vehicles, and efficiency standards. Chief among them is the "Climate Action Plan to Reduce Pollution." This bill sets economy-wide carbon emissions reduction targets relative to 2005 of 26 percent by 2025, 50 percent by 2030, and 90 percent by 2040. A separate bill echoes Xcel Energy's latest 2050 goal of providing 100 percent carbon-free electricity by 2050. A public utilities commission (PUC) bill contains a groundbreaking requirement that the PUC must include a value for the social cost of carbon (SCC), beginning at $46 per short ton of carbon dioxide emissions in its economic analyses (this includes the benefits of electrification).

Colorado's shift toward renewable electricity has resulted in the closure of coal plants, which are traditionally located in low-income neighborhoods where the resulting air pollution causes asthma and other health issues for the poorest residents. A parallel shift from gasoline to EVs will also reduce vehicle emissions in those neighborhoods with the most highway traffic, which again tends to impact low-income residents disproportionately. Thus, the shift to clean energy in Colorado provides strong support for greater social equity. Investing in clean energy in Colorado by improving energy efficiency standards and expanding the supply of clean renewable energy sources will also expand job opportunities in the industry. An annual investment of $14.5 billion in clean energy from 2021 to 2030 can generate 100,000 jobs a year in the state.[36] In addition, the growth of employment will create more opportunity for women and people and communities of color.

Case Study - Whisper Valley Community in Texas

Whisper Valley is a 2,000-acre multi-use residential community located outside of Austin, Texas, consisting of 7,500 all-electric homes, two schools, two million square feet of commercial space, a pool and recreation center, and a 600-acre park.[37] Building heating and cooling are provided by heat pumps connected to vertical geothermal wells. The homes in each block are connected by a buried, uninsulated water piping loop that communicates with the geothermal wells. The piping loop provides additional surface area in contact with the ground (which is at approximately the average annual ambient temperature), thus enhancing the heat source/sink. Homeowners have the option of including a 5-kW solar photovoltaic system on their roof to operate the heat pump and the various appliances in their all-electric homes, such as heat pump water heaters, electric dryers, and inductive stovetops.

Figure 4.2.7. Geothermal heat pump piping and rooftop photovoltaic array in Whisper Valley community (Whisper Valley, 2020).

Taurus Investment Holdings, an international real estate development firm, established EcoSmart Solution to develop sustainable communities, which they view as both a business development opportunity and environmentally beneficial. Shell New Energies is also an investor in EcoSmart Solution, as they want to expand into the low-carbon energy space. Austin has long been progressive in terms of energy efficiency and renewable energy, and was a logical location for their first planned sustainable community. Taurus believes that people will want to buy homes that are sustainable not only because they are better environmentally but because they won't become obsolete. Taurus sees Whisper Valley as just the first of many similar projects in the future.

Buildings and housing

Buildings typically represent a large portion of GHG emissions at the local level. Implementing energy efficiency projects in municipal facilities is a great way for states and cities to lead by example, engage the private sector, and demonstrate that reducing emissions can also save money. States and cities should implement municipal building policies that standardize and institutionalize sound energy management, ensuring that savings are realized even with changing administrations. Municipal building energy consumption reductions benefit both a city's government as well as its residents and businesses. By investing in energy efficiency within the municipal building stock and other operations, cities can achieve significant reductions in operating costs, thereby reducing long-term taxpayer burdens.[38]

In general, it is considerably more expensive to retrofit energy efficiency measures in existing buildings than to include them in new construction. Decarbonizing existing buildings can be achieved through a combination of the lowest-cost energy efficiency retrofits and electrification, so that a building's energy comes from renewable sources, including utility-scale wind and solar, community solar projects (also called solar gardens), and rooftop solar.

The National Renewable Energy Laboratory (NREL) has developed two modeling tools that use large databases of existing buildings to rank order the cost-effectiveness of different energy efficiency measures as a function of building type, location, fuel type, and building age. These tools are ResStock for residential buildings and ComStock , for commercial buildings.[39] ResStock fact sheets have been developed for the 48 contiguous states.[iv] For determining the best energy retrofit measures for both existing and new buildings, the DOE developed building modeling tools BEopt for residential buildings and OpenStudio for both commercial and residential buildings.[40]

One significant objection many homeowners raise to eliminating natural gas is their preference for natural gas stove tops because they heat more quickly and are more controllable than electric resistance elements. However, modern electric induction stovetops offer a number of advantages over electric resistance heating. Because the heating energy occurs directly in the pot or pan, heating is very rapid, and the stovetop does not get as hot as an electric resistance stovetop. In addition, induction heating can be finely adjusted. As a result, many top chefs now prefer induction stovetops to natural gas heating.

iv Available at https://resstock.nrel.gov/factsheets/.

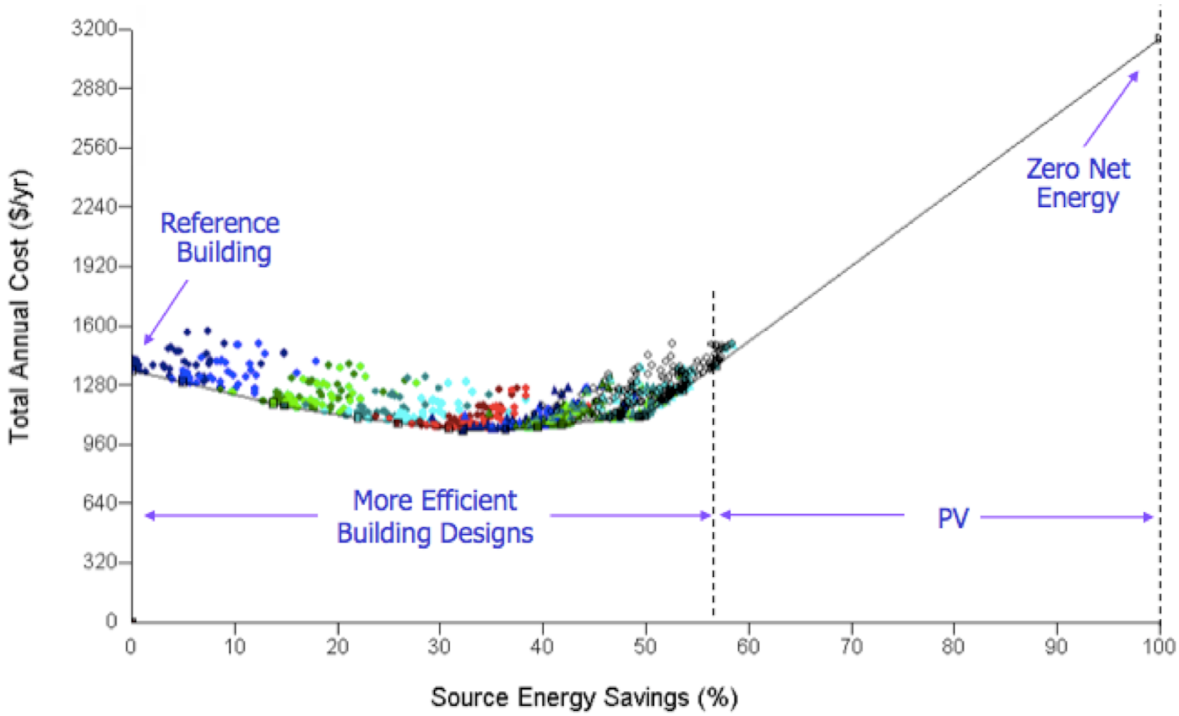

Figure 4.2.8. BEopt™ (Building Energy Optimization Tool) schematic (NREL, 2018).

Building materials

It has historically been assumed that the carbon emissions resulting from a building's energy use over the life of the building are much greater than the carbon emissions associated with the building's construction materials. That thinking is now being challenged for two reasons. First, as buildings become more efficient and as they are electrified with electricity provided by renewable sources, the carbon emissions due to energy use rapidly decrease. Second, because climate change is increasingly being recognized as an immediate crisis, the near-term carbon emissions associated with a building's construction become significantly more important. As a result, more attention is now being paid to reducing the embodied carbon emissions associated with both building construction materials and energy efficiency products.

Concrete and steel are examples of key construction materials with significant embodied carbon emissions. Also, certain types of insulation materials can contain a significant amount of embodied carbon. Blown-in materials such as fiberglass and cellulose have a lower carbon footprint than rigid and spray foam insulations. The organization Architecture 2030 has developed a Carbon Smart Materials Palette to allow designers to choose versions of materials that minimize embodied carbon.[41]

Land use and zoning

Renewable infrastructure siting, increased soil carbon sequestration, biofuel production, reforestation, and shifting away from animal agriculture all have positive and negative (and likely competing) implications for land use change and land-based activities, and authority over each of these activities is spread across several areas of the U.S. government, including the Department of Defense, Department of Energy, Department of the Interior, Department of Agriculture and the Environmental Protection Agency.

Land use, land use change, and forestry have the potential to address a significant portion of domestic greenhouse gas emissions. Forests, grasslands, and wetlands currently play a vital role in sequestering 10 to 15 percent of U.S. carbon emissions. Cities aiming to create or expand their urban forestry initiatives can receive technical assistance, financial guidance, peer-to-peer learnings, and scientific advice through groups like Cities4Forests, an initiative that aims to catalyze political, social, and economic support among city governments and urban residents to integrate forests into development plans and programs.[42]

Effective land zoning policies are needed to achieve decarbonization in agriculture, forestry, transportation, bioenergy, and low-carbon gaseous fuels.[43] Cities should adopt transit-oriented development policies that decrease single occupant vehicle trips and vehicle-miles traveled, such as expanded public transportation options, improved infrastructure for safe walking and biking, and urban mixed-use development with legitimately affordable housing.

Municipal permitting offices and public utility commissions should streamline and accelerate the build-out of EV charging infrastructure, particularly for public chargers near commercial areas or multifamily residential units. New pricing systems may be developed to encourage EV charging and integrate with local grid needs.

Single-family zoning and large lot size requirements are just two traditional land use planning policies that should be reformed by cities and states across the U.S.[v] Single-family zoning laws prevent the development of any housing that is not a detached, single-family home. Originally designed to separate homes from highly polluting industries, single-family zoning has also proliferated as a tool to segregate neighborhoods by affluence and race. In addition to single-family zoning, many cities across the country currently require that homes be built on large lot sizes, another contributor to sprawl. For most of today's urban and suburban communities, these rules are unnecessary, impede the densification of housing, and reduce the viability of reasonable access to public transit. Minimum lot sizes also hamper affordable housing developments by resulting in large, expensive homes.[44]

Avoiding lock-in

Path dependencies in infrastructure, technologies, institutions, and behavioral norms need to be considered when integrating strategies for mitigation and adaptation to climate change to avoid locking into high-emission pathways and low-resilience urban futures.[45] An effective decarbonization plan focuses on long-lived infrastructure, replacing assets at the end of their life with low-carbon successors, and policy interventions (see the Buildings chapter for more on this). A learning-by-doing approach, combined with permanent intervention, is necessary for effective structural change.[46]

v Oregon, Minneapolis, and Houston have recently changed policies related to single-family zoning or lot size.

Case Study - New Mexico's 100% Clean Energy Future

In March 2019, New Mexico passed the Energy Transition Act (SB 489), putting the state at the forefront of energy transition in the United States. The bill requires New Mexico's electricity to be carbon free by 2045 with several interim goals, including:

- The shutdown of New Mexico's last coal plant by 2022,
- 50 percent carbon-free by 2030, and
- 80 percent of energy consumption from renewable energy by 2040.[2]

One of the methods New Mexico is adopting to meet the bill's goals is called securitization. Securitization is "a low-cost financing method to pay off coal plant costs and close the facilities." It can reduce the price of closing a coal plant by up to 40 percent, accelerating the transition to renewable energy, which is also cheaper for consumers.

New Mexico was previously dependent on coal plants, which are no longer economical. They were responsible for the harmful nitrogen oxides (NO_X) and sulfur dioxide (SO_2) emissions that were compromising the state's air quality. With New Mexico 50 percent carbon-free by 2030 commitment, the power sector's NO_X and SO_2 emissions are expected to decrease by 90 and 70 percent, respectively (based on 2017 levels), greatly decreasing respiratory related health issues and improving public health. In addition, a clean energy economy in New Mexico is anticipated to create 8,830 new jobs and $4.6 billion of new investment by 2030.

Since 1970 New Mexico's annual average temperature has warmed by 1.5°C, making it the United States' sixth fastest warming state. The warming temperatures are causing extreme summer temperatures and exacerbating drought and wildfire risk. With the Energy Transition Act, New Mexico has become a leading example for the rest of the country.

Case Study - Climate Resilience Planning in the Treasure Valley, Idaho

The Treasure Valley of Idaho is a rapidly growing metropolitan region of around 750,000 people encompassing rural agricultural communities, exurban towns, several small cities, and the state capitol, Boise. Situated within a high desert ecosystem in the Intermountain West, the Treasure Valley faces a range of growing climate impacts, such as droughts, chronic wildfire smoke, and heat waves. While the region is composed of numerous distinct municipalities, their capacity to mitigate and adapt to climate change are interlinked through transportation and economic networks, shared environmental resources such as watersheds and public lands, and mutual exposure to trans-boundary climate impacts. Coordinating collective climate action across this varied landscape of communities – whose population size, economic bases, and politics vary widely – is a central challenge for this region.

The Hazard and Climate Resilience Institute (HCRI) at Boise State University, one of the region's anchor institutions, is bringing together stakeholders from across the Treasure Valley to build climate resilience.[47] Starting in 2017, the group began building relationships across the Treasure Valley, and is convening a multi-year, collective process to develop a "Resilient Treasure Valley" plan. This plan will emphasize the communities' capacity to respond to a broad range of hazards and disasters, including both climate change impacts as well as non-climate hazards such as earthquakes.

HCRI's framing of "resilience planning" – instead of "climate planning" – speaks to local notions of self-reliance in one of the most geographically isolated metropolitan regions in the country. This planning process is unique in that it is being facilitated by a local, well-regarded public university, rather than directly by governments themselves. Leveraging their status as both facilitator and research institution, HCRI is convening a wide range of stakeholders, including both government officials and academic researchers. By doing so, HCRI is opening up avenues for collaborative, applied research that will also serve to evaluate the effectiveness of new resilience-focused policies as they are adopted.

Several municipalities within the Treasure Valley have also begun to adopt their own climate strategies, with Boise most actively driving new policy.[48] The city recently established a Climate Action Division, which is tasked with advancing climate resilience efforts. In tandem with this Division, recent initiatives brought forward under the city's new mayor emphasize equity as a central tenet of climate action. For example, existing energy and water efficiency programs will be redirected towards low-income earners in an attempt to integrate climate mitigation and affordability goals. Additionally, funding has been allocated for a citywide environmental justice assessment, which will map the distribution of environmental harms and climate impacts (e.g., wildfire risk, and heatwave hotspots), as well as environmental amenities and climate adaptation resources (e.g., tree canopy cover, and parks). By pairing these spatial evaluations with demographic data, Boise will be able to strategically focus climate mitigation and adaptation efforts towards more vulnerable and traditionally underserved communities.

The Federal Government can provide resources to support a transition from single-occupant vehicles to transit and shared/pooled services in ways that enhance accessibility by disadvantaged travelers. In addition to funding Federal Government building retrofits, the Federal Government should provide financial resources via grants to states, counties, and cities, for extensive building retrofits.

Some combination of federal and state financial incentives may still be necessary to ease the fuel-switching cost for the consumer. Carbon pricing could also help by increasing the cost of natural gas or other fossil fuels compared to renewable electricity.

A key barrier to implementing programs to increase soil carbon at large scale is the need for credible and reliable monitoring, reporting and verification (MRV) platforms. There is a need for more investment in GHG inventories and other measuring and monitoring programs, such as remote sensing,[vi] to track progress toward net carbon goals. For natural and working lands, enhanced techniques for measuring, monitoring, and modeling soil and forest carbon can be developed through partnerships between states and universities.

4.2.4 Economic and Financial Resources

Cities and states cannot fund all of the needed climate change actions on their own. Multiple funding sources are required to deliver the full complement of financing that is essential to low-carbon development and climate risk management (see Figure 4.2.9).[49]

vi Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft).

As one example, Portland adopted a resolution backing green bond issuance in the city in 2015. Green bonds can support cities with financing the infrastructure needed to reduce carbon emissions and become more resilient to the effects of climate change. Portland's action could drive the wider development of the green bond market in other cities.

Public-sector finance can facilitate action, and public resources can be used to generate investment by the public sector; however, private-sector contributions should extend beyond financial investment. The potential role of the private sector in urban climate mitigation and resilience is important and multifaceted.

Climate-related policies should also provide cities and states with economic development benefits as they shift to infrastructure systems associated with low-carbon development.

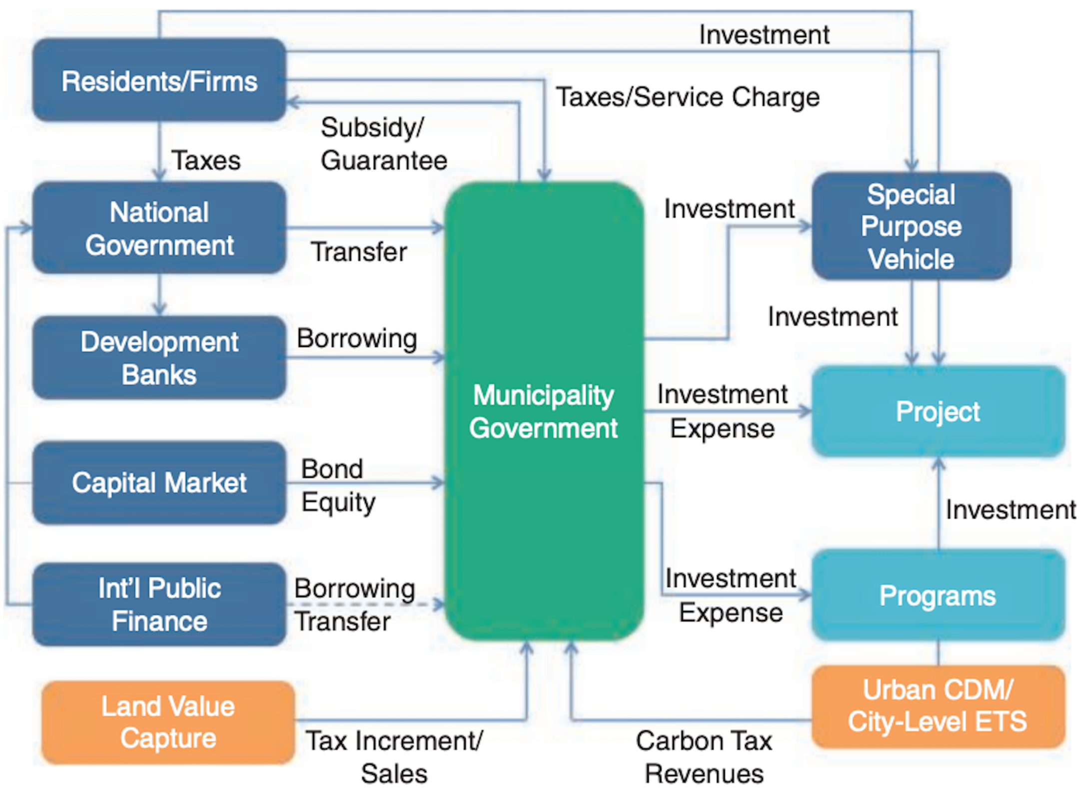

Figure 4.2.9. Potential sources of municipal climate finance (UCCRN, 2015).

Case Study - University of Michigan

As previously stated, the clean energy transition is going to take collaboration from various stakeholders across various levels of government and our community institutions. The University of Michigan, a top-ranked public university, announced its Sustainability Plan that included a goal of a 25 percent reduction in greenhouse gas emissions by 2025. In January 2019, Mark S. Schlissel, the President of the University, announced a new Commission on Carbon Neutrality to further this goal.[50] In June 2020, the Commission released its interim report.[51] The Commission started from a strong base of interest and programs for sustainability throughout the University through its Planet Blue program.[52]

The Commission's charge is to outline a timeline, pathway and approaches for achieving carbon neutrality that are environmentally sustainable; involve the regional community; create scalable and transferable models; include the participation and accountability of all members of the university community; and are financially responsible in the context of University of Michigan's mission of education, research and service. The major areas and potential pathways include, but are not limited to:

- Heat and Power. Geo-exchange, high-, mid- and low- temperature hot water systems, thermal energy storage, bio fuels, and sequestration.
- Mobility Electrification. Investments in new electric vehicles and associated campus infrastructure.
- Electricity Purchasing. Power Purchase Agreements and Virtual Power Purchase Agreements.
- Carbon Neutral Building Retrofits. Specific energy reduction measures/strategies (e.g., electrical and mechanical systems, and the building envelope), with estimated capital investment needs and return on investment.
- Building Standards. Building performance minimums; timeframes for economically feasible net-zero emissions outcomes relative to new standards; holistic algorithm to determine optimal solutions in terms of cost per emission.
- Internal Energy Consumption Policies. Internal price on carbon, and revolving energy fund to be used for energy efficiency projects.
- University Sponsored Travel. Changes for travel-related data management systems; strategies to educate the University of Michigan community on the carbon footprint of travel; mechanisms to reduce the amount of university travel, including internal price on travel emissions.
- External Collaboration. Engagement framework outlining how the university should engage, and which stakeholders it should engage, as it moves towards carbon neutrality.
- Biosequestration. Protecting existing natural lands as passive carbon sinks; restoring and enhancing natural lands in lieu of external offsets; prioritizing environmentally and ecologically friendly landscaping practices on campus.
- Carbon Offsets. Third-party validated project credits, cap-and-trade program credits, direct partnerships to develop new projects, offset project decision matrix.
- Carbon Accounting. A multi-dimensional model spanning all emission categories that will allow the Commission to evaluate various scenarios.

Multiple public engagement activities have been key to developing the plan, both to educate the community and to gather input from multiple stakeholders. The final report promises to be a global model for universities and communities.

Case Study - Feed in Tariff Program in Gainesville, Florida

In 2009, the city of Gainesville, Florida wanted to respond to the climate change crisis but had few financial resources to do so. The solution was to create a feed-in-tariff (FIT) program. Feed-in-tariffs are a popular policy tool for communities to accelerate the use of renewable energy, particularly solar, with little cost to the city. The city modeled their program after successful programs in Germany, and became the first city in the U.S. to offer a FIT program.[53]

The city of Gainesville, which controls the electric utilities, agreed to pay a higher price for any electricity produced from renewable resources, including electricity from residential homes. Gainesville's guaranteed rate of 32 cents per kWh for renewable energy was locked in for 20 years. The high cost for renewable energy was offset by increasing everyone else's bill by about 74 cents a month. In addition, while rates for other energy sources for the city will increase over the next 20 years, the 32 cent rate will stay fixed, and at some point the city anticipates actually paying less for the renewable energy than its other sources.[54]

The city contract with homeowners only pays for the 32 cents per kWh rate for energy generated by the home in excess of what they actually use for themselves. This policy keeps homeowners from using all of their solar energy to make profits on the high rate without cutting down any fossil fuel use themselves.

Because the city guaranteed the rate for 20 years, local banks agreed to loan homeowners the money to install the solar panels. In many cases, the loans were structured so that the homeowner would not have any additional cost, even with the loan, above what they were paying for utilities before. Once the loan is paid off, the homeowner receives all the benefits of the savings on utilities each month plus the extra fees for the energy they produce over their needs. This in turn encourages conservation and energy efficiency to make the solar investment pay back faster.

This method of financing allowed the city to achieve remarkable growth in solar without having to finance the solar development. The program began in March 2009 and by September 2010, electricity from solar panels in Gainesville had grown by more than 500 percent, with a combined capacity of more than 2 MW.

Since then, the program has continued to grow beyond expectations. Thirty megawatts of solar capacity were successfully applied for and reserved by 2017. In addition, two solar "farms" designed to produce nearly 2,400 MWh of energy each year are currently in construction, and a 2 MW rooftop system will crown Gainesville's largest shopping center by the end of the year.

Since the Gainesville FIT program began, several communities across the U.S. have adopted and implemented their own version of the program.

FITs are one of the best and easiest ways for local governments and utility companies to promote the acceleration of renewable energy.

4.2.5 Measurement, Reporting, Verification (MRV)

Emission inventories (EIs) are the fundamental tool to quantify the amount of man-made emissions and to keep track of their change over time. For GHGs, nationally reported EIs are regularly compiled following the guidelines prepared by the Intergovernmental Panel on Climate Change (IPCC) (e.g., IPCC 2006). National EIs are primarily based on statistical data (e.g., on fuel production, consumption, and trade data), and emission estimates are often made at the national scale by economic sector or by fuel type.

Production footprints account for flows associated with all in-boundary activities and trans-boundary flows of key infrastructures, whereas consumption footprints account for all in- and trans-boundary flows associated only with local household consumption. The two approaches may yield different "footprint" estimates for any one community. As a result, debates remain as to the best way to inventory GHG emissions at the local level, and inconsistencies often exist among city inventories.[55] World Resources Institute, C40 Cities Climate Leadership Group and ICLEI – Local Governments for Sustainability (ICLEI) have partnered to create a GHG Protocol standard for cities known as the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC).[56]

Using national household surveys, econometric models of demand for energy, transportation, food, goods, and services may be used to derive average household carbon footprints (HCF) for U.S. zip codes, cities, counties, and metropolitan areas.[57] Carbon footprint estimates are available for 31,000 zip codes in the United States. Carbon footprint profiles of almost all U.S. zip codes, cities, counties and states are available on the *CoolClimate* project website and an interactive mapping website.[58]

States and cities need to measure, report, and verify (MRV) data associated with climate mitigation and adaptation actions to understand trends, create strategy, determine the effectiveness of adaptation and mitigation approaches, assure accuracy of information, and adjust strategies.[59] MRV can be applied to greenhouse gas emissions, mitigation actions, or support (see Figure 4.2.10).

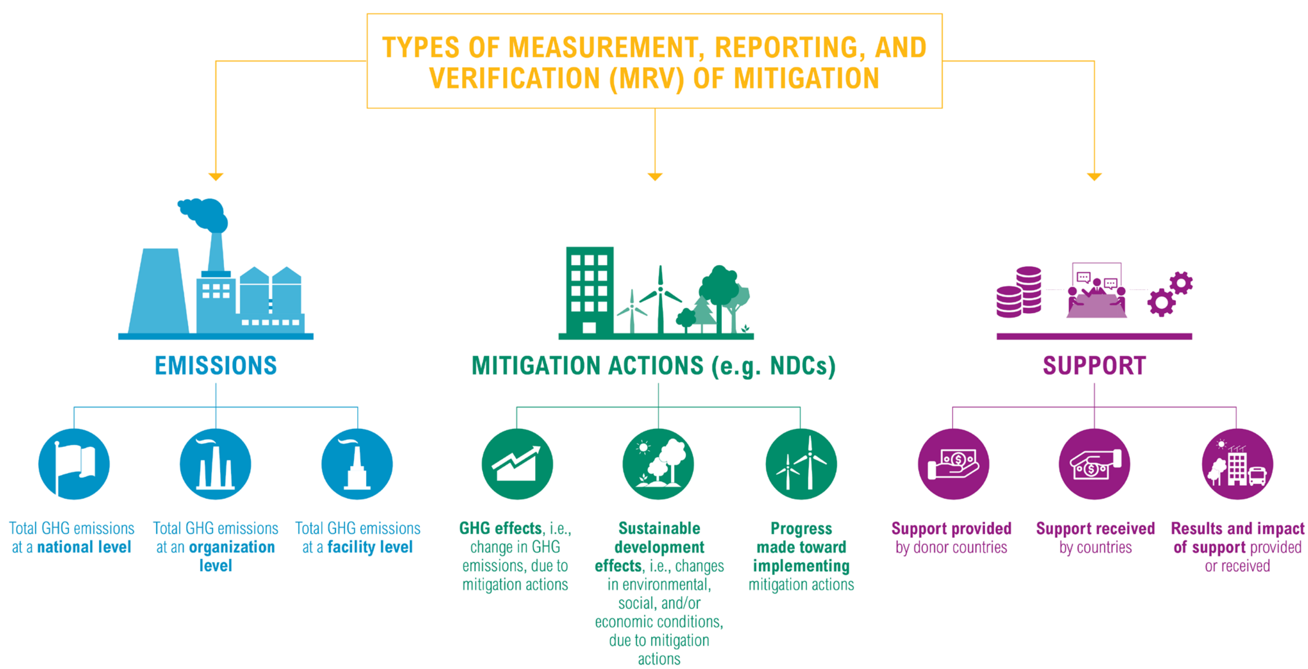

Figure 4.2.10. Types of measurement, reporting, and verification (WRI, 2016).

Remote sensing may be utilized to granularly observe and measure atmospheric CO_2 with satellite data, making it especially useful for accurately and consistently measuring changes in the spatial patterns of emissions as well as monitoring urban heat island effects and air quality.[60] By utilizing remote sensing technology, scientists can improve the accuracy of emission inventories, inform key stakeholders of climate risks and patterns, and advise policymakers. Researchers have mapped the carbon footprint of over 13,000 cities globally.[61]

Case Study - Using Remote Sensing to Track Air Pollution in Northeast United States

By using remote sensing, National Aeronautics and Space Administration (NASA) scientists are able to effectively monitor changes in air pollution. Shortly after the northeast U.S. was under shelter-in-place orders due to COVID-19, NASA observed a 30 percent drop in air pollution due to the decrease in human activity. Nitrogen oxide is a gas emitted primarily from burning fossil fuels, and can be used as a measure for human activity. As shown in Figures 4.2.11 and 4.2.12, air pollution in the northeast U.S. is significantly less in March 2020 when compared the average atmospheric nitrogen oxide levels in March from 2015 to 2019.[62] The average atmospheric nitrogen oxide levels in March 2020 were the lowest on record since tracking began in 2005. Similar reductions were consistent in other regions of the world, such as China and Italy.

Because remote sensing technology allows NASA scientists to monitor and track air pollution, it is also a powerful way to determine the effectiveness of strategies for mitigating and adapting to climate change. These changes in atmospheric composition were observable to NASA satellites after only a few weeks. By continuing to utilize remote sensing technology, scientists can inform policymakers, track changes in pollution, and monitor environmental injustices associated with emissions.

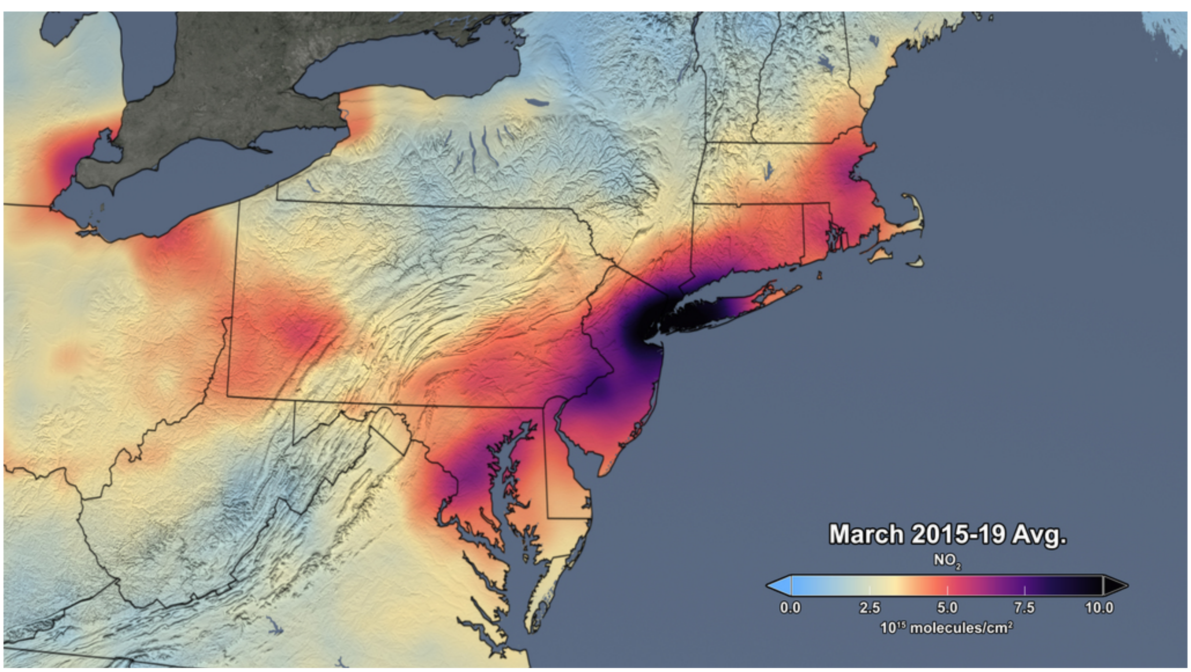

Figure 4.2.11. Average nitrogen dioxide (NO_2) concentration in March (2015-2019) (NASA, 2020).

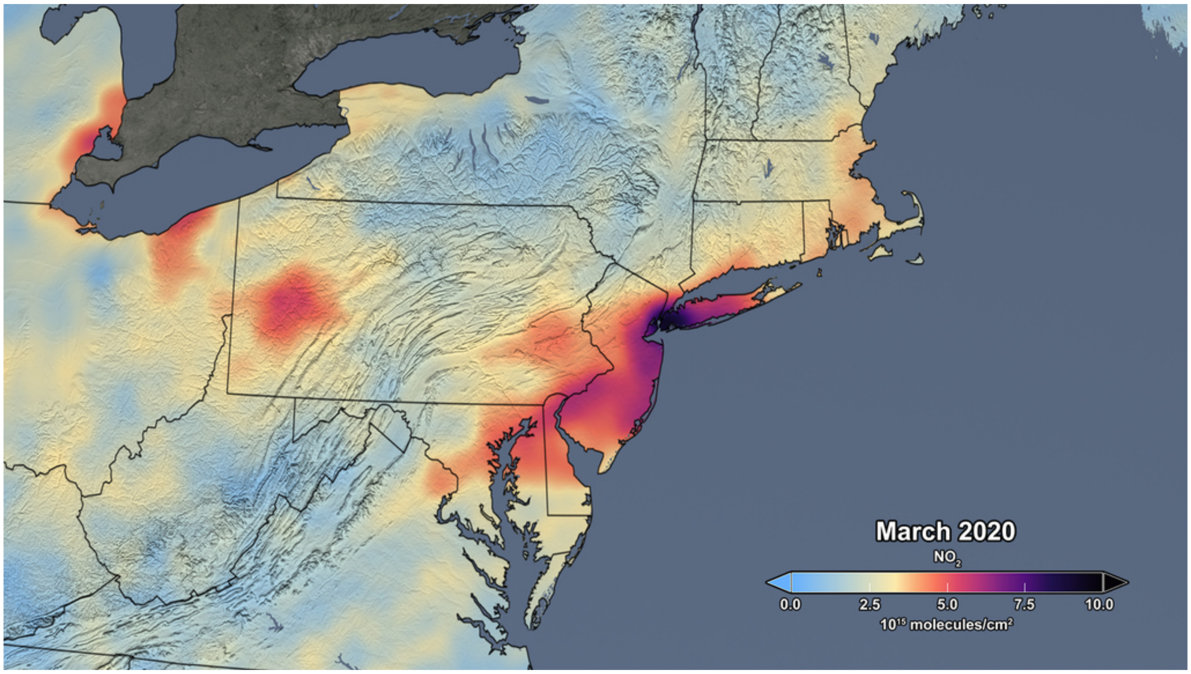

Figure 4.2.12. Average nitrogen dioxide (NO_2) concentration in March 2020 (NASA, 2020).

4.2.6 Leveraging New Technologies and Partnership Frameworks

According to Lazard, wind and solar electricity now have the lowest levelized costs of all electricity-generating technologies.[63] Because they are carbon-free sources (except for some carbon emissions associated with equipment manufacture), they offer the best options for transitioning away from fossil fuels. To take advantage of them, states and cities need to electrify as much of their energy services as possible. The two sectors that will be the easiest to electrify are light-duty transportation and buildings.

Transportation

Policies to reduce vehicle emissions are largely under the jurisdiction of federal and state governments. As of 2020, nine states have adopted California's zero emission vehicle requirements, and thirteen states have adopted California's GHG vehicle emission standards. These states account for 30-40 percent of total light duty vehicle (LDV) sales, and the emissions requirements have accelerated emissions reductions, as well as the development and commercialization of advanced technology.

Great strides have already been made in developing electric vehicles. Both federal and state tax incentives have been enacted to incentivize the purchase of EVs. Electrify America, which resulted from the Volkswagen diesel lawsuit, has been installing thousands of fast-charging stations around the country.[64] Because battery costs are dropping rapidly, EVs are now approaching the cost of gasoline vehicles for light-duty transportation.[65] Nissan, Chevy, Kia, and Hyundai are among the growing number of manufacturers that produce EVs with a range of over 200 miles and a retail price under $35,000.

Heavy duty vehicles (HDVs) typically run on diesel engines that emit a variety of air pollutants, like particulate matter and black carbon, which are linked to cardiovascular and respiratory illness, and NOx, which undergo reactions to create ground-level ozone and smog. These vehicle types are commonly used in shipping logistics settings like ports, rail yards, and warehouses, which tend to be located near low-income communities in which the pollution disproportionately impacts Black, Indigenous and People of Color. Thus, pursuing HDV electrification has important implications for human health, environmental justice, and emissions reduction goals.[66]

Private Sector Engagement

Cities are showing leadership in their ability to collaborate with the private sector to promote sustainability while enhancing safety and livability.[67]

- In 2014, the City of Houston partnered with private sector providers to convert 165,000 conventional light bulbs to LEDs. This initiative is expected to reduce street light electricity usage by about 50 percent and reduce municipal emissions by 5 percent. As a result, the city will save around $1.4 million on its annual electricity bill. Long-term reductions in maintenance costs are also expected to offset the up-front cost of installation.[68]
- Colorado is home to an important new all-electric housing development that will demonstrate the use of heat pumps and demand response measures in a cold climate. The Basalt-Vista project consists of 27 new housing units located in the Colorado mountain town of Basalt, located 18 miles from Aspen.[69] It is being developed by Habitat for Humanity Roaring Fork. Financial assistance is being provided by the local electric utility, Holy Cross Energy, as well as by the Community Office for Resource Efficiency, a local nonprofit. The houses will serve as a test bed for the performance of heat pumps in a very cold climate and for using various electric loads such as EV charging, hot water heating, and batteries. The goal is to better match the building loads to the utility supply. The challenge ahead will be to convert existing home heating systems from cheap natural gas to electric heat pumps without causing an increase in homeowner heating bills.

Figure 4.2.13. Air source heat pump (Best, 2020).

New Technologies

As the U.S. works towards decarbonization, further Research, Development, Demonstration, and Deployment (RDD&D) is still required to achieve a future carbon-free energy system. RDD&D is especially important for technologies that have been identified as needed to reach decarbonization goals, but are not available at a commercial scale. For example, technology for carbon capture and storage and biofuel production still need to be advanced in order to be fully utilized as a decarbonization approach. Additional funding for RDD&D is needed.

Federal and state governments should also work together to revise building and infrastructure codes to incentivize the commercialization of green industrial products.

Case Study - The Hawai'ian Clean Energy Initiative

The state of Hawaii has high electricity prices because of the high cost of imported petroleum. Transitioning to lower-cost renewable electricity sources could greatly reduce electricity bills, benefitting lower-income families and positioning Hawaii to be a model for other states. To address the high electricity costs as well as environmental concerns, the Hawaiian Clean Energy Initiative was launched in 2008.[70] Its goal was to achieve 70 percent of the state's energy needs through renewable energy by 2030. Progress has been ahead of schedule, and the goal has been expanded to achieving 100 percent renewable electricity by 2045.

One concern that arose is how to limit overvoltage caused by too much solar electricity feeding into the grid. Whereas California can export excess electricity to other states, Hawaii's isolation prohibits that option. Based on concerns about reliability and safety to line workers, the Hawaii's Public Utilities Commission has directed Hawaiian Electric Company (HECO), the utility for the most populated island, Oahu, to limit the amount of solar electricity on the distribution system.

To address these concerns, HECO partnered with the National Renewable Energy Laboratory (NREL) to study the issues. NREL tested four "smart" inverters to determine how they would handle the overvoltage situations on a simulated Oahu grid. The tests showed that all the inverters would safely and quickly reduce power under transient overvoltage conditions.

The Hawai'i example demonstrates showing that solar energy systems can provide similar types of grid services as well as conventional fossil fuel power plants, despite lacking the generator inertia of conventional plants. As reported by NREL, "Tests determined that the inverters successfully provided six grid functions—fixed-power-factor operations, volt-watt control, volt-VAR control (baseline testing only), voltage ride-through, frequency ride-through, and soft-start reconnection – during normal and abnormal conditions, and two of the inverters provided ramp-rate control during normal operation."[71]

Case Study - Carbon Sequestration in Indiana

Carbon sequestration officially began in Indiana in July 2019. A carbon sequestration pilot project was authorized in Terre Haute under Indiana Code section 14-39-1-3.5, permitting Wabash Valley Resources (WVR) to build an ammonia production facility to reduce Indiana's carbon footprint by storing it underground.[72] With funding from the Oil and Gas Climate Initiative (OGCI) Climate Investments and the Department of Energy's Carbon Storage Program, WVR is anticipating to capture and store an estimate of 1.5-1.75 million tonnes per annum in Indiana's Mount Simon Sandstone.[73] In addition to carbon sequestration, the plant will produce an affordable, low-carbon fertilizer.

While some stakeholders, such as members of the Citizens Action Coalition, are concerned about the potential effects of injected carbon on ground water and earthquakes, other stakeholders view carbon sequestration as a method to quickly reduce the state's carbon footprint and encourage economic development. Indiana is still heavily reliant on its coal industry for electricity. The Wabash Valley Resources pilot project will provide valuable lessons regarding carbon sequestration as a whole and inform future projects.

4.2.7 Integrating Mitigation and Adaptation

Investing in mitigation strategies that yield concurrent adaptation benefits should be prioritized in order to achieve the transformations necessary to respond effectively to climate change. Cities and towns should use improved bond ratings to fund infrastructure improvements that increase resilience to climate impacts, including updates to buildings, backup power, and stormwater and emergency management systems.[74]

Developing urban areas into denser, more compact areas with mixed land use and mass transit can reduce a city's carbon footprint. Dense urban districts can be reconfigured to reduce the impact of urban heat and storms due to the changing climate, while enhancing quality of life for residents.[75] Over 35 percent of total U.S. carbon dioxide emissions are associated with residences and cars, so changing patterns of urban development and transportation is critical for decarbonization. U.S. cities generally have significantly lower emissions than suburban areas, and the city-suburb gap is particularly large in older areas (e.g., New York).[76]

Case Study - Gowanus, Brooklyn – Integrating Climate Adaptation and Climate Mitigation

The Urban Land Institute's (ULI) New York District Council and Urban Resilience Program partnered with the New York Institute of Technology (NYIT), and the Urban Climate Change Research Network (UCCRN), a global consortium of climate experts on the Gowanus Cool Neighborhood Project. The project was initiated by an Urban Design Climate Workshop (UDCW) for the Gowanus neighborhood in Brooklyn, New York, focused on urban heat stress adaptation integrated with flood resiliency and GHG emission mitigation.

UDCWs were conceived by UCCRN and NYIT as hands-on, capacity-building exercises to engage the local community, industry professionals, and city officials as they confront climate challenges in a 21st-century neighborhood. This planning process, which derives its value proposition from positive public health and economic growth outcomes, envisions that urban design can help shape transformative climate action in evolving districts like Gowanus. It also shows how a rezoning or other redevelopment initiative can incorporate climate projections to better understand not only likely climate impacts, but also opportunities for climate mitigation.

The Gowanus UDCW addressed how to mitigate local greenhouse gas emissions and address resilience to climate impacts in ways that are aligned with New York City's Gowanus Rezoning Proposal. The primary goal of the Gowanus UDCW was to propose regulatory strategies that can be "actionable" in a complex city like New York.

This project integrates climate mitigation and climate adaptation by prioritizing actions that reduce greenhouse gas emissions while strengthening climate adaptation (to both urban heat stress and coastal floods).

This project intersects with another project, the *Climate Mitigation: Net-Zero District* initiative, which is led by the American Institute of Architects New York Chapter and NYIT, in collaboration with the In-Source Belmont Forum-National Science Foundation, a European-American research consortium. The two Gowanus efforts overlap: integrated climate adaptation to reduce cooling loads, and climate mitigation (net-zero) to achieve net-zero carbon emissions, by balancing a measured amount of carbon (or CO_2 equivalency) release with an equivalent amount of CO_2 generated on-site or offset. Peer-reviewed scientific research shows that integrating mitigation and adaptation can be an important approach for confronting climate change in cities.[77]

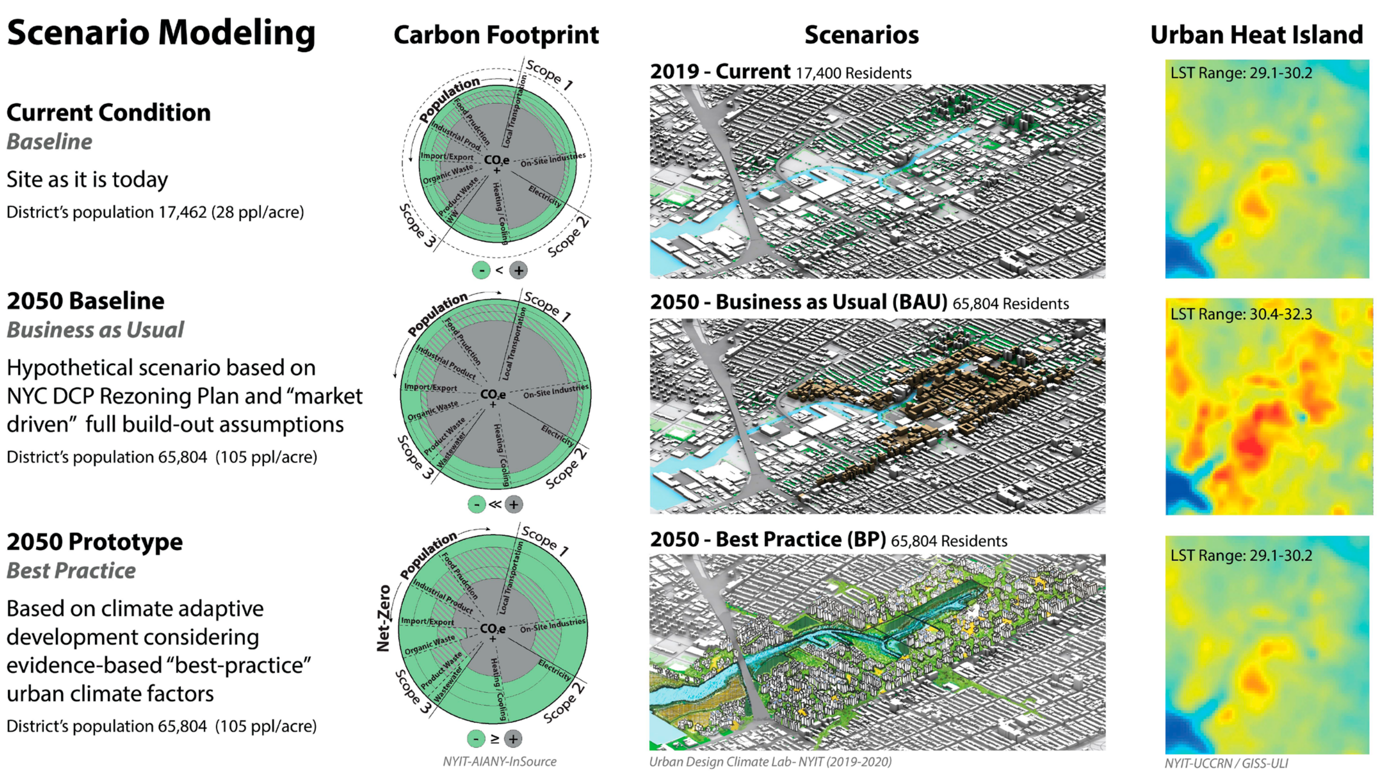

Figure 4.2.14. Carbon footprint and urban heat island scenarios for Gowanus community in Brooklyn, NY under different development scenarios (Raven et al., 2018).

Case Study - Microgrids and Disaster Risk Management in Puerto Rico

Puerto Rico, the United States' largest unincorporated territory, is an archipelago with rich cultural and ecological diversity. Located in the Caribbean Sea, Puerto Rico has a tropical climate that hosts El Yunque rainforest in the northeast, coastal mangroves and coral reefs, and much more. Puerto Rico is experiencing rising sea levels, intensified storms, decreased total rainfall, ocean acidification, ecosystem shifts, and other impacts due to the changing global climate.[78]

Efforts to both mitigate and adapt to these changes are of the utmost importance. Worsening climate systems, vulnerable populations, and unresponsive governments have already led to catastrophe in Puerto Rico – most horrifyingly when Hurricane Maria, a Category 5 hurricane, hit the island in the fall of 2017. What would have been a devastating storm under most circumstances led to prolonged suffering due to a fragile island power grid and subsequent lack of response from the U.S. Federal Government.[79] (The territory's government has also been criticized for corruption that led to delays in aid delivery and, ultimately, the resignation of the governor at the time).[81] Three months after Maria hit, about half (more than 1.5 million people) of the archipelago's residents still lacked power[82] – and continued to have limited access to food and other necessities.[83]

Growing efforts are underway to shore up Puerto Rico's energy grid resilience for the future, which will hopefully both decarbonize its energy sources and decrease its dependence on often slow-moving disaster relief funds. A series of 2019 laws established by the territorial government call for all power to be generated by renewable resources by 2050 (40 percent by 2025), among other stipulations.[84] To keep pace with the electrification of the grid, the Puerto Rico Electric Power Authority (PREPA) is now focused on developing a robust "microgrid" system.

Microgrids are "mini-energy service stations that maximize locally generated renewable energy, such as wind and solar power, and are backed by battery storage and intelligent software."[85] Such systems, though still in development, are ideal for hurricane- or other natural-disaster-prone areas. Despite these encouraging possibilities, the Environmental Defense Fund has argued that the current microgrid plan put forth by PREPA does not sufficiently address the urgency of deep decarbonization.[84] Ultimately, it may not be possible for Puerto Rico's communities to build resilient, decentralized energy grids (and other disaster risk management necessities) without deeper financial commitments at both the territorial and federal levels – demonstrating a striking need for both localized resilience methods and multi-level government coordination.[86]

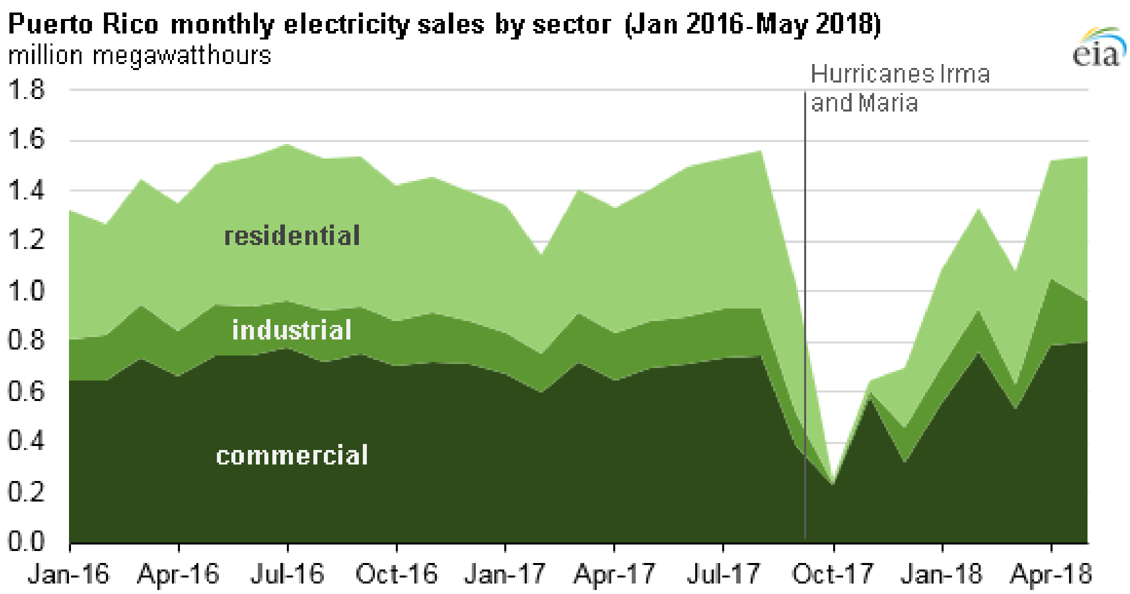

Figure 4.2.15. Puerto Rico monthly electricity sales by sector ("Puerto Rico", 2020) (Jan 2016 - May 2018).

4.2.8 The Circular Carbon Economy

Transitioning from a Linear Economy

Municipal solid waste (MSW) management is inextricably linked to increasing urbanization, development, and climate change. The U.S. is among the world's most urbanized nations, and cities play a pivotal role across the country.[87] Over 85 percent of the United States' population lives in urban areas and, by 2050, it is expected that metropolitan populations will grow to 360 million people. In 2015, 90.8 percent of U.S. GDP was generated in metropolitan areas. However, as Chapter 5.6 (Accelerating Sustainable Materials Management in the U.S.) explores in more detail, our current socioeconomic system is based on a linear economy that uses the "make it / use it / dispose it" (see Figure 4.2.16) pathway. The municipal authority's ability to improve solid waste management also provides large opportunities to mitigate climate change and generate co-benefits, such as improved public health and local environmental conservation.[88]

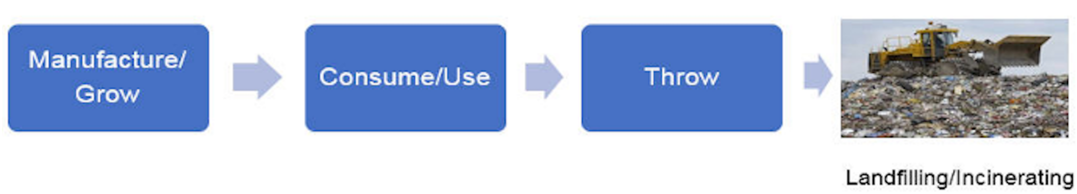

Figure 4.2.16. *Linear Economy* resource management (Guran, 2019).

The linear economy pathway of material movement is rooted in exponentially increasing resource consumption, excessive energy use, degradation of ecosystems and a massive amount of waste generation.[89] As urbanization increases, the global solid waste problem is also expected to expand if waste generation is not minimized and residents continue to use linear waste disposal practices. Literature suggests that a city resident generates twice as much waste as their rural counterparts of the same affluence. If we account for the fact that urban residents are generally more affluent, their waste generation rate is estimated to be almost four times higher than rural residents.[90] United Nations Environmental Programme (UNEP) and International Solid Waste Association (ISWA)'s Global Waste Management Outlook (GWMO) estimated that in 2015, 2 billion people around the world lacked access to regular waste collection and 3 billion people lacked access to controlled waste disposal services. Waste management remains a global challenge in the 21st century.[91]

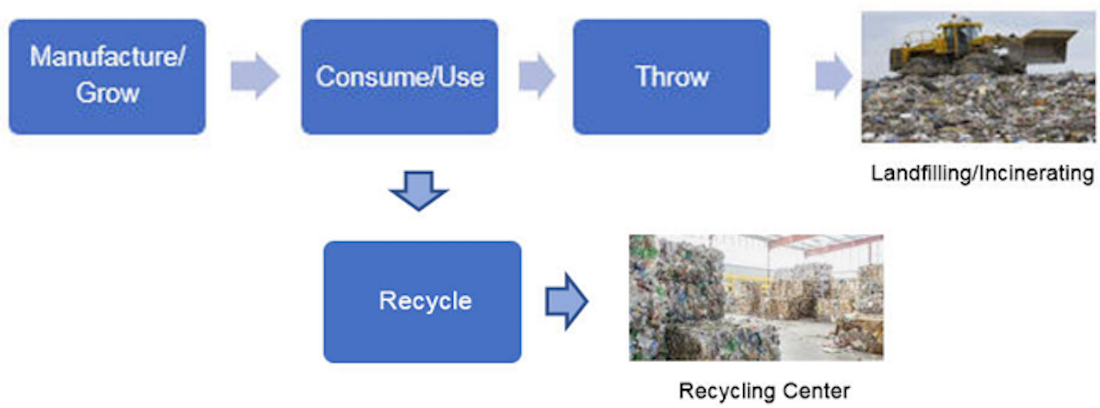

Figure 4.2.17. *Linear Economy* resource management with recycling (Guran, 2019).

Recycling

Globally, it is estimated that only one quarter to a third of the total 3.4-4 billion tons of municipal solid waste (MSW) and industrial waste produced annually is recycled.[92] While some cities and towns have reached 50 percent, 60 percent, and even 70 percent recycling rates, most major U.S. cities recycle at 20 percent or less.[93] The national recycling rate in 2000 was about 29 percent, and grew to 35 percent in 2017.[94] However, it is expected that 2019 data will likely show a drop below 35 percent, "and [recycling] shows no signs of picking up steam again."[95] Recycling is a process to separate valuable materials into new products; it can be further sub-classified as downcycling or upcycling, converting materials to lower value or higher value products respectively. Some communities practice single-stream recycling in which mixed recyclable materials are moved together to be sorted at a Materials Recovery Facility (MRF). Global recycling practices also vary from region to region and country to country. While some growing economies do not practice recycling at all, some low-income communities practice recycling (as well as reuse) to create economic benefits.

In the U.S., some communities require "source separated recycling" in which materials are separated and collected in separate containers at the point of discard. Source separated recycling requires more effort by the consumer; however, it reduces the cross contamination of the waste. Single-stream recycling undeniably increases the quantity of recycled materials collected, but reduces the quality, resulting in a contaminated supply and reduced economic viability of recycling operations.[96]

It is estimated that the residue amount at the MRFs is approximately 10-15 percent, higher if an MRF is receiving single-stream waste as compared to MRFs receiving source separated recycled waste. Cross contamination of waste streams, such as plastics contamination with paper waste or vice versa, and plastic waste contamination in food waste also negatively impact efficient reutilization practices, such as composting. The cross contamination of recycled materials affects their market penetration, which is highly dependent on the materials' physical and chemical characteristics.[97]

Circular Carbon Economy & Resource Management

The "circular economy" is an industrial system to restore and regenerate all systems by design in order to preserve and enhance natural capital, optimize resource yields, and foster effectiveness.[98] It has the potential to be an effective pathway towards less carbon-intensive systems. The transformation from a linear make-it/use-it/dispose-it pathway to circular resource recovery pathways can provide the foundation for a "circular carbon economy". The circularity approach also redefines waste as a "resource" and efficiently feeds waste back into the economy. Chapter 5.6 further discusses the benefits of a circular economy.

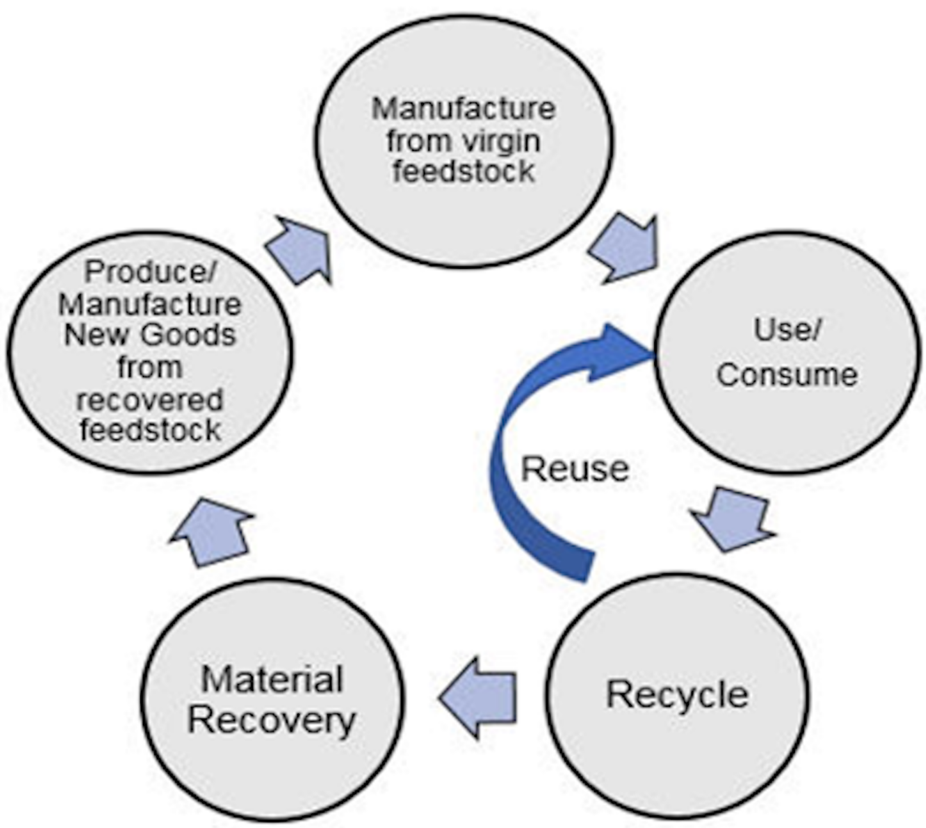

Figure 4.2.18. Closing the loop for resource recovery (Guran, 2019).

Case Study - The National Western Center in Denver, Colorado

The National Western Center in Denver, Colorado, a multi-use district that was approved by Denver voters, is being constructed on the site of Denver's annual National Western Stock Show, which is held for two weeks every January.[99] It incorporates many energy design features. One key feature is that it makes thermal use of a six-foot diameter pipe carrying the city of Denver's wastewater that runs through the property.[100] Because this water is at a temperature of between 61°F and 77°F throughout the year, it provides an excellent heat source and sink for heat pumps operating in heating and cooling mode. A heat exchanger exchanges heat between this pipe and a buried water loop circulating through the district. Heat recovery chillers (heat pumps that can simultaneously heat and cool) utilize this water to provide efficient heating and cooling to the various buildings.[101]

The electricity used to operate the heat pumps, provide lighting, and power other equipment will be supplied by solar photovoltaic arrays that are located on the district campus. This will be augmented by wind- and solar-powered electricity provided from off-site installations.[102]

Figure 4.2.19. Artist's rendering of the National Western Center (Alvarez, 202).

4.2.9 Conclusions and Policy Recommendations

The U.S. federal system allows state and city governments to set policy and targets, design laws and standards, implement financial mechanisms to develop and support markets (e.g., green bonds), and enforce regulatory compliance. These are key levers through which decarbonization actions can be – and are already being – delivered, and through which a thriving low-carbon goods and services sector is being developed. However, the Federal Government oversees interstate electricity transmission, aviation, shipping, interstate pipelines, and coal and gas leasing on public lands. Key regulatory requirements, such as those for the power sector and for energy intensive industries like cement and steel, may be difficult to implement at the state level because of interstate competitiveness and leakage concerns.

Climate-related policies at the federal level should provide cities and states with economic development benefits as states and cities shift to infrastructure systems associated with low-carbon development. Cities and states cannot fund climate change responses on their own. Multiple funding sources are needed to deliver the financing that is essential to low-carbon development and climate risk management.

As states and cities plan and implement bold strategies for reducing GHG emissions, an opportunity exists to address existing disparities and to create stronger, more equitable communities for everyone. Making climate action plans more responsive to equity concerns will also help to galvanize broader constituencies of support for bold climate solutions.

Transportation Strategies

- State-level vehicle standards and ZEV policies should be encouraged by the Federal Government as some states may be able to go further faster.
- Link federal and state transportation funding to metropolitan planning organizations (MPOs) to per capita vehicle miles traveled (VMT) reductions.
    - Example: California has a goal of 19 percent per capita VMT reduction by 2035 for major metro areas (SB375).
    - Create a similar national target to be used in all states.
- Create state and city pricing systems that encourage more intensive use of vehicles.
    - Example: Incentives for multiple occupants in Transport Network Companies (TNCs), personally owned vehicles, and transit.
    - Discourage single occupant vehicles and single passenger services.
    - Include VMT pricing, congestion pricing, and parking policies.

Aligning Policies Across Scales

- States and cities should implement land use policies that promote densification, transit-oriented development, and complete streets[vii]
  - Urban populations are encouraged to walk, bike, or use public transit, as opposed to single-occupant vehicles, for commuting and other trips.
- Cities should align incentives and programs for building retrofits with state climate goals and begin efficient retrofit of existing buildings.
- Provide jurisdiction to cities/municipalities that enables them to create hauler contracts that sorting and separation quality of materials.
  - Municipalities need different state level goals that broaden their jurisdiction; keeping the system localized for product sorting, recycling, refurbishment (and sale) needs to be incentivized.
- Reduce post-harvest losses by 50 percent compared to 2010 levels. Reduce household-level food waste from 30 percent to 15 percent by 2050.
  - San Francisco passed an ordinance in 2009 requiring all businesses and households to sort organics for collection and composting. The city now collects more than 220,000 tons of organic waste each year, and is considered the country's most successful composting program. It provides a model for Congress, states, and localities to follow when designing legislation banning food waste in landfills.
- The 2018 Farm Bill would benefit from federal-state coordination to disseminate information to potential applicants, and it should be linked to other long-term policy initiatives to promote its use and longevity.
  - This program appears to be underutilized, based on an announcement from USDA in July 2019, which solicited applications and noted $400 million still remaining of its $565 million FY2019 budget.[103]

Public/Private Funding Partnerships

- Allocate RDD&D investments toward industrial process and product redesign, electric and low-carbon manufacturing process development, and enhanced material efficiency.
- The Federal Government should invest directly in key parts of the national energy system, including inter-state power transmission, public land use for power generation, and supporting infrastructure.
  - The Federal Government should engage in innovative green financing, such as government guarantees for green bonds, tax incentives on utility bonds for renewable energy, direct equity, funding of state-level green banks, and others, and in the needed regulation of the financial sector for the disclosure of climate risks.

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vii Complete Streets are streets designed and operated to enable safe use and support mobility for all users. Those include people of all ages and abilities, regardless of whether they are travelling as drivers, pedestrians, bicyclists, or public transportation riders.

- Establish state-level programs to promote forest conservation and restoration, agroforestry, and urban forestry.
  - Example: Create trusts or funds to help landowners enhance climate-friendly management capabilities, require evaluations of carbon impacts in land use decision-making, and integrate forest-level carbon sequestration into carbon pricing schemes as avoided emissions credits.

No-Regret Policies

- Promote interstate and interagency coordination, including electricity demand modeling as well as land use change and land-based activities.
  - Regional planning (at level of Western Interconnection or REGGI, for example) improves planning outcomes.
  - More robust policies with explicit requirements for assessing the impacts on host communities and engaging impacted communities in the siting process (as well as decisions on compensation) are needed.
- Local governments and states should engage in regional planning efforts that bring multiple states and municipalities together.
- Direct resources toward a just transition through a variety of approaches including workforce programs and hiring preferences.
  - In states and localities with fossil fuel-dependent communities, establish hiring preferences that help people transition from work in the fossil fuel industry.
  - Ensure equity is a key consideration in building retrofit efforts.
  - Example: New York's goal of net-zero carbon emissions by 2050 is now law (with New York State sources required to reduce their direct emissions by at least 85 percent by 2050 and 40 percent by 2030). It specifies that a third of the benefits of the investments go to disadvantaged communities.[104]
- Cities and local governments should adopt building codes and practices that encourage or require zero-emission, all-electric buildings so that all new buildings are 100 percent electric and retrofits for existing buildings are actively underway.

References

1. "Deadline 2020: How Cities Will Get The Job Done". 2020. London: C40 Cities Climate Leadership Group; Arup. https://www.c40.org/researches/deadline-2020.

2. Rapoport, Elizabeth, Michele Acuto, and Lenora Grcheva. 2019. *Leading Cities: A Global Review of City Leadership*. JSTOR Open Access Monographs. UCL Press. https://books.google.com/books?id=xvWNDwAAQBAJ.

3. Coalition for Urban Transitions. 2019. Urban Opportunity: How National Governments Can Secure Economic Prosperity and Avert Climate Catastrophe By Transforming Cities. Washington D.C.: Coalition for Urban Transitions, C40 Cities Climate Leadership Group, WRI Ross Center for Sustainable Cities. https://urbantransitions.global/wp-content/uploads/2019/09/Climate-Emergency-Urban-Opportunity-report.pdf.

4. Lynch, A., A. LoPresti,, and C. Fox. 2019. The 2019 US Cities Sustainable Development Report. New York: Sustainable Development Solutions Network (SDSN). https://www.sustainabledevelopment.report/reports/2019-us-cities-sustainable-development-report/.

5. Moran, Daniel, et al. 2018. Environ. Res. Lett. 13 064041

6. Jones, Christopher M., and Daniel M. Kammen. "Spatial Distribution of U.S. Household Carbon Footprints Reveals Suburbanization Undermines Greenhouse Gas Benefits of Urban Population Density". Environ. Sci. Technol., 2013, dx.doi.org/10.1021/es4034364

7. "Deadline 2020".

8. Wiser, Ryan H., Galen L. Barbose, Jenny Heeter, Trieu Mai, Lori Bird, Mark Bolinger, and Alberta Carpenter et al. 2016. "A Retrospective Analysis Of The Benefits And Impacts Of U.S. Renewable Portfolio Standards". Berkeley, CA: Lawrence Berkeley National Laboratory. https://emp.lbl.gov/publications/retrospective-analysis-benefits-and.;

   "State Renewable Portfolio Standards And Goals". 2020. National Conference Of State Legislatures. https://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx.;

   "C40: One Year After Trump Decision To Withdraw From Paris Agreement, U.S. Cities Carry Clima…". 2020. *C40 Cities*. https://www.c40.org/press_releases/one-year-after-trump-decision-to-withdraw-from-paris-agreement-u-s-cities-carry-climate-action-forward.

9. "GHG 1990 Emissions Level & 2020 Limit | California Air Resources Board." n.d. Accessed August 10, 2020. https://ww2.arb.ca.gov/ghg-2020-limit.;

   "California Leads Fight to Curb Climate Change." n.d. Environmental Defense Fund. Accessed August 10, 2020. https://www.edf.org/climate/california-leads-fight-curb-climate-change.

10. "AB 32 Global Warming Solutions Act of 2006 | California Air Resources Board." n.d. Accessed August 10, 2020. https://ww2.arb.ca.gov/resources/fact-sheets/ab-32-global-warming-solutions-act-2006.;

   "California Leads Fight to Curb Climate Change."

11. Farber, Daniel A. 2018. *Beyond the Beltway: A Report on State Energy and Climate Policies*. Berkeley: Berkeley Law University of California, Center for Law, Energy & the Environment. https://www.law.berkeley.edu/wp-content/uploads/2018/02/Beyond-the-Beltway.pdf.

12. "California Sets Rules for Post-2020 Cap-and-Trade Program." n.d. Environmental Defense Fund. Accessed August 10, 2020. https://www.edf.org/media/california-sets-rules-post-2020-cap-and-trade-program.

13. "GHG Current California Emission Inventory Data | California Air Resources Board." n.d. Accessed August 10, 2020. https://ww2.arb.ca.gov/ghg-inventory-data.

14. Ibid.

15. California Air Resources Board. 2019. *California Greenhouse Gas Emissions for 2000 to 2017: Trends of Emissions and Other Indicators*. California Air Resources Board. https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2017/ghg_inventory_trends_00-17.pdf.

16. Cullenward, Danny, Mason Inman, and Michael D. Mastrandrea. 2019. "Tracking Banking in the Western Climate Initiative Cap-and-Trade Program." Environmental Research Letters 14 (12): 124037. https://doi.org/10.1088/1748-9326/ab50df.

17. Cullenward, Danny. 2017. "California's Foreign Climate Policy." *Global Summitry* 3 (1): 1–26. https://doi.org/10.1093/global/gux007.

18. "The 2017-18 Budget: Cap-and-Trade." n.d. Accessed August 10, 2020. https://lao.ca.gov/publications/report/3553#Conclusion.

19. Wara, Michael. 2014. "California's Energy and Climate Policy: A Full Plate, but Perhaps Not a Model Policy." *Bulletin of the Atomic Scientists* 70 (5): 26–34. https://doi.org/10.1177/0096340214546832.

20. Komanoff, Charles, Ralph Cavanagh and Peter Miller. 2019. *California Stars: Lighting the Way to a Clean Energy Future*. New York: Natural Resources Defense Council. https://www.nrdc.org/sites/default/files/california-stars-clean-energy-future-report.pdf.
"State Actions". 2020. Price On Carbon. https://priceoncarbon.org/business-society/state-actions/;

"GHG Current California Emission Inventory Data". 2020. *Ww2.Arb.Ca.Gov*. https://ww2.arb.ca.gov/ghg-inventory-data.

21. Cities of Oakland Park & Wilton Manors. 2019. *Climate Action Plan: Two Cities. One Sustainable Future*. Florida: Oakland Park & Wilton Manors. https://www.wiltonmanors.com/DocumentCenter/View/4747/OP-WM-Climate-Action-Plan-FINAL-February-2019.

22. Lonergan, Tim, and Gary Resnick, "Why Two South Florida Cities Are Partnering to Face Climate Change | Opinion," South Florida SunSentinel, August 24, 2018, https://www.sun-sentinel.com/opinion/fl-op-viewpoint-cities-climate-change-partnership-20180823-story.html.

23. Coalition for Urban Transitions. 2019. *Climate Emergency, Urban Opportunity: How National Governments Can Secure Economic Prosperity and Avert Climate Catastrophe by Transforming Cities*. Washington DC: Coalition for Urban Transitions, C40 Cities Climate Leadership Group, WRI Ross Center for Sustainable Cities. https://urbantransitions.global/wp-content/uploads/2019/09/Climate-Emergency-Urban-Opportunity-report.pdf

24. Kwok, Gabe, Jamil Farbes, and Ryan Jones. 2020. "Low-Carbon Transition Strategies for the Southeast," 38. https://irp-cdn.multiscreensite.com/be6d1d56/files/uploaded/SDSN_Southeast%20Report_FINAL.pdf

25. Farbes, Jamil, Gabe Kwok, and Ryan Jones. 2020. "Low-Carbon Transition Strategies for the Midwest," 36. https://irp-cdn.multiscreensite.com/be6d1d56/files/uploaded/SDSN_Midwest%20Low%20Carbon%20Strategies_FINAL.20200713.pdf

26. "Accelerating America's Pledge | Americas Pledge On Climate". 2020. *Americas Pledge On Climate*. https://www.americaspledgeonclimate.com/accelerating-americas-pledge-2/.

27. Arup-C40, 2015. Climate Action in Mega-Cities 3.0. http://cam3.c40.org/#/main/home

28. Bloomberg Philanthropies American Cities Challenge. 2019. "Climate Action Playbook Brief". Bloomberg Philanthropies. https://data.bloomberglp.com/dotorg/sites/2/2019/10/American-Cities-Climate-Challenge-Climate-Action-Playbook.pdf.

29. "World Resources Institute - America's New Climate Economy - GPSEN". 2020. *GPSEN*. https://gpsen.org/project/world-resources-institute-americas-new-climate-economy/.

30. Gimon, E., M. O'Boyle, C. Clack, and S. McKee. 2019. The Coal Cost Crossover: Economic Viability of Existing Coal Compared to New Local Wind and Solar Resources. San Francisco: Energy Innovation; Boulder, CO: Vibrant Clean Energy.

31. "2019 Was a Watershed Year for Clean Energy Commitments from U.S. States and Utilities." 2019. World Resources Institute. December 20, 2019. https://www.wri.org/blog/2019/12/2019-was-watershed-year-clean-energy-commitments-us-states-and-utilities.

32. Barbose, Galen. 2019. *U.S. Renewables Portfolio Standards*. Berkeley: Lawrence Berkeley National Laboratory and Office of Electricity Delivery and Energy Reliability. https://eta-publications.lbl.gov/sites/default/files/rps_annual_status_update-2019_edition.pdf.

33. Ibid.;

"State Actions". 2020. *Price On Carbon*. https://priceoncarbon.org/business-society/state-actions/.

34. "Colorado Gov Polis Unveils Roadmap to 100% Renewables by 2040, Signs 11 Clean Energy Bills." n.d. Utility Dive. Accessed August 10, 2020. https://www.utilitydive.com/news/colorado-gov-polis-unveils-roadmap-to-100-carbon-free-by-2040-signs-11-cl/555975/.

35. Pollin, Robert, Jeannette Wicks-Lim, Shouvik Chakraborty, and Tyler Hansen. 2019. "A Green Growth Program For Colorado," 145.

36. "Whisper Valley, Austin's First EcoSmart, ZeroEnergy Community." 2020. Whisper Valley. Accessed August 10, 2020. https://www.whispervalleyaustin.com/.

37. Bloomberg Philanthropies American Cities Challenge, "Climate Action Playbook Brief"..

38. "Comstock". 2020. *Comstock.Nrel.Gov*. https://comstock.nrel.gov/.;

"Restock". 2020. *Restock.Nrel.Gov*. https://restock.nrel.gov/

39. "Home | BEopt." n.d. Accessed August 11, 2020. https://beopt.nrel.gov/home.; "OpenStudio." n.d. Energy.Gov. Accessed August 11, 2020. https://www.energy.gov/eere/buildings/downloads/openstudio-0.

40. "Carbon Smart Materials Palette." n.d. Accessed August 11, 2020. https://materialspalette.org/palette/.; Available tools for conducting a whole building life-cycle assessment are described at: https://www.buildinggreen.com/news-analysis/embodied-carbon-tools-assessing-options.
41. "Accelerating America's Pledge".
42. Fisher, Weston A. Fisher. 2020. Legal pathways to deep decarbonization in the United States, Impact Assessment and Project Appraisal, 38:4, 354-355, DOI: 10.1080/14615517.2020.1719651
43. "Accelerating America's Pledge".
44. Ürge-Vorsatz, Diana, Cynthia Rosenzweig, Richard J. Dawson, Roberto Sanchez Rodriguez, Xuemei Bai, Aliyu Salisu Barau, Karen C. Seto, and Shobhakar Dhakal. 2018. "Locking In Positive Climate Responses In Cities". *Nature Climate Change* 8 (3): 174-177. doi:10.1038/s41558-018-0100-6.
45. Mattauch, Linus, Felix Creutzig, and Ottmar Edenhofer. 2015. Avoiding Carbon Lock-In." *Economic Modelling* 50 (November 2015): 49-63. https://doi.org/10.1016/j.econmod.2015.06.002.
46. HCRI. n.d. "Hazard and Climate Resilience Institute." HCRI. Accessed August 11, 2020. https://www.boisestate.edu/research-hcri/.
47. "Climate Action | City of Boise." n.d. Accessed August 11, 2020. https://www.cityofboise.org/programs/climate-action/.
48. Urban Climate Change Research Network (UCCRN). 2015. Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network.;

    Leseur, Alexia, Vivian Dépoues, Cécile Bordier, Cynthia Rosenzweig, Chantal Pacteau, Luc Abbadie, and Somayya Ali Ibrahim. 2020. "LPAA Focus On Cities & Regions Climate Action, 2015 December The 8Th". Paris: Institute for Climate Economics; New York: Urban Climate Change Research Network. Accessed October 16. https://unfccc.int/sites/default/files/scientific-brief-cop21-lpaa.pdf.
49. "University Launches Commission On Carbon Neutrality". 2019. *The University Of Michigan Record*. https://record.umich.edu/articles/university-launches-commission-carbon-neutrality/.
50. President's Commission on Carbon Neutrality. 2020. "Spring 2020 Interim Progress Report". Ann Arbor, Michigan: University of Michigan. http://sustainability.umich.edu/media/files/U-M-Carbon-Neutrality-Spring-2020-Report.pdf.
51. "Planet Blue". 2020. Planet Blue. http://sustainability.umich.edu/.
52. Queiroz et al., 2017. Implementation and Results of Solar Feed-In-Tariff in Gainesville, Florida. Journal of Energy Engineering.
53. "Gainesville Feed In Tariff". 2020. *Energy Democracy For All*. https://energydemocracy.centerforsocialinclusion.org/gainesville-feed-in-tariff/.
54. Marcotullio, P. J., Sarzynski, A. Sperling, J., Chavez, A., Estiri, H., Pathak, M., and Zimmerman, R. (2018). Energy transformation in cities. In Rosenzweig, C., W. Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, and S. Ali Ibrahim (eds.), Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. New York. 443–490
55. "GHG Protocol For Cities | Greenhouse Gas Protocol". 2020. *Ghgprotocol.Org*. https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities.
56. Jones and Kammen, "Spatial Distribution of U.S. Household Carbon Footprints".
57. "Coolclimate Calculator". 2020. *Coolclimate.Org*. https://coolclimate.org/calculator.; "Cool Climate Maps". 2020. *Coolclimate.Berkeley.Edu*. http://coolclimate.berkeley.edu/maps.
58. "3 Types of Measurement, Reporting, and Verification (MRV)." 2016. World Resources Institute. August 30, 2016. https://www.wri.org/resources/charts-graphs/3-types-measurement-reporting-and-verification-mrv.
59. Oda, Tomohiro, Rostyslav Bun, Vitaliy Kinakh, Petro Topylko, Mariia Halushchak, Gregg Marland, and Thomas Lauvaux et al. 2019. "Errors And Uncertainties In A Gridded Carbon Dioxide Emissions Inventory". *Mitigation And Adaptation Strategies For Global Change* 24 (6): 1007-1050. doi:10.1007/s11027-019-09877-2.
60. "Sizing Up The Carbon Footprint Of Cities". 2020. *Earthobservatory.Nasa.Gov*. https://earthobservatory.nasa.gov/images/144807/sizing-up-the-carbon-footprint-of-cities.
61. NASA."How to Find and Visualize Nitrogen Dioxide Satellite Data | Earthdata." Earthdata NASA. March 26, 2020. Accessed August 11, 2020. https://earthdata.nasa.gov/learn/articles/feature-articles/health-and-air-quality-articles/find-no2-data/.
62. Ray, Douglas. 2019. "Lazard's Levelized Cost of Energy Analysis—Version 13.0," 20. https://www.lazard.com/media/451086/lazards-levelized-cost-of-energy-version-130-vf.pdf.

63. "Electrify America: U.S. EV Public Charging Network." n.d. Electrify America. Accessed August 11, 2020. https://www.electrifyamerica.com/.

64. "A Behind the Scenes Take on Lithium-Ion Battery Prices." 2019. *BloombergNEF* (blog). March 5, 2019. https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/.

65. California Air Resources Board, "Overview: Diesel Exhaust and Health," 2019, https://ww2.arb.ca.gov/resources/overview-diesel-exhaust-and-health

66. "Deadline 2020".

67. C40 Cities and Sustainia. 2015. "Cities 100". C40 Cities; Sustainia. https://issuu.com/sustainia/docs/cities100/91?e=4517615/31305566.

68. Best, Allen. 2020. "All-Electric Homes Offer A Prototype For Low-Carbon Housing In Colorado". Energy News Network. https://energynews.us/2019/10/17/west/all-electric-homes-offer-a-prototype-for-low-carbon-housing-in-colorado/.

69. Ibid.

70. National Renewable Energy Laboratory (NREL). 2018. *Celebrating 10 Years of Success: Hawaii Clean Energy Initiative*. Golden, Colorado: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy18osti/70709.pdf.

71. Nelson, Austin, Adarsh Nagarajan, Kumar Prabakar, Vahan Gevorgian, Blake Lundstrom, Shaili Nepal, Anderson Hoke, Marc Asano, Reid Ueda, Jon Shindo, Kandice Kubojiri, Riley Ceria and Earle Ifuku. 2016. Hawaiian Electric Advanced Inverter Grid Support Function Laboratory Validation and Analysis. Golden, Colorado: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy17osti/67485.pdf.;

NREL.gov. 2020. NREL Evaluates Advanced Solar Inverter Performance For Hawaiian Electric Companies. https://www.nrel.gov/workingwithus/partners/partnerships-heco-solar-inverter.html.

72. "Indiana Law Creates Carbon Sequestration Pilot Program," Environmental Law News, accessed July 31, 2020, https://www.indybar.org/index.cfm?pg=EnvironmentalLawNews&blAction=showEntry&blogEntry=8636.

73. Wabash Valley Resources. "The Largest US Carbon Capture and Sequestration Project to Be Developed by Wabash Valley Resources with Funding Support from OGCI Climate Investments." PR Newswire: news distribution, targeting and monitoring. May 20, 2019. https://www.prnewswire.com/news-releases/the-largest-us-carbon-capture-and-sequestration-project-to-be-developed-by-wabash-valley-resources-with-funding-support-from-ogci-climate-investments-300852906.html.

74. "Accelerating America's Pledge".

75. Raven, J., Stone, B., Mills, G., Towers, J., Katzschner, L., Leone, M., Gaborit, P., Georgescu, M., and Hariri, M. (2018). Urban planning and design. In Rosenzweig, C., W. Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, and S. Ali Ibrahim (eds.), Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. New York. 139-172

76. Glaeser, Edward L., and Matthew E. Kahn. 2008. "The Greenness Of Cities: Carbon Dioxide Emissions And Urban Development". Cambridge, MA: Harvard Kennedy School Taubman Center for State and Local Government. https://www.hks.harvard.edu/sites/default/files/centers/taubman/files/glaeser_08_greencities.pdf.

77. Raven et al. 2018, "Urban Planning and Urban Design".

78. "What Climate Change Means For Puerto Rico". 2016. *19January 2017snapshot.Epa.Gov*. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-pr.pdf.

79. Robles, Frances, and Jugal K. Patel. 2018. "On Hurricane Maria Anniversary, Puerto Rico Is Still In Ruins". *The New York Times*, September 20, 2018. https://www.nytimes.com/interactive/2018/09/20/us/puerto-rico-hurricane-maria-housing.html?action=click&module=RelatedCoverage&pgtype=Article&region=Footer.

80. Phillips, Amber. 2019. "Why Puerto Rico's Governor Is Resigning". *The Washington Post*, 2019. https://www.washingtonpost.com/politics/2019/07/19/why-puerto-rico-is-crisis/

81. Robles, Frances and Jess Bidgood. 2017. "Three Months After Maria, Roughly Half of Puerto Ricans Still Without Power". *The New York Times*, 2017. https://www.nytimes.com/2017/12/29/us/puerto-rico-power-outage.html

82. Evans, Melanie. 2017. "Two Months After Maria, Puerto Rico's Health System Struggles to Meet Needs". *The Wall Street Journal*, 2017. https://www.wsj.com/articles/two-months-after-maria-puerto-ricos-health-system-struggles-to-meet-needs-1510960587

83. "United States Climate Alliance 2019 State Factsheets: Puerto Rico". 2019. https://static1.squarespace.com/static/5a4cfbfe18b27d4da21c9361/t/5d8e533c9ef9643a4472975f/1569608509328/USCA_2019+State+Factsheet-PR_20190924.pdf.

84. "A Plan To Strengthen Puerto Rico's Electric Grid". 2020. Environmental Defense Fund. Accessed October 16. https://www.edf.org/sites/default/files/content/PuertoRicoFactSheet01.29.20.pdf.

85. Carbó, Agustín and Amalia Saladrigas. 2020. "Resilience in the Eye of the Storm: How Puerto Rico Can Build a Stronger, More Sustainable Energy Future". Environmental Defense Fund. http://blogs.edf.org/energyexchange/2020/06/30/resilience-in-the-eye-of-the-storm-how-puerto-rico-can-build-a-stronger-more-sustainable-energy-future/

86. Whittle, Daniel. 2020. "The Federal Government and PREPA Must do Better for Puerto Rico". Environmental Defense Fund. https://www.edf.org/media/federal-government-and-prepa-must-do-better-puerto-rico;

"Puerto Rico Monthly Electricity Sales By Sector". 2020. https://upload.wikimedia.org/wikipedia/commons/5/55/Puerto_Rico_monthly_electricity_sales_by_sector%2C_January_2016_through_May_2018_%2843165035474%29.png.

87. Oteng-Ababio, M., Annepu, R., Bourtsalas, A., Intharathirat, R., and Charoenkit, S. (2018). Urban solid waste management.

88. In Rosenzweig, C., W. Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, and S. Ali Ibrahim (eds.), Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. New York. 553–582;

Guran, S. 2019. "Options to feed plastic waste back into the manufacturing industry to achieve circular carbon economy" AIMS Environmental Science, 6(5): 341-355. DOI: 10.3934/environsci.2019.5.34

89. Lahti, Tom, Joakim Wincent, & Vinit Parida. 2018. "A definition and theoretical review of circular economy, value creation, and sustainable business models: where are we now and where should research move in the future?" Sustainability, 10, 2799-2817, doi:10.3390/su10082799.;

Kok, L., Wurpel, G., & Ten Wolde, A., (2013). "Unleashing the power of the circular economy", IMSA and Circle Economy, Amsterdam, Netherlands. https://mvonederland.nl/system/files/media/unleashing_the_power_of_the_circular_economy-circle_economy.pdf (accessed on 1/21/2019);

Michelini, Gustavo, Renato N. Moraes, Renata N. Cunha, Janaina M. H. Costa, Aldo R. Ometto. 2017. "From linear to circular economy: PSS conducting the transition" Procedia CIRP, 2-6 doi: 10.1016/j.procir.2017.03.012.

90. Hoornweg, Daniel, Perinaz Bhada-Tata, and Chris Kennedy. 2013. "Environment: Waste Production Must Peak This Century". *Nature* 502 (7473): 615-617. doi:10.1038/502615a.

91. United Nations Environment Programme (UNEP) and International Solid Waste Association (ISWA). 2015. *Global Waste Management Outlook*. UNEP International Environment Technology Centre: Osaka. http://web.unep.org/ourplanet/september-2015/unep-publications;

Wilson, David C., & Costas Velis. 2015. "Waste management –still a global challenge in the 21st century: an evidence based call for an action", Waste Management & Research, 33(12), 1049-1051.

92. Hannon, Jonathon, & Atiq U. Zaman. 2018. "Exploring the phenomenon of zero waste and future cities', Urban Science, 2, 90, 3-26, doi:10.3390/urbansci2030090.

93. Seldman, Neil. 2020. "Monopoly And The U.S. Waste Knot – Institute For Local Self-Reliance". *Ilsr.Org*. https://ilsr.org/monopoly-and-the-us-waste-knot/.

94. "National Overview: Facts and Figures on Materials, Wastes and Recycling," US Environmental Protection Agency (EPA), Accessed July 31, 2020, https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials.

95. Seldman, "Monopoly And The U.S. Waste Knot";

"Land Of Waste: American Landfills And Waste Production". 2020. *Saveonenergy.Com*. https://www.saveonenergy.com/land-of-waste/.;

Pendergrass, John, Mike Italiano, John A. "Skip" Laitner, Elizabeth Richardson, and Meagan Weiland. 2018. "American Waste: Paradigm Shifting Toward A Circular Economy". Presentation, Washington D.C.;

USEPA. 2018. "Advancing Sustainable Materials Management: (2015) Fact Sheet- Assessing Trends in Material Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling in the United States".; USEPA. 2014. "Protecting Communities-Restoring Land-Conserving Resources: RCRA's Critical Mission & The Path Forward", https://www.epa.gov/sites/production/files/2015-09/documents/rcras_critical_mission_and_the_path_forward.pdf.

96. The New Plastics Economy – Rethinking the future of plastics, http://www3.weforum.org/docs/WEF_The_New_Plastics_Economy.

97. Cobo, Selene, Antonio Dominguez-Ramos, & Angel Irabien. 2018. "From linear to circular integrated waste management systems: A review of methodological approaches:. Resour. Conserv. Recycl. 135, 279–295.

98. Hobson, Kersty. 2016. "Closing the loop or squaring the circle? Locating generative spaces for the circular economy" Progress in Human Geography, 40(1), 88-104. https://doi.org/10.1177%2F0309132514566342.;

The Ellen McArthur Foundation. 2012. Towards circular economy- Economic and Business Rationale for an Accelerated Transition, https://www.ellenmacarthurfoundation.org/assets/downloads/TCE_Ellen-MacArthur-Foundation_9-Dec-2015.pdf. (Accessed on January 21, 2019).;

Ritzen, Sofia, & Gunilla Ölundh Sandstrom. 2017. "Barriers to the circular economy-integration of perspectives and domains", Procedia CIRP 64, 7-12. Doi:10.1016/j.procir.2017.03.005.

99. Alvarez, Alayna. 2020. "Denver Seeks Partner For National Western Center Redevelopment Project". *Colorado Politics*. https://www.coloradopolitics.com/denver/denver-seeks-partner-for-national-western-center-redevelopment-project/article_6f919320-211b-11ea-8ad7-077186c5adff.html.

100. "National Western Center". 2020. *National Western Center*. https://nationalwesterncenter.com/.

101. Ibid.

102. Ibid.

103. United States Department of Agriculture. 2019. "USDA Has More Than $400 Million Still Available For Renewable Energy System And Energy Efficiency Loan Guarantees". https://www.usda.gov/media/press-releases/2019/07/18/usda-has-more-400-million-still-available-renewable-energy-system.;

United States Department of Agriculture. 2019. FY 2019 Budget Summary. Washington D.C.: United States Department of Agriculture.

104. New York State Assembly, Bill No. S2992B, "New York state climate leadership and community protection act," https://legislation.nysenate.gov/pdf/bills/2019/s2992b

5. APPROACHES FOR KEY SECTORS

5.1 Accelerating Deep Decarbonization in the U.S. Power Sector

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5.1.1 Introduction, Context and Goals

Decarbonization of the power sector is essential to overall decarbonization goals, as electricity production alone represents 27 percent of U.S. GHG emissions as of 2018.[1] It is relatively easy to imagine how a decarbonized electric supply system could help achieve multiple social and environmental goals. More complicated is envisioning the diverse political and organizational factors aligning at the needed scale and pace. Thus, much of this chapter looks not simply at technologies and long-term aspirations, but also practicalities. This chapter looks at these issues from four different perspectives: (1) supply of electricity; (2) demand for electricity; (3) the topology of the evolving grid; and (4) policy incentives and implementation.

5.1.2 The Pivotal Role for Electric Power

Nationwide, the bright spot in decarbonization is the electric power sector. While new technologies are appearing in other sectors, such as transportation and industry, emissions continue to rise. In the power sector, however, emissions have been going down modestly since 2005 – about a 33 percent decline in emissions from the sector.[2] That trend might be described as shallow decarbonization, but may be auspicious. So far, decarbonization of the power sector has come from factors partly related to climate policy, the surge in inexpensive natural gas, and rising supply of renewables and energy efficiency. These factors have shrunk the share of power generation from coal in favor of lower to zero-carbon emissions. For the first time since 1885 the share of renewables in U.S. power supply now exceeds that of coal (Figure 5.1.1).[3]

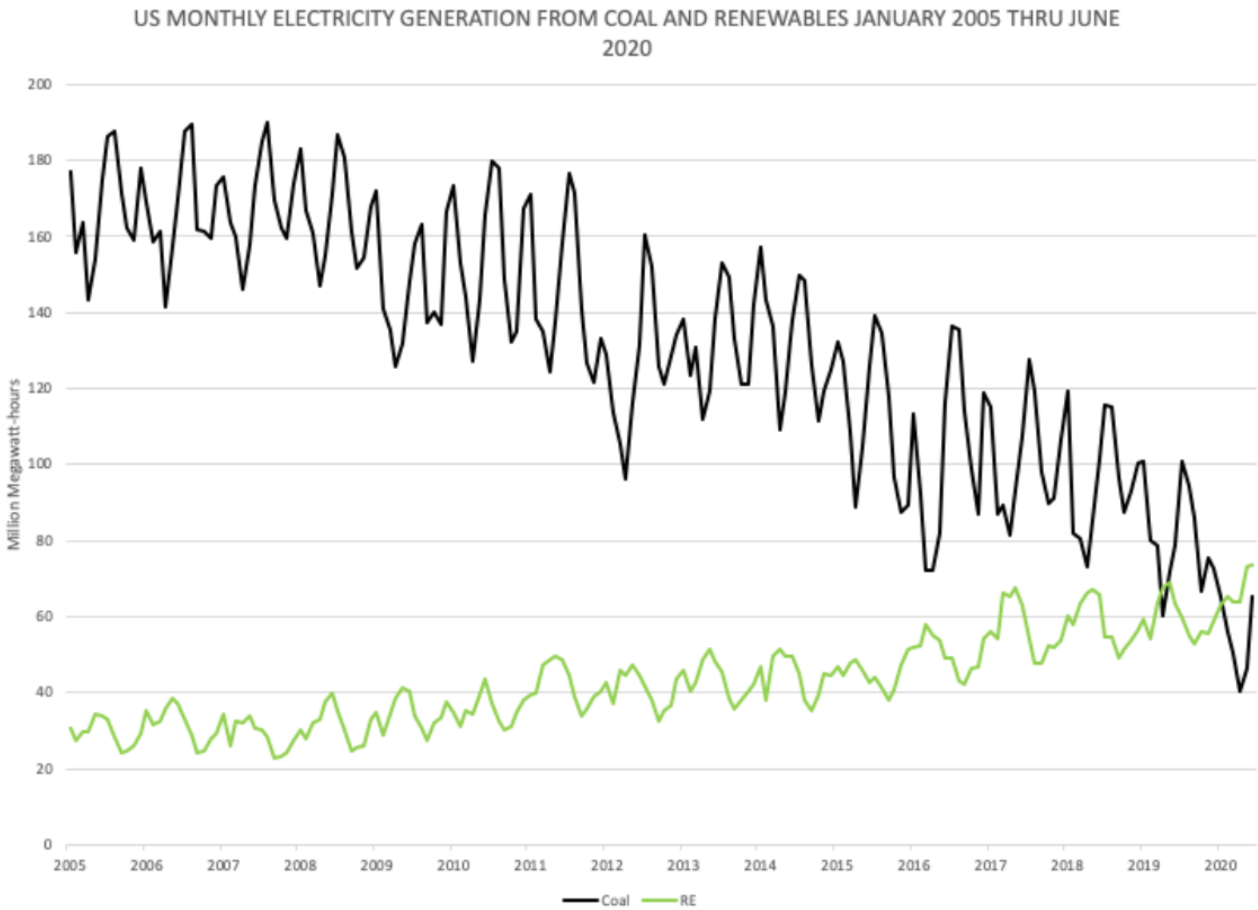

Figure 5.1.1: The contest between coal and renewables on the U.S. power grid (figure original; data from U.S. Energy Information Administration, 2020).

Looking to the future, the rate of decarbonization of the U.S. power sector will need to accelerate (Figure 5.1.2). Some states have visions for that change already—such as California, Hawaii, and New York—but federal policy has not yet been supportive of the speed and extent of change. Moreover, decarbonization of the entire U.S. economy will likely require that many applications that currently rely on direct combustion of fossil fuels—for example, vehicle transportation, heating in buildings and many industrial applications—be electrified. This "electrification" of the economy is one of the most consistent results from large-scale energy models. Electrification of those end uses, while promising, involves a large number of uncertainties including, performance of end-use electric technologies, electricity storage, and the rapid scale up of rival approaches to deep decarbonization (e.g., using hydrogen as an energy carrier).

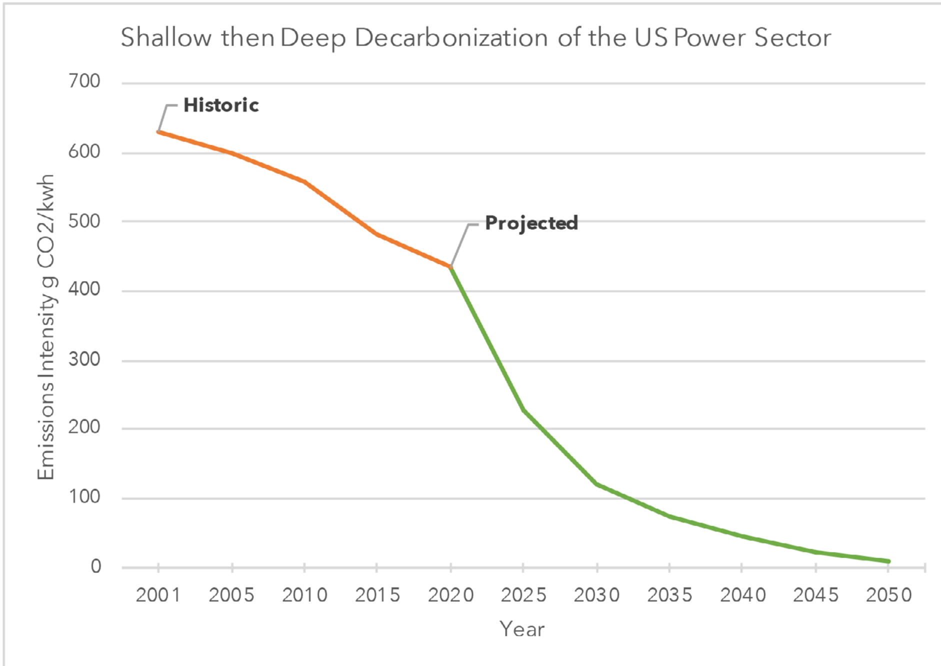

Figure 5.1.2. Shallow then deep decarbonization of the U.S. power sector. (original figure)

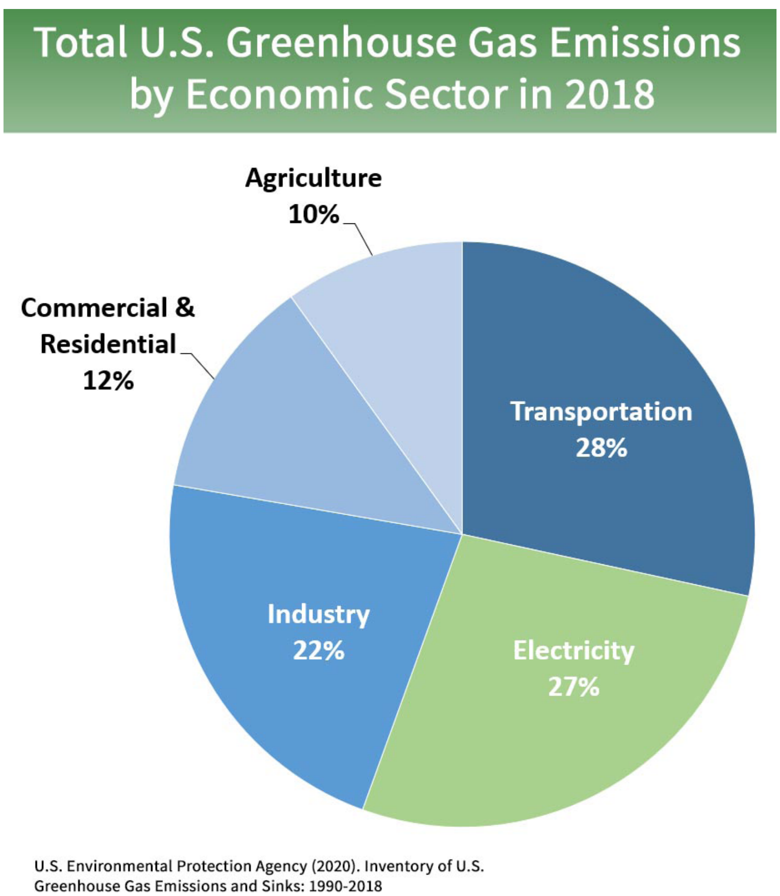

Figure 5.1.3. Total emissions from the power sector (Sources of Greenhouse Gas Emissions, 2020).

This chapter considers how the power sector could play a pivotal role in deep decarbonization of the entire economy. While the focus is heavily on the technological opportunities, transformation of the power sector is not merely a technical question. Instead, it is a matter of industrial organization, socio-economic interactions, and political choice. Organizationally, a key challenge in the U.S. power sector is the sheer number and diversity of owners.

The last century has seen the rise of a large number of investor-owned utilities (IOUs) that provide the backbone of U.S. electric service—as measured by the volume of electricity supplied. All of these companies are heavily regulated due to fears of monopolistic behavior. Within this group there are vertically integrated companies that provide all services—from power generation to transmissions, distribution and marketing—along with firms in markets that have been "restructured" in various ways to unbundle those services. Unbundling has, in theory, allowed portions of electric service that are natural monopolies (e.g., transmission and distribution) to be separated from those where competition is more viable (e.g., generation). In recent decades, unbundling has created more firms and competition where policymakers have allowed. Meanwhile, in the most regulated markets, consolidation has created a smaller number of huge integrated utilities. Looking beyond IOUs, the U.S. also has a number of publicly owned enterprises that provide similar services (e.g., Tennessee Valley Authority), including enterprises owned by states (e.g., NY Power Authority) and a large number of locally owned power enterprises (e.g., LA Department of Water and Power, Orlando Utilities Commission, or Dairyland Power Cooperative). All told, approximately 200 investor-owned utilities and Approximately 2,900 publicly owned utilities (including cooperatives, municipal utilities, and special-purpose utility districts) own and operate the U.S. power supply system.[3] This dispersion in ownership is important because it reflects highly diverse incentives and fragmentation in the imperative and ability to reap the rewards of innovation.

Many trends point to continued, if not accelerating, fragmentation, such as with the rise of community choice aggregation (CCA)—publicly owned local power marketing authorities that are replacing IOUs in some states (Figure 5.1.3).[5]

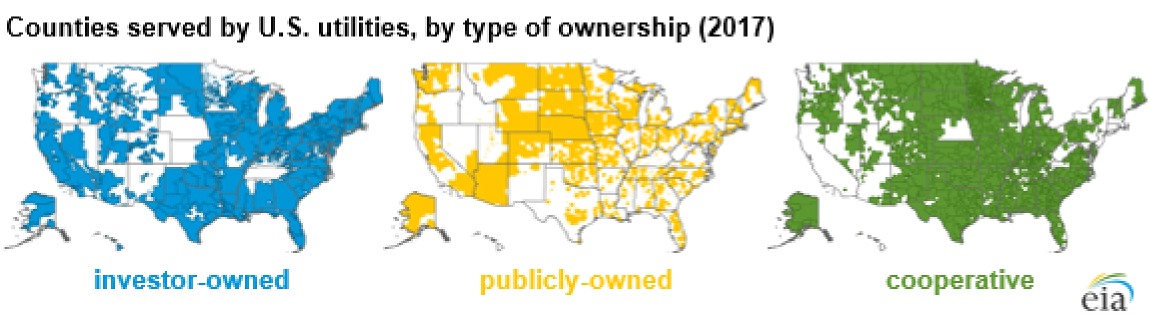

Figure 5.1.4. Load service by ownership type (Darling and Hoff, 2020).

Political choices surrounding the power grid depend not only on how the industry is organized—and its incentives for change—but also what society wants from electric power. Over the last century, reliable and affordable electric service has become pivotal to modern society. It has been the backbone of waves of economic productivity that spanned nearly the whole century. It is vital to modern life—illumination, security, telecommunications and computing. Because of that central role—and because key elements of the grid are natural monopolies—electricity has not been treated as just any industry—it has been regulated (or the means of production state-owned and thus assumed to operate in public interest) in ways needed to assure electricity services align with public interest. This goal takes the form of a "regulatory compact"—that is, a requirement that electricity be available to essentially all households at affordable tariffs and that the grid service be kept at a sufficient level of reliability. Over many decades the "compact" has been extended to include environmental attributes—a clean power system whose environmental burdens do not fall disproportionately on one segment of society.

This background of diverse ownership with diverse incentives, coupled with a social compact that focuses the industry on much more than simply providing a commodity at low cost helps frame the new challenge: decarbonization. Deep decarbonization will need to be seen not simply as an attractive attribute of the grid, but one that reliably contributes to what the society wants from electric power. Failure to do that will create policy pressures that are not deeply sustainable politically.

It is relatively easy to imagine futures for the electric supply system that achieve multiple social and environmental goals. More complicated is envisioning the diverse political and organizational factors aligning at the needed scale and pace. Thus, much of this chapter will look not simply at technologies and visions but also practicalities. Those practicalities arise in at least three dimensions. One is design and implementation of policy in the highly fragmented federalized U.S. system. In that system for decades, policy at the federal level has been largely gridlocked, although some changes have emerged through federal regulatory action, notably at the Federal Energy Regulatory Commission (FERC). So far, FERC action has had mixed implications for deep decarbonization. Some states are more decisively aligned around this goal, but they account for perhaps one third of U.S. electric service. A second dimension is building and sustaining political and community support for decarbonization of a sector that must meet other political goals. Third is how to craft and implement a policy process that addresses seriously the high uncertainties about which technology and investment strategies will be best. This process encourages experimentation and rapid learning, which is efficient about how capital is allocated and also bound to realities about how real firms think about investment under uncertainty.

This chapter will look at these three challenges from four different perspectives: (1) supply of electricity; (2) demand for electricity; (3) the topology of the evolving grid; and (4) policy incentives and implementation.

5.1.3 Decarbonization of Supply

Laws in eight U.S. states require either by goal or mandate the installation of zero-carbon electricity systems by mid-century. Thirteen other states are actively considering similar measures.[6] An even larger group of states have some form of renewable portfolio standard (RPS) in place. While most state targets are between ten percent and 45 percent, 14 states—California, Colorado, Hawaii, Maine, Maryland, Massachusetts, Nevada, New Mexico, New Jersey, New York, Oregon, Vermont, Virginia, Washington, as well as Washington, D.C. Puerto Rico and the Virgin Islands—have requirements of 50 percent or greater.[7]

Given the trajectory of clean energy state policies, multiple technology options are available to deeply decarbonize the supply of electricity. However, due to fragmented federalism, states differ widely on decarbonization goals in the U.S. and consequently necessitate the installation of different types of technologies. Some states have expressed goals for 100 percent renewable energy (Hawaii, Maine, Virginia, D.C., Puerto Rico); others seek 100 percent zero-carbon (California, Washington, New York, Nevada, New Mexico). Some of the states with 100 percent clean goals set sub-goals for renewables, such as 80 percent renewable in New Mexico by 2040 or 60 percent renewable in California by 2030. When combined with supportive regulatory action, such as procurement requirements aligned with integrated resource plans (IRPs), these targets can steer power grids down certain pathways and favor investment in certain groups of technologies. Still, even among the states that are highly committed to action, the diversity in approaches is striking. For example, Washington has no renewables requirement as it relies heavily on hydroelectric with large reservoirs which, like nuclear, is low/zero-carbon but not strictly renewable by most definitions used in RPS, the policy instrument used in most of the country to advance renewable energy. As not all states have hydropower resources, there is no one-size-fits-all clean electricity technology solution for the 50 states. The cost-optimal technology mix differs significantly for different states and targets.

Generation Technology Options

Electricity supplying technologies may be grouped according to their policy definition (whether they fall under renewable, low/zero-carbon, or neither) and also according to the type of service, or functional role they play in the grid. Here we categorize electricity technologies into the following categories: (1) variable renewable energy, (2) firm/dispatchable low-carbon options, and (3) carbon capture utilization and storage (CCUS). We review at a high level below and in Table 5.1.1 some benefits and challenges of each technology option in reaching deep decarbonization goals. Additionally, there are a suite of technologies that are necessary to better enable the use of the aforementioned options which are described later in this section.

Variable renewable energy (VRE) resources refer to resources whose electricity generation profiles are inherently variable due to factors exogenous to the control of electric grid or power station operators (i.e., weather). Specifically, this class includes but is not limited to solar photovoltaic, concentrated solar power, onshore wind, offshore wind, and marine hydrokinetic (under development).

VRE resource potential varies by region. States on the east coast like NY, Virginia, and NJ may ultimately depend on large capacities of off-shore wind to meet zero-carbon targets. Midwest states have the highest quality on-shore wind resources, while southern states have the highest quality solar resources and may depend on these to meet their decarbonization goals. Concentrated solar power resources are even more localized as they benefit from direct solar radiation rather than diffuse radiation that works with photovoltaic (PV).

Table 5.1.1 – Characteristics of Select Low-Carbon Electricity Supply Options.

	Current all-in costs	Projected 2050 all-in costs	Flexibility Score	Typical Capacity Factor	Issue 1	Issue 2	Issue 3
VRE							
Onshore Wind			Medium	40	Variable & regional	Transmission	Offshore cost decline?
Offshore Wind			Medium	50	Currently still more expensive than onshore wind or solar	Floating offshore needed for wide deployment	High capacity factors and close to population centers
Solar			Medium	25	Daytime & regional	Declining value as % rises	Perovskite breakthroughs?
Clean and Dispatchable							
Nuclear		?	Low	90	New plants w/ current tech are economically uncompetitive	Existing plants provide lots of zero carbon e-	How will SMRs evolve?
Geothermal		?	Medium	80	Difficult development pathway	Limited locations for conventional	Large resource base for advanced geothermal, but engineering challenges remain
Hydro			Depends	30-80	Ecosystem conflicts	Many existing non-powered dams could be targeted	Pressure to remove existing dams
Biopower			Medium	65-85	Food/water/ ecosystem conflicts	True lifecycle GHG profile unclear	Relatively high fuel costs and engineering problems operating biogas plants
CSP			Medium	20-40*	CSP with storage adds value	Relies on steam turbine, but potential to reduce overall costs	Operational problems at some plants have damaged the industry's reputation
NGCC			High	50-90	Emits GHGs and local pollutants in air and water	Complements VRE	Social license to operate concerns
Capture							
BECCS		?	Medium	60-80	Food/water/ ecosystem conflicts	Negative emission potential	Alignment of biomass production and geological storage needs
CCUS		?	Medium	60-80	NG CCUS has low CO_2 concentration (costly)	Good target for pure CO_2 streams like ethanol	Backstop for existing coal and hard-to-decarbonize sectors

Note: We use the "green-yellow-red" light classification here, with darker shades indicating intensity of positive/negative attributes. VRE=variable renewable energy, CSP=concentrating solar power, CCUS=carbon capture utilization and storage, BECCS=bioenergy with carbon capture and storage. Source: Synthesized by authors from Lazard, NREL, and BNEF data.

As a class, VRE resources tend to have very low variable costs and no fuel costs, with capital costs for certain VRE resources such as solar PV and onshore wind having decreased rapidly in the past decade and continuing to do so. These attributes help explain why, as the economic depression from the pandemic emerged in early 2020, most countries (including the U.S.) saw the share of renewables rise. Compared with coal or gas-fired power plants, where operating costs were higher, it was less costly to let renewable supply take a larger share of declining total power needs. A recent study reported that VRE resources have the lowest unsubsidized costs in delivering bulk power to two thirds of the globe.[8] The return on investment for these technologies can also depend on the quality of the wind and solar resource in locations where these are installed. However, the inherently variable electricity generation profiles from these resources do not necessarily align with that of the load demand. Therefore, these resources need to be complemented by other resources such as firm/dispatchable generation, energy storage, or demand-side flexibility, each of which entail other costs.

Firm or dispatchable low-carbon resources refer to electricity generation technologies that can be inherently controlled to follow the profile of the electric load demand on a consistent and long-duration basis, in contrast to VRE resources. In a decarbonizing context, this class includes but is not limited to nuclear, hydropower, natural gas with carbon capture and storage (CCS), geothermal, and biomass-and biogas-fuel power plants. Some of these resources are strongly geographically constrained: across the U.S., the Pacific northwest has access to abundant hydropower resources, while conventional geothermal resources are concentrated in some Western locations such as California and Nevada. Biomass and biogas resource potential vary depending on the type of biomass or biogas source and are therefore concentrated in specific areas and entail different environmental externalities (i.e., air pollutant emissions, land or water use).

As a class, firm or dispatchable low-carbon resources tend to exhibit high capacity factors and the ability to provide a diverse array of services for the electric grid in addition to the provision of bulk generation, such as grid reliability and reserve capability. Most of these technologies can operate flexibly within the constraints of their physical capabilities with the exception of hydropower, which must often balance electricity generation with water supply, flood control, and environmental quality priorities. Capital costs for resources such as hydropower, geothermal, and nuclear tend to be high upfront, but the lifetimes of these systems can be long and fuel costs are either low or non-existent. Variable costs can be high depending on the type of resource. By contrast, resources such as biomass and biogas can have relatively lower capital costs but entail continuing and potentially volatile fuel costs. CCS systems added to natural gas power plants will increase costs both through the need for extra equipment and reduction in the efficiency of the power plants that use them. Additionally, it is unclear whether natural gas with CCS is allowed as a zero-carbon compliant technology under regional clean power laws such as California's SB100.

Carbon Capture Utilization and Storage (CCUS) refers to a class of technologies that enable the capture and diversion of CO_2 emissions to either a use or storage that prevents these emissions from entering the atmosphere. Of particular importance are technologies that capture and divert the carbon emissions from primary electricity supply resources such as natural gas and biomass. In a renewable heavy grid, the dynamic operation of fuel-fired power plants can create a technical challenge for CCUS integration. Another alternative is to use CCUS in conjunction with natural gas-based hydrogen production, and use hydrogen as a zero-emission fuel.

Technologies that rely on CCS may be constrained depending on the method of carbon storage—storing in geological reservoirs will constrain the use of these technologies to areas with suitable reservoirs. CCUS allows for continued use of limited fossil fuels (which are easy to store, inexpensive and flexible—especially gas) while also allowing for near zero emissions from the power plants. However, the fossil fuel life cycle processes such as incomplete capture, mining, and leakage will still contribute added carbon emissions. Additionally, the economic viability of CCUS technologies will need to improve before these fulfill any substantial role in a decarbonized electricity system (Table 5.1.1).

Enabling Technologies

In addition to technologies that serve as primary sources of electricity generation, a suite of additional technologies must often be installed to enable the electric grid to utilize the aforementioned low/zero-carbon supply options to serve electric demand and maintain the reliability of the system. These include but are not limited to: short-duration energy storage, long-duration energy storage, and flexible loads from systems such as electric vehicle smart charging and dispatchable hydrogen electrolysis, among others. Particularly, while these technologies do not provide electricity generation on their own, their presence in the system enables functions such as shifting variable renewable generation to coincide with demand, reducing the dynamic requirements of firm/dispatchable resources, and providing short-term grid reliability services. These technologies are varied in their costs, externalities, and functions.

Short-duration energy storage includes various electrochemical batteries (i.e., batteries, capacitors, flywheels) that can store relatively small amounts of energy but can charge from and discharge to the broader electric grid at rapid rates. These enable generation from VRE resources to be shifted over the course of a few hours to one day to better coincide with demand, as well as enable the provision of grid reliability services such as frequency regulation that do not require a significant amount of energy. The costs of battery systems have decreased rapidly over the past decade, partly due to benefitting from improvements in batteries for electric vehicles, and these costs are expected to continue to decrease. However, the need to secure adequate materials supply, implement recycling infrastructure, and improve battery system lifetimes are persisting needs. Although redox flow batteries theoretically could be built for long-duration applications, most are built for short-duration with 1-4 hour storage capabilities. With strong incentives for innovation, which now exist, battery platforms could lead to new systems with much longer storage durations. For example, Form Energy is building a 150 hour battery with metal air chemistry.

Long-duration energy storage refers to technologies that can store very large amounts of energy typically over ten hours. These include but are not limited to pumped hydropower, compressed air, and hydrogen or ammonia (Power-to-Gas-to-Power; PGP) energy storage that charge with otherwise curtailed VRE generation. These technologies enable the electric grid to compensate for relatively long periods of time, such as multiple weeks, seasons, or even multiple years. For example, long-duration storage can fill in for summertime resource gaps in U.S. wind power. Today, more than 90 percent of installed storage on the U.S. grid with these attributes is pumped hydro, although with innovation other technologies may take some of that share. Despite low round-trip efficiencies of long-duration storage systems compared to shorter-duration options like batteries, long-duration storage fulfills a different and distinct grid need.[9] Hydrogen energy storage can provide expandable, relatively geography-neutral long-duration storage.

Currently, hydrogen production and consumption via electrolyzers and fuel cells is cost-effective in reliable wind-solar-battery systems.[10] However, hydrogen energy storage in existing infrastructure such as natural gas pipelines, underground salt caverns, and depleted natural gas reservoirs is even more affordable.[11] Costs of the hydrogen energy long-duration storage system could be improved by replacing fuel cells with hydrogen combustion turbines. Ammonia is another option similar to hydrogen that could emerge as an option to store energy in the future.

Also critical is the need to recognize that storage requirements on a grid depend not just on the ability to install storage systems (and the costs of those systems) but also other attributes of the grid that could be complements and substitutes. For example, expanding the capacity of clean firm generation (nuclear, geothermal, hydropower) would reduce the required storage capacity to meet a given decarbonization target.[12] Additionally, flexible loads such as smart electric vehicle (EV) charging can further reduce energy storage requirements.[13]

Flexible loads

Flexible loads refer to changing the temporal profile of electric loads to better coincide with low-carbon electricity generation. These options are significantly varied in their flexibility and magnitude, but include smart electric vehicle charging (V1G) and vehicle-to-grid (V2G), building demand response, and flexible fuel production loads (i.e., electrolysis to produce fuels for non-grid applications). Grid-responsive electric vehicle charging can provide significant renewable integration benefits for the grid and makes use of already-manufactured battery capacity in the EV fleet. However, this practice is not widely implemented and questions persist as to the willingness of drivers to participate in these programs and the adequate valuation of their services. Additionally, the flexibility of electric vehicle charging loads depends on the travel needs of the driver or vehicle fleet operator and is generally lower than a stationary energy storage system. Building demand response can entail strategies such as reducing lighting and heating, ventilation, and air conditioning (HVAC) loads to reduce demand during times when low/zero-carbon generation is limited, and is limited by building occupant comfort limits and functionality needs. Finally, flexible fuel production entails shaping the load profile of electrolytically produced fuels (i.e., hydrogen or renewable natural gas) for use in non-electric grid applications to better coincide with the low/zero-carbon electricity generation.

Integration of Supply on the Electric Grid System

Deep decarbonization is generally defined as an 80-100 percent reduction in emissions from current or recent levels. Evaluating 40 studies revealed two common paths to deep decarbonization.[14] One electricity sector path depends primarily on VRE supported by grid enabling technologies such as energy storage, flexible demand, and expansion of transmission. A second electricity sector path relies on a wider range of low-carbon resources (i.e., wind and solar) but also ‘firm’ resources such as nuclear, geothermal, biomass, and fossil fuels with CCS.[15]

By mid-century, the U.S. electricity sector should meet zero-carbon emissions, reliability, and affordability. In addition to zero-carbon emission state mandates, the electricity sector must adhere to high reliability and resource adequacy standards of 99.97 percent from FERC and the North American Electric Reliability Corporation (NERC).[16] Achieving about 80 percent carbon-free with solely wind and solar generation is feasible based on current understanding.[17]

Electricity systems transitioning from 50 percent to 70 percent VRE will expand balancing areas, use shorter gate closures and advanced forecasting, build transmission, and increase storage. However, given historical resource gaps in wind and solar resources that can span weeks (especially for wind), the transition to 100 percent carbon-free reliable electricity based only on VRE requires other technologies such as seasonal energy storage, supplemental generation, flexible demand, and transmission expansion.[18] Most of these options, especially overbuilding wind and solar in conjunction with high capacities of Li-ion battery storage increases electricity costs.

Studies indicate that the U.S. electricity sector will expand by 60-110 percent by 2050 due in large part to increased electrification of energy end uses.[19] If decarbonized electricity is not affordable, other sectors such as transportation, heating, and industry will be more likely to continue to use fossil fuels, and therefore affordability of decarbonized electricity is crucial. Using a multi-decadal wind and solar data set, one study showed that long-duration storage, at current technology costs, can improve the affordability of variable renewable electricity systems by filling seasonal and multi-year functional roles.[20] Another recent study demonstrated that the addition of low- or zero-carbon ‘firm’ generators lowers the overall costs of electricity systems with high fractions of VRE sources, and demonstrates the need for both classes of low/zero-carbon electricity generation resources in facilitating decarbonized electricity systems (Figure 5.1.5).[21] That study shows that for two different types of grids (left side and right side of Figure 5.1.5), when clean firm power supplies are utilized optimally, the average cost of electricity is cut in half as emission limits are tightened close to zero. The comparison is with an electric grid that does not allow for clean firm power supplies and thus achieves deep decarbonization entirely with solar, wind and batteries.

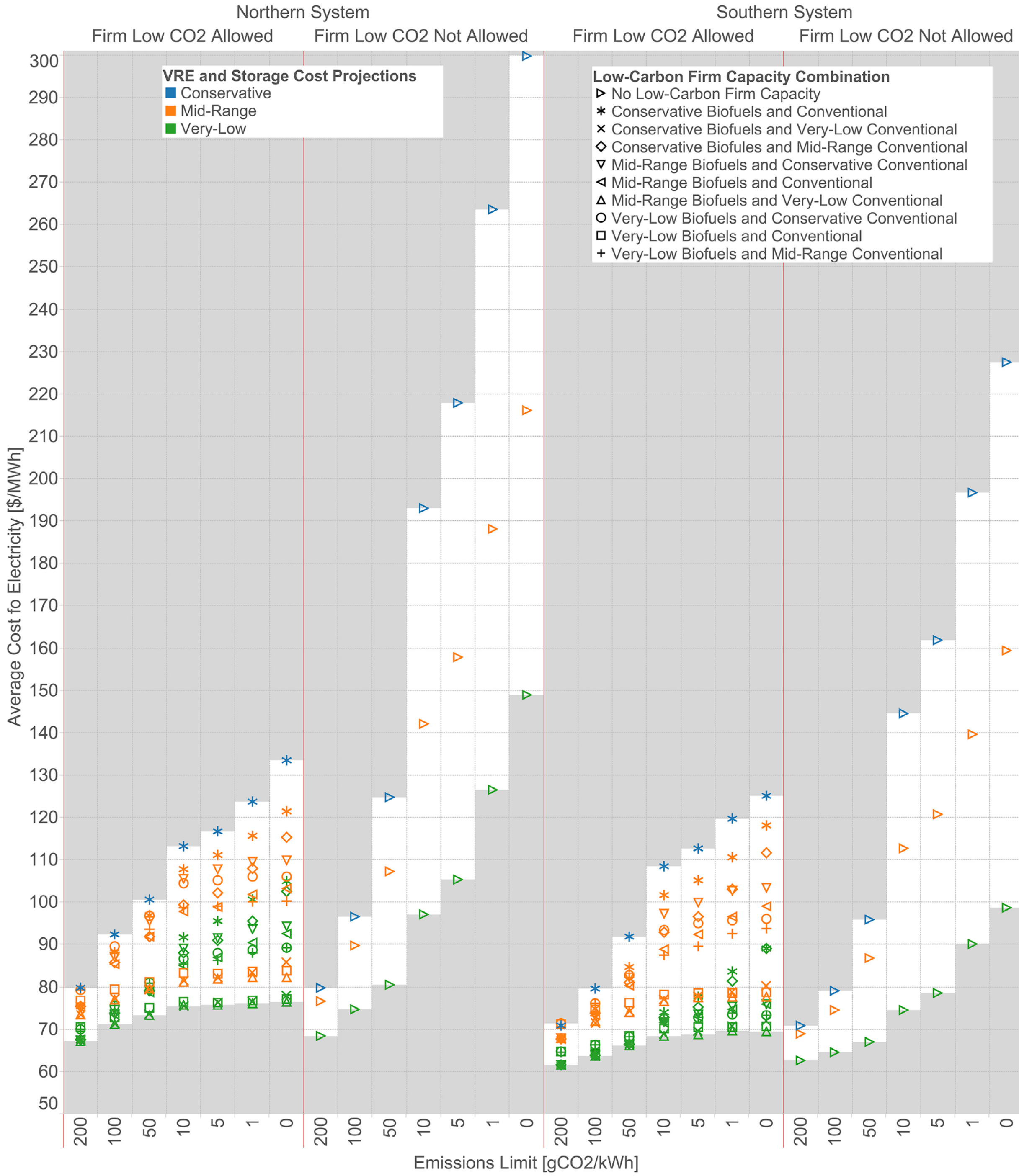

Figure 5.1.5. Cost of electricity associated with different greenhouse gas emissions intensity targets under pathways that include vs. do not include firm low-carbon electricity generation capacity (Sepulveda, Nestor A. et al., 2018).

To best facilitate the development of a deeply decarbonized electricity system, however, decarbonizing electricity supply and managing supply resources is only one part of the needed effort and transformation of the electricity system. Reducing the electric demand through increasing the efficiency of electrified end-uses with technologies such as efficient heat pumps for HVAC systems, improved building envelopes, improved electrified transport efficiencies, and the like will reduce the scale of decarbonized supply capacity and enabling technologies required to provide needed electricity services and the associated costs. Details on these technologies and strategies are the focus of the next section.

5.1.4 Demand for Electricity

Over the last century there has been autonomous expansion of electrification. Applications that did not exist have emerged into widespread utilization (e.g., microwave ovens, the internet, server farms, air conditioning, refrigeration), applications that used to rely on mechanical power or direct combustion of fuels were electrified (e.g., washing machines or elevators replacing stairs for vertical mobility), and demand for useful energy expanded with the economy and population. Combined, these patterns have led to rising demand for electricity overall and a growing fraction of final energy consumed as electricity (Figure 5.1.6). The modeling results in Chapter 2 find that these patterns will continue, resulting in a further doubling of the share of final energy from electricity—starting from 20 percent today and increasing to more than 50 percent by 2050.

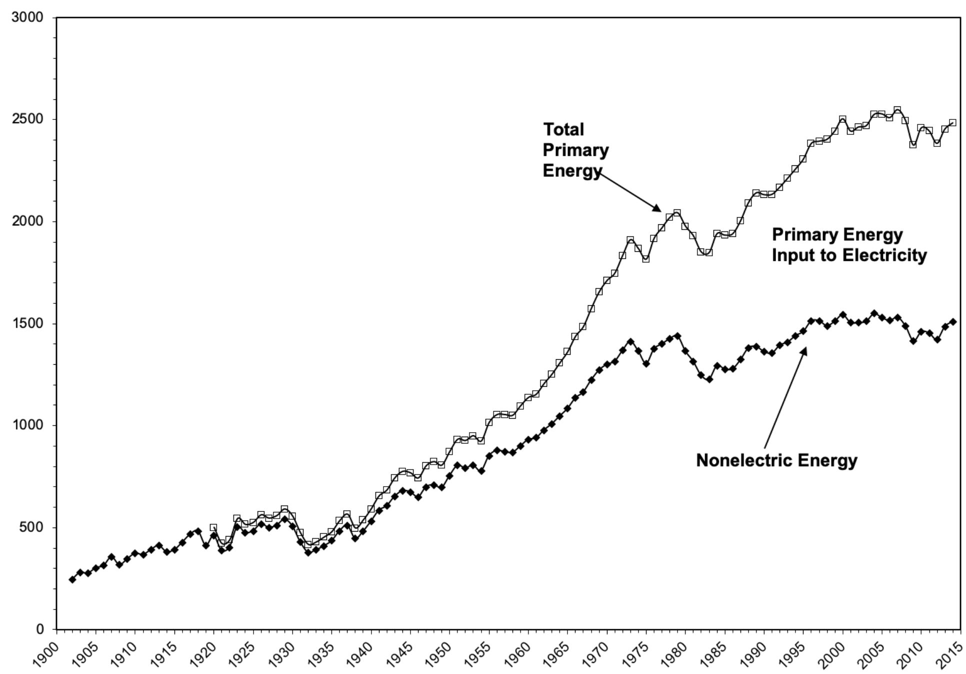

Figure 5.1.6. Long term electrification of the economy. Figure shows total primary energy converted to electricity before consumption over time historically (EIA Monthly Energy Review) and projected into the future (Chapter 2).

Looking to the future, there are at least two major attributes of demand that must be understood: the total level of demand (by region and locality, since that is how infrastructure is planned and built) and the shape of the demand curves (again, by region and locality). As a general rule, the latter is becoming particularly important to understand because peak demand is what drives the needed size and capabilities of transmission and distribution infrastructure and because VRE sources introduce substantial variability in supply. If changes in supply and demand curves are managed well, the needs for infrastructure could be much lower than if supply and demand are out of sync.

A large and growing number of energy uses are ripe for electrification and are often called "easy to electrify." These include low grade heating systems—already, resistance heating is used in water heaters and some space heating—and with more efficient heat pumps there could be more widespread utilization of electricity for these services. Heat pump technology has been known for a long time but has, historically, been costly and unreliable; with ongoing investment the situation is changing quickly.

Most attention is focused on electrification of transportation—a process evident in light duty vehicles in some parts of the world (e.g., Norway, California, Monaco) where active policy support has been combined with wealthy and engaged consumers. Similar patterns may spread to heavier duty transportation (e.g., trucks). Rail systems are already highly electrified, especially where tracks have high usage and the extra cost of power supply systems can be amortized more fully. Whether shipping and aircraft become electrified is harder to fathom, for the costs are higher and rival methods for decarbonization more numerous and competitive.

In terms of overall impact on demand, electrification of light duty transportation has a surprisingly small impact. More interesting is the potential for EV charging to assist in load management and shape demand curves by altering the time and intensity of charging activities. However, as shown in Figure 5.1.7, in the absence of explicit incentives to vary charging behavior—that is, flat tariffs—there is substantial variation across days and over time and people, for the most part, charge when convenient to themselves.[22] This figure, taken from the largest public facing charging network in the U.S. (on the UC San Diego campus), shows that charging ramps up quickly in the morning when people arrive for work, tapers over about four hours (when special access to EV charging spaces expires) and stays lower during mid afternoon when California grid solar supplies are actually peaking. Different incentives could shift those charging blocks around during the day.

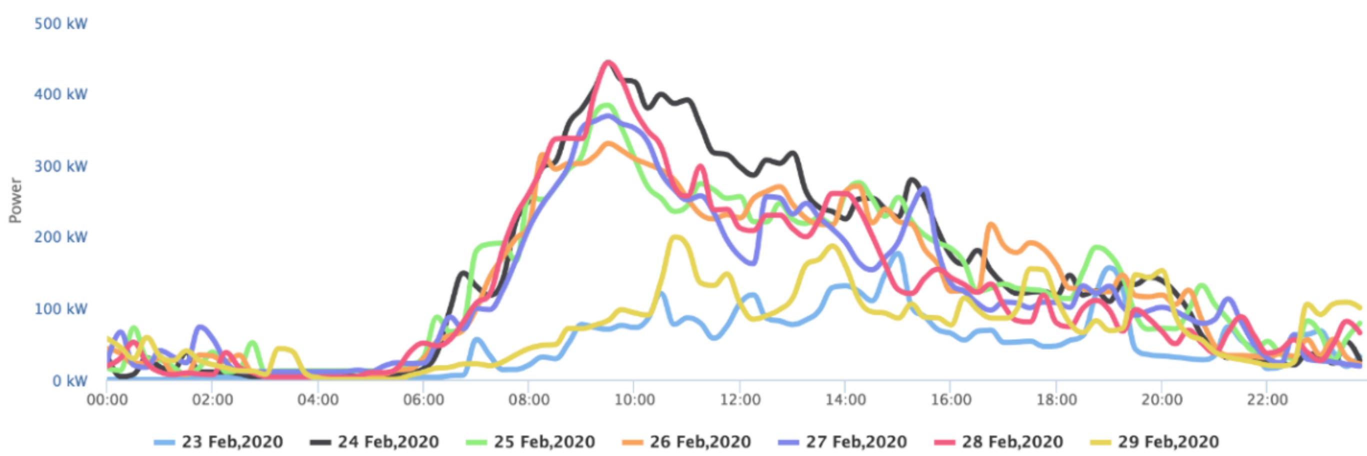

Figure 5.1.7. Daily electric vehicle charging profile (Level 2 chargers only) for UC San Diego during the 9th week of 2020 (February 23-29) (10 hr dwell time, $.15/kWh). (Washom, 2020).

This same logic could be extended to two-way charging—technology is already available, but business models are still being tested—that could pull and reinject power during optimal times.

Looking beyond these easier to electrify options are those that will be much more challenging. In addition to the transportation options already mentioned (e.g., aircraft) a critical set of challenges and opportunities for innovation arise with industrial energy uses such as high heat applications and chemical processing. Here electricity, coupled with CCS, is one of several contenders for deep decarbonization; others include hydrogen and biogas that could replace conventional natural gas.

Electricity is important for deep decarbonization not simply because electric supply is readily decarbonized but also because electrification can contribute to efficiency. Over the last decade (before the pandemic) efficiency has roughly doubled compared with the previous decade. Much of that improvement came from electrification, especially in the emerging economies, and from efficiency improvement in electric generators. That rate of improvement is not as rapid as would be needed globally for deep decarbonization, but is another example of an area where electricity has offered good news for deep decarbonization (Figure 5.1.8).[23] This may be just the beginning—electricity, because it allows for flexible movement of useful energy exactly to the point where it is most needed, can play a big role in more integrated designs that focus on providing services that people need (e.g., illumination, or movement of a person) with primary energy needs that are radically lower than today.

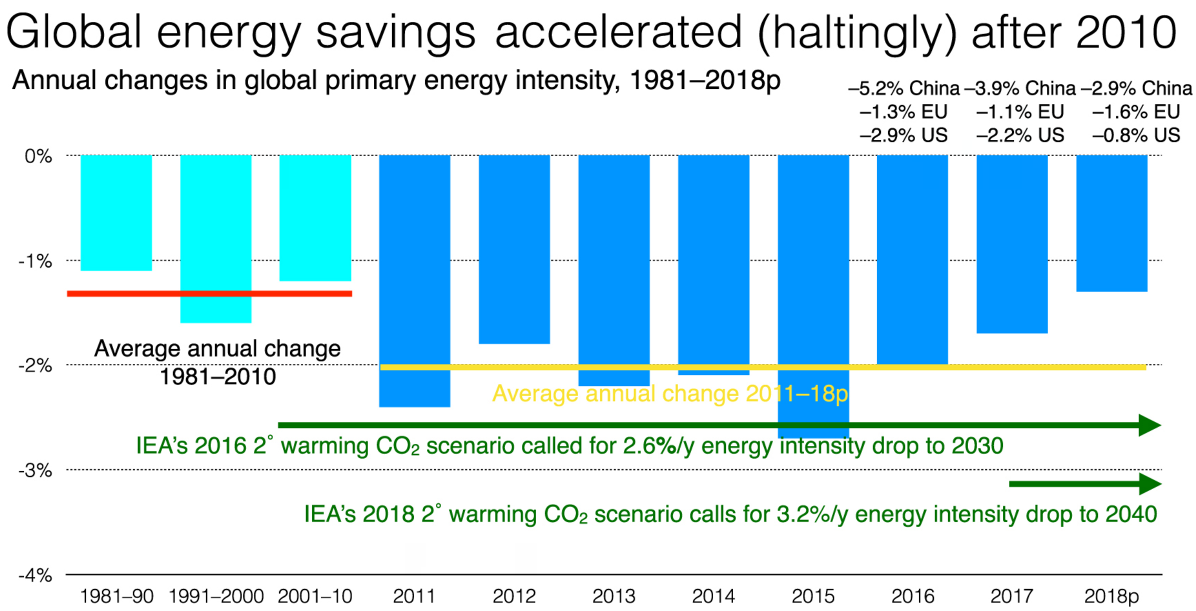

Figure 5.1.8. Improving Efficiency of the Global energy system (Lovins et al., 2019).

5.1.5 Evolution in Grid Topology

Today's power grid was designed to connect a network of large power generators with a large number of end consumers spread over a wide geographical area, creating a linked ecosystem of public and private enterprises operating within a web of government institutions: federal, regional, state, and municipal. Interconnection of the power generation sources and the demand centers is backboned by the complex, often-meshed high-voltage transmission network and typically-radial medium-and low-voltage power distribution systems. While the integrated power grid has been traditionally operated through centralized generation, monitoring and control mechanisms, a transformation to a more dynamic, flexible, and decentralized grid architecture has been emerging driven by:

- rapid proliferation of distributed energy resources (DERs), diverse renewables, and decentralization of the energy production;
- accelerated inclusion of controllable demand-side resources into the grid operation;
- millions of connected "things" to the grid, advancements in sensor technologies, grid-edge power electronics, edge-computing, and evolutions toward distributed intelligence, and;
- intensified requirements for a resilient power grid against natural and made-made extremes.

With the ongoing and future arrival of heterogeneous resources, interactive devices, and additional complexities, the increasingly dynamic smart grids are transforming to a "grid of grids" architecture: a transition from the existing unified network to a collection of smaller networks that can operate in concert or independently as needed.[24] The Grid 2030 is expected to be a fully automated power delivery network that monitors and supports every customer and node, ensuring a two-way flow of electricity and information between the source of power generation and the appliances, and all points in between.[25] Its distributed intelligence through a number of sophisticated sensors, coupled with communications and automated control systems closer to where the data is generated, enables online situational awareness, real-time market transactions, and seamless interfaces among various entities and the electric grid. We here describe several drivers that contribute to such transformations in the grid topology.

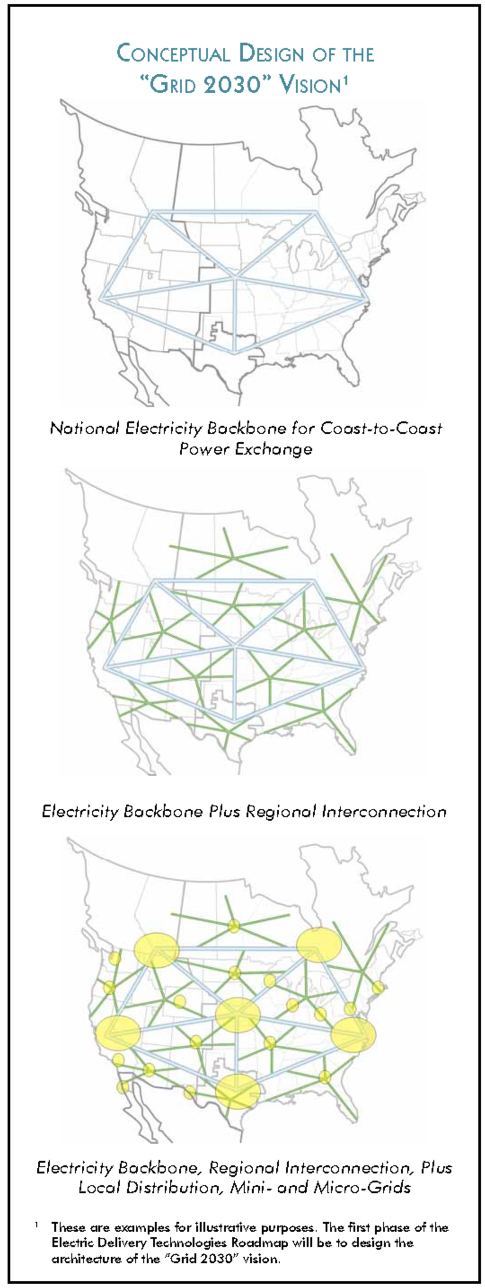

Fig. 5.1.9 Conceptual design of the grid 2030 vision. Transition from existing unified network to a collection of smaller networks that can operate in concert or independently (US DOE, 2003).

Hybrid AC/DC Topology. The increasing deployment of large renewables in power grids, which are typically located at distance from the demand centers, has highlighted the need to build-in additional transmission lines and interconnections with more flexibility to handle the emerging uncertainties. HVDC systems present advantages in bulk transmission networks, namely higher power transferability for transmission lines and better control of power flows across the network (in particular during the transient and emergency conditions that can often lead to blackouts). Thus, the transmission network topology of the future will be made up of a hybrid of AC/DC transmission lines. The other important, but often quiet, driver for such a hybrid structure of the future transmission grid is the rapid growth of DC loads facilitated by the developments in advanced control and electronics technologies to improve the efficiency of energy utilization and control flexibility. A hybrid AC/DC grid topology (i) eliminates the unnecessary AC/DC and DC/AC multi-conversion processes, reducing the total conversion losses; (ii) simplifies the equipment design, reducing the cost of electronic products; and (iii) facilitates the direct connection of the DC loads, making it easier to control harmonic injections into the grid.[26]

Flexible Transmission Grid Topology for Cost Efficiency and Resilience services. The transmission grid is built to be a redundant network in order to ensure mandatory reliability standards. Bulk electric transmission systems have been traditionally characterized with “fixed” and “static” configuration over time except in the cases of faults and forced outages when the topology changes as a consequence of circuit breakers tripping, or due to the scheduled maintenance and operator intervention. Given a fixed system topology with a certain power generation pattern and load profile, the system operator commonly dispatches the committed generating units to optimize the cost while ensuring that the system security and reliability constraints are met. This traditional view does not assume the topology changes during a power dispatch calculation interval. This shortcoming in today’s electricity grid operations needs to be alleviated since it is very unlikely that with all variations in uncertain load and stochastic generation, there exists solely one single optimal network topology for all periods in the operation time horizon.

It is acknowledged that system operators can actually change the grid topology by operating circuit breakers to improve various system conditions and constraints. Power system topology control, often called transmission line switching, is reported as a transmission technology of the future that offers the system operators an opportunity to harness the flexibility of the transmission system topology. By changing the way the electricity flows through the system, transmission switching can be employed during normal operating conditions for higher economic benefits and during emergency conditions for resilience and reliability benefits. Though being performed for decades on a very limited scale with rather focused aims, transmission topology control has recently gained further importance with the increased penetration of renewable energy resources and the growing demand for more reliable operation of power systems. Supported by several national and international directives, this ideology has sparked a series of studies in recent years aiming at discussing the impacts of optimal topology control on the grid operation efficiency and resilience against extreme events.[27] Policymakers should be sure that funding for grid electrification also includes funding for improving grid resilience.

Active Flexible Power Distribution Grids. Both structurally and operationally, power distribution grids are distinct from the high-voltage transmission networks. While a typical distribution grid is made up of a collection of disjoint tree graphs, each growing from substations at the root to customers, its complete layout is loopy, allowing multiple alternative paths to energize operationally. Switching from one layout to another, viable through many switching devices located on different segments of the distribution grid, can take place rather often.[28] The power distribution system was not designed to accommodate an in-mass deployment of DERs while sustaining high levels of electric quality and reliability. In the structurally-changed distribution grid of the future, a growing share of electricity will be produced by an expanding network of diverse more-distributed higher-intermittent DERs—including rooftop photovoltaics and other forms of distributed generation, as well as energy storage technologies and grid-connected electric vehicles—located locally on customer premises (prosumers). Unlike today, where electricity travels "one way", electricity flows bi-directionally, which would necessitate growing needs for local balancing by the distribution grid operator. The local distribution utility will then transform to a "coordinating platform" that enables and supports interfaces and communications among a variety of things including the grid-interactive buildings and appliances, distributed energy storage technologies, as well as transactions between customers, some of whom will be selling excess power from their DERs at certain times.

For resilience, many customers will be able to "island" themselves from the grid, becoming self-reliant as necessary,—the electricity distribution network will be able to instantly disassociate itself into pieces (microgrids) and recombine as needed to handle disruptions. So far, rapidly expanding deployments of DER are connected to the grid but not integrated into grid operations, which is a pattern that is unlikely to be sustainable. To manage this greatly increased degree of operational and transactional complexity and flexibility, it becomes necessary to coordinate distributed resources with utility infrastructure and local autonomous controls (i.e., local optimization inside global coordination),[29] through a massive grid modernization. This would involve reconfiguration of sensors, communications and control systems. Augmenting the present collage of legacy approaches, digitization of the grid will occur by overlaying a set of sensors and cloud-based optimization and command services—some of which will be based on distributed predictive analytics or enabled by blockchain—that facilitates seamless coordination among and between any and all parties that are connected to the grid.

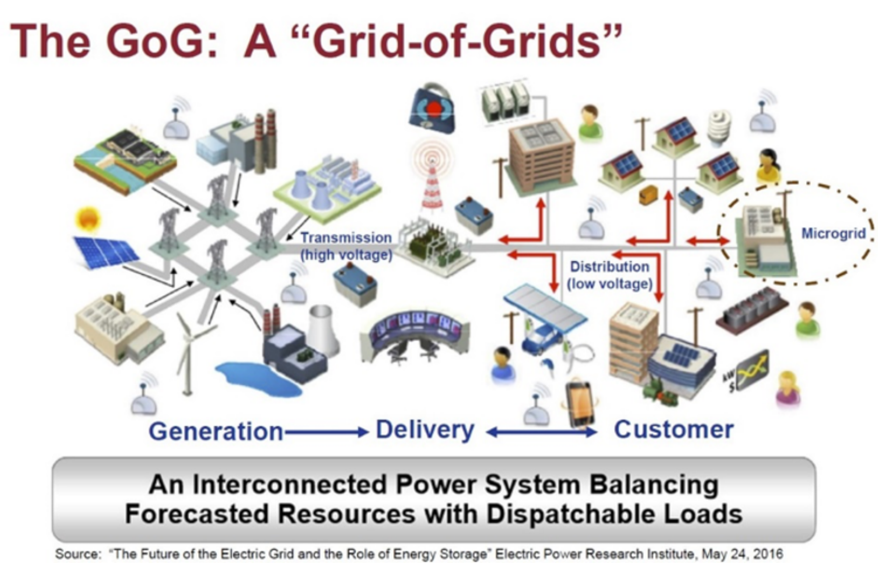

Figure 5.1.10. A "Grid-of-Grids" (EPRI, 2014).

5.1.6 Steering the System with Policies and Markets

There is no single approach or solution to decarbonization. There is, hence, no single policy instrument that is sufficient for reaching electricity decarbonization goals alone, therefore key considerations must be taken into account to develop policies that are effective in promoting progress towards decarbonization goals. These considerations, described in this chapter, are aimed at the development of "no regrets" decarbonization policies, those with significant co-benefits beyond decarbonization and those that may pay for themselves.

On one level, deep decarbonization policy implies navigating and balancing along three dimensions (Figure 5.1.11):

- Environmental Effectiveness: maximizing emissions reductions and reducing air and water pollution associated with a given socio-technical pathway;
- Economic Efficiency: minimizing economic costs in the moment (static efficiency) and across time (dynamic efficiency); and
- Political Efficacy: politically palatable and account for considerations such as distributional and equity concerns.

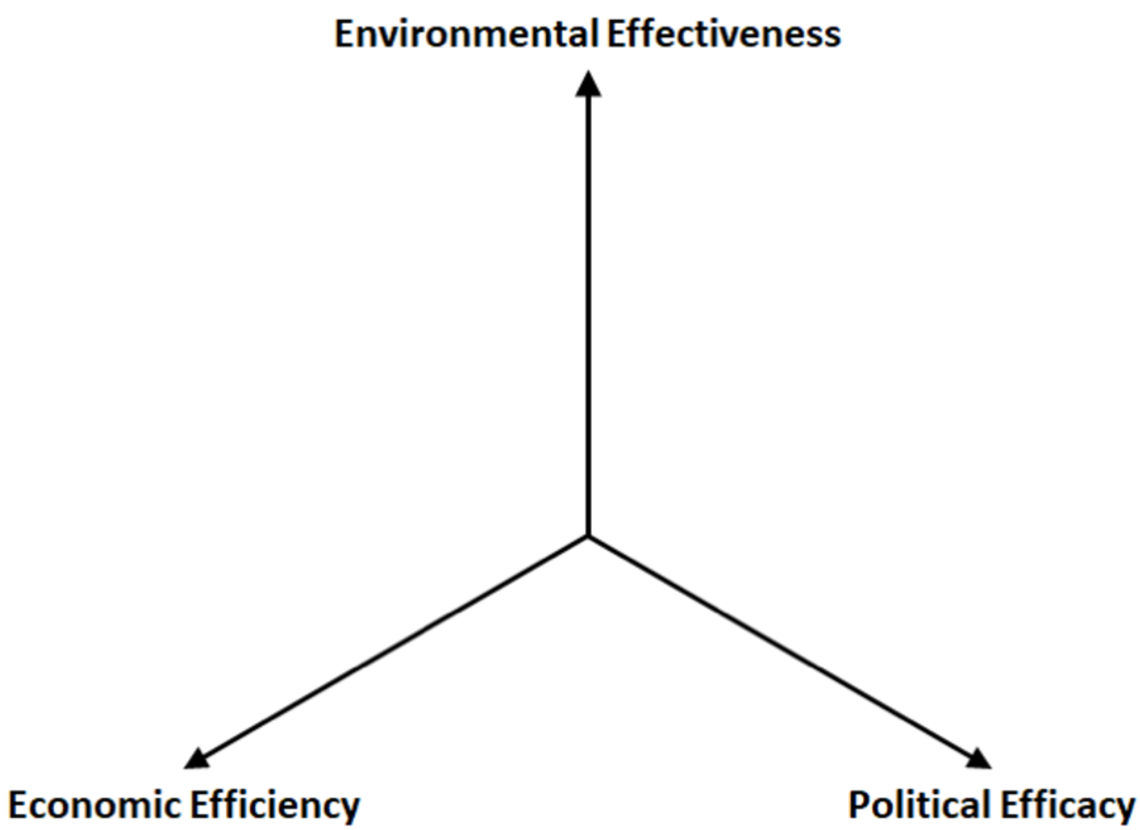

Figure 5.1.11. Competing decarbonization policy priorities (original figure).

All three dimensions are important in designing decarbonization policy instruments and any given instrument often involves trade-offs between these dimensions. Some of the most effective policies make costs explicit, potentially decreasing political efficacy. Politically efficate policies, in turn, may not be among the most efficient or effective, often requiring hard tradeoffs.

Policy instruments fall broadly into three categories:

- Direct regulation: This often takes the form of mandates, standards, and other command-and-control interventions. Examples include state-level Renewable Portfolio Standards (RPS) and building energy efficiency standards.
- Market instruments: These include price incentives and interventions in existing market structures or the creation of new ones. Examples include cap-and-trade systems or the implementation of a carbon tax.
- Technological interventions: These refer to either direct or indirect subsidies on the one hand, or broader industrial policy on the other. Examples include production tax credits.

None of these instruments are exclusive of each other. Many approaches, in fact, span more than one dimension. Reflecting a fine balance of priorities and tools, we here identify three areas of focus where policies will be critical.

First, is the need for policies to promote investing in the electricity network to better support the integration of decarbonizing technologies. Historically, policy has been designed around the characteristics and business models of incumbent technologies, which has meant that the network could expand and risks to investors were low, but incentives for innovation were few. These incentives need to be balanced within existing regulatory frameworks that are often tethered to rate-of-return expectations and state ownership. A key set of questions center around how classic rate-of-return regulations can be repurposed to meet deep decarbonization objectives. For example, which policies need to be reformed so as not to block progress?

Second, is the need for policies to incentivize the adoption of existing decarbonizing technologies and practices. While the need for new technologies in different areas to support decarbonization has been identified, in parallel there will also need to be policies that promote the use of existing technologies to better support electricity decarbonization. Examples include but are not limited to carbon pricing affecting dispatch of known, built technologies for more efficient, lower-carbon emitting operation or adopting currently available appliances to reduce energy consumption and carbon emissions. These policies emphasize static economic efficiency.

The third set of policies focuses on incentives for fundamental innovation and adoption of new technologies--for example, direct investments in RDD&D that contribute to dynamic economic efficiency over time.[30] As examples, such technologies include conventional silicon-based solar photovoltaic, battery energy storage for stationary and mobile applications, and efficient building envelopes and appliances. Currently, while many options for decarbonizing the electricity system exist or are emerging and their adoption rate is increasing, the current rate of adoption must be accelerated to meet regional decarbonization goals.[31] Accelerating the development and adoption of decarbonizing technologies involves building the technological base (and political support) for deep decarbonization over the long term—over decades—rather than only maximizing today's decarbonization potential.

Examples include Germany's and other jurisdictions' subsidies for renewable deployment through instruments such as feed-in tariffs, or U.S. federal tax credits for the purchase of plug-in electric vehicles. The investment in subsidies and learning-by-doing externalities is squarely focused on driving down future costs (Figure 5.1.12).[32]

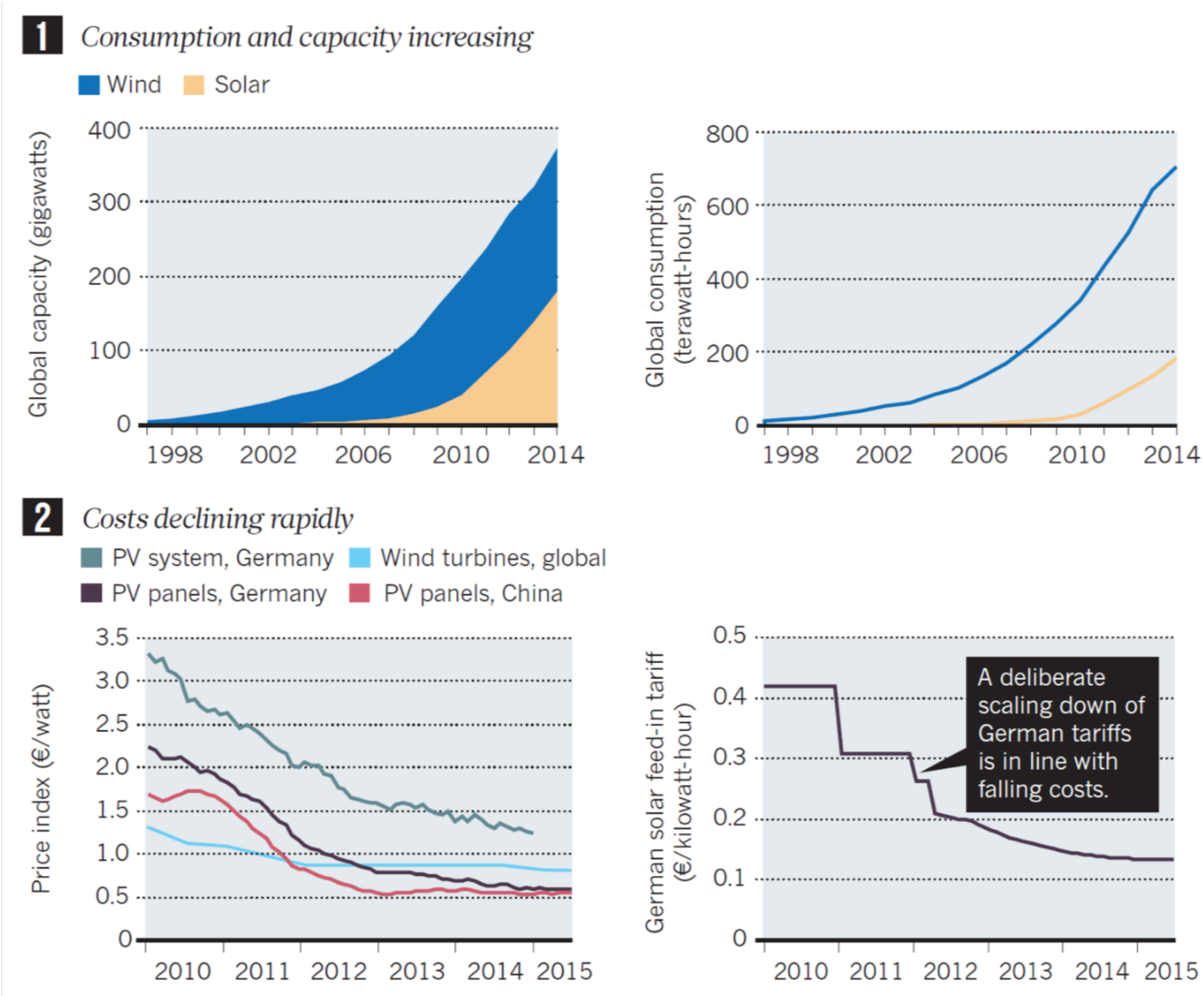

Figure 5.1.12. The rapid solar price decline and global deployment (Wagner et al., 2015).

The design of decarbonization policy must also critically recognize the role of non-carbon co-benefits in either initiating or supporting the incentive for development and adoption of new technologies. The process of building popular and political support for policies aimed at electricity decarbonization will significantly benefit from policy designs that in parallel help to solve tangible issues for different groups. Decarbonization policy is more likely to gain support from populations burdened by local air quality issues or water supply issues if such a policy is structured to adopt technologies and practices that also benefit these issues. Similarly, decarbonization policy must also provide tangible benefits for populations and demographics disproportionately burdened by economic and environmental quality burdens both as a matter of principle and as a means to increase political support and effectiveness.

For example, the initial interest in zero-emission vehicles (ZEVs) in California was based on goals to improve air quality in the state in the early 1990s.[33] In the following years, ZEVs became a powerful means for decarbonization, but due to their benefits for also helping to alleviate local air quality issues, these technologies were able to gain a wider base of support.

There are important considerations, however, regarding the size and importance of co-benefits in designing decarbonization policy. Where does the focus on co-benefits align with decarbonization goals? Where does the pursuit of co-benefits potentially inhibit progress towards decarbonization goals? Other environmental or social externalities can also either initiate or increase the value proposition for developing and adopting new technologies, as well as influencing what types of technologies are developed and deployed. How large does RDD&D spending need to be relative to historic baseline and how can policies be designed to maximize the benefits (decarbonization and otherwise) provided as a result of such spending levels? In a more current context, how much of it can double as post-COVID-19 stimulus spending? Some of these questions have been addressed in previous chapters but the historic spending trends are demonstrated below in (Figure 5.1.13).[32]

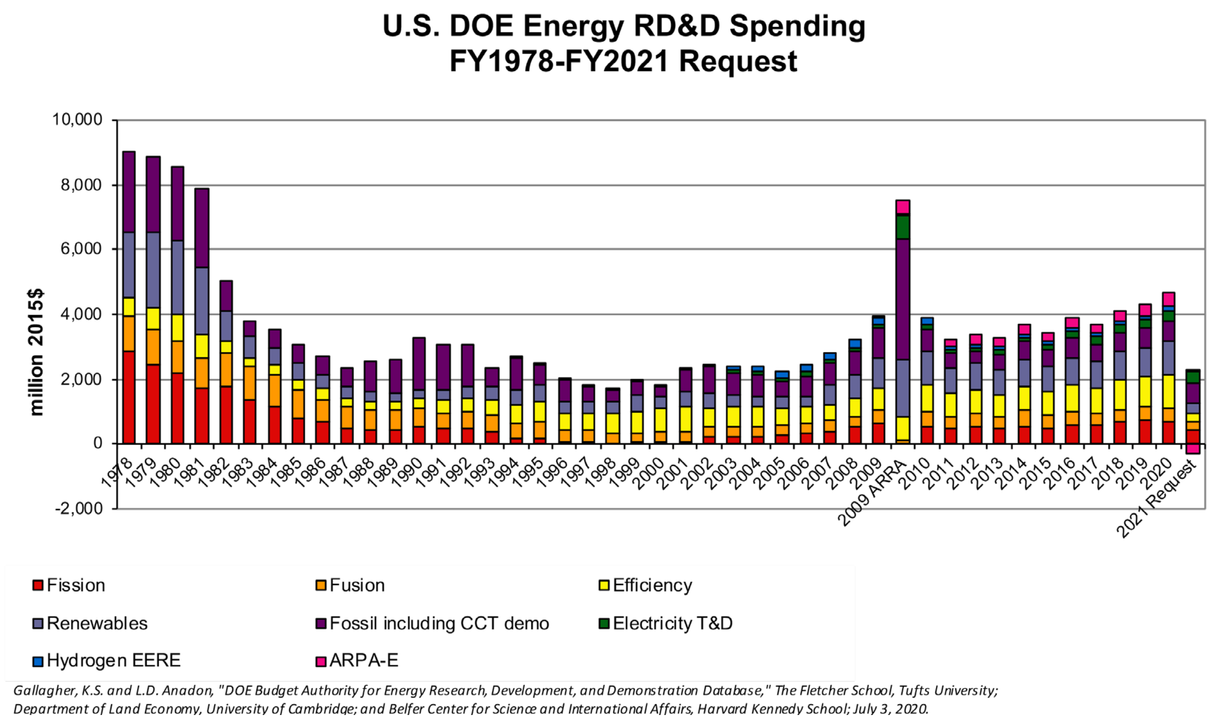

Figure 5.1.13. Historical spending on energy-related public sector RDD&D spending, showing it has largely been flat (Gallagher and Anadon, 2020).

In the end, failure to consider the dimensions, focus areas, and key questions described in this chapter can result in the development of detrimental or ineffective policy designs. Delaying optimal policy design does not just lead to increased costs, it might also lead to different pathways for the evolution of the electricity system altogether.

All that implies that policy design should prioritize looking for “no regrets” pathways towards reaching regional decarbonization goals, and avoid actions with the potential for lock-ins that could lead to more expensive end states.

5.1.7 Conclusions and Policy Recommendations

This chapter briefly considered aspects of the rapidly changing U.S. power sector, first considering supply and demand, then turning to grid typology, and finally markets and policy formulation and implementation.

We noted that, nationwide, the bright spot in decarbonization is the electric power sector. While new technologies are appearing in other sectors, such as transportation and industry, emissions continue to rise. Decarbonization of the grid requires not only dramatic increases in the use of clean energy for supply, but also a focus on energy efficiency across various sectors, and all of this coupled with changes to how the grid is designed, operated, and planned. In concert with decarbonizing the current system, "electrifying" other sectors of the economy to help them move at the pace and scale required by the climate imperative will be crucial.

A large and growing number of energy uses are ripe for electrification and are often called "easy to electrify." These include low grade heating systems. As an example, heat pump technology has been known for a long time but has, historically, been costly and unreliable; with ongoing investment the situation is changing quickly. Considerable attention is focused on electrification of transportation—a process evident in light duty vehicles in some parts of the world where active policy support has been combined with consumer demand. Similar patterns may spread to heavier duty transportation. Electrification of shipping and aircraft is a space for additional innovation as the costs are higher and rival methods for decarbonization more numerous and competitive.

This "electrification" of the economy is one of the most consistent results from large-scale decarbonization models and is clear also in the modelling in Chapter 2. This implies that the economic benefits of focusing on the power sector are significant. Also, finding areas for early and large-scale "wins" tends to provide its own important inertial benefits in the political arena. That said, this section has highlighted that the U.S. power sector is characterized by fragmentation in regulation, ownership, financial incentives, and institutions. This fragmentation can make it difficult to make big changes in short time periods.

Most other jurisdictions do not suffer from this fragmentation. It tends to require a high-level of federal policy mandates to help organise the various actors. As a result, a federal effort that is coherent and well-designed, and aligns with and incentivises state decisions, is likely to be a key step for an administration that prioritizes decarbonization. The electricity sector will need to play a leadership role to help support and motivate other sectors of the economy.

Policy Recommendations

Decarbonization will be achieved through the coordination of varying policy instruments, approaches, and solutions. However, there are key considerations that must be taken into account to help any policy or strategy be effective in promoting progress towards decarbonization goals. Additionally, these considerations, described in this previous section, can aid in developing "no regrets" decarbonization policies that have significant co-benefits beyond decarbonization and may even pay for themselves.

At least three such policies types should be prioritised under this framework:

- Use an expansive Clean Energy Standard or policies like (sector-specific) carbon pricing to price the negative carbon externality. Either policy allows a degree of technological agnosticism, coupled with considerable flexibility in implementation. In the past the states have relied mainly on renewable portfolio standards and federal tax incentives to encourage renewables; those have a role to play in accelerating use of these technologies and will need to be migrated to carbon terms.
- Dramatically increase clean energy RDD&D funding, providing incentives for fundamental innovation and adoption of new technologies. Such a policy would help increase the provision of public goods in the form of new ideas and tested technologies, accelerating the commercial deployment of clean energy systems.
- The third part of this approach would focus on learning and coordination. The states, as they push for deployment of renewables and other low-carbon power generators, will learn a lot about how to integrate these resources onto the grid, especially in the context of other shifts in the power industry such as grid decentralization. An active effort to compare experiences and learn quickly and to identify places of needed coordination--especially between states and federal authorities that have overlapping jurisdiction--will be needed.

These policies all require a new type of grid system as foundational. With the ongoing and future arrival of heterogeneous resources, interactive devices, and additional complexities, the increasingly dynamic smart grids are transforming to a "grid of grids" architecture: a transition from the existing unified network to a collection of smaller networks that can operate in concert or independently as needed. The Grid 2030 is expected to be a much more (if not completely) automated power delivery network that monitors every node, has pervasive yet decentralized controls, and allows multi-directional flows of electricity and information between sources of power generation and users. Its distributed intelligence through a number of sophisticated sensors, coupled with communications and automated control systems closer to where the data is generated, enables online situational awareness, real-time market transactions and seamless interfaces among various entities and the electric grid.

In crafting electricity policy it is crucial to keep the larger context of electric service in mind—including the "social contract" that informs how the sector is regulated. Focusing solely on the technical issues can often be an easier discussion but will not create politically viable pathways if decarbonization is not seen as contributing to other important social goals. Inclusion in decision-making of "just" and equitable transitions will mean policies focused on jobs as well as community benefits—including how decarbonization can help reduce a wide array of environmental ills and not just pollution of warming gases.

References

1. "Sources Of Greenhouse Gas Emissions | US EPA". 2020. US EPA. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.
2. "Monthly Energy Review September 2020 203". 2020. *U. S. Energy Information Administration*. https://www.eia.gov/totalenergy/data/monthly/pdf/sec11_9.pdf/.
3. US Energy Information Administration. "Electric Power Monthly". 2020. *Eia.Gov*. https://www.eia.gov/electricity/monthly/.
4. "Industry Statistics And Reports | American Public Power Association". 2020. *Publicpower.Org*. https://www.publicpower.org/public-power/stats-and-facts/industry-statistics-and-reports.;

   Darling, David, and Sara Hoff. 2020. "Investor-Owned Utilities Served 72% Of U.S. Electricity Customers In 2017". *Eia.Gov*. https://www.eia.gov/todayinenergy/detail.php?id=40913.;

   "Members List". 2020. *Eei.Org*. https://www.eei.org/about/members/uselectriccompanies/Documents/memberlist_print.pdf.;

   "NRECA Fact Sheet". 2020. *NRECA*. https://www.electric.coop/wp-content/uploads/2020/05/NRECA-Fact-Sheet-%205-2020-1.pdf.
5. "Sources Of Greenhouse Gas Emissions | US EPA". 2020. *US EPA*. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.
6. Deyette, Jeff. 2019. "States March Toward 100% Clean Energy - Who's Next?". Blog. *Union Of Concerned Scientists*. https://blog.ucsusa.org/jeff-deyette/states-march-toward-100-clean-energy-whos-next.
7. "State Renewable Portfolio Standards and Goals." n.d. Accessed August 20, 2020. https://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx.
8. "Scale-Up Of Solar And Wind Puts Existing Coal, Gas At Risk". 2020. *BNEF*. https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk/.
9. Dowling, Jacqueline A., Katherine Z. Rinaldi, Tyler H. Ruggles, Steven J. Davis, Mengyao Yuan, Fan Tong, Nathan S. Lewis, and Ken Caldeira. 2020. "Role Of Long-Duration Energy Storage In Variable Renewable Electricity Systems". *Joule*. doi:10.1016/j.joule.2020.07.007.
10. Dowling et al., *Joule* 4, 1907–1928. September 16, 2020 [a] 2020 Elsevier Inc. https://doi.org/10.1016/j.joule.2020.07.007
11. A. Amid, D. Mignard, and M. Wilkinson. 2016. "Seasonal storage of hydrogen in a depleted natural gas reservoir." *International Journal of Hydrogen Energy*, Volume 41, Issue 12, Pages 5549-5558. https://doi.org/10.1016/j.ijhydene.2016.02.036
12. Jenkins, Jesse D., Max Luke, and Samuel Thernstrom. 2018. "Getting To Zero Carbon Emissions In The Electric Power Sector". *Joule* 2 (12): 2498-2510. doi:10.1016/j.joule.2018.11.013.
13. Forrest, Kate E., Brian Tarroja, Li Zhang, Brendan Shaffer, and Scott Samuelsen. 2016. "Charging A Renewable Future: The Impact Of Electric Vehicle Charging Intelligence On Energy Storage Requirements To Meet Renewable Portfolio Standards". *Journal Of Power Sources* 336: 63-74. doi:10.1016/j.jpowsour.2016.10.048.
14. Jenkins, Jesse D. et al., "Getting to Zero Carbon".
15. Sepulveda, Nestor A., Jesse D. Jenkins, Fernando J. de Sisternes, and Richard K. Lester. 2018. "The Role Of Firm Low-Carbon Electricity Resources In Deep Decarbonization Of Power Generation". *Joule* 2 (11): 2403-2420. doi:10.1016/j.joule.2018.08.006.
16. Shaner, Matthew R., Steven J. Davis, Nathan S. Lewis, and Ken Caldeira. 2018. "Geophysical Constraints On The Reliability Of Solar And Wind Power In The United States". *Energy & Environmental Science* 11 (4): 914-925. doi:10.1039/c7ee03029k.
17. Ibid.
18. Ibid.
19. Jenkins, Jesse D. et al., "Getting to Zero Carbon".;

    Mai, Trieu, Paige Jadun, Jeffrey Logan, Colin McMillan, Matteo Muratori, Daniel Steinberg, Laura Vimmerstedt, Ryan Jones, Benjamin Haley, and Brent Nelson. 2018. *Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71500. https://www.nrel.gov/docs/fy18osti/71500.pdf.
20. Dowling, Jacqueline A. et al., "Role of Long-Duration Energy Storage".

21. Sepulveda, Nestor A. et al., "The Role of Firm Low-Carbon".

22. Washom, Byron. 2020. EV Charging Performance February 23 – 29, 2020 Based Upon 210 Chargepoint Ports At UC San Diego. Image.

23. Lovins, Amory B., Diana Ürge-Vorsatz, Luis Mundaca, Daniel M Kammen & Jacob W Glassman. 2019. "Recalibrating climate prospects". *Environ. Res. Lett*. 14, 120201. doi:10.1088/1748-9326/ab55ab.

24. Electric Power Research Institute. 2014. "The Integrated Grid: Realizing The Full Value Of Central And Distributed Energy Resources". Palo Alto, CA: Electric Power Research Institute. https://www.epri.com/research/products/000000003002002733.;

Taft, JD, and A Becker-Dippman. 2015. "Grid Architecture". Prepared For The U.S. Department Of Energy. Richland, WA: Pacific Northwest National Laboratory. https://gridarchitecture.pnnl.gov/media/white-papers/Grid%20Architecture%20%20-%20DOE%20QER.pdf.

25. United States Department of Energy Office of Electric Transmission and Distribution. 2003. "'Grid 2030': A National Vision For Electricity's Second 100 Years". Washington D.C.: U.S. Department of Energy.

26. Wang, P., L. Goel, X. Liu, and F. H. Choo. 2013. "Harmonizing AC And DC: A Hybrid AC/DC Future Grid Solution". *IEEE Power And Energy Magazine* 11 (3): 76-83. doi:10.1109/mpe.2013.2245587.

27. Dehghanian, Payman. 2017. "Power System Topology Control For Enhanced Resilience Of Smart Electricity Grids". Doctor of Philosophy, Texas A&M University.

28. Deka, Deepjyoti, Scott Backhaus, and Michael Chertkov. 2016. "Learning Topology Of The Power Distribution Grid With And Without Missing Data". In *2016 European Control Conference (ECC), Aalborg*, 2016, 313-320. http://10.1109/ECC.2016.7810304.

29. Kassakian, J.G., R. Schmalensee, G. Desgroseilliers, T.D. Heidel, K. Afridi, A.M. Farid, J.M. Grochow, W.W. Hogan, H.D. Jacoby, J.L. Kirtley, H.G. Michaels, I. Perez-Arriaga, D.J. Perreault, N.L. Rose, G.L. Wilson. 2011. *The Future of the Electric Grid: An Interdisciplinary MIT Study*. Boston, MA: Massachusetts Institute of Technology, MIT Energy Initiative. http://energy.mit.edu/wp-content/uploads/2011/12/MITEI-The-Future-of-the-Electric-Grid.pdf.

30. *Climate Change 2007 - Mitigation Of Climate Change: Working Group III Contribution To The Fourth Assessment Report Of The IPCC*. 2007. Cambridge University Press.

29. Wang, Seaver. 2020. "We Need To Plan Ahead For The Narwhal Slope". *The Breakthrough Institute*. https://thebreakthrough.org/issues/energy/narwhal-slope.

31. Wagner, Gernot, Tomas Kåberger, Susanna Olai, Michael Oppenheimer, Katherine Rittenhouse, and Thomas Sterner. 2015. "Energy Policy: Push Renewables To Spur Carbon Pricing". *Nature* 525 (7567): 27-29. doi:10.1038/525027a.

32. McConnell, Virginia, and Benjamin Leard. 2019. "The California ZEV Program: A Long And Bumpy Road, But Finally Some Success". *Resources*, December 2, 2019. https://www.resourcesmag.org/common-resources/california-zev-program-long-and-bumpy-road-finally-some-success/.

33. Gallagher, Kelly Sims, and Laura Diaz Anadon. 2020. *DOE Budget Authority for Energy Research, Development, and Demonstration Database*. Medford, MA: Fletcher School of Law and Diplomacy, Tufts University; Cambridge, England: Department of Land Economy, Center for Environment, Energy and Natural Resource Governance (C-EENRG), University of Cambridge; Cambridge, MA: Belfer Center for Science and International Affairs, Harvard Kennedy School. https://www.belfercenter.org/publication/database-us-department-energy-doe-budgets-energy-research-development-demonstration-1.

5.2 Accelerating Deep Decarbonization in the U.S. Transportation Sector

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5.2.1 Introduction, Context, and Goals

Introduction

Transportation is the largest GHG-emitting sector in the U.S., accounting for 28 percent of total emissions (See Figure 5.2.1).[1] Reducing emissions in this sector is therefore critical in order to achieve the pathways to zero carbon laid out in Chapter 2. Thus, the focus of this chapter is on-road vehicle transportation (cars, buses, trucks) and domestic aviation. These sources contribute 93 percent of transportation-sector emissions in the United States.[2] Rail (2 percent), water-borne transport (2 percent), pipeline (2 percent), and off-road vehicles (<1 percent) will be addressed lightly. International aviation and maritime will not be directly addressed, nor will upstream emissions from producing energy, manufacturing vehicles, and transportation road infrastructure. All of these additional sources of GHG emissions are important, and merit study and policy attention, but are beyond the scope of this chapter.

The most compelling strategy for deep GHG emissions reductions, elaborated upon in this chapter, is to electrify surface vehicles: to switch vehicles from fossil fuel combustion (e.g., gasoline and diesel) to electric propulsion (e.g., battery, plug-in hybrid, and fuel cell electric vehicles). California has set aggressive sales targets for zero-emission vehicles, including a new executive order on September 23, 2020 to reach 100 percent of light-duty sales by 2035, along with a recent rule requiring up to 75 percent of truck sales by that date. The cost of transitioning to electric propulsion is not expected to be great. A comparison of recent studies of a rapid transition to an electric-vehicle dominated car and truck system in California estimated $7 billion between 2020 and 2030 in additional cost for vehicles, energy systems, and refueling/recharging infrastructure due to declining costs.[3] This equates to less than 1 percent of the costs residents of the state would otherwise be paying over those years for gasoline and diesel vehicles and fuels. Approximately after 2030, with this rapid transition, there would be no additional costs. Indeed, the savings to consumers would steadily increase—on a total cost of ownership basis—as a result of the lower energy and maintenance costs more than offsetting the higher (but diminishing) purchase cost of the vehicles. With this affordability in mind, in the near term, policies are needed to accelerate fuel efficiency in the gasoline and diesel fleets. Parallel and increasingly important is to accompany vehicle electrification strategies with policies to expand the production of low-carbon hydrogen and sustainable, low-carbon biofuels.

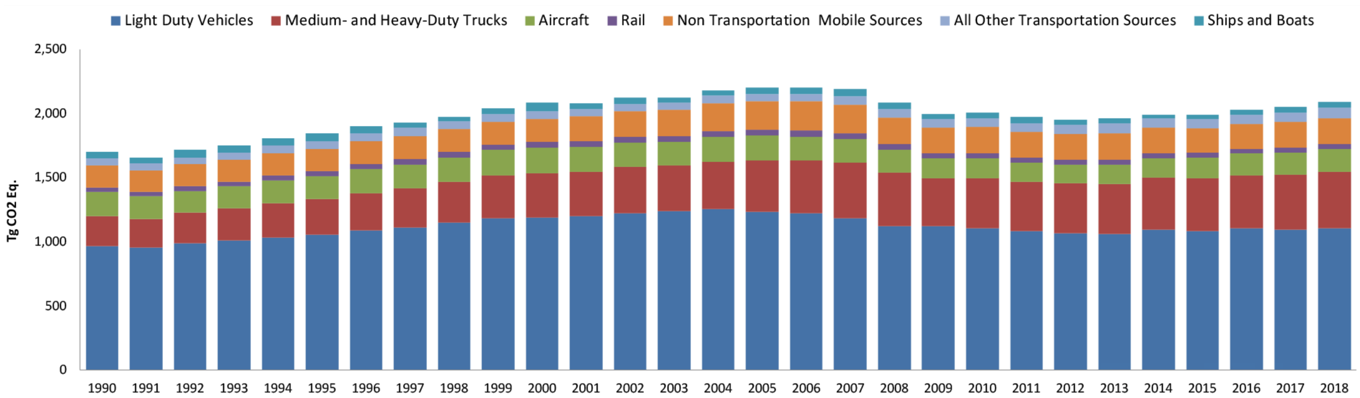

Figure 5.2.1. Change in GHG emissions by source: 1990-2018 (U.S. EPA, 2015).

The second most compelling strategy is reduction in vehicle use—while enhancing accessibility to health, education, jobs, and other services for the mobility disadvantaged. In recent years, vehicle use per capita has been increasing—heightening the need to address vehicle use. Even if most vehicles were powered by electricity and renewable hydrogen, significant GHG emissions would be emitted in vehicle manufacturing and building and maintaining roads. The justification for reducing vehicle use is heightened by the large economic, health, land use, and social equity co-benefits. Strong policies and strategies are needed to alter the travel behavior of Americans; most, but not all of these policies are the prerogative of state, regional, and local governments. The Federal Government does retain a very important role, though. Through legislation and funding, it can empower and support state and local efforts to reduce single-occupant vehicle use and increase the use of less carbon-intense mobility. Federal and state policies can award more funding for low-carbon infrastructure, low-carbon modes of travel, pooled and shared private mobility services, and alter fuel and vehicle taxation practices. These federal policies could assure that most automated vehicles in urban areas are used to carry multiple riders (not zero or one occupants), impose pricing on interstate highways to favor pooled (and electric) vehicles, and support local governments adopting zero-emission zones. A diversity of policies will be needed; the path forward will be at times uneven due to the dramatic variation across states and urban, suburban, and rural communities.

What this chapter does not address is: 1) upstream emissions for producing vehicle energy (e.g., in oil refineries, electricity generation facilities, bio-refineries, and hydrogen production plants); and 2) manufacturing of vehicles and batteries, and manufacturing and building infrastructure, including roads, ports, and other terminals.[4] These manufacturing and upstream emissions are considerable; with today's gasoline cars, manufacturing emissions are less than 10 percent of total emissions, but for battery electric vehicles they account for about 40 percent of total emissions (in part because there are no tailpipe emissions and upstream emissions are relatively small), and could amount to as much as two-thirds of a future battery electric vehicle (BEV) operated on a primarily renewable grid.[5] Upstream emissions of oil production amount to another 20 percent (and increasing) of vehicle energy use, and emissions associated with the manufacture of cement and concrete for roads adding another few percent. Both direct energy emissions as well as upstream and manufacturing emissions would be reduced if the carbon intensity of electricity were lowered, a necessary change detailed in the first section of this chapter.

In summary, the potential for large reductions in transportation emissions is achievable, but a diverse mix of strategies and policies will be needed. The most effective approach, given political realities, is a suite of policy instruments that address the production and use of vehicles and fuels, while providing enhanced mobility and accessibility to disadvantaged travelers. In other words, we must address the sale and use of the vast array of bicycles, scooters, cars, trucks, buses, ships, trains and planes, and reduce the carbon footprint of the energy and fuels that power them. A simple carbon tax could be effective, but most research suggests that to be successful it would need to be far higher than taxpayers and consumers would accept in order to accomplish significant emissions reduction.[6] The behavior of a vast array of travelers, companies, and governments must be altered to achieve deep carbon reductions—which requires a diverse mix of regulations, investments, incentives, and education.

We organize this chapter as follows: the social, economic, and equity implications of transportation investments and policy; overarching scenarios of deep decarbonization; and then strategies and policies to reduce car and truck use, the carbon intensity of car and truck technology, and jet travel, followed by conclusions and recommendations.

Societal Context and Goals

The U.S. transportation system is vital to the national economy and has major impacts on equity, access to jobs and services, and public health. In addition to travel by individuals, the U.S. transports a daily average of over $50 billion in freight.[7] Across all levels of government, the U.S. spends approximately $300 billion annually on transportation infrastructure; still, major investments are needed to repair, maintain, and improve our network of transit, roads, waterways, rail, and aviation systems.[8]

Transportation emissions have been relatively flat in the past 15 years, the result of small reductions in emissions per vehicle (cars and trucks), largely offset by small increases in car and truck use (measured as vehicle miles traveled (VMT)). Total aviation emissions have increased slightly, with substantial increases in passenger airplane travel somewhat mitigated by small continuing improvements in aircraft efficiency as well as operational savings due to routing, take-offs, landings, and ground operations (see Figure 5.2.1). Deep decarbonization will therefore have an enormous impact, and will require reprioritizing transportation infrastructure investments to facilitate low-carbon mobility while growing jobs and our economy.

The transportation system is also a major contributor to air pollution, which impacts public health. Policies to reduce transportation emissions that contribute to air pollution are largely under the jurisdiction of federal and state governments. As authorized by the Air Quality Act of 1967, the precursor to the Clean Air Act of 1970, car and truck emissions are regulated by the US Environmental Protection Agency, with California allowed to set its own standards, including zero emission requirements, as long as they are more stringent. A later amendment to the Clean Air Act (1977) allowed other states to follow either the California or U.S. standards, although the Trump Administration's 2019 attempt to withdraw California's waiver, granting it authority to regulate GHGs, is being litigated. As of 2020, 9 other states have adopted California's zero emission vehicle requirements and 13 states have adopted California's GHG vehicle emission standards. These states, representing 30-40 percent of total light duty vehicle sales, accelerate emissions reduction, as well as the development and commercialization of advanced technology.

With the transportation sector's vast reach and impact, it is critical as we plan and implement pathways for deep decarbonization that we take the social and economic impacts of our regulatory policies into account such that transportation infrastructure investments maximize opportunities for co-benefits that are equitably shared.

Economic Impact

The policies and investments described in this chapter are expected to come at a relatively small net monetary cost to society and can be designed to have a minimal net fiscal impact.[9] Considerable additional resources will be needed during the early years of the transition to accelerate the introduction of low and zero-carbon vehicles and fuels. But most or perhaps all of these additional costs need not come from taxpayers. They can come as transfers between industries and companies, as in California where Chrysler buys zero emission vehicle credits from Tesla, and Chevron buys low-carbon fuel standard credits from electric utilities. Moreover, revenue generated from carbon pricing programs, such as carbon cap-and-trade, and fuel use fees, can be used to incentivize low-carbon transportation investments. Carbon pricing policies that have generated significant proceeds for low-carbon investments include California's cap-and-trade program, which has generated over $11 billion in auction proceeds over the past decade for various clean transportation programs.[10] In addition to direct carbon pricing and investment, other means of incentivizing electric vehicles include revenue neutral fee-bate programs, where high-carbon and less efficient vehicles pay a fee based on their emissions, and low-carbon vehicles (especially ZEVs) receive a rebate.

The likelihood of electric vehicles eventually costing little or nothing additional to society is dependent on the continued drop in the cost of batteries and electric vehicles. In 2010, batteries cost around $1,000/kWh. Now, they are estimated to be around $150/kWh and are projected to drop below $100/kWh by 2025 or sooner.[11] With vehicle prices dropping and significantly lower operating costs, breakeven purchase prices compared to internal combustion engines (ICE) could be achieved before 2025 for many light duty vehicles.

There are significant opportunities to expand domestic clean transportation manufacturing and technology production throughout the supply chain for vehicles and batteries, which can create significant job growth and economic activity. In assessing the economic impact of decarbonization pathways, it is important to also consider the indirect economic benefits of policies such as smart growth and sustainable community planning—for example, transit investment and transit-oriented development patterns. These indirect economic benefits can increase incomes and housing values in local communities.

A key consideration is how the costs and the benefits of the policies impact different groups of people—including between households of different income levels, social and racial demographics, geographies, and place types. Transportation policies and investments should be designed to account for these differences and enhance equity.

Equity and Public Health

An equitable transportation decarbonization pathway addresses the needs of individuals in communities underserved by the transportation system, as well as those overburdened by transportation pollution.

Decarbonization policies can lead to major improvements in public health through the reduction of co-pollutant emissions and the resulting air quality improvements. The transportation sector is responsible for over 50 percent of emissions from nitrogen oxides and a significant contributor of particulate matter and volatile organic compounds emissions, contributors to smog, respiratory ailments, cancer, and other health impacts.[12] The transition to zero-emission vehicles provides a critical opportunity to reduce these tailpipe pollutants. There are particularly impactful opportunities to reduce harmful air pollution through the electrification of medium- and heavy-duty vehicles, including urban delivery trucks, transit fleets, school buses, and port equipment.

Air pollution from transportation sources is concentrated in low-income communities and communities of color, often as a result of historical inequities and policy decisions, such as the siting of highways, ports, industrial facilities, airports, and bus depots. A just and equitable transportation decarbonization pathway will prioritize investments in these overburdened communities. National policies can build from state climate programs and frontline community leadership, such as enacted climate legislation in both California and New York that requires investments that benefit disadvantaged communities. In addition to requiring investment to benefit designated communities, each of these legislative frameworks prioritizes community engagement to inform and direct investments in zero emission transportation programs that best meet the needs of local populations.

Through strategic use of policy, low-income and other mobility-disadvantaged travelers can see significant improvements via expanded public transportation, more and cheaper pooled transportation network companies (TNC), and more and safer micro mobility options, such as shared bicycle and scooter services. It is important for decarbonization strategies to balance VMT reduction goals with the need to increase mobility and access for individuals and communities, including physically disadvantaged and elderly populations. Rethinking transportation planning to prioritize access to jobs and services (rather than speed of travel or other metrics) can create major decarbonization co-benefits.

The transportation decarbonization pathway must also include low-carbon mobility opportunities for rural communities, including car-dependent low-income populations and an aging population. An increased variety of zero-emission vehicle offerings, including light-trucks and SUVs and models with longer range batteries, will have a significant impact. In addition to personal vehicle transportation, rural microtransit services, inter-city public transit route expansion, and increased availability of rural broadband internet and cellular data to promote telecommuting and telemedicine can provide additional benefits to rural populations and reduce the need to travel longer distances to obtain services.

COVID-19 response

In the era of COVID-19, investments in infrastructure, such as broadband, enable more access to services and economic activity through telecommunications. Transportation has been significantly affected by the pandemic, including dramatic decreases in public transit use and increases in telework. It remains to be seen how long-lasting these impacts will be. Transportation policymakers should design policies accordingly to enable continued access to jobs, healthcare, education, social interactions, and other critical services during and beyond the pandemic.

COVID-19 has also brought increased attention to the impact of air pollution on cardiovascular and respiratory illness, including the racial and socio-economic disparities in how the pandemic is affecting communities and individuals across the U.S. A low-carbon transportation future can have the important co-benefit of reducing air pollution, which exacerbates risk.

Additionally, as we consider economic recovery and stimulus opportunities in the face of a recession and significant job losses, the nation should resist repeating the pattern where we expand capacity on our existing car-dependent system. The decarbonization pathway should include opportunities for investments in low-carbon transportation systems to stimulate job creation and economic development and provide alternative transportation options. These could include investments to enable smart growth, such as redevelopment in urban centers and mixed-use development in suburban settings; EV fast charging along highway corridors; expanded transit systems in high volume corridors; and rural broadband infrastructure. Low-carbon investments, such as upgraded transit systems, are often found to be more effective at long-term job creation and economic stimulus than traditional highway infrastructure projects.[13]

5.2.2 Scenarios and Overall Decarbonization Strategies

Transportation can contribute to deep CO2 reductions in the 2050 time frame through a number of different decarbonization pathways. While achieving an 80 percent reduction in CO2 between 1990 and 2050 has been a common target, here we focus on achieving net-zero emissions (excluding manufacturing and upstream energy emissions) within the transportation sector by 2050 (see Figure 5.2.2) based on Chapter 2. We consider the business-as-usual or *reference scenario* compared to the low-carbon *central scenario* with the results demonstrated in Table 5.2.1.[14] These cases assume that the COVID-19 pandemic does not have any lingering effects beyond 2025.

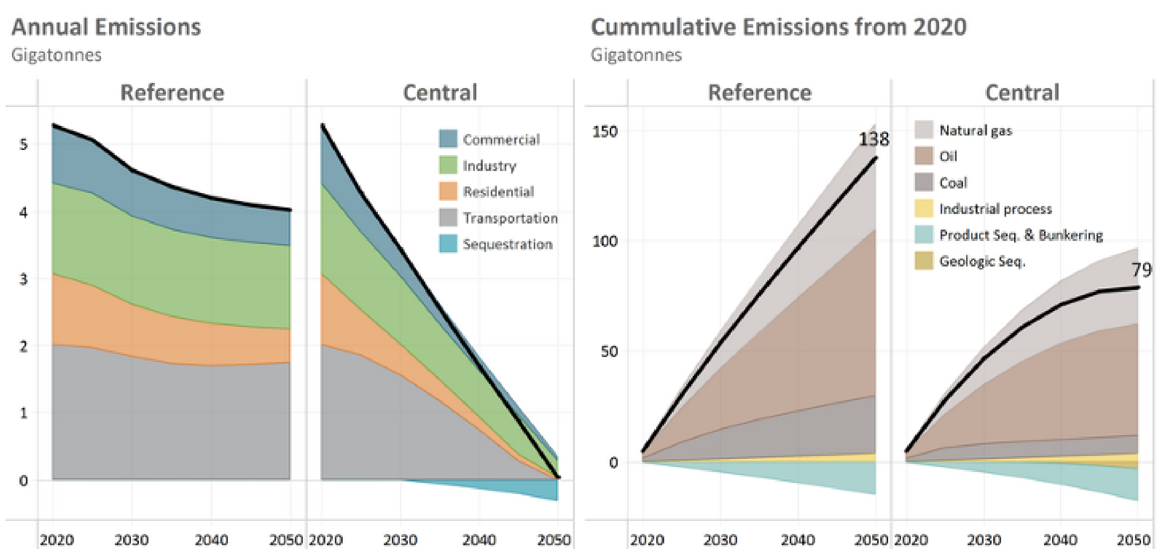

Figure 5.2.2. Emissions from industries across scenarios (Chapter 2).

Table 5.2.1: Assumptions and trends for low-carbon vehicles and fuels by scenario

		Reference Scenario			Central Scenario		
		2030	2040	2050	2030	2040	2050
Zero-emission sales shares	Light-duty Vehicles	10%	15%	20%	50% of sales	100% of sales	100%
	Medium-duty Vehicles	0	0	0	40% of sales	>80% of sales	100%
	Heavy-duty Vehicles	0	0	0	30% of sales	>60% of sales	100%
Zero-emission vehicle stocks	Light Duty Electric Vehicle Stock	5 Million	10 Million	24 Million	>15% of light-duty vehicles are battery electric	>65% are battery electric	95%
Low-carbon fuel share (e.g. advanced biofuels) for ICE vehicles		5%	5%	5%	5%	15%	100%

BAU Reference Scenario

We begin by considering a baseline or *reference scenario*, reflecting current trends and policies, but no new actions to lower CO_2 emissions further into the future. The penetration of low-carbon vehicles and fuels out to 2050 is small in this scenario. The policies undertaken to date spur some uptake but not enough to shift the energy use or CO_2 picture significantly.

Central Scenario

Based on the Chapter 2 model, we consider a low-carbon *central scenario* of near-100 percent reduction in domestic transportation GHG emissions by 2050 there is a strong uptake of zero emission light-duty vehicles with a somewhat slower, but still very ambitious, adoption of zero emission vehicles in the trucking sector. Furthermore, there is a reduction in passenger light-duty vehicle travel relative to the “reference” case. This is achieved from a mix of incentives and disincentives and shifts in transportation funding, resulting in more intensive use of existing modes (mostly light duty vehicles) and some shifting to other modes. We do not do a detailed tracking of these changes in travel but assume a net reduction of 15 percent.

There is an increase in the use of biofuels to replace liquid fossil fuels with advancements in the growth of all biofuels which are to be cellulosic-based, and some algae-based, post-2030. Some electrofuels could also be used. In any case, these fuels would need to provide at least 80 percent well-to-wheels (life cycle) GHG reductions relative to gasoline or diesel fuel. By 2050, transportation-focused fuels such as gasoline and diesel are shown to be largely derived from biomass and (especially) hydrogen conversion in most scenarios apart from the reference. Hydrogen itself is derived from electrolysis and biomass in varying shares depending on the scenario.

The impact of the electric vehicles on grid electricity demand in the *central scenario* is about a 20 percent increase to electricity demand above what would otherwise occur in 2050. There are also liquid and gaseous fuels derived from electricity and used by the remaining internal combustion engine vehicles that add to electric demand. The final energy use in transportation in the *central scenario* is shown in Figure 5.2.3. Energy use drops by more than half to 2050, and electricity accounts for more than half of the energy in that year. Nearly all gasoline has been eliminated and diesel fuel use has been cut by about half.

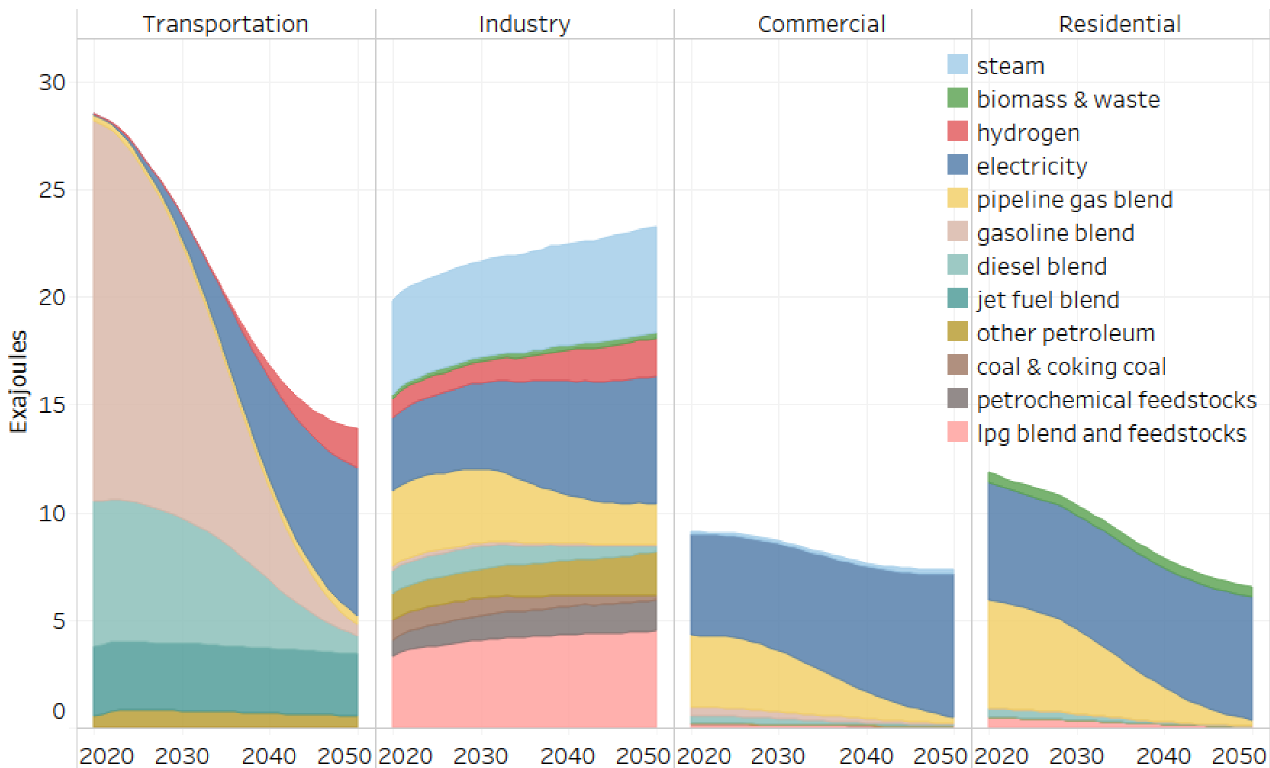

Figure 5.2.3. Final Energy use by sector in the *central scenario*. (Chapter 2)

It may be possible to hit our overall energy and CO_2 targets for 2050 with slower rates of change than shown in this central case, especially in the early years. For example, a 50 percent sales target for light-duty zero-emission vehicles in 2030 may be very challenging to achieve. A lower target such as 30 percent may be reasonable, as long as it is part of a trajectory to approach 100 percent shares by 2040.

5.2.3 Reducing Passenger Travel

Vehicle technology improvements, especially electrification, will dramatically reduce emissions (especially as renewable energy is used for electricity generation and hydrogen production), but substantial emissions will remain from vehicle manufacturing and upstream energy production. Reductions in the amount of vehicle-travel are central to meet GHG reduction goals. This is measured by VMT, representing how far each vehicle travels during a given time-period (e.g., a year). We posit a VMT reduction goal of 25 percent per capita by 2050.

Numerous policies can be enacted to reduce the use of single-occupant vehicles while simultaneously providing additional benefits to communities, including reduction in vehicle crashes, traffic noise, and criteria pollutants, while improving the livability of communities and improving accessibility to opportunities for all, especially disadvantaged communities. Different approaches are needed for different trip purposes and across urban, suburban, exurban, and rural areas.

VMT reductions will be challenging, but are key to achieving deep GHG reductions in transportation. These reductions can be achieved by 1) increasing the occupancy of passenger vehicles, 2) switching to low-carbon modes including active transportation, and 3) replacing trips with telecommunications. Many of these VMT-reducing strategies and policies are under the jurisdiction of local governments, but there is also an important role for the Federal Government, as we highlight in this section.

In urban and some suburban areas, conventional bus and rail transit are compelling solutions if used intensively. They provide an alternative to driving and allow commuters to avoid traffic congestion, improve the economic productivity of transport infrastructure, and provide an important public service by providing access to those who are physically impaired and economically disadvantaged. Public transit accounts for a steadily dwindling share of passenger travel outside of major metropolitan areas. On average today's buses have about the same GHG emissions per passenger mile as cars and light trucks, highlighting the need to fill these vehicles top capacity with passengers, electrify these modes, or convert to less carbon-intensive fuels.

A principal strategy, to reduce VMT and GHG emissions while enhancing the public service benefits of conventional transit, is to focus buses (including Bus Rapid Transit) and rail lines on dense routes and urban centers—and increase their utilization. Land use changes are key to enhancing the economic and environmental performance of transit. Transit performs better when cities focus development around transit stations, increasing utilization and load factors. Various policies can encourage more compact, walkable, and transit-oriented development. These include easing local zoning regulations that restrict denser development and increasing incentives for retail and dense residential development near stations, and creating a more walkable environment so that more people can easily access bus and rail service. As part of any new or expanded transit project, funding incentives should be provided for municipalities to restructure their zoning to allow mixed use and transit-oriented development.

Making streets safer for pedestrians and cyclists will result in a reduction in motorized VMT and GHG emissions, by replacing vehicle trips and providing a feeder service to transit. Funding is clearly an issue, but investments and actions are also frequently hindered by local regulations. For example, even when communities desire safer streets, state Department of Transportations (DOTs) may require expensive studies that only examine the consequences on vehicular traffic flow. Any reduction in the automotive level-of-service may be a roadblock to making a street safer for all users. Relaxing or replacing this arcane but influential policy is important.

Perhaps the most important overarching strategy to reduce VMT is to expand mobility choices. New mobility options include bikeshare, e-bikes, e-scooters, demand-responsive transit (referred to as microtransit), and pooled ride-hailing (especially if automated). More choice means people are not dependent on their personal vehicles, encouraging them to own fewer cars. The result is greater use of low-carbon modes, less cost, more healthy living, less VMT, and less GHG emissions. In urban areas, this less car-centric transportation system provides higher quality service—less time and effort caring for vehicles, fewer parking hassles, and more free time as a result of being "chauffeured."

Federal funding for bicycle, e-bicycle, and e-scooter lanes can lead to safer streets and increased use. These new technologies can also help to extend the reach of existing transit systems, making them more attractive, more efficient, and more equitable, and reduce carbon emissions.[15]

State and local governments make decisions on providing safe infrastructure but this can also be enabled by dedicated federal funding, such as through the Transportation Alternative set-aside program enabled under the Fixing America's Surface Transportation (FAST) Act. Currently some states shift this money to traditional projects; this flexibility should be eliminated and the total funding available should be increased significantly.

Ride-hailing services, including companies such as Uber and Lyft and micro-transit providers such as Via, offer a new mobility option for many travelers. These provide a convenient door-to-door travel option for many trips; they are essentially a cheaper, more convenient taxi. They can serve as a complement to existing high-speed transit services by providing last-mile access and egress, and to replace low quality bus service in suburbs and small cities. In these settings, these services may be less expensive than conventional bus service and can provide higher quality service. A compelling strategy, for transit operators, ride-hailing companies, and travelers, is for these ride-hailing companies to partner with existing transit providers to provide affordable service in suburban, exurban, and rural areas, improving mobility and allowing transit agencies to invest in areas in need of higher capacity and more frequent service.

The promise of vehicle automation could provide greater mobility for many more people. While there was considerable buzz over the last half decade for automated vehicles, automotive and technology companies continue to invest in advancing the technology. It is widely believed that the first lucrative (on-road) application will be food delivery and automated taxis, sometimes referred to as robo-taxis. These robo-taxi services are still under development and while their debut is just beginning (Waymo began operating a sparse commercial service in Arizona in 2019) they build on a strategy of expanded choice; and if shared rides are common could lead to large reductions in VMT.

Another potentially important strategy for reducing VMT is the use of telecommunications to replace travel for work commutes, health services, long distance business trips, shopping and some social interactions. A substantial fraction of jobs can be performed from home, even if only on some days of the week. COVID-19 is demonstrating the feasibility and constraints of a home workforce. One of the constraints is inadequate broadband and hardware; policy can be aimed at increasing broadband connections and subsidizing hardware for homeworkers. Funding can be aimed at subsidizing broadband, especially in rural areas that may have inadequate coverage. Employer tax-credits for providing hardware to employees should be provided.

Likewise, online shopping has surged due to COVID-19, and can be more efficient than having people drive to shops. This trend can be facilitated by increased broadband. One downside is reducing the viability of small-scale retail which is one component of a mixed-use neighborhood and transit-oriented development. These developments already have difficulty attracting a good mix of retail (partly due to competition from big-box stores but also from online retailers). Smaller scale retail in a mixed-use setting allows customers to walk or cycle to the store, or to drive shorter distances. One potential opportunity is to leverage online shopping by converting retail space to centralized delivery locations for customers to pick up products. This could increase the efficiency of online deliveries while maintaining mixed-use and transit-oriented developments.

The Federal Government can play an instrumental role in reducing VMT and GHG emissions, while improving accessibility. Financial actions include altering the distribution of funds from the transportation trust fund and empowering and facilitating local and state actions. Most important is to shift funds, including those in stimulus packages, away from new highway capacity and lane expansions to support transit in dense areas, public-private partnerships between transit operators and ride-hailing providers, bicycle, pedestrian and e-scooter infrastructure, and transit-oriented development. The key mechanism for doing so is to link federal and state transportation funding to per capita VMT reductions. In this way, federal policy can be redesigned to encourage better planning at the local level—by providing funding and incentives to reduce VMT, support walkable and safer streets, and providing residents with alternative modes to avoid driving.

Individually, many of these initiatives would result in small reductions in VMT and GHG. Collectively, they can add up to substantial per capita reductions in VMT and also result in substantial co-benefits of increased accessibility for mobility disadvantaged travelers, reductions in traffic crashes and fatalities, improved air quality, increased walking and physical activity, and an overall better quality of life. It could also result in less costly infrastructure and a more efficient overall transportation system.

5.2.4 Light Duty Vehicle Technology

The overall strategy for decarbonizing light-duty vehicles (LDVs) is quite straightforward: electrify them all and use clean sources of power generation. Electric drivetrain vehicles (EVs), including battery electric, plug-in hybrid, and fuel cell vehicles, all offer large reductions in emissions with today's grid as well as a pathway to net-zero as electricity is further decarbonized. Improved efficiency can reduce emissions, but in and of itself does not offer a pathway to net-zero given the overall constrained supply of low-carbon liquid fuels—in short, fossil-fuel powered vehicles are a technological dead end.

Full electrification of the LDV fleet is therefore both necessary and sufficient to decarbonize this subsector. Getting more specific on how to execute this overall strategy reveals much more complexity and several challenges to deployment. Economics, range and charging, model availability, awareness and attitudes, and lifecycle emissions will all need to be taken into account in developing a comprehensive and effective policy strategy. Because most of the deployment so far has been of plug-in vehicles rather than fuel cells, most of this strategy focuses on these vehicles.

To accelerate the transition to EVs, supportive policy is needed. The first challenge is economics. EVs are currently more expensive to buy than gasoline and diesel vehicles, due mainly to battery costs.[16] However the mean price differential between electric and conventional cars has decreased dramatically in recent years. This is because costs for batteries have dropped by more than 80 percent since 2010. Still EV driving range (and battery size) has grown, the purchase price of EVs has remained higher than conventional vehicles. But within a few years, the total cost of ownership for an EV over its life will tend to become lower than for a conventional vehicle because maintenance is less, due to fewer moving parts, and electricity is generally less costly than the gasoline it replaces. While there were early concerns that batteries would require regular replacement, modern batteries in most applications seem to perform well for over 100,000 miles, with further advances suggesting even longer lives.

While EVs will soon be cost competitive in total costs, the reality is that consumers tend to weigh the initial purchase price of the vehicle more heavily than future maintenance and energy cost savings and thus incentives will be needed for some time, though the need for policy intervention should diminish over time as battery costs continue to drop.

A second challenge is range and charging time. Here is a tradeoff between cost and range, because the simplest way to extend the range of the vehicle is to add a bigger (and therefore more expensive) battery. Ranges of available EVs have increased steadily, with all new models having more than 200 miles of range and some market leaders having more than 400 miles on a single charge. While this is sufficient range for the vast majority of daily travel—since the average car travel per day is less than 40 miles—consumers often consider their most unusual use case when buying a vehicle and so expect a vehicle with long range, fast charging, or a combination of both.[17] This range anxiety issue is addressed in part by providing more fast chargers.

A third challenge is availability of a diverse set of vehicle models. Consumers have come to expect a wide variety of vehicle sizes, shapes and performance, including number of seats, cargo capacity, 4-wheel drive, and power. They want compact or large sedans, small or large pickups with perhaps two rows of seats, minivans with more seats and doors, and SUVs of various shapes and sizes, with different expectations of power, luxury, and style. Over time, a greater variety of EVs will be made available, but for many years, the choice will be much more limited than for conventional vehicles.

A fourth challenge is awareness and perception. Even as sales have increased and a greater diversity of models have become available, general awareness of EVs remains low.[18] Most Americans cannot name a single EV even though more than 50 are now available for sale. Car dealerships often have little to no experience with EVs, and studies of dealers show that many dealers attempt to dissuade potential EV buyers and sell them a conventional vehicle instead. There are also groups of potential buyers who have negative attitudes towards EVs, which may prove challenging to change. On the other hand, people with familiarity with EVs—those who own or have driven them—tend to have positive impressions.

Fifth is social equity and justice. Low income communities, often suffering higher levels of pollution, would benefit from EVs. However, early adopters of EVs have been wealthier, and have benefited from the zero or low emissions of EVs. This pattern is reinforced by more affluent people tending to live in single-family homes where they can easily install home chargers, whereas lower income residents tend to live in multi-family housing and use off-street parking, where charging is more difficult. Public policy should encourage increasing equity in EV ownership as a key goal.

One fact, sometimes questioned, is the net GHG impact of electric vehicles. In virtually all circumstances for all EVs, the lifecycle emissions of EVs, including manufacturing, charging, and disposal, will be significantly less than for conventional vehicles.[19] As electricity generation and industrial processes transition to lower emissions, the gap will grow. Setting policies with the lifecycle in mind can accelerate the greening of electric vehicles.

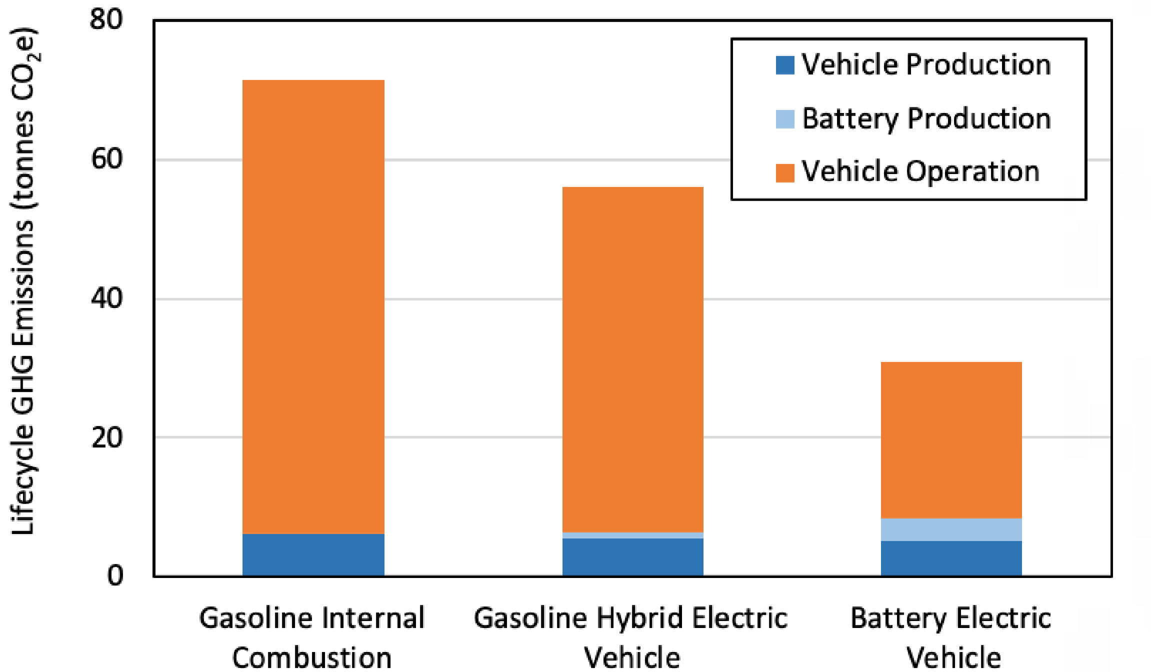

Figure 5.2.4. Life cycle GHG emissions from vehicle production and operation (Kendall et al., 2019). While many factors affect the relative emissions of battery vs. conventional vehicles, under current real world conditions, EVs are much lower emissions. These emissions will decrease as the grid and industrial emissions are reduced.

Policies

While EVs are environmentally superior, and will soon be economically superior, EV market shares will be limited unless the challenges above are addressed. The key elements of policy should include 1) long-term binding rules requiring or motivating automakers to electrify their vehicles; 2) incentives for buyers in the near- and mid-term that improve equity; 3) public investment in charging infrastructure, with a focus on multi-family dwellings and public charging; 4) increased outreach, education, and engagement; and 5) local leadership by cities and regions in support of these aforementioned policies.

EV sales mandates are the single most important policy for decarbonizing transportation. California and nine additional states have a ZEV mandate, which requires automakers to sell an increasing portion of EVs. This mechanism provides a long-term policy signal to manufacturers that they will need to invest in EV development to be competitive in these markets. It also sends a transparent, unequivocal signal to the entire ecosystem of organizations and companies that need to support this transition, including automotive suppliers, dealers, charging companies, electric utilities, public utility commissions, local governments, employers, and more. The current version of the ZEV mandate, adopted by the 10 states, is expected to lead to approximately 10 percent of sales of LDVs in those states being electric by 2025.[20] The mandate will need to be sharply ratcheted up after 2025 if there is to be any hope of deep decarbonization of transportation in the next few decades.

A complementary policy will be the use of greenhouse gas and/or fuel economy performance standards for new vehicles. To accelerate on-going improvements in gasoline and diesel vehicles, these standards will need to be tightened at least 5 percent per year in MPG terms. If tightened even faster, as is happening in Europe, a ZEV mandate might not be needed, since automakers would accelerate their commitment to EVs as a way of meeting these fuel economy/CO_2 performance standards. One advantage of standards is that they could in principle be developed to account for the full lifecycle of the vehicle, encouraging more efficient manufacturing and reuse or recycling as a component of compliance.

Mandates, standards, or a combination should be affirmed in statute to provide policy certainty to automakers. The fact that all other major car markets in the world—China, Europe, Japan, and Korea—have adopted aggressive vehicle fuel economy and electrification policies provides additional market and policy certainty to automakers.

Clean vehicle purchase incentives are a second complementary policy. Incentives are needed to overcome the higher purchase price of EVs in the near term, and the continuing reluctance and resistance of consumers, which may persist for many years, perhaps decades. These incentives could be in the form of rebates, feebates (a revenue-neutral rebate for EVs paid for by a fee on high GHG emitting vehicles), tax credits, or reduced registration fees. In the U.S., many states have had incentives for purchasers of EVs, in addition to the federal tax credit of up to $7,500. Many European countries are providing even larger incentives. Such incentives are highly influential in purchase decisions.[21] Incentives for new vehicles should be limited to either lower income households or subject to a vehicle price cap. High income buyers are less influenced by incentives; these restrictions are effective at improving the equity effects of incentives. Since about two-thirds of all vehicle purchases are used vehicles, usually by lower income households, opportunities to apply incentives to used vehicles should be given high priority.

The costs of funding vehicle purchase incentives need not be imposed on taxpayers. Since subsidies will continue to be needed as the market expands, expanding the magnitude of needed incentives, revenue source creativity is a necessity. For instance, rebates can be included as part of feebate programs, whereby fees would be placed on purchases of bigger, higher fuel-use, and more expensive vehicles. Relatively small fees on these vehicles could, in aggregate, pay for fairly large rebates, at least until the clean vehicle market grows to a sizable share of the total new vehicle market. These feebates can be based on sales taxes or registration fees. Another mechanism is to use revenues from carbon taxes or cap and trade programs to pay for incentives. And still another non-taxpayer mechanism is to package credits generated from sales of electricity to households within a transportation low-carbon fuel standard (LCFS) program, as California is doing. In this case, oil companies are buying credits from electric utilities, in effect creating a subsidy from the oil industry for electric vehicles.

Charging and hydrogen infrastructure support is a third complementary policy. The vast majority of EV charging today occurs at home and at work. Public charging is still important, however, in enabling long-distance trips, providing an occasional emergency charge, and increasing consumer confidence. Public charging will be a mix of medium-power 'level 2 charging', well-suited to situations where vehicles are stationary for extended times, such as at workplaces, shopping malls, overnight at multi-family dwellings. There is no widely accepted single method for estimating the number of needed chargers for a fleet of EVs. EV infrastructure demand depends heavily on the specific geography, fleet mix, and vehicle-use patterns of the scenario in question.

However, one recent analysis from the National Renewable Energy Laboratory (NREL) –based on another NREL report by Wood (2017) –suggests that "on average 0.57 DCFC stations (and 1.85 plugs) and 40 non-residential L2 plugs per thousand [plug-in electric vehicles] (PEVs) [are] needed to provide minimum coverage requirements".[22] This implies that 15,000 DCFC plugs and 320,000 L2 plugs would be needed to support a fleet of 8 million EVs by 2025 (the amount forecast by the U.S. Department of Energy's (DOE) Annual Energy Outlook 2019). This represents approximately five times the number of plugs available in the United States today.

Faster charging is needed to support taxis, work vehicles, ride-hailing vehicles and long-distance trips. The revenue from electricity sales rarely covers costs, and thus support from electric utilities, employers, and others is needed. In the early years, support is also needed for hydrogen stations, until utilization of stations increases. Hydrogen stations can become profitable more quickly since the energy throughput is faster and larger.

Outreach and awareness: Private companies will, in the long run, need to advertise and sell EVs. In the early market, however, there may be a public role in increasing awareness of the benefits and availability of EVs in general. Outreach and partnership with dealers can also improve their awareness of the benefits of EVs.

Local policy: Although the focus of this is federal policy options, many local actions can support the transition to EVs. Several U.S. cities, including Austin, TX, Los Angeles, CA, and Seattle, WA have signed the "Green and Healthy Streets" declaration are moving to adopt zero emission areas, which allow access only to clean transportation modes such as walking, bicycling, transit, and EVs. Other cities and regions allow free or discounted use of priorities lanes and other forms of preferential access.

Summary Policy Recommendation for LDVs:

We recommend a foundational policy of a national LDV ZEV mandate at a minimum of 30 percent by 2030 and 100 percent by 2040. This will provide the long-term policy certainty to allow the automotive industry to invest in EV development with confidence.

This policy should be supported by a suite of other policies, including:

- Incentives as a subsidy or feebate that phases out over time, for example as EVs pass 10 percent of a particular vehicle market segment. Include an incentive for used EVs, avoiding potential for gaming the system through multiple resales.
- Increase Corporate Average Fuel Economy (CAFE)/GHG standards to keep pace with the ZEV mandate and also increase the efficiency of conventional vehicles as a transitional emissions reduction option
- Invest in charging infrastructure through federal investments
- Government fleet EV purchase requirements to demonstrate buy in

5.2.5 Medium and Heavy Duty Truck Technology

While most attention to vehicle electrification has been focused on light-duty vehicles, trucks are increasingly seen as appropriate for using the same technologies. There are many different types of trucks, notably varying in terms of overall weight, driving patterns, and daily driving distances. Given the relatively high efficiency of battery electric vehicles in an urban cycle, most medium duty urban trucks (such as delivery vans and even larger trucks up to class 6), are good candidates for electrification with savings on both operating and energy costs, and short payback times for initial higher cost vehicle investments. These higher costs are also dropping, along with the on-going reductions in battery costs, and many truck types should reach purchase cost parity with diesel trucks within the next 10 years, and have overall "total cost of operation" that is significantly lower.[23]

The bigger challenge is with very heavy (class 7 and 8) trucks, both for long haul and urban "day truck" use. These trucks would need large battery packs to move the heavy loads they typically carry (up to 30 tons of payload). Various studies suggest that it will be possible and even cost effective to run such trucks on batteries up to at least 200 miles per day, especially if their operation allows for some periods of recharge during the day.[24] The use of such trucks in long haul operation (e.g., up to 500 miles or more per day) becomes increasingly problematic without significant periods of recharge or use of ultra-fast charging, such as using one megawatt (or greater) charging power levels, which will be expensive and create energy/power issues for grid power systems. Since trucks traveling such long distances account for a high share of overall trucking fuel use, this is an important issue.

For such long haul trucks, as well as other types of vehicles with long range requirements, fuel cells are expected to be an attractive option, given their potential for much longer range driving per refueling, and much faster refueling. However these trucks are currently expensive, as is the retail cost of hydrogen (such as is used for light duty vehicles in California). It is widely estimated that the cost of fuel cell trucks will continue to decline to where, at high volumes, they will be competitive with diesel trucks in the 2030-2035 time frame; the bigger question is the cost of hydrogen. In theory, use of electrolytic hydrogen from renewable power generation could eventually provide very low production costs, with a final retail price of hydrogen dropping to as low as $5/kg, compared to typical prices of $15/kg today.

At $5/kg (about equivalent on an energy basis to $5/gallon gasoline), and with the efficiency advantage of fuel cells, fuel cost per mile could eventually be competitive with diesel or gasoline fuel. But this also is unlikely to be achieved before 2030. More RDD&D and much investment is needed to reduce the costs and improve the efficiency of fuel cells, hydrogen storage tanks, and electrolytic (green) hydrogen production—similar to what happened with batteries over the past decade. Policies that accelerate the commercialization of fuel cell vehicles will play a large role in inducing the needed investments.

Finally, an important low-carbon fuel strategy for existing gasoline and diesel trucks is advanced biofuels and synthetic liquid fuels. It is feasible that either advanced biofuels, with truly low-carbon life cycle emissions, or fuels created from electricity (via production of synthesis gases and then long-chain hydrocarbons as "drop in" fuels), can provide essentially net-zero GHG emissions operation. However, in the case of biofuels, the challenge is scaling up technologies that allow production from biomass such as grasses, other cellulosic materials, and algae, and moving away from starches and oil-seed crops that do not perform as well from either a carbon nor general environmental impact perspective.

Determining the quantities of any biofuels that can be produced sustainability is an additional challenge, suggesting that any biofuel used in transportation be allocated to their most valuable applications (including aviation).

In the case of electro fuels, a pathway from electricity to liquid fuels, building molecules with CO_2 captured from exhaust gases or the atmosphere, can provide zero emissions, but the issue is cost. Currently these technologies can cost on the order of $10/gallon or more to produce; eventually, at large scale and with learning, and done in certain locations, it is believed this cost could come down to below $5. But even then, unlike an equivalent price for hydrogen, there is no vehicle efficiency benefit from these fuels and the fuel cost would thus be significantly higher than for hydrogen.

There are a range of changes that could be considered in our freight systems that could be coupled with the technology solutions, and some that would help enable these solutions. For example, some freight truck systems could be restructured to facilitate use of (shorter range) battery-powered trucks—such as relocating distribution centers closer to final destinations, using more, smaller trucks on shorter routes, and shifting some delivery to micro-systems such as e-bikes or even drones. Achieving an overall electric urban freight system should not require trucks that can travel more than 100 miles per day, and system adjustments to allow this should be possible—the challenge as always will be to reconfigure systems in a cost-effective manner.

For long haul shipments, there is a long, on-going discussion of moving more freight to rail, where it is viable and cost effective. Rail is already a major mover of bulk raw materials around the country, though shipments of coal have declined substantially in the past 10 years, possibly increasing capacity for other goods. One challenge in the U.S. is the shift in recent years to “just in time” delivery, which reduces the attractiveness of (more circuitous and slower) rail systems. Still, moving entire containers from trucks onto rail, and back to trucks again is common and probably could be expanded if pricing systems incentivized this. Most studies suggest that the effects of such policies might be small without strong price signals, which may be problematic for other reasons but is worth exploring. Finally, if rail is to take on a greater role and provide substantial GHG reductions over trucks, rail would need to be fully decarbonized, which means either widespread catenary systems or shifting to fuel cell locomotives, neither of which is currently being widely pursued. If trucks achieve very low CO_2 emissions by transitioning to electric propulsion and low-carbon biofuels, then the advantages of switching freight to rail mostly dissipates.

5.2.6 Intercity Passenger Travel: Aviation, Coach, Rail and Personal Vehicles

While decarbonization of daily travel within communities and metropolitan areas is critically important, approximately 30 percent of the passenger miles of travel in the United States are estimated to be long-distance or intercity.[25] Intercity, including international, travel is undertaken by personal vehicle, motor coach, rail, and aviation. Long-distance travel, both personal and business, was projected to significantly increase before the COVID-19 pandemic and may again as growth is driven by disposable income, the large global tourism industry, wide-spread social networks, and globally dispersed manufacturing and business operations. Aviation and rail account for 9 percent and 2 percent of transportation emissions in the U.S.[26]

Much of the future growth in passenger aviation was projected for international travel, requiring coordinated policy actions. The US Department of Commerce estimates that only about 15 percent of international trips were for business purposes, which suggests lingering COVID-19 impacts on business travel might not have significant effects on GHG emissions.[27]

The length of intercity trips and shipments vary significantly. Policy solutions vary by distance range and here we focus on passenger travel on “intra-regional” as less than 400 miles one-way and “inter-regional” as greater than 400-miles one-way. Note that in many cases “inter-regional” trips are 1000s of miles or even intercontinental in length. Ultimately, different modes incur different levels of energy and embody different efficiencies per passenger mile but ultimately trip length and how full the vehicle is. The longer the trip the more energy and thus emissions and therefore the vehicles should be operating with as close to capacity of passengers as possible.

Significant replacement of liquid petroleum-derived jetfuel upon which the inter-regional trips rely will be a challenge due to energy density. Airplanes have steadily improved efficiency since the 1970s, reducing energy use per passenger mile by 3 percent per year since 1970, and 2.6 percent annually since 2007.[28] Through 2050, researchers expect a net improvement of 2 percent per year in energy per passenger mile but most of this improvement is attributable to fleet turnover and operational improvements not merely aircraft design. Sustainable aviation fuel (SAF) or bio-jet is being tested in several markets but the generation of the quantities needed for complete, or even substantial, substitution is not feasible with expected fuel stocks. Policies to incentivize reasonable levels of SAF for use in flight for trips over 400-miles is recommended. This effort should include an international low-carbon jet fuel standard. For interregional long-distance travel above 400-miles (or travel across water, to Hawaii for example) airlines have little modal competition and there are no time-effective alternatives. In this range, reducing travel demand (or holding it constant without growth) through significant increased ticket fees and allocation of these resources based on efficiency-based metrics to airlines and airports is a viable policy option. Given that flying is needed for national and international communities and economies, the decarbonization solution for long-haul passenger aviation (>400-miles) is based on the assumption that these aircraft will remain legacy users of petroleum. Although the policy goal should be reducing short-haul segments (<400-miles) even when the overall trip is longer, in total we must aim to hold passenger flight miles constant at pre-COVID-19 levels. Note as well some shorter flights in places without alternatives will remain such as for Alaska, Puerto Rico and Hawaii, especially for freight. Fees on international arrivals may be a reasonable way to raise revenue for green airport infrastructure.

Miles flown on petroleum fuel for trip lengths or segment lengths less than 400 miles must be minimized if not completely eliminated. This goal can be accomplished through a combination of investment in alternative modes, reduction of travel demand and both electric flight and electric surface vehicles. This diversion of inter-regional travel from air to surface will require fees of a substantial level and incentives for development of higher passenger capacity for reasonable range electric flight. In the 120 to 400 mile range there must also be incentives and infrastructure investment where demand is high for reliable rail service and electric coach service. Travelers should be encouraged to use flying for trips where efficient surface alternatives are not viable.

The needed modal substitution in intercity travel will include switches from airlines to automated electric coaches and vans.[29] Incentivizing multi-person commercial vehicle services, including motor coaches, will be critical especially in congested corridors. To achieve decarbonization, long-distance automated vehicle travel must be via electric vehicles.

While high-speed rail, similar to what is available in other countries is desirable, there are other lower cost solutions that can improve rail service. Selective upgrading of current infrastructure that allow higher average speeds (above 120 mph) and more reliable speeds can be beneficial in high volume corridors. Exploration of more effective high capacity rail or coach service potentially along interstate highway corridors with airports as multimodal mobility hubs is advisable. In short, policies to discourage short-haul flights, even those that are part of longer trips, will be necessary replacing these with electric ground transportation that is better integrated with air scheduling. Finally, trips generally under 120 miles should most often be ground-based and can be converted to EVs but require regional coordination to ensure access to those who may be transit-captive especially in rural areas. There will be a need to develop more efficient ground-based services for essential air service routes.

There is the need for an expanded role of the USDOT and Federal Aviation Administration (FAA) in national mobility and infrastructure system planning for long-distance travel. The aviation system operates on a large geographic scale within which only the USDOT has jurisdiction for coordinated system-wide planning. An optimized national aviation system (including the expanded use of electric ground equipment, flight path optimization to reduce emissions, increased renewable energy generation at airports, use of underutilized airports to reduce induced driving and reduce infrastructure investment and coordination of surface mode connections including rival heavy and light rail systems) requires data, modeling and strong vision-based decision-making. Airlines and private actors should be expected to optimize for their own system, but they require strong national public policy and robust international agreements to set system-wide objectives and operating rules. Federal policy, largely driven by funding, should be balanced between modes to provide the best solutions. Currently aviation funding is separate from ground transportation funding, leading to non-optimal investment decisions. There should be one unified transportation trust fund, instead of one for highways and one for aviation.

In general, airport infrastructure expansion should be limited with an emphasis on improving the environmental performance of existing airports and using existing capacity. Moreover, national travel data and a demand forecasting model is needed to guide a potential re-alignment of the hub and spoke routing patterns which may be resulting in more passenger air miles than required to meet actual passenger origins and destinations.

In short, for intercity travel (including any part of a trip) under 400-miles, modal substitution to electric surface vehicles is necessary. In rural areas, this will include electric motor coaches and in urban corridors rail, light rail, and motor coaches. Policies to accelerate conversion to these systems will be needed. For travel or segments over 400-miles in length, shorter legs must be eliminated and ground transportation and total passenger miles flown must be held constant powered by liquid petroleum fuel and where feasible limited biofuel stocks encouraged by international low-carbon fuel standards.

5.2.7 Conclusions and Policy Recommendations

To reduce GHG emissions in the transport sector, one strategic initiative stands out: the transition from combustion engines to electric propulsion for virtually all cars, trucks, and buses and a limited number of airplanes—including the use of battery, plug-in hybrid, and hydrogen fuel cell electric vehicles. But even in this transition to electric propulsion, a suite of policies is needed, including aggressive GHG vehicle performance standards, vehicle sales requirements, incentives for vehicle purchase (especially during the next decade), and incentives and subsidies for public charging and hydrogen stations.

The cost of this transition will be relatively modest in the context of our massive expenditures for vehicles and fuels. Indeed, in most vehicle segments electric vehicles will eventually be less expensive in terms of total cost of ownership—eventually generating large cost savings to the economy and society. If one adds reductions in external costs, especially health and climate, then the savings to society become quite large.[30]

The second most important strategy is reduction in vehicle use and filling vehicles to passenger capacity, but with an understanding that greater accessibility is desired for mobility disadvantaged groups such as those with low incomes, those with mobility disadvantages, and elderly travelers. In simple terms, this means improving services that carry more passengers and discourage those that serve single occupants or drivers, including zero occupants (as could be the case with automated vehicles). The types of services to be incentivized include conventional buses and rail, pooled ride-hailing services, and bicycles, e-bikes, and e-scooters. Reducing VMT and improving accessibility for mobility disadvantaged travelers is especially challenging, but the number of co-benefits is large, including cleaner air, improved public health, less land for parking and roads, lower road infrastructure costs, and more equitable access to jobs, school, health services, recreation, and more.

Overall, the top priority policies to reduce emissions from the transport sector are the following:

- Make ZEVs a high share of vehicles
- National ZEV sales requirements for cars as described in chapter 4:
  - National LDV ZEV mandate at a minimum of 30 percent of new sales by 2030 and 100 percent of new sales by 2040.
  - National medium duty vehicle (MDV) and HDV ZEV mandate at a minimum of 20 percent of new sales by 2030 and 80 percent of new sales by 2050.
- National ZEV sales and fleet purchase requirements for trucks
- Incentives for ZEV vehicle purchases and support for investments in needed ZEV infrastructure
- Tightened fuel economy/GHG standards for all new cars and trucks
- Low-carbon fuel standards covering all fuels for road vehicles and airplanes

- Reduce passenger travel and vehicle dependence—while increasing access for walking, bicycling, new micro mobility modes, telecommunications, transit, pooled ride-hailing services, and other low-carbon choices, especially for disadvantaged travelers, via:
  - Altering distribution of funds from the federal transportation trust fund and stimulus packages away from new highway capacity and lane expansions, and toward bicycle, pedestrian and new micro mobility modes infrastructure; transit in dense areas; and public-private partnerships between transit operators and ride-hailing providers.
  - Supporting local and state actions to increase low-carbon travel and investments, reduce single-occupant vehicle use, and support transit-oriented development.
  - Pricing policies that create incentives and generate funds for investments in low-carbon alternatives

Other priorities include investment in and support of low-carbon biofuels for aviation, ships, and long haul trucks, and the use of automation for electric, pooled vehicles. Automated vehicles (AVs) are desired, from an environmental (as well as an economic and equity) perspective, only if they are used in commercial mobility services that feature pooled services (versus single passengers)—and not individually owned. If individually owned they will likely lead to large increases in VMT, largely offsetting emission reductions from electrification. When used in commercial pooled services, this new technology provides the opportunity to reduce vehicle use, provide low-cost accessibility to mobility disadvantaged travelers, reduce the cost of travel to individuals and society, and sharply reduce the amount of land devoted to transportation.

Transportation is generally seen as the most challenging sector to decarbonize, but it may also prove one of the least costly—even eventually providing large economic saving. It is also the sector with the greatest opportunity to provide a large number of associated co-benefits to travelers and society and to create a more environmentally sustainable and equitable society.

References

1. US Environmental Protection Agency, OAR. 2015. "Fast Facts on Transportation Greenhouse Gas Emissions." Overviews and Factsheets. US EPA. August 25, 2015. https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions;

   U.S. Environmental Protection Agency. 2020. *Fast Facts U.S. Transportation Sector Greenhouse Gas Emissions 1990-2018*. Washington D.C.: Office of Transportation and Air Quality, Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100ZK4P.pdf.

2. Davis, Stacy C. and Robert G. Boundy. "Transportation Carbon Dioxide Emissions by Mode, 1990–2017." In *Transportation Energy Data Book*. 38th ed., 12-10. Oak Ridge, TN: Oak Ridge National Laboratory, 2020. https://tedb.ornl.gov/wp-content/uploads/2020/02/TEDB_Ed_38.pdf.

3. Fulton, Lewis, Marshall Miller, Andrew Burke, Qian Wang, and Chris Yang. 2019. *Technology and Fuel Transition Scenarios to Low Greenhouse Gas Futures for Cars and Trucks in California*. Davis, CA: UC Davis, Institute of Transportation Studies. https://escholarship.org/uc/item/8wn8920p;

   Fulton, Lew, and Dan Sperling. 2020. "Zero Cost For Zero-Carbon Transportation?". Blog. *UC Davis Institute Of Transportation Studies*. https://its.ucdavis.edu/blog-post/zero-cost-for-zero-carbon-transportation/.

4. Davis and Boundy, "Transportation Carbon Dioxide Emissions".

5. Ambrose, H., Kendall, A., Lozano, M., Wachche, S., & Fulton, L. 2020. Trends in life cycle greenhouse gas emissions of future light duty electric vehicles. Transportation Research Part D: Transport and Environment, 81.

6. Boyce, James K. 2018. "Carbon Pricing: Effectiveness And Equity". *Ecological Economics* 150: 52-61. doi:10.1016/j.ecolecon.2018.03.030.

7. U.S. Department of Transportation, Bureau of Transportation Statistics. 2017. "Freight Facts and Figures". https://www.bts.dot.gov/sites/bts.dot.gov/files/docs/FFF_2017.pdf.

8. Congressional Budget Office. 2018. "Public Spending on Transportation and Public Infrastructure, 1956 to 2017". CBO. October 2018. https://www.cbo.gov/system/files/2018-10/54539-Infrastructure.pdf.

9. Fulton et al., *Technology and Fuel Transition Scenarios*.

10. "About California Climate Investments – Background". California Climate Investments. http://www.caclimateinvestments.ca.gov/about-cci.

11. "Battery Pack Prices Fall As Market Ramps Up With Market Average At $156/KWh In 2019." 2019. BloombergNEF (blog). December 3, 2019. https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/.

12. US EPA, OAR. 2015. "Smog, Soot, and Other Air Pollution from Transportation." Overviews and Factsheets. US EPA. September 10, 2015. https://www.epa.gov/transportation-air-pollution-and-climate-change/smog-soot-and-local-air-pollution.

13. Smart Growth America. 2011. "Recent Lessons from the Stimulus: Transportation Funding and Job Creation". Smart Growth America. February 2011. https://smartgrowthamerica.org/app/legacy/documents/lessons-from-the-stimulus.pdf.

14. Ibid.

15. Alemi, Farzad, & Caroline Rodier. 2020. "Ride-Hailing Holds Promise for Facilitating More Transit Use in the San Francisco Bay Area." *UC Davis: National Center for Sustainable Transportation*. http://dx.doi.org/10.7922/G2M043N5.;

    Lazarus, Jessica, Jean Carpentier Pourquier, Frank Feng, Henry Hammel, and Susan Shaheen. 2020. "Micromobility Evolution And Expansion: Understanding How Docked And Dockless Bikesharing Models Complement And Compete – A Case Study Of San Francisco". *Journal Of Transport Geography* 84: 102620. doi:10.1016/j.jtrangeo.2019.102620.

16. Weiss, Martin, Andreas Zerfass and Eckard Helmers. 2019. "Fully electric and plug-in hybrid cars - An analysis of learning rates, user costs, and costs for mitigating CO2 and air pollutant emissions". *Journal of Cleaner Production* 212, 1478-1489. https://doi.org/10.1016/j.jclepro.2018.12.019.

17. Bureau of Transportation Statistics. "National Household Travel Survey Daily Travel Quick Facts." n.d. Accessed August 18, 2020. https://www.bts.gov/statistical-products/surveys/national-household-travel-survey-daily-travel-quick-facts.

18. Kurani, Kenneth S. 2019. *The State of Electric Vehicle Markets, 2017: Growth Faces an Attention Gap*. Davis, CA: National Center for Sustainable Transportation, Institute of Transportation Studies, UC Davis. https://doi.org/10.7922/G2D50K51.

19. Ambrose, Hanjiro, Alissa Kendall, Mark Lozano, Sadanand Wachche, and Lew Fulton. 2020. "Trends In Life Cycle Greenhouse Gas Emissions Of Future Light Duty Electric Vehicles". *Transportation Research Part D: Transport And Environment* 81: 102287. doi:10.1016/j.trd.2020.102287.;

    Kendall, Alissa, Hanjiro Ambrose, Erik Maroney. 2019. *Brief: Life Cycle-Based Policies Are Required to Achieve Emissions Goals from Light-Duty Vehicles*. Davis, CA: Institute of Transportation Studies, University of California, Davis. https://doi.org/10.7922/G2FB515B.

20. "State Electric Vehicle Mandate | Alliance of Automobile Manufacturers." n.d. Accessed August 14, 2020. https://autoalliance.org/energy-environment/state-electric-vehicle-mandate/.;

    Nealer, Rachael, David Reichmuth, and Don Anair. 2015. "Cleaner Cars From Cradle To Grave". Union of Concerned Scientists. https://www.ucsusa.org/sites/default/files/attach/2015/11/Cleaner-Cars-from-Cradle-to-Grave-full-report.pdf.

21. Jenn, Alan, Jae Hyun Lee, Scott Hardman, Gil Tal. 2019. *An Examination of the Impact that Electric Vehicle Incentives Have on Consumer Purchase Decisions Over Time*. Davis, CA: University of California Institute of Transportation Studies. https://doi.org/10.7922/G2S46Q51.

22. Bedir, Abdulkadir, Noel Crisostomo, Jennifer Allen, Eric Wood, and Clément Rames. 2018. California Plug-In Electric Vehicle Infrastructure Projections: 2017-2025. California Energy Commission. Publication Number: CEC-600-2018-001.;

    Mai, Trieu T., Jadun, Paige, Logan, Jeffrey S., McMillan, Colin A., Muratori, Matteo, Steinberg, Daniel C., Vimmerstedt, Laura J., Haley, Benjamin, Jones, Ryan, and Nelson, Brent. Fri . "Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States". United States. doi:10.2172/1459351. https://www.osti.gov/servlets/purl/1459351.

23. Burke et al. 2020. Evaluation of the Economics of Battery-Electric and Fuel Cell Trucks and Buses. Davis, CA: UC Davis Sustainable Freight Program.

24. Ibid.

25. Aultman-Hall, Lisa. 2018. *Incorporating Long-Distance Travel into Transportation Planning in the United States*. UC Davis: National Center for Sustainable Transportation. https://escholarship.org/uc/item/0ft8b3b5.

26. U.S. EPA. 2018. *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016*. Washington D.C.: U.S. Environmental Protection Agency. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016.

27. Aultman-Hall, Lisa, *Incorporating Long Distance Travel*.

28. Davis, Stacy C, and Robert G Boundy. "Table 2.15." In *Transportation Energy Data Book*. 38th ed. Oak Ridge, TN: Oak Ridge National Laboratory, 2020.

29. LaMondia, Jeffrey J., Daniel J. Fagnant, Hongyang Qu, Jackson Barrett, and Kara Kockelman. "Shifts in Long-Distance Travel Mode Due to Automated Vehicles: Statewide Mode-Shift Simulation Experiment and Travel Survey Analysis', Transportation Research Record, 2566.1 (2016), 1–11 <https://doi.org/10.3141/2566-01>.

30. Fulton, Lewis, Marshall Miller, Andrew Burke, Qian Wang, and Chris Yang. 2019. *Technology and Fuel Transition Scenarios to Low Greenhouse Gas Futures for Cars and Trucks in California*. Davis, CA: UC Davis, Institute of Transportation Studies. https://escholarship.org/uc/item/8wn8920p.

5.3 Accelerating Net-Zero Emissions Industry in the U.S.

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5.3.1 Introduction, Context, and Goals

Industrial activities are a major source of global CO_2 emissions, including both energy-related emissions from the combustion of fossil fuels and process emissions related to entailed chemical reactions. In the U.S., industry accounts for roughly a quarter of emissions in recent years, with ~68 percent related to energy demands (electricity and heat) and the other 32 percent from various industrial processes.[1] As such, a relatively large share of industry emissions from light industries such as manufacturing of durable goods, food and textile processing, and even mining and non-ferrous metal production may be avoided by coordinated efficiency improvements, electrification, and decarbonization of electricity generation.[2] Thus, this chapter will focus on those industrial activities which produce large quantities of process emissions, require very high temperatures, and/or whose equipment and infrastructure are especially long-lived (highlighted in Figure 5.3.1).[3] In particular, we address potential technologies and related policies for eliminating emissions during the production of cement, iron and steel, and key feedstock chemicals. Our goal is to explore the potential technical pathways for decarbonizing these industries and the different policies that would support these pathways.

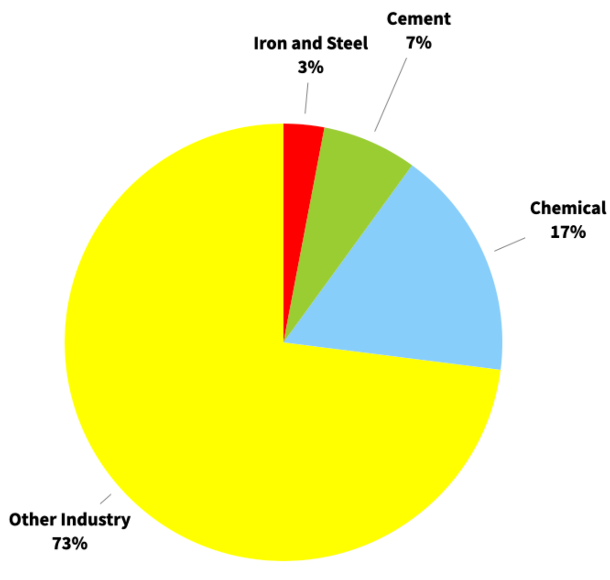

Figure 5.3.1. U.S. Industry emissions as of 2014 (Hoesly et al., 2018).

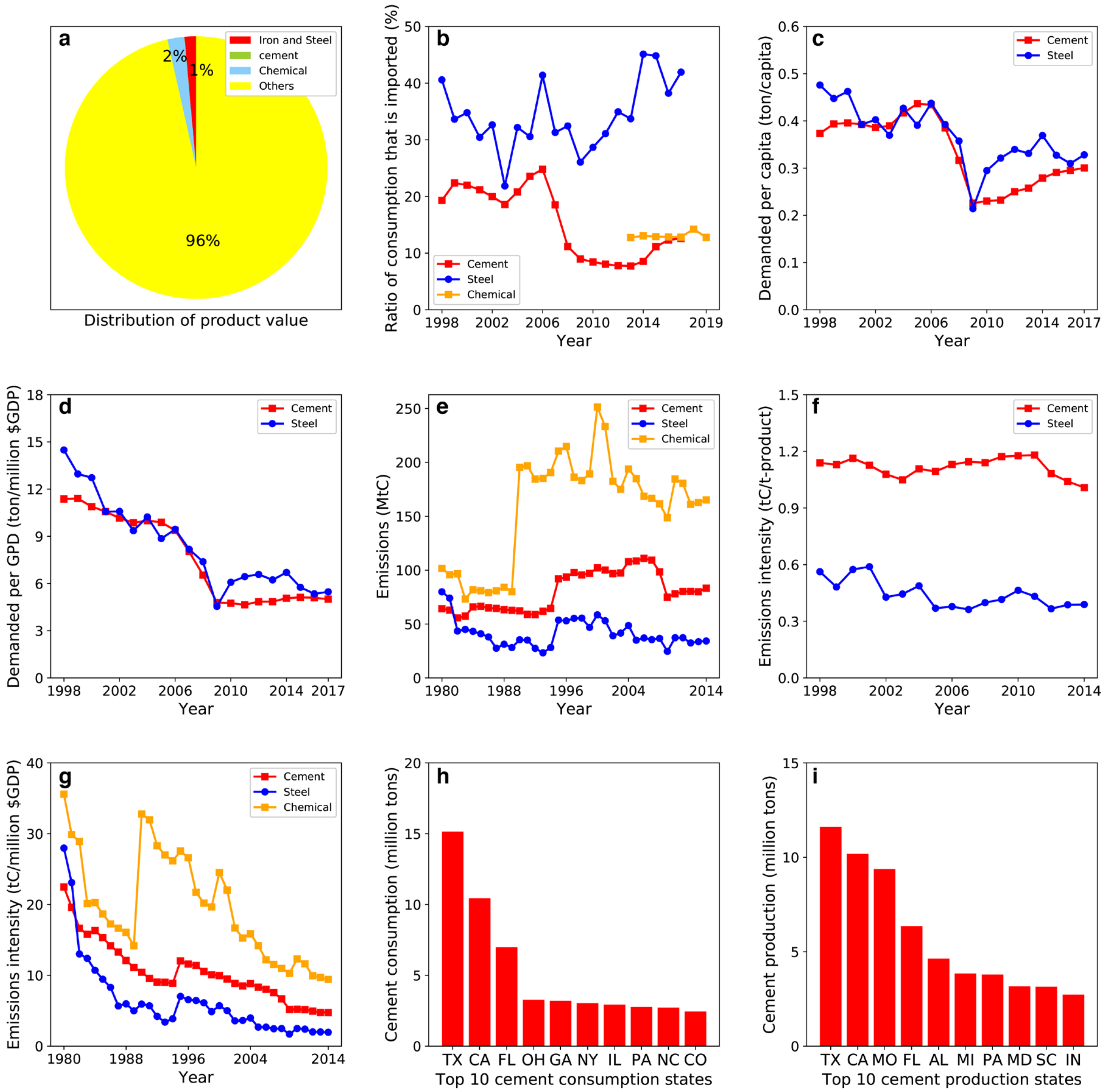

Figure 5.3.2. Economic and emissions data on heavy industries in the U.S.
Panel (a) shows the relative product value of iron and steel (red), cement (green) and chemicals (blue) relative to other industries in the U.S., Panels (b) through (g) show time trends in the share of U.S. consumption of cement, steel, and chemicals that are imported (b), the U.S. demand for cement and steel per capita (c), the intensity of demand for cement and steel per dollar of U.S. GDP (d), total U.S. emissions related to cement, steel, and chemicals (e), the emissions intensity per ton of cement and steel produced (f), and the emissions intensity per dollar of U.S. GDP (g). Panels (h) and (i) show the top 10 states by consumption and production of cement, respectively (figures original; data from Dunham and Associates, Inc., 2018; "Chemical Industry", 2020; "Cement Statistics", 2020.; "Gross Output", 2020; "Total U.S. Chemical", 2020; "Iron And Steel", 2020; "Population", 2020; "GDP", 2020; Hoesly et al., 2018; Tong et al., 2019).

Figure 5.3.2 summarizes several important aspects and trends related to such heavy industries in the U.S. First, the value of industrial products is overwhelmingly related to light industry, with the iron and steel, cement, and chemical industries together representing <5 percent of the aggregate value of industrial products in recent years (Fig. 5.3.2a).[4] A substantial fraction of the cement, steel, and chemicals consumed in the U.S. is imported, with this fraction trending slightly up in the cases of steel and cement in recent years (Fig. 5.3.2b).[5] Per capita demand for cement and steel in the U.S. dipped during the global recession of 2008-2009 but had nearly recovered to pre-crisis levels by 2017. Americans each use ~0.8 kg of both steel and cement every day (Fig. 5.3.2c).[6] Yet the material intensity of the U.S. economy has decreased by about 50 percent over the past two decades. In 2017, every million dollars of gross domestic product (GDP) required 5-6 tons each of cement and steel (Fig. 5.3.2d).[7] Emissions from cement and steel industries have been relatively stable since the 1980s, with a substantial uptick in emissions from the chemical sector in the late 1980s (Fig. 5.3.2e).[8] Meanwhile, the emissions per unit of cement and steel produced in the U.S. have decreased only very slightly since the late 1990s (Fig. 5.3.2e).[9] Finally, cement consumption is concentrated in a few large and fast-growing states (Texas, California, and Florida; Fig. 5.3.2h). Each state produces considerable quantities of cement, added to by other production centers with large, young cement plants in states like Missouri, Alabama, and Maryland (Figs. 5.3.2i and 5.3.3).[10]

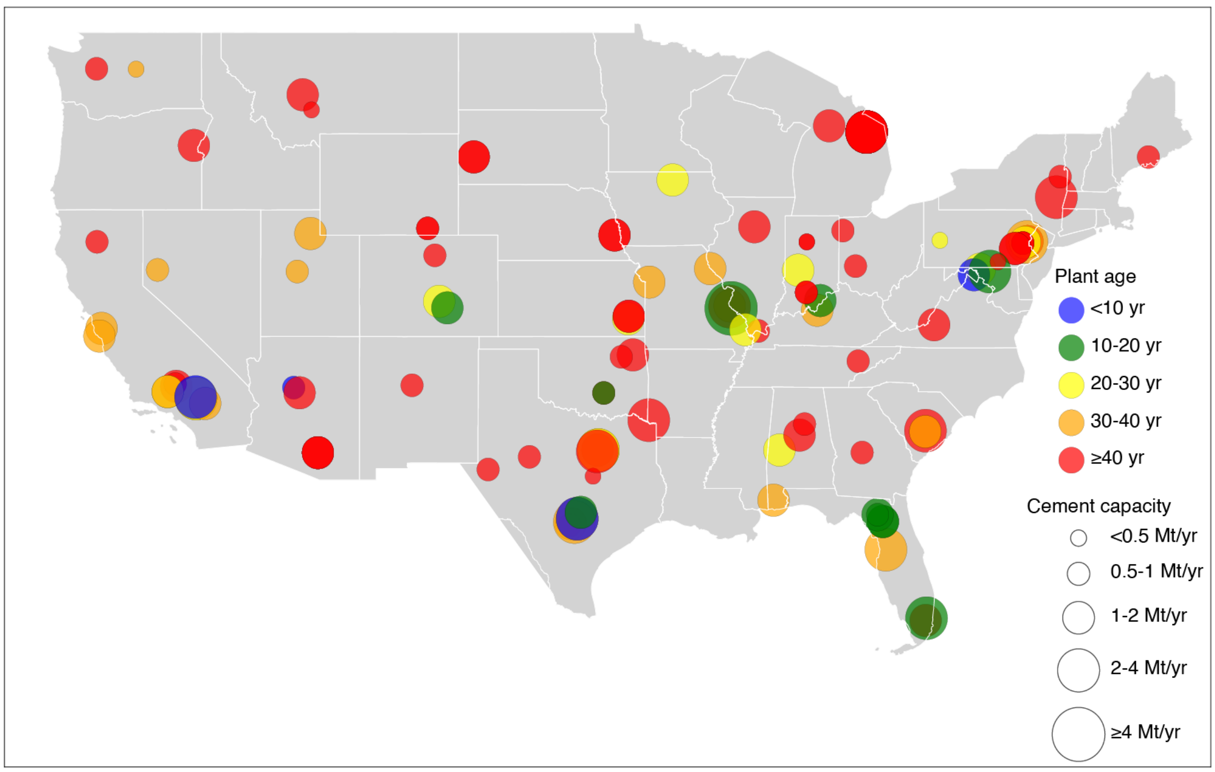

Figure 5.3.3. Locations, capacity (size of points), and age (color of points) of U.S. cement plants as of 2018 (figure original; data from Global Cement, 2020)

Ownership and control

As noted above, this chapter's focus industries—iron and steel, cement, and feedstock chemicals—are of particular interest in a decarbonization context precisely because their conventional production processes entail emissions that are difficult to avoid and their capital infrastructure tends to be long-lived. Although the U.S. heavy industry as a category is highly heterogeneous, the magnitude of capital investments in steel, cement, and chemical industries tends to make the industries relatively concentrated and location-bound. For example, just four companies accounted for over 75 percent of the value of U.S. petrochemical industry shipments and receipts as of 2012 (the most recent economic census data compiled as of this writing).[11] The nine blast furnace-basic oxygen furnace steelworks operating in the U.S. are owned by three companies, and all but one are located in the upper Midwest. Further, industry groups (e.g., the Portland Cement Association, the American Iron and Steel Institute, and the National Glass Association) are relatively organized and influential, often representing large multinational companies that operate both in and outside the U.S. (see, e.g., Fig. 5.3.4).

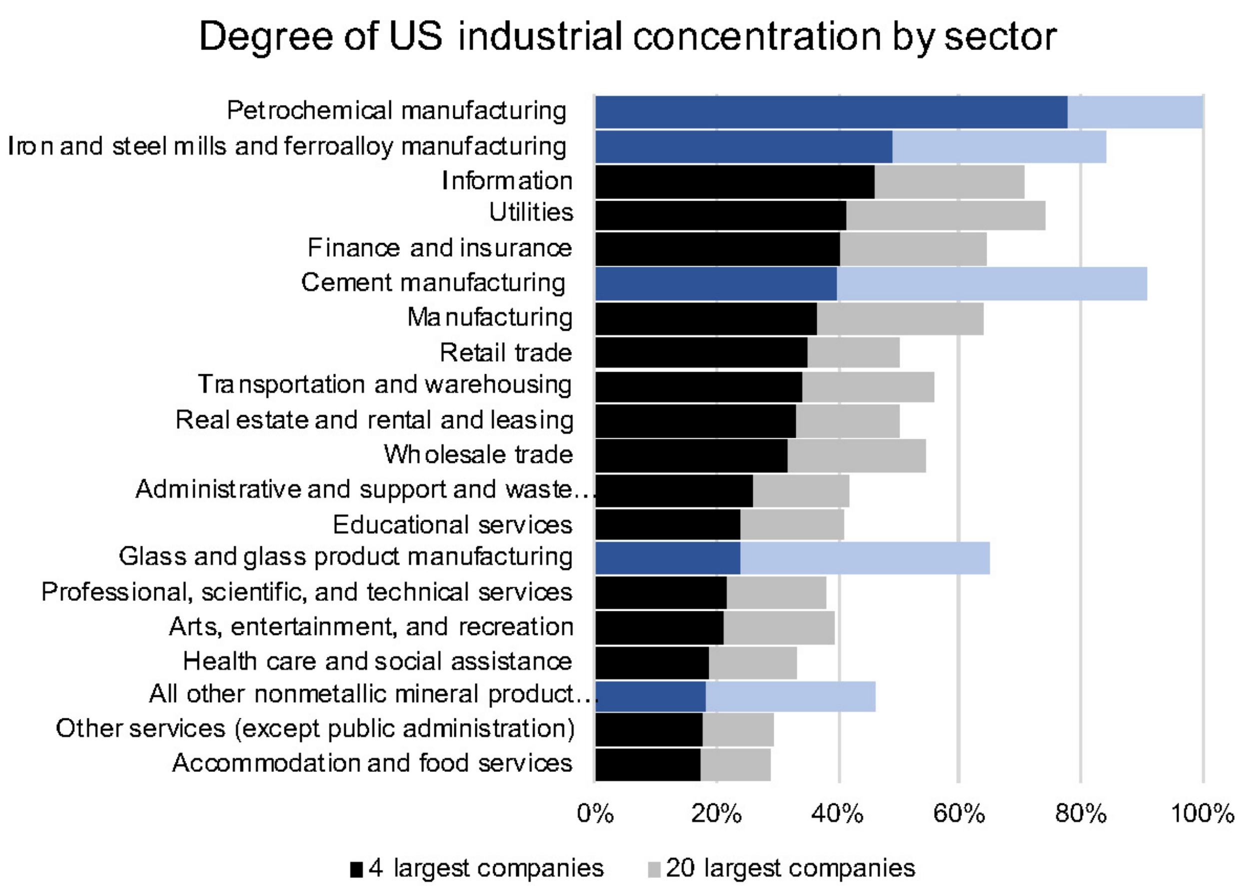

Figure 5.3.4. Degree of U.S. industrial concentration by sector. Sectors of interest highlighted in blue. Note: concentration in manufacturing sectors is measured as percent of total value of shipments and receipts; concentration in other sectors is measured as percent of total revenue. (U.S. Census Bureau, 2015; 2017 data to be released November 2020).

However, unlike utilities, heavy industry in the U.S. is not typically overseen by a Public Utility Commission (PUC) or similar entity focused on issues like output levels and pricing. The main targets of industrial regulation are environmental, safety, and antitrust considerations. In the decarbonization context, the Environmental Protection Agency (EPA) is currently the primary relevant federal regulator, often via its authority over point source air and water emissions.

The economic downturn related to COVID-19 is expected to have large, lasting effects on U.S. heavy industry. Demand for industrial products often depends on economic growth (e.g., construction) or consumer spending (e.g., feedstock chemicals), though targeted stimulus efforts might alter this dynamic. Based on past experience, facility closures are often permanent, with reinvestment in more financially favorable parts of the U.S. or internationally.[12]

5.3.2 Deep Decarbonization of Harder to Abate Sections: Cement, Steel, and Chemicals

Importantly, the technologies and options for abating industry CO_2 emissions are not all available or well-represented in models like PATHWAYS and RIO, particularly concerning systems integration (e.g., electrolytic hydrogen for steel and chemicals and long-duration energy storage via power-to-gas-to-power; synfuels such as methanol for chemicals).[13] Rather, such models focus on options of reducing demand for industrial outputs, electrifying industrial energy inputs, and carbon capture and storage (CCS) of process CO_2 emissions. This means that it may be possible to reduce industry carbon emissions more synergistically than such models suggest.

Following is a brief description of the technical options for decarbonizing the cement, iron and steel, and chemicals industries in the U.S.

Cement

Cement production relies on driving two sets of reactions: firstly, calcination (the removal of CO_2 from $CaCO_3$ to produce CaO) and secondly the clinkering reactions, where the CaO reacts with silica and other materials including clay (at very high temperatures > 1600°C) to produce cement clinker (which is then ground and mixed with other materials to produce cement). The initial calcination means that a large amount of CO_2 is produced intrinsically during cement production, and this cannot easily be avoided. Carbon capture and storage (CCS), directly removing CO_2 from the exhaust of the cement plant, is therefore likely to be required for cement production. An alternative would be to subsequently remove CO_2 from the atmosphere and store it (Direct Air Capture (DAC)). However, this is less efficient since CO_2 in the atmosphere is at 400 ppm, as opposed to 30 percent by volume in the exhaust from a cement plant.

Inherently, cement manufacture is one of the more polluting activities in terms of tons of CO_2 emitted per $ of value added. Yet there is currently large variation in the CO2 emissions per ton of cement produced globally—and within individual countries—depending upon the exact process route chosen.[14]

Electrification. Electrical heating is potentially of interest to drive both the calcination and clinkering reactions, but approximately 60 percent of the CO_2 emitted in a cement plant is directly from the calcination reaction. This means that it will still be necessary to compress, transport and store the CO_2 produced from this reaction in order to eliminate CO_2 emissions to the atmosphere.15 Initial studies demonstrate that the energy use may be around 4.6 MJ per kg per clinker for a plasma-driven process.[16]

One possible route to drive calcination using electricity (CO_2 transport and storage would still be required) is to operate a direct separation reactor. This reactor (essentially an externally heated tube, through which $CaCO_3$ falls, with heat transfer from the tube driving the calcination process) produces a relatively pure stream of CO_2 from the calciner, meaning that chemical separation is not required.[17] An electrically-driven direct separation reactor for the calcination, coupled with a plasma process for the clinkering reactions in the kiln might bring the energy use down to around 3.3 MJ/kg. However, because electrical energy is significantly more expensive than the thermal energy from coal or other fuels, the cost of cement from a fully plasma-driven process has been estimated to be roughly double that of currently produced cement.18 Moreover, although electrically-driven processes produce a relatively pure stream of CO_2, it may be challenging to ensure leak-tightness of equipment so that the CO_2 is not contaminated with air.

CCS. Prior to examining CCS on cement, it is instructive to examine the variety of cost estimates available in the literature for a number of technologies. Figure 4, from Leeson et al., shows that there are a wide variety of prices estimated for CCS applications to different industrial processes, even for the same underlying technology.[19] Some technologies are more suited to one process than another (in particular, it is frequently found that post-combustion amine scrubbing is significantly more expensive than many other technologies, owing to the paucity of waste heat in a modern integrated cement plant). In the case of cement production, the main CCS technologies available are discussed below.

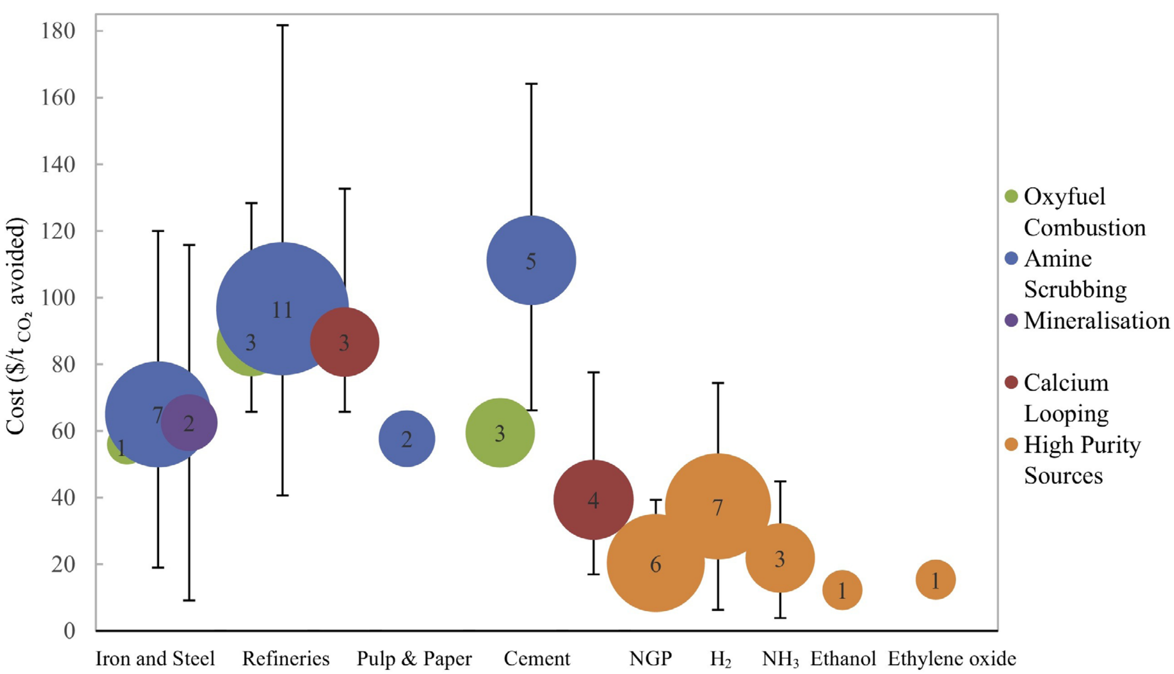

Figure 5.3.5. Costs of CO_2 avoided for a variety of different processes, using a number of different CCS technologies (Leeson, et al., 2017).

Solvent Scrubbing: A solvent scrubs CO_2 from the exhaust of the cement plant. This solvent is then regenerated after passing to a 2nd reactor by steam from (in general) a combined heat and power (CHP) system. CHP is necessary because insufficient low-grade heat is present on the cement works to regenerate the solvent, and because direct heating using, for example, natural gas is very inefficient.

Calcium looping: CaO (produced from limestone) reacts with CO_2 in the exhaust gases. The $CaCO_3$ formed is then transferred to a second reactor (normally, both reactors are circulating fluidized beds) where the reaction is reversed by burning a fuel, usually with pure O_2 (and recycled CO_2). This reactor is also where the initial limestone feed is decarbonized. The result is a pure stream of CO_2. The reaction of CO_2 with CaO is highly exothermic and takes place at around 650°C, so heat can be removed from the carbonator and used efficiently in a steam cycle to generate power. This process has significant synergy with cement production, since the CO_2 sorbent is the main feedstock for cement production, allowing a high purge rate of exhausted material.

Oxyfuel (full): The cement kiln and the precalciner are both fired with a mixture of fuel and oxygen, rather than air. This means that pure CO_2 (and H_2O) are produced. The system requires an air separation unit, which is where the majority of the electricity use (the main energy cost of this system) comes from. It has the potential to be highly efficient because the nitrogen in air is essentially heated up in the kiln for no purpose, so that reducing the volume of gas can improve the efficiency of the process. Issues lie in sealing the (rotating) kiln against air ingress, which reduces the CO_2 percent in the exhaust and potentially mild changes in the chemistry in the kiln. Since sealing the kiln is challenging, an alternative is only to oxyfuel the precalciner. Kiln CO_2 emissions are not captured, but 60 percent overall capture is possible, and at low cost.

A review of different CCS technologies described in a literature survey suggests that the addition of CCS to any system will end up significantly increasing the cost of the process.[20] Approximately, a doubling in price of cement would be necessary to account for the additional costs. Importantly, though, this would actually add very little to the overall cost of a building because the cost of cement is often a small share of the total cost of building construction.[21]

Hydrogen. The use of hydrogen for decarbonization of cement production suffers from the same issue as electrification; that use of hydrogen to provide heat again fails to address the CO_2 emissions from calcination of the limestone (~60 percent of the total). Other issues include safety considerations with the use of hydrogen gas in the kiln and significant differences in the kiln flame when using hydrogen.

One possible use of hydrogen in the system would be to provide the external heat to drive a direct separation reactor. It is also possible to utilize hydrogen to boost the temperature in an electrically-driven process. A study has shown that resistance heating may struggle to raise sufficient volumes of air to the high temperature required, but that a combination of electrical heating with hydrogen to "boost" the air temperature to the temperature required to effect clinkering reactions may be viable.[22] However, it is likely that the cost and complexity of a hydrogen-driven kiln, together with the limitation in overall CO_2 capture potential, would mean that hydrogen is unlikely to take off as a decarbonization vector for cement production. This is also the view of International Energy Agency (IEA) studies.[23]

Supplementary Cementitious Materials, and Fillers. It is possible to directly replace cement clinker with a number of alternative materials (notably coal ash and ground granulated blast furnace slag, but also potentially naturally occurring rocks (pozzolans) and potentially biomass and other ashes). Such replacements can reach a high-level, data for China suggests an average replacement rate of more than 40 percent in the recent past.[24] Displacing demand for clinker in the cement with such alternative materials may directly reduce the emissions from cement manufacture while meeting current building standards (up to a level) for Ordinary Portland Cement. However, some of the materials used (coal ash and blast furnace slag) may become scarcer moving to a decarbonised future.

Supplementary cementitious materials are an active replacement (in that they actively take part in the chemical reactions leading to the production of solid cement). Another potential class of materials is fillers such as powder limestone.[25] These do not take part in the chemical reactions that give cement its strength, but the fillers can act to reduce the overall requirement for cementitious materials when making concrete. The use of limestone in such a context has been known about for many years, but it tends to reduce the strength of the blend unless alterations to the water content are made. This is an area under active research.

Backstop, DAC, and Alternative Cements. Due to the high concentration of CO_2 in the flue gas from cement manufacture, and because of the large amount of CO_2 emitted per unit of value added, CCS would be preferable as a technology to address the emissions of CO2 from this industry, as opposed to capturing CO_2 directly from the atmosphere (Direct Air Capture, DAC). There are potentially alternative formulations of cement which drastically reduce the CO_2 emissions, but none have been commercialized and all face significant issues with end-user acceptability as mentioned in chapter 5.4 on Buildings. Regarding CO_2 removal from the atmosphere, it should be noted that cement does actually, over a sufficiently long period of time, recarbonate.[26] Depending on how it is used and the conditions of its disposal, cement recarbonation may, over the long term (>30 years), take up as much as 30 percent of the emissions produced during its manufacturing process.

A 2019 report discussed various alternative cement formulations.[27] These various types of alternative cements could reduce CO_2 emissions by 20-100 percent. However, properties and feedstock requirements limit the practical use of the formulations with high CO_2 reduction potential. For example, geopolymer binders are made out of a mix of silica-rich sand and sodium carbonate processed at temperatures hundreds of degrees lower than those required to produce traditional Portland cement clinker. As a result, the theoretical energy requirements to produce the sodium silicate is 0.306 GJ per ton, while 1.059 GJ per ton is needed for Portland cement clinker. Moreover, the use of limestone is eliminated, enabling further reductions in CO_2 emissions. Sodium silicate generates 45 percent less CO_2 per ton than conventional cement clinker (0.29 versus 0.54 tons of CO_2 per ton).

Advanced technological and experimental methods are needed to establish the viability of these alternative cements. Alternative binders could provide a simple yet promising solution for cement clinker replacement by making the cost competitive at industrial scale, but their potential can only be realized through detailed investigation and characterization with the help of cutting-edge technologies. Establishing codes, standards, and setting guidelines with training will be essential in developing alternative cement concepts. For example, performance-based regulations for concrete, instead of cement type specifications are beneficial for the growth of geopolymer research and industry.

In the future, it may be that novel cement formulations gain traction. However, the cement industry (and in particular cement end users) remain inherently conservative. A sentiment sometimes heard is "build a bridge, have it stand up for 20 years, and we might examine your cement substitute." An example of the difficulty of commercializing new cements is the failure of the company Novacem, which was setup to commercialize a novel cement material.[28] It may be that there are opportunities available for alternatives in non-structural cement, though these are a relatively small market in comparison to that for ordinary Portland Cement.[29]

Steel

In addition to substantial emissions from combustion of fossil fuels for required heat, the process emissions from steel production (i.e., excluding fossil energy inputs) accounts for roughly 5 percent of global CO_2 emissions in recent years, mainly related to the coking coal used to reduce iron ore in blast furnaces (i.e., removing oxygen from raw Fe_2O_3).[30] Although the U.S. imports >40 percent of the steel consumed in the country in recent years (Fig. 1b), steel-related emissions in the country remain substantial: ~40 Mt CO_2 per year, or just shy of 1 percent of the country's emissions in recent years.

There are two main pathways for producing steel from raw iron ore. The first is in an integrated steel mill where iron ore, coke, and flux materials (e.g., lime, to remove impurities) are melted in a blast furnace to produce pig iron, which is then converted to steel in a basic oxygen furnace (i.e., blast furnace-basic oxygen furnace (BF-BOF). The second is by directly reducing the iron using a reducing gas or carbon from natural gas or coal to remove oxygen from the ore at temperatures below the melting point of the iron (i.e., direct reduced iron (DRI)), and then converting the DRI iron to steel using an electric arc furnace (EAF). Of these two, the first is more common in the U.S. Although there have been numerous analyses of how to decrease CO_2 emissions from these steelmaking processes, there are still relatively few analyses of how to achieve net-zero steel emissions.[31] In addition to CCS, which is what many scenarios anticipate and which will face similar challenges to those related to cement-CCS, there are a few options:

Recycling. Already, more than half of the steel produced in the U.S. is via processing of scrap steel in EAFs. The electricity required to energize this process can be decarbonized, and such recycling avoids the process emissions associated with reducing raw iron ore. The main challenge to meeting more steel demand via this pathway are impurities such as tin, copper, nickel, molybdenum, chromium, and lead that may compromise the quality and integrity of such steel.[32] With better sorting and product design (to facilitate separation of metals at the end of a product's life), recycled steel could meet 50-75 percent of global demand.[33]

Biocharcoal. It is possible to replace fossil coke in the BF-BOF process with charcoal derived from biomass, as has been demonstrated at scale by the Brazilian steel industry.[34] This would theoretically render process CO_2 emissions net-zero, and any emissions related to heat inputs could be captured and stored by CCS technologies.[35] However, as with cement, the addition of CCS would substantially increase costs and complexity, and the biomass and land requirements related to charcoal production also pose their own emissions challenges.[36]

Hydrogen. Another option is to use renewable hydrogen as the reducing gas in the DRI-EAF process.[37] This pathway is increasingly of interest; three Swedish companies (SSAB, LKAB and Vattenfall), are working with the Swedish Energy Agency in a joint venture to pilot this system (named HYBRIT).[38]

Electrowinning. Yet another possible pathway to emissions-free steel is to use decarbonized electricity to electrolyze iron ore in an acid or alkaline solution (separating oxygen from iron ore by adding electrons to Fe_2O_3) at low temperatures (~110°C), and then further processing the iron into steel either in an EAF or by molten oxide electrolysis at 1600°C.[39] Although the low temperatures of ore reduction may enable a wide range of cathodes and anodes, this process remains far from commercial-ready, and further research and development is especially needed to identify and develop cathodes and anodes which are both cost-effective and can survive the process.[40]

Chemicals

The chemicals industry represented 5 percent of global CO_2 emissions in 2016, and 16 percent of heavy industry emissions.[41] In 2018, the U.S. chemicals industry emitted 286 Mt CO_2e of 6676 Mt, or 4.2 percent of total national emissions. Petrochemical and plastics synthesis accounted for 80.1 Mt (38 percent), ammonia fertilizer production 39.5 Mt (19 percent), and other organic chemicals 89.7 Mt (43 percent).[42] There are several main precursor chemicals which represent a majority of emissions coming from several different feedstocks with very different production processes, and some variation within with the chemical families (e.g., hydrogen and hence ammonia is mostly commercially made via steam methane reformation of natural gas, but has been made commercially by electrolysis, and ethane can be extracted directly from natural gas (NG) or catalyzed from crude oil). Net-zero decarbonization of chemicals production is very chemical and process specific, but targeting the decarbonization of key feedstocks like hydrogen and carbon monoxide, accompanied by decarbonization of process heat, will cascade through the production system.[43] Given there are thousands of chemicals produced and used, here we focus on the main feedstock chemicals: hydrogen, ammonia, carbon monoxide, methane, methanol, ethanol, ethane, olefins (e.g., polyethylene), and the aromatic BTX family (benzene, toluene, and xylene isomers).

Hydrogen is a key feedstock for almost all organic chemicals and fuels, and it is normally made through reforming of methane or coal followed by a water-gas shift reaction to maximize the hydrogen production.[44] Thus, substantial CO or CO_2 emissions are standard. However, there are at least two routes to decarbonize hydrogen production with existing technology.[45] The simplest and cheapest way today is to partially decarbonize its production is the use of relatively cheap CCS ($<40/ton CO_2e) for the concentrated process emissions associated with steam methane reforming.[46] The process heat requirement for this process remains, however, and would require more expensive post-combustion CCS (>$80/ton CO_2e) unless another net-zero source of heat could be found. The second route is by direct electrolysis of water to create hydrogen; this route produces no CO_2 but requires significant amounts of electricity. The standard process of alkaline electrolysis is up to 60 percent efficient but the large capital investment requires that units be run at relatively high capacity factors (40-50 percent or more) to be cost-effective.[47] Both solid oxide and polymer electrolyte membrane (PEM) fuel cells offer the possibilities of smaller units that can be operated more dynamically and reversibly, offering the possibility of valuable demand response services.[48] On the technology horizon, there are several ways to directly separate hydrogen from the carbon in methane (pyrolysis).

Ammonia is a key feedstock for fertilizer production, which accounts for 4 percent of industrial emissions. It is made by catalyzing (usually methane steam reformed) hydrogen with nitrogen using the Haber-Bosch process. However, recent analyses suggest that if electricity can be purchased for less than $30/MWh and electrolyzers run steadily for more than 50 percent of the time, carbon emissions-free, “green” ammonia might be cost-competitive with natural gas-based ammonia, particularly if modest carbon prices (i.e., ~$30/ton CO_2) are incorporated.[49]

Carbon monoxide (CO) & biogenic carbon. CO is a highly reactive precursor chemical to many hydrocarbon compounds. CO is usually made by partially oxidizing a carbon source, using coal or methane reformation. It can also be made from CO_2 by reacting it with carbon. Chemicals made using CO are often combusted at their end of life, releasing the constituent carbon to the air as CO_2. In order to make CO-based chemicals net-zero, CO_2 could be captured from the air using DAC and reduced or else biomass carbon feedstocks might be used (assuming the production of this biomass can be carbon-neutral).

Methane is the simplest stable hydrocarbon. It can be made if necessary for combustion or as a chemical feedstock via methanation, which combines hydrogen and carbon oxides into methane and water, typically using nickel catalysts. The key is that these processes use net-zero heat or electricity sources, and that the feedstock hydrogen and carbon are also net-zero, the former by one of the means described above and the latter by biomass gasification or direct air capture.[50] Methanol and ethanol can similarly be made from carbon, hydrogen and oxygen using biocatalytic (e.g., fermentation), thermocatalytic (e.g., gasification), or electrocatalytic processes.[51]

Ethane and the simplest olefin, **ethylene**, are key chemical feedstocks (e.g., for plastics) that are currently derived directly from natural gas or else processed from crude oil or coal. Both can be made thermo-catalytically using existing or more efficient near horizon electrocatalytic processes from net-zero methane or methanol.[52]

More generally, De Luna et al. 2019 indicate that most chemical feedstocks (from hydrogen through olefins) can be made electro catalytically, either by themselves or in combination with known biogenic methods (e.g., fermentation), which could radically reduce heat requirements.[53] Although this is a more sophisticated role for electrification in chemical production, if necessary, electrification could also provide most of the process heat.

The processing and use of aromatic BTX chemicals are very complex, but if they are produced with cleaner hydrogen and non-fossil carbon (biomass or captured from the air by DAC), their carbon emissions intensity will decrease.

Although all of the chemical processes described above are well-known and many have been used commercially, most have not been used at large scale in an integrated way because cheap fossil fuels have been readily available as the historical industry norm, and the combustion and process CO_2 emissions could be freely emitted to the atmosphere. With the possible potential exception of electrocatalysis, without a price on carbon, all the processes will be fundamentally more costly than using fossil fuels and full scale commercialization will require substantial policy support and dedicated lead markets.[54]

As a general rule, the combustion emissions intensity of hydrocarbons rises with their molecular length, and chemicals are often combusted at the end of their life. A simple yet effective strategy for reducing CO_2 emissions related to chemicals is to use the lightest hydrocarbons possible for feedstocks and fuels, e.g., prefer methane, methanol, ethanol, butane, and propane over heavier, longer-chain carbons, with coal at the very bottom of the list.

In the North American context, the presence of very cheap fossil methane from hydraulically-fractured wells (which often comes up with C5 pentanes +), co-located with both similarly cheap (and projected to get cheaper) renewable electricity, as well as geologic carbon storage capacity, may make pairing steam methane reformation with CCS, DAC for synthetic hydrocarbons, or DAC and storage for negative emissions more affordable than in other places in the world.

5.3.3 Future: Infrastructure and Demand

The challenge of decarbonizing industrial activities is made easier if overall demand for industrial products can be reduced. For example, the MATTER (MATerials Technologies for greenhouse gas Emission Reduction) project found that 35 percent of the potential reductions in materials-related emissions relate to materials systems optimization, ranging from reductions in materials used per unit of product to waste management. Yet, although dematerialization and materials efficiency can play a key role in the deep decarbonization of the U.S. economy—particularly as related to the key industries of cement, steel, and chemicals, detailed data and modeling of materials demands remain rare.[55]

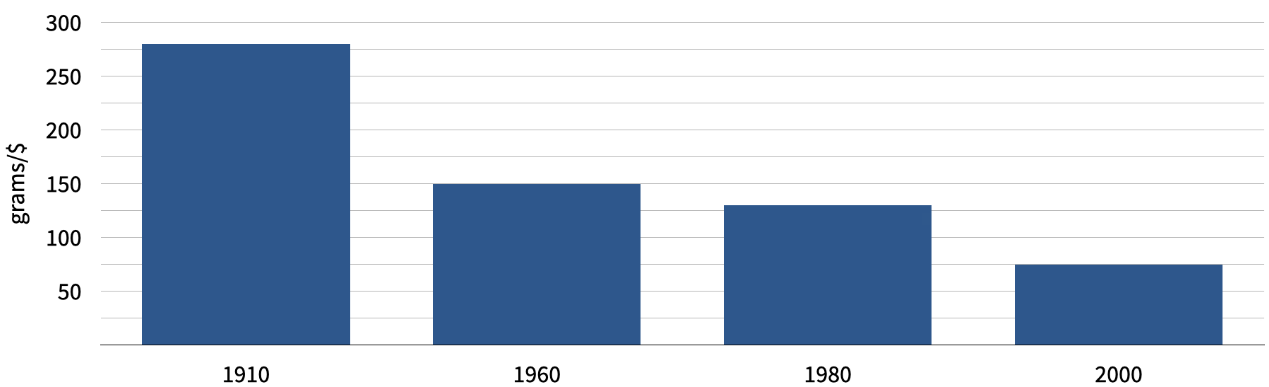

Figure 5.3.6. Materials intensity continues to fall dramatically. In the U.S., the amount of resources extracted per dollar of GDP has decreased by nearly 75 percent over the past 90 years (figure original; data from Smil, 2014).

Although potentially misleading, (e.g., because substantial materials may be virtually embodied in imports), aggregate materials intensity is often measured as the mass of a material per $ of GDP (see, e.g., Fig. 5.3.2d). However, materials are versatile and widely deployed. In the case of steel, 50 percent is used for building & infrastructure; 18 percent transport; 16 percent mechanical equipment; 11 percent metal products (packaging, etc.); 5 percent electrical and domestic appliances. Because of this versatility, opportunities to reduce demand must be considered in the light of the specific application, usually by a product-specific life cycle analysis. The complexity of such bottom-up analyses is what makes estimates of materials efficiency scarce.

As mentioned in the chapter introduction, the cement and steel intensity of U.S. economic activity has declined over time (Figs. 5.3.2d and 5.3.6), but per capita consumption has not.[56] The intensity trend is a net result of structural change in demand (e.g., buying software instead of a house) and technical efficiency gains (e.g., lightweighting and recycling).

Potentials quantified: case studies

Wood construction (cement and steel). The built environment represents an enormous and growing stock of materials, especially of cement and steel. Although these materials have the potential to be a source of secondary materials, reliable and consistent information about such stocks, especially at the global level, is missing. Recent estimates are that residential buildings worldwide contain 240 billion tons of concrete, projected to grow by 25-50 percent by 2050.[57]

However, there are a number of opportunities to reduce the materials and thus emissions intensity of the buildings sector both by using materials more efficiently and by substituting less emissions-intensive materials. Recent IEA reports indicate that the cement and steel intensity of building and infrastructure can be reduced by up to 26 percent and 40 percent, respectively, by reducing use of greenhouse gas (GHG) intense materials, extending infrastructure lifetimes, and reusing or recycling more building materials.[58] As a prominent example, if wood can be used instead of cement or steel, industrial emissions during materials production are reduced, and carbon is meanwhile stored in the wood products. A recent review of 51 studies suggests that for each kilogram of C in wood products that substitute non-wood products, on average 4.4 kg CO_2 emissions are avoided (with 95 percent of the values ranging from an increase of 2.6 kg of CO_2 emissions up to 18.7 kg CO_2 avoided).[59] These substitution benefits from using wood over alternative non-wood products are largely gained from less fossil CO_2 emissions during the production of the wood product (two-thirds of the benefit, on average). The other third of the substitution benefits are obtained from energy recovery at the end-of-life stage. These substitution benefits are sensitive to type of application, with benefits in construction of 4.8 to 5.9 kg of CO_2 avoided per kg of wood C, whereas using wood for producing textiles may lead to a substitution effect of 10.3 kg CO_2 / kg C (the largest benefit across all product types considered). It should be noted that these numbers do not include land use change emissions which might result from increased demand for forest products (see Chapter 5.5).

However, the extent to which wood can replace other construction materials varies. In the U.S., context wood frame buildings have traditionally been widely deployed for single family residences, but the U.S. is also leading a trend to use more wood in high-rise buildings (up to seven floors high in places where the codes have been relaxed).[60] Materials such as cross-laminated timber may even enable the use of wood in buildings taller than ten stories, but such applications will require alteration of materials and building standards.

Cement substitutes (cement). Cement clinker may also be substituted by other materials with similar properties, thereby reducing demand for cement. Supplementary cementitious materials (SCMs) can be used either as fillers or for their pozzolanic properties. Natural pozzolans are pyroclastic rocks (volcanic ash) and do not need pretreatment to react with calcium hydroxide. However, their availability is limited to specific locations, and shipping costs are a substantial barrier to trade given the relatively low cost of cement. Abundant and globally extensive silicon and aluminum oxide clays such as kaolinite (widely available is tropical and subtropical regions) may also be suitable substitutes after calcination at temperatures between 600 and 800°C. Fillers such as ground limestone are widely used in some regions such as China and can have positive effects on cement quality. However, standards have yet prevented the growth of this practice elsewhere, and extensive testing is needed before new standards are approved. Coupled substitution of limestone, calcined clay, and clinker (a so-called ternary blend) have been shown to give good mechanical performances at 50 percent clinker content.[61]

Other major options include blast furnace slag and fly ash from coal-fired power plants (of which 330 and 900 Mt are produced annually in recent years, respectively), both of which may have quality issues. Moreover, the amount of blast furnace slag is projected to decline as DRI iron-making processes gain importance. Similarly, the quantity of fly ash substitute is also projected to decline as coal consumption for power generation declines.

The majority of cement is used for concrete production, where cement is mixed with gravel, sand and water to yield a slurry that hardens.62 Proske designed low-cement concretes (using superplasticizer and limestone filler) and concluded that: "CO_2-emissions can be reduced significantly in structural concretes. A significant reduction in Portland cement demand may be achieved by using high performance superplasticizer, high-strength cement and optimized particle-size distribution."[63] This can result in: "a reduction in the global warming potential of up to 35 percent compared with conventional concrete... ".[64] However new concrete formulations are subject to strict and long testing procedures before they are approved. The most potential seems to be in concrete types that have been approved for challenging environments such as high-rise buildings and bridges. It's a matter of cost reduction through learning and upscaling to apply these in less demanding environments.

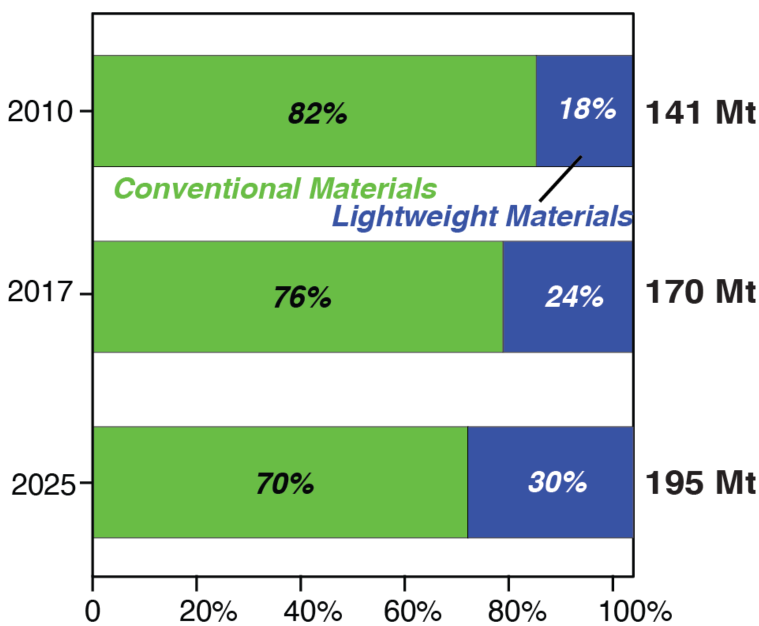

Figure 5.3.7. Trends and forecasts for global materials in the automotive industry (Fitzgerald etal., 2018)

Car lightweighting (steel). Figure 5.3.7 shows an example of how lightweighting in the automotive sector (with materials such as aluminum and plastic) could decrease the share of heavy (and emissions-intensive) conventional materials such as steel, with weight reductions leading to fuel savings (but note that the total weight of materials used by the automotive sector nonetheless increases over time as the number and average size of vehicles increases). Yet, public policies focused on reducing road transport emissions focus on fuel economy or tailpipe CO_2, neglecting potential life cycle and industry emissions reductions. Fortunately, car manufacturers recognize the potential of using lightweight materials to help meet fuel economy standards. For example, in 2015, Ford began making the body structure of its most successful vehicle, the F-150 pickup truck, entirely out of aluminum, reducing the mass of each vehicle by 700 pounds (318 kg) and improving fuel economy by ~20 percent relative to the 2014 model.[65]

Reduction, redesign and recycling of plastic packaging (chemicals). Packaging materials include various types of paper,, glass containers, wood pallets, aluminum and steel cans, and—relevant to the chemical industry—plastic films, plastic boxes, and plastic bottles. More than a third of all plastics and fibers are used for packaging, around 150 Mt per year.[66] Accounting for 26 percent of the total plastics market, it is argued that plastic packaging offers benefits in terms of convenience and performance. It is not possible to come up with a verifiable statement of how much plastic is discarded each year. This is largely due to problems with government tracking. One estimate has the figure at 32 million tons, and another has it at 39.9 million tons.[67] In any case, either number represents an amount of discarded materials that burdens local government budgets and overwhelms management systems.[68] One analysis has 81.4 percent of this material being landfilled, and 13.4 percent incinerated, leaving 5.2 percent recycled.[69] This analysis does not account for plastic waste that becomes litter. Annual global production of plastic has reached 335 million tons and continues to rise, and global plastic production will triple by 2050, accounting for twenty percent of global oil consumption.[70] Of the 8.3 billion metric tons of plastic produced in the past 60 years, 6.3 billion metric tons have become plastic waste.[71] This reflects the fact that most plastic packaging is designed for single use. Improvements to product design and waste management systems, coupled with a national phase-out of single use plastics (see Chapter 5.6), might drastically reduce the amount of discarded plastic materials, and increase plastic recycling, thereby reducing demand for chemicals such as ethylene.[72]

5.3.4 Conclusions and Policy Recommendations

Policy Recommendations

- Target funding of research and development to decarbonized cement, steel, and chemical processes, ideally in the context of public-private projects where technical bottlenecks are preventing private investment.
- Establish and encourage lead markets for decarbonized industrial commodities via, e.g., green procurement policies, GHG content regulations, and guaranteed production subsidies.
- Revise codes and regulations to allow testing and use of alternative building materials, and to reward more efficient use of emissions-intensive materials.
- Convene and coordinate forums of key stakeholders to map out complex system transitions and develop and establish standards and supporting institutions.

Incentives to innovate

We have established in earlier sections that the basic technologies to decarbonize most heavy industry emissions already exist, but at technology readiness levels that range from the lab bench to commercially demonstrated. In most cases, such alternatives have not been adopted because without policy interventions, fossil fuels are cheaper (e.g., electric vs. natural gas boilers). This has meant that, despite substantial and consistent improvements in the energy efficiency of industry, emissions intensities have remained high.

Reduce risks with lead markets. Innovations to decrease such emissions will be slow without policy drivers because profit margins on undifferentiated products are low; there is intense global competition; capital costs are high and can take decades to amortize; it may be difficult to capture the benefits of innovation; facility lives are long and turnover is slow; and most importantly, there is no market for more expensive low-carbon materials. Policies to encourage deep decarbonization of heavy industry must address these physical and market barriers.[73] Fundamentally, deep decarbonization of heavy industries like cement, steel, and chemicals is about reorienting the economy towards use of less emissions-intense materials while directing and reducing the risks of innovation to reduce emissions intensity. This will require a layered, mutually reinforcing policy package that tackles the numerous challenges directly.

First, the federal and state governments, industry associations, and large firms should signal directionality for investment and operation going forward with policy commitments to transition to a net-zero emissions industry.[74]

As discussed in Section 3, reducing industrial emissions isn't just about decarbonizing production, but demand as well.[75] Material efficiency and enhanced circularity have great potential to eliminate heavy industry emissions before they happen by reducing our need for primary steel, cement, chemicals, and other GHG intense materials. However, many of the opportunities for using materials more efficiently and using alternative materials would require sophisticated geotechnical testing and revision of buildings codes. For example, amended codes should: allow more substitution of low-carbon cementitious materials; mandate professional concrete mixing – the better concrete is made, the less needed for a given task; and explicitly consider emissions intensity in building and infrastructure design. Architects, designers, civil engineers, and contractors could also increasingly be trained to use steel and concrete only where needed.[76]

Decarbonizing key industrial processes will likely require a process to plan transition pathways that will include all the various stakeholders (i.e., sector associations, firms, governments, unions, interested and influential non-governmental organizations (NGOs), banks that do industrial finance) to assess technical options, strategic and competitive advantages, critical barriers, and uncertainties. The goal would be to reach sufficient working consensus to establish a long run industrial policy, including a policy package, collective innovation and finance needs, labour re-education, and a sequence of target markets for which low-emissions materials have value to end consumers.

Incentives to deploy

As discussed in previous sections of this chapter, technologies exist to decarbonize heavy industry. Moreover, the additional costs associated with these technologies may represent modest increases in the overall cost of buildings or vehicles. However, policy will be vital to accelerating remaining research, development, and—especially—commercialization of these technologies. Specifically, policies can create lead or niche markets to reduce risk for early innovators and to build economies of scale, much as satellites, calculators and remote electronics allowed solar photovoltaic (PV) to evolve beyond the lab.[77] For example, green public procurement, public GHG content regulations (e.g., California AB 262), private supply chain branding (e.g., luxury electric vehicle (EV) car manufacturers could use green steel and add it to the branding), supply chain linkages (e.g., the HYBRIT steel and ELYSIS aluminum projects), or guaranteed pricing & output subsidies.

The latter can be applied using “contracts for difference”(CfDs), a common mechanism used for renewable electricity generation, where the government or a private buyers consortium agrees upfront to offer a premium over market prices for usually generic commodities.[78] The ELYSIS project to make virtually zero GHG aluminum (via inert electrodes, eliminating electrolysis smelting process CO_2 emissions) not only links the supply chain from aluminum producer (Rio Tinto and Alcoa) to consumer (Apple), it allows the high cost of the inert electrodes to flow through to consumer, for whom the costs will be less than a dollar per computer. Applying this logic to electric car manufacturing, if VW, Tesla, or BMW committed to using only ultra-low-emissions steel when available, it would add an estimated $200-400 per vehicle, improve the company’s green branding, and dramatically reduce the risks for steel producers.

Overcome system technical, financial and logistic barriers with public-private coordination. Sometimes fundamental technical challenges beyond any one firm’s technical or financial capability stand in the way of innovation. The U.K. Offshore Wind Accelerator project, initiated by the U.K. government and including participation by all the key North Sea wind turbine firms, was set up to analyse the supply chain for a potential offshore floating wind industry, identify and solve the technical bottlenecks collectively with government support, and then return to competition all owning the necessary new intellectual property.[79] This project was key to recent successful unsubsidized auctions at 5-7 euro cents/kWh. The Federal Government and its agencies could similarly catalyze progress by initiating similar programs around specific technical challenges such as demonstrating alternative cement binders, green steel-making process, or electrosynthesis of key chemical feedstocks.

Ensure competitiveness of green industries. It is highly likely once the best available technology standard is to reset to very low or zero levels that in most jurisdictions green steel or cement will still cost more than today’s commodity until a high level of general carbon pricing or standards is applied to all market participants. When lead market subsidies are eventually removed, U.S. industry will need to be gradually exposed to full carbon pricing or equivalent performance standards. If trading partners do not have equivalent policy, the U.S. may need to apply competitiveness protections such as border carbon adjustments or border standards to even the playing field while adhering to WTO rules.[80] Importantly, such measures should be designed to allow new supply green material supply chains to evolve. For example, green steel might be made using hydrogen DRI EAFs in Australia or other locations with good solar insolation and iron ore, or more general intermediate commodities (e.g., green sponge iron, ammonia, methanol, etc.) could be processed where it is least costly and transported for final low-emissions processing where they are needed (e.g., hydrogen DRI iron made with solar energy in South Africa or Australia or with wind and hydroelectricity in Québec, and then shipped to BF-BOFs or EAFs for final processing into steel products in Europe, North America or China).[81] Eventually, full supply chain carbon pricing will be needed to “mine” material efficiencies across the economy.

Manage phase-out of existing infrastructure. Given the large existing fleet of steel and cement plants, with an especially young fleet in China, locked-in production may start to interfere with uptake of new ultra-low- and zero-emissions technologies.[82] Much of it will be retrofittable, but for the elements that aren’t, “sunsetting” or early retirement may be necessary, with real costs for companies to the extent these facilities are not yet amortized.[83] It also implies that the costs of industrial decarbonization may be geographically concentrated in the communities and regions where current infrastructure exists, similar to what is occurring with coal mining today globally.

The political economy implications of this must be planned for ahead of time including retraining, new investment in growing industry in the region, etc. (see general discussion of environmental justice in Chapter 3).

Supporting institutions for all the above will be required. Infrastructure planning and construction, because of its natural monopoly nature and long life, tends to be a joint public and private activity, and such planning will be critical for a capital-intensive transition of U.S. industry. In particular, a clear, easy-to-implement, and broadly-used method of life cycle accounting for materials will be required to support effective carbon pricing and border carbon adjustments policies. Education must be enhanced for building and infrastructure architects and designers, civil engineers, trades, building code regulators and everyone else involved with the building and infrastructure supply chain. Last but not least, the regulatory and legal environment must be clarified: who is liable for what with regard to carbon capture and storage, storage and transport of hydrogen, contracts for difference, etc.

Finally, depending at what jurisdictional level policy enforcement takes hold, which will depend on the constellation of willing jurisdictions and firms, arm's length institutions to monitor progress and suggest policy adjustments will be needed; successful examples include the role of the California Air Resources Board in driving innovations to reduce transport emissions and improve air quality in the state and nationwide, as well as the U.K. Commission on Climate Change, which monitors the U.K. economy-wide policies and carbon budgets. If the U.S. were to establish a White House Office of Climate Change, as we recommend in Chapter 4, that body could oversee and coordinate monitoring and policy adjustments, which would have the additional benefit of preventing inter-state leakage (i.e., emissions-intensive industries migrating to states and jurisdictions with less regulation of emissions).

Monitoring and regulating the emergent system

Decarbonizing the industrial sector will take place in the context of two major dynamics: a changing industrial base and a changing climate. Designing an effective monitoring and regulatory regime thus motivates a clear understanding and acknowledgment of these changes and their likely impact on climate and other outcomes. Socio-environmental assessment before and during transitions should account for the possibility (and probability) that assumptions made today might not be valid in the future. Some of these changes might be relevant during the life cycle of equipment installed today, and others might become more relevant in the far future, after decarbonization is mostly complete. For example, evaluation of the climate impact of electrifying a process now should account for expectations that the electricity grid will continue to decarbonize, which is immediately relevant.[84] Evaluation of the relative merits of alternative zero carbon energy carriers, however, should consider both the immediate impacts relative to a present-day counterfactual (e.g., displacing a fossil fuel) as well as the potential impacts relative to a far-future counterfactual (e.g., displacing a different zero-carbon energy carrier).[85]

Scenario-based assessments of the transitioning industrial sector can help highlight possible conditional weaknesses and increase confidence in the robustness of a decision in the face of considerable uncertainty.[86] Scenario analysis could be a particularly valuable tool in the early stages of industrial transition, especially with respect to identifying sectoral interdependencies and potentially hidden assumptions about integrated systems.

Just as investing in electric trucks relies on the assumption that roads and electricity will be available, investing in specific industrial technologies relies on assumptions about the broader system that might or might not be realistic amidst industrial and climate dynamics. For example, the cement industry has already observed that the supply of fly ash from coal-fired power plants for use as a supplementary cementitious material (SCM) depends on coal-fired electricity generation, which is expected to disappear as decarbonization proceeds.[87] Monitoring the emergent system should therefore include the goal of identifying such dependencies.

Both monitoring and regulation of emergent zero- or low- carbon industrial activities should also consider the impact of scale on socio-environmental characteristics. Problems that are negligible at pilot scale might not remain negligible at industrial scale, and vice versa. For example, small-scale demand for a mined resource could be easily met with waste streams from other mined resources or high-grade mines, but extensive demand might require development of larger, costlier mining complexes. Similarly, repurposing infrastructure might require reconsideration of maintenance schedules and needs. For example, natural gas pipelines repurposed to transport alternative hydrogen carriers might have different product loss rates (e.g., hydrogen is a smaller molecule than methane and more readily escapes pipes designed for methane); different operating pressures; different costs; and different safety requirements.

The impact of the changing climate is another major consideration for industry monitoring and regulation. Design standards, maintenance requirements, reliability assumptions, and other characteristics should all be considered in the context of expectations about the future, rather than current climate. See, for example, Lopez-Cantu et al. thoughtful analysis of future climate risks in designing stormwater system standards.[88] Today's capital investments are the future's committed infrastructure, so carefully considering issues like heat, humidity, extreme storms, and other impacts of climate change while designing, monitoring, and regulating those investments may be critical to their cost-effectiveness and long-term success.

Conclusions

Industrial processes to produce cement, steel, and chemicals are expected to be among the most challenging parts of modern economies to decarbonize.[89] In addition to CCS, technical solutions are available to both reduce demand for emissions-intensive products and decarbonize the underlying processes. However, such alternatives face a number of barriers that can be directly addressed by policies. Such policy priorities include:

- Revising building and infrastructure codes and best practices of design to encourage material efficiency improvements and explicitly consider emissions intensity of materials
- Increase public funding of research and development of new technologies that could eliminate CO_2 emissions from the cement, steel and chemical industries, and foster public-private collaborations to support the demonstration of the most-promising technologies at commercial scale.
- Convening and coordinating forums of key stakeholders, including manufacturers, regulators, scientists, and research institutions, to map out complex system transitions and develop and establish standards and supporting institutions.
- Incentivizing commercialization by establishing lead markets for more expensive green industrial products and, eventually, protecting nascent green industries with border standards or border carbon adjustments.
- Proactively addressing challenges of lock-in and environmental justice associated with existing industry infrastructure, for instance by targeted public support for “sunsetting” of emissions-intensive capital, retraining industry workers, growing new industry in affected regions.

References

1. "Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2018". 2020. US EPA. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018.

2. EPA, Inventory.;

   Bataille, Chris. 2019. "Physical and policy pathways to net-zero emissions industry". *WIRES Wiley Interdisciplinary Reviews,* 1-20, doi:10.1002/wcc.633.

3. Hoesly, Rachel M., Steven J. Smith, Leyang Feng, Zbigniew Klimont, Greet Janssens-Maenhout, Tyler Pitkanen, and Jonathan J. Seibert et al. 2018. "Historical (1750–2014) Anthropogenic Emissions Of Reactive Gases And Aerosols From The Community Emissions Data System (CEDS)". *Geoscientific Model Development* 11 (1): 369-408. doi:10.5194/gmd-11-369-2018.

4. John Dunham and Associates, Inc. 2018. "The Economic Impact Of The American Iron And Steel Industry". American Iron and Steel institute. https://www.steel.org/-/media/doc/steel/policy/reports/economicimpact/dunham-methodology.ashx?la=en&hash=143B7B196B37FEFED363FFC013E60E90D1ED9780.;

   "Chemical Industry Spotlight | Selectusa.Gov". 2020. *Selectusa.Gov*. https://www.selectusa.gov/chemical-industry-united-states.;

   "Cement Statistics And Information". 2020. Usgs.Gov. https://www.usgs.gov/centers/nmic/cement-statistics-and-information.; "Gross Output Of All Industries". 2020. *Fred.Stlouisfed.Org*. https://fred.stlouisfed.org/series/GOAI.

5. "Total U.S. Chemical Import Value 2019". 2020. Statista. https://www.statista.com/statistics/258904/us-chemical-imports-since-2001/.; "Iron And Steel Statistics And Information". 2020. *Usgs.Gov.* https://www.usgs.gov/centers/nmic/iron-and-steel-statistics-and-information?qt-science_support_page_related_con=0#qt-science_support_page_related_con.; "Cement Statistics".

6. "Cement Statistics".;

   "Iron And Steel Statistics".;

   "Population, Total - United States | Data". 2020. *Data.Worldbank.Org*. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=US.

7. "Cement Statistics".;

   "Iron And Steel Statistics".; "GDP (Current US$) - United States". 2020. *Data.Worldbank.Org*. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=US.

8. Hoesly et al., "Historical (1750–2014) Anthropogenic Emissions".

9. Ibid.

10. Tong, D, Qiang Zhang, Yixuan Zheng, Ken Caldeira, Christine Shearer, Chaopeng Hong, Yue Qin and Steven J. Davis. 2019."Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target". *Nature* 572, 373-377, doi:10.1038/s41586-019-1364-3.; "Cement Statistics".; *Global Cement Directory*. 2020. Epsom, UK: Pro Publications.

11. U.S. Census Bureau. 2015. "Manufacturing: Subject Series: Concentration Ratios: Share of Value of Shipments Accounted for by the 4, 8, 20, and 50 Largest Companies for Industries: 2012".

12. Kollmeyer, C. 2018. "Trade Union Decline, Deindustrialization, and Rising Income Inequality in the United States, 1947 to 2015". *Research in Social Stratification and Mobility* 57, 1–10, doi:10.1016/j.rssm.2018.07.002.

13. Dowling, Jacqueline A., Katherine Z. Rinaldi, Tyler H. Ruggles, Steven J. Davis, Mengyao Yuan, Fan Tong, Nathan S. Lewis, and Ken Caldeira. 2020. "Role Of Long-Duration Energy Storage In Variable Renewable Electricity Systems". *Joule*. doi:10.1016/j.joule.2020.07.007.

14. EPA, Inventory.;

    Dean, Charles C., Denis Dugwell, and Paul S. Fennell. 2011. "Investigation Into Potential Synergy Between Power Generation, Cement Manufacture And CO2 Abatement Using The Calcium Looping Cycle". *Energy & Environmental Science* 4 (6): 2050. doi:10.1039/c1ee01282g.

15. Davis, Steven Joseph, Nathan S. Lewis, Matthew Shaner, and Sonia Aggarwal. 2018. "Net-zero emissions energy systems". *Science* 360, 1419. 10.1126/science.aas9793.;

    Dean, C. C.; Dugwell, D.; Fennell, P. S. 2011. Investigation into Potential Synergy between Power Generation, Cement Manufacture and CO 2 Abatement Using the Calcium Looping Cycle. *Energy & Environmental Science* 2011, 4 (6), 2050–2053.

16. Kilhelmsson, Bodil; Kollberg, Claes; Larsson, Johan; Eriksson, Jan; Magnus, E. 2018. A Feasibility Study Evaluating Ways to Reach Sustainable Cement Production via the Use of Electricity. Cementa and Vattenfall.

17. Hills, Thomas P., Mark Sceats, Daniel Rennie, and Paul Fennell. 2017. "LEILAC: Low Cost CO2 Capture For The Cement And Lime Industries". *Energy Procedia* 114: 6166-6170. doi:10.1016/j.egypro.2017.03.1753.

18. Mineral Products Association, Cinar Ltd., and VDZ gGmbH. 2019. "Options For Switching UK Cement Production Sites To Near Zero CO2 Emission Fuel: Technical And Financial Feasibility.". SBRI Competition. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866365/Phase_2_-_MPA_-_Cement_Production_Fuel_Switching.pdf.

19. Leeson, D., Mac Dowell, N., Shah, N., Petit, C. & Fennell, P. 2017. "A Techno-Economic Analysis and Systematic Review of Carbon Capture and Storage (CCS) Applied to the Iron and Steel, Cement, Oil Refining and Pulp and Paper Industries, as Well as Other High Purity Sources". *International Journal of Greenhouse Gas Control* 61, 71–84.

20. Fennell and Ganzer. 2020. *Literature review of Capital and Operating costs of Cement Plants with CCS*. Final report to BEIS.

21. "NAHB: Cost Of Constructing A Home". 2020. *Nahbclassic.Org*. https://www.nahbclassic.org/generic.aspx?genericContentID=260013#:~:text=On%20average%20in%20the%202017,to%20marketing%20costs%2C%20leaving%2010.7.

22. Kilhelmsson, et al., *A Feasibility Study Evaluating Ways to Reach Sustainable Cement Production*.

23. IEA. 2018. *Technology Roadmap - Low-Carbon Transition in the Cement Industry*. Paris, France: International Energy Agency. https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry.

24. Andrew, R. 2019. Global CO2 emissions from cement production. *Earth Systems Science Data*(11), 1675 - 1710.

25. Bentz, D. P., Irassar, E. F., Bucher, B. E., & Weiss, W. J.. 2009. Limestone Fillers Conserve Cement Part 1: An analysis based on Powers' model. Concrete International.

26. Cao, Z., Myers, R., Lupton, R., Duan, H., Sacchi, R., Zhou, N., Reed Miller, T., Cullen, J., Ge, Q. and Liu, G., 2020. The sponge effect and carbon emission mitigation potentials of the global cement cycle. *Nature Communications*, 11(1).;

Xi, F., Davis, S., Ciais, P., Crawford-Brown, D., Guan, D., Pade, C., Shi, T., Syddall, M., Lv, J., Ji, L., Bing, L., Wang, J., Wei, W., Yang, K., Lagerblad, B., Galan, I., Andrade, C., Zhang, Y. and Liu, Z., 2016. Substantial global carbon uptake by cement carbonation. *Nature Geoscience*, 9(12), pp.880-883.

27. Naqi, A. & Jang, J. G. 2019. "Recent Progress in Green Cement Technology Utilizing Low-Carbon Emission Fuels and Raw Materials: A Review". *Sustainability* 11, 1-18.

28. Majcher, Kristen. 2015. "What Happened To Green Concrete?". *MIT Technology Review*. https://www.technologyreview.com/2015/03/19/73210/what-happened-to-green-concrete/.

29. Sonter, L. J., Barrett, D. J., Moran, C. J. & Soares-Filho, B. S. 2015. "Carbon emissions due to deforestation for the production of charcoal used in Brazil's steel industry". *Nature Climate Change* 5, 359-363.

30. Davis, Stephen Joseph et al., "Net-zero emissions energy systems".

31. Hasanbeigi, A., Arens, M. & Price, L. 2014. "Alternative emerging ironmaking technologies for energy-efficiency and carbon dioxide emissions reduction: a technical review". *Renewable and Sustainable Energy Reviews* 33, 645-658.;

Morfeldt, J., Nijs, W. & Silveira, S. 2015. "The impact of climate targets on future steel production - an analysis based on a global energy system model". *Journal of Cleaner Production* 103, 469-482.;

Quader, M. A., Ahmed, S., Ghazilla, R. A. R., Ahmed, S. & Dahari, M. 2015. "A comprehensive review on energy efficient CO2 breakthrough technologies for sustainable green iron and steel manufacturing". *Renewable and Sustainable Energy Reviews* 50, 594-614.;

Neuhoff, K. et al. 2014. "Carbon Control and Competitiveness Post 2020: the Steel Report".

32. Allwood, J. 2016. Bright Future for UK Steel: a Strategy for Innovation and Leadership through Up-cycling and Integration.

33. Morfeldt, J. et al., The impact of climate targets on future steel production.;

Allwood, J. M., Cullen, J. M. & Carruth, M. A. 2012. *Sustainable Materials: with Both Eyes Open*. UIT Cambridge.;

Pauliuk, S., Milford, R. L., Müller, D. B. & Allwood, J. M. 2013."The Steel Scrap Age". *Environmental Science & Technology* 47.

34. Sonter, L. J., Barrett, D. J., Moran, C. J. & Soares-Filho, B. S. 2015. "Carbon emissions due to deforestation for the production of charcoal used in Brazil's steel industry". *Nature Climate Change* 5, 359-363.

35. Leeson, D et al., "A Techno-Economic Analysis and Systematic Review".;

IRENA. 2014. *Renewable Energy in Manufacturing, a Technology Roadmap for REmap 2030*.

36. Sonter, L.J. et al., "Carbon emissions due to deforestation".;

Piketty, M.-G., Wichert, M., Fallot, A. & Aimola, L. 2009. "Assessing land availability to produce biomass for energy: The case of Brazilian charcoal for steel making". *Biomass and Bioenergy* 33, 180-190.

37. Åhman, M., Nikoleris, A. & Nilsson, L. J. 2012. "Decarbonising Industry in Sweden - an Assessment of Possibilities and Policy Needs".;

Fischedick, M. et al. 2014. In Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change 739-810.;

McMillan, C. et al. 2016. "Generation and Use of Thermal Energy in the U. S. Industrial Sector and Opportunities to Reduce its Carbon Emissions".;

Weigel, M., Fischedick, M., Marzinkowski, J. & Winzer, P. 2016. "Multicriteria analysis of primary steelmaking technologies". *Journal of Cleaner Production* 112, 1064-1076.

38. Kilhelmsson, Bodil et al., A Feasibility Study Evaluating Ways to Reach Sustainable Cement Production.;

IEA. 2019. World energy balances. IEA World Energy Statistics and Balances 2018, doi:10.1787/data-00510-en.;

Vattenfall. 2017. "Fossil Free Within One Generation". Annual And Sustainability Report 2017. Solna, Sweden: Vattenfall. https://group.vattenfall.com/siteassets/corporate/investors/annual-reports/2017/vattenfall_annual_and_sustainability_report_2017_eng.pdf.

39. Åhman, M. et al., Decarbonising Industry in Sweden.;

Fischedick, M. et al., *In Contribution of Working Group III*.;

Lechtenböhmer, S., Nilsson, L. J., Ahman, M. & Schneider, C. 2016. "Decarbonising the energy intensive basic materials industry through electrification – implications for future EU electricity demand". *Energy* 115, 1623–1631.;

Allanore, A., Yin, L. & Sadoway, D. R. 2013. "A new anode material for oxygen evolution in molten oxide electrolysis". *Nature* 497, 353-356.

40. Allanore, A. 2015. "Features and challenges of molten oxide electrolytes for metal extraction". *Journal of The Electrochemical Society* 162, E13-E22.

41. IEA. 2019. *World energy statistics*. Paris, France: IEA. https://www.iea.org/reports/world-energy-statistics-2019.

42. Greenhouse gases from oil, gas, and petrochemical production;

"Environmental Integrity". 2020. *Environmentalintegrity.Org*. https://environmentalintegrity.org/.

43. Friedmann, B. Y. S. J., Fan, Z. & Tang, K. E. 2019. *Low-Carbon Heat Solutions for Heavy Industry : Sources , Options , and Costs Today.*

44. IEA. 2018. *The Future of Petrochemicals : Towards more sustainable plastics and fertilisers*. 1-66. Paris, France: International Energy Agency.

45. IEA. 2019. *The Future of Hydrogen*. Paris, France: International Energy Agency.

46. Leeson, D. et al., "A Techno-Economic Analysis and Systematic Review".

47. Philibert, C. 2017. *Producing ammonia and fertilizers: new opportunities from renewables*. Paris, France: International Energy Agency.

48. Bazzanella, A. M. & Ausfelder, F. 2017. *Low carbon energy and feedstock for the European chemical industry*. DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V.

49. Philibert, C., Producing ammonia and fertilizers.

50. Keith, D. W., Holmes, G., St., A., D. & Heidel, K. 2018. "A process for capturing CO2 from the atmosphere. *Joule* 2, 1573–1594".

51. Meijden, C. M., van der Rabou, L. P. L. M., Vreugdenhil, B. J. & Smit, R. 2011. "Large scale production of bio methane from wood". The International Gas Union Research Conference IGRC.;

Lechtenböhmer, S. et al., "Decarbonising the energy intensive basic materials industry".;

Luna, P. D. et al. 2019. "What would it take for renewably powered electrosynthesis to displace petrochemical processes?" *Science* 364, 350.

52. Bazzanella & Ausfelder, Low carbon energy and feedstock.;

Luna, P. D. et al., "What would it take for renewably powered electrosynthesis".

53. Luna, P. D. et al., "What would it take for renewably powered electrosynthesis".

54. Ibid.;

Wesseling, J. et al. 2017. "The transition of energy intensive processing industries towards deep decarbonization: characteristics and implications for future research". *Renewable and Sustainable Energy Reviews* 79, 1303-1313.;

Bataille, C. et al. 2018. "A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris Agreement". *Journal of Cleaner Production* 187, 960–973, doi:10.1016/j.jclepro.2018.03.107.;

Wyns, T., Khandekar, G., Axelson, M., Sartor, O. & Neuhoff, K. 2019. *Industrial Transformation 2050: Towards an industrial strategy for a climate neutral Europe*. Brussels, Belgium: Institute for European Studies.;

Material Economics. 2019. *Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry*. Cambridge, England: University of Cambridge Institute for Sustainable Leadership.

55. Gielen, D., 1999. *Materialising Dematerialisation: Integrated Energy And Materials Systems Engineering For Greenhouse Gas Emission Mitigation*. Ph.D. Delft University of Technology.;

Levi, P. and Cullen, J., 2018. Mapping Global Flows of Chemicals: From Fossil Fuel Feedstocks to Chemical Products. *Environmental Science & Technology*, 52(4), pp.1725-1734.

56. Smil, V. 2014. Making the Modern World: Materials and Dematerialization. John Wiley & Sons, 2014.

57. Marinova, S., Deetman, S., van der Voet, E. and Daioglou, V., 2020. Global construction materials database and stock analysis of residential buildings between 1970-2050. *Journal of Cleaner Production*, 247, p.119146.

58. IEA. 2019. Material efficiency in clean energy transitions. Paris, France: IEA. https://www.iea.org/reports/material-efficiency-in-clean-energy-transitions.

59. Leskinen, Pekka, Giuseppe Cardellini, Sara González-García, Elias Hurmekoski, Roger Sathre, Jyri Seppälä, Carolyn Smyth, Tobias Stern and Pieter Johannes Verkerk. 2018. *Substitution effects of wood-based products in climate change mitigation*. From Science to Policy 7. European Forest Institute.

60. "Bloomberg - Are You A Robot?". 2020. *Bloomberg.Com*. https://www.bloomberg.com/news/articles/2019-08-05/the-problem-for-business-when-inventory-is-no-problem-justin-fox.

61. Naqi & Jang, "Recent Progress in Green Cement Technology".

62. Teger, A., 2015. *The Minimal Cement Content Of Workable Concrete*. MSc. Israel Institute of Technology.

63. Proske, T., Hainer, S., Rezvani, M. and Graubner, C., 2013. Eco-friendly concretes with reduced water and cement contents — Mix design principles and laboratory tests. *Cement and Concrete Research*, 51, pp.38-46.

64. Teger, A., *The minimal cement content of workable concrete*.; Proske et al., Eco-friendly concretes;

Geyer, R. in *Taking stock of industrial ecology* (eds R. Swift & A. Druckman) (Springer, 2016).;

Fitzgerald, B., Mazumdar & Lucintel, S. 2018. *The new plastics economy - Catalysing action*. Ellen MacArthur Foundation, 2018.

65. Clift, Roland, and Angela Druckman, Eds. 2016. *Taking Stock Of Industrial Ecology*. Springer.

66. BloombergNEF. 2019.

67. Data cited from: "Home | Break Free From Plastic". 2020. *Break Free From Plastic*. https://www.breakfreefromplastic.org/.;

Udall and Lowenthal, "Legislative Blueprints for Reducing Plastic";

Analysis and summary conclusions based on: 1) US EPA 2015 data (the EPA will next publish data in 2021 based on 2018 information), 2) US Census Bureau 2018 data, 3) estimates via mass balance analysis, and 4) incorporating an assumed 5% annual growth rate for single-use plastics based on increases in US bottled water sales, as reported in: "Six Times More Plastic Waste Is Burned In The U.S. Than Is Recycled". 2019. Blog. *Plastic Pollution Coalition*. https://www.plasticpollutioncoalition.org/blog/2019/4/29/six-times-more-plastic-waste-is-burned-in-us-than-is-recycled.

68. Data cited.

69. Analysis and summary conclusions.

70. Data cited.

71. Data cited.

72. Garcia, Jeannette M., and Megan L. Robertson. 2017. "The Future Of Plastics Recycling". *Science* 358 (6365): 870-872. doi:10.1126/science.aaq0324.;

"Impact Of Plastics Recycling On The Future Of Energy Transition". 2020. *IHS Markit*. https://ihsmarkit.com/research-analysis/impact-of-plastics-recycling-on-future-energy-transition.html?ite=988080&ito=1274&itq=13593fbb-6058-4a35-a1b3-ca38a2f9dab2&itx%5Bidio%5D=24716138.

73. Bataille, C. 2019. Physical and policy pathways to net-zero emissions industry. *WIRES Wiley Interdisciplinary Reviews*, 1-20, doi:10.1002/wcc.633.;

Bataille, C. et al. 2018. A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris Agreement. *Journal of Cleaner Production* 187, 960–973, doi:10.1016/j.jclepro.2018.03.107.

74. Wesseling, J.H., S. Lechtenböhmer, M. Åhman, L.J. Nilsson, E. Worrell, and L. Coenen. 2017. "The Transition Of Energy Intensive Processing Industries Towards Deep Decarbonization: Characteristics And Implications For Future Research". *Renewable And Sustainable Energy Reviews* 79: 1303-1313. doi:10.1016/j.rser.2017.05.156.;

Åhman, Max, Lars J. Nilsson, and Bengt Johansson. 2016. "Global Climate Policy And Deep Decarbonization Of Energy-Intensive Industries". *Climate Policy* 17 (5): 634-649. doi:10.1080/14693062.2016.1167009.

75. Bataille, C., Physical and policy pathways to net-zero emissions industry.

76. Scrivener, Karen & John, Vanderley & Gartner, Ellis. 2018. *Eco-efficient cements: Potential economically viable solutions for a low-CO2 cement-based materials industry*. UN Environment.

77. Kavlak, Goksin, James McNerney, and Jessika E. Trancik. 2018. "Evaluating The Causes Of Cost Reduction In Photovoltaic Modules". *Energy Policy* 123: 700-710. doi:10.1016/j.enpol.2018.08.015.

78. Sartor, Olivier & Chris Bataille. 2019. *Decarbonising basic materials in Europe : How Carbon Contracts-for-Difference could help bring breakthrough technologies to market*. IDDRI Policy Brief. Paris, France: IDDRI.

79. "Offshore Wind Accelerator (OWA)". 2020. *Carbon Trust*. https://www.carbontrust.com/our-projects/offshore-wind-accelerator-owa.

80. Mehling, Michael A., Harro van Asselt, Kasturi Das, Susanne Droege, and Cleo Verkuijl. 2019. "Designing Border Carbon Adjustments For Enhanced Climate Action". *American Journal Of International Law* 113 (3): 433-481. doi:10.1017/ajil.2019.22.

81. Vogl, Valentin, Max Åhman, and Lars J. Nilsson. 2018. "Assessment Of Hydrogen Direct Reduction For Fossil-Free Steelmaking". *Journal Of Cleaner Production* 203: 736-745. doi:10.1016/j.jclepro.2018.08.279.;

Gielen, Dolf, Deger Saygin, Emanuele Taibi, and Jean–Pierre Birat. 2020. "Renewables–Based Decarbonization And Relocation Of Iron And Steel Making: A Case Study". *Journal Of Industrial Ecology*. doi:10.1111/jiec.12997.;

Bataille, C., 2019. Physical and policy pathways to net-zero emissions industry. *WIRES Wiley Interdisciplinary Reviews* 1–20. doi:10.1002/wcc.633

82. Tong, D. et al., Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target.;

Seto, Karen C., Steven J. Davis, Ronald B. Mitchell, Eleanor C. Stokes, Gregory Unruh, and Diana Ürge-Vorsatz. 2016. "Carbon Lock-In: Types, Causes, And Policy Implications". *Annual Review Of Environment And Resources* 41 (1): 425-452. doi:10.1146/annurev-environ-110615-085934.

83. Fofrich, Robert, Dan Tong, Katherine Calvin, Harmen Sytze De Boer, Johannes Emmerling, Oliver Fricko, Shinichiro Fujimori, Gunnar Luderer, Joeri Rogelj, and Steven J Davis. 2020. "Early Retirement Of Power Plants In Climate Mitigation Scenarios". *Environmental Research Letters* 15 (9): 094064. doi:10.1088/1748-9326/ab96d3.

84. Kiss, Benedek, Enikő Kácsor, and Zsuzsa Szalay. 2020. "Environmental Assessment Of Future Electricity Mix – Linking An Hourly Economic Model With LCA". *Journal Of Cleaner Production* 264: 121536. doi:10.1016/j.jclepro.2020.121536.

85. Grubert, Emily. 2020. "At Scale, Renewable Natural Gas Systems Could Be Climate Intensive: The Influence Of Methane Feedstock And Leakage Rates". *Environmental Research Letters* 15 (8): 084041. doi:10.1088/1748-9326/ab9335.

86. Maier, H.R., J.H.A. Guillaume, H. van Delden, G.A. Riddell, M. Haasnoot, and J.H. Kwakkel. 2016. "An Uncertain Future, Deep Uncertainty, Scenarios, Robustness And Adaptation: How Do They Fit Together?". *Environmental Modelling & Software* 81: 154-164. doi:10.1016/j.envsoft.2016.03.014.

87. "Tackling The Fly Ash Supply Issue". 2020. Materials That Perform: Building Materials Suppliers. https://www.materialsthatperform.com/tackling-fly-ash-supply-issue.

88. Lopez-Cantu, Tania, and Constantine Samaras. 2018. "Temporal And Spatial Evaluation Of Stormwater Engineering Standards Reveals Risks And Priorities Across The United States". *Environmental Research Letters* 13 (7): 074006. doi:10.1088/1748-9326/aac696.

89. Bataille, Chris, "Physical and policy pathways to net-zero".;

Davis, Steven J., Nathan S. Lewis, Matthew Shaner, Sonia Aggarwal, Doug Arent, Inês L. Azevedo, and Sally M. Benson et al. 2018. "Net-Zero Emissions Energy Systems". *Science* 360 (6396): eaas9793. doi:10.1126/science.aas9793.;

Bataille, Chris, Max Åhman, Karsten Neuhoff, Lars J. Nilsson, Manfred Fischedick, Stefan Lechtenböhmer, and Baltazar Solano-Rodriquez et al. 2018. "A Review Of Technology And Policy Deep Decarbonization Pathway Options For Making Energy-Intensive Industry Production Consistent With The Paris Agreement". *Journal Of Cleaner Production* 187: 960-973. doi:10.1016/j.jclepro.2018.03.107.

5.4 Accelerating Deep Decarbonization in the U.S. Buildings Sector

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5.4.1 Introduction, Context, and Goals

To advance the building sector's deep carbon reductions, we propose policies to create—in a job-intensive fashion—a new generation of greener and healthier low-carbon buildings and communities. Today, the U.S. residential buildings sector by itself has a larger footprint than the entire greenhouse gas (GHG) output of Germany or Brazil. In bringing those and associated carbon emissions to zero, the U.S. can lead in the development of cutting edge technology, restore its productive capacities and global competitiveness, create millions of well-paid construction related jobs, and cut the energy bills for those Americans who can least afford them.

The policy plan put forward in this chapter would ensure that by 2050, GHG emissions from onsite fossil fuel consumption in buildings have been reduced by at least 90 percent. Instead, buildings would be powered by clean electricity (including from on-site renewables where it is reliable and cost-effective), or in limited circumstances from low-to-no-carbon gas, pending the development of more affordable technologies. Electrification supported by renewables, energy efficiency, and grid-wide demand-response strategies will ensure the 2050 goals of this overall report are achieved at the lowest incremental cost to society improving the health, security, and livelihoods of Americans across the country.

Prominent and highly progressive policy proposals have set forth ambitious goals for the building sector – either directly, such as "reducing the carbon footprint of the U.S. building stock 50 percent by 2035," or by implicitly assuming those types of savings by requiring the entire U.S. economy to reduce greenhouse gas emissions by 37 percent below 2010 levels by 2030.[1] They also include detailed lists of possible legislation including potential revisions to existing financial incentives (tax or financing) or capacity-building programs that impact the U.S. building stock. The proposals in this chapter present a holistic, data-supported action plan for assessing and prioritizing these more granular ideas. This chapter also details how the building sector is currently using and wasting energy resources, the strategies that are necessary to decarbonize the sector, and, where appropriate, how these proposals advance beyond the status quo trends in policymaking at the federal and sub-national levels.

Finally, this chapter provides a distillation of the roadmap to those policies and practices most critical to meeting the ambitious 2050 target date for a carbon-free U.S. economy.

Building Sector Decarbonization for Job Creation, Cost Minimization, and Poverty Reduction

Efficiency Gains Ensure Lowest Cost Pathway & Energy Poverty Reduction

The deep decarbonization pathway to net-zero by 2050 laid forth in this plan is built on the firm assumption that across all sectors we can achieve a 40 percent per capita reduction in energy demand (energy efficiency) by 2050 and a 300 percent increase in the share of energy from electricity (see Figure 5.4.2). Failure to accomplish this level of efficiency (principally from the transportation and building sectors) could increase the total costs of building out and managing the new and expanded clean energy grids by as much as 300 percent in major metropolitan population centers (See e.g., Figure 5.4.1).[2] In short, efficient buildings fueled by clean energy are the lowest cost pathway to accomplishing the broader policy action plan set forth in this document.

The value of energy efficiency will not be limited to reducing the overall costs to our society of decarbonization. Individual Americans, especially those in low income housing, will also be beneficiaries, through reduced energy costs. Energy poverty reduction was a large part of the Obama administration's clean energy stimulus initiatives included in the American Recovery and Reinvestment Act (ARRA) passed in the Winter of 2009. For example, through ARRA's Energy Efficiency and Conservation Block Grant (EECBG), for every federal $1 spent, the beneficiaries received $1.76 in annual bill savings over the lifetime of the measures installed with total cumulative savings on energy bills assessed to be $5.2B.[3] This chapter builds on and surpasses these types of outcomes.

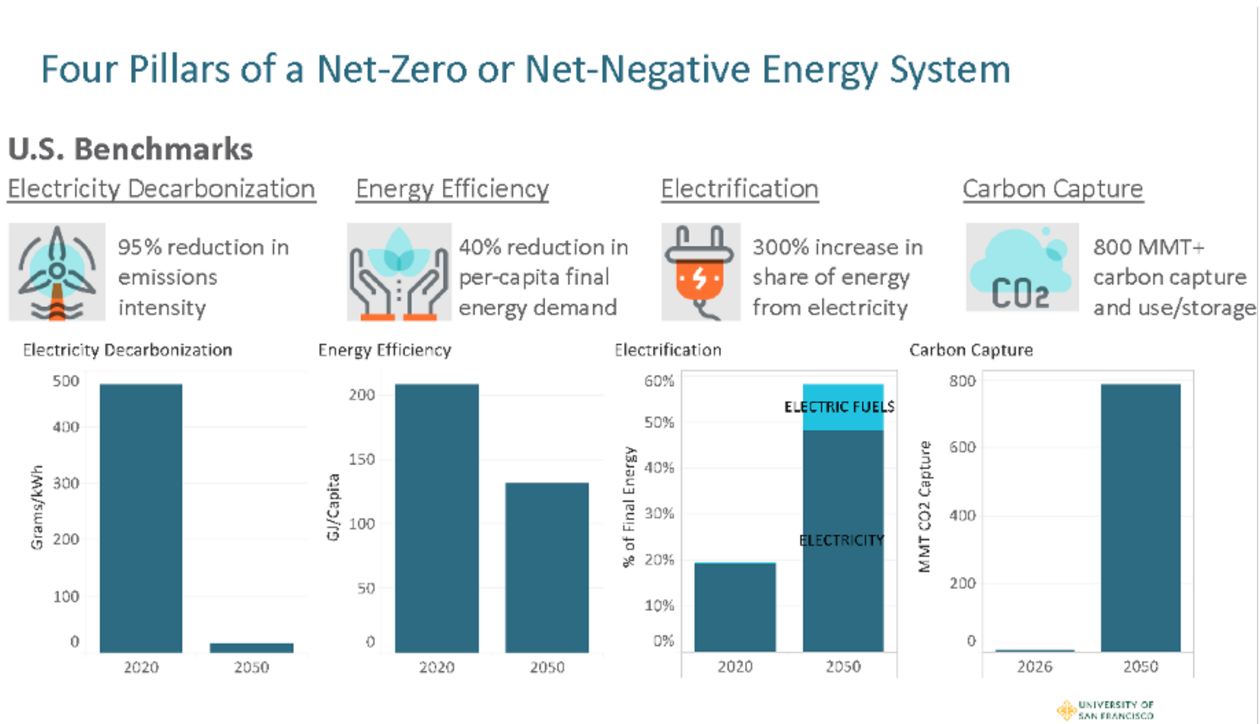

Figure 5.4.1. Four main strategies to achieve deep decarbonization, 2020 vs. 2050 (Williams, Jones and Farbes, Chapter 2).

Daily city-wide energy demand for natural gas and electricity in 2015 (left) and 2050 (middle and right). The values represent the maximum hourly quantity of electricity or gas consumed in a given day. The Electrification Only scenario reflects deep electrification of the buildings and transportation sectors, with no additional action by the City to improve energy efficiency in buildings, or to dampen the demand for travel in personal EVs. In the third scenario (far right), deep electrification is coupled with deep efficiency gains and demand reduction in the buildings and transportation sectors. Source: model calculations

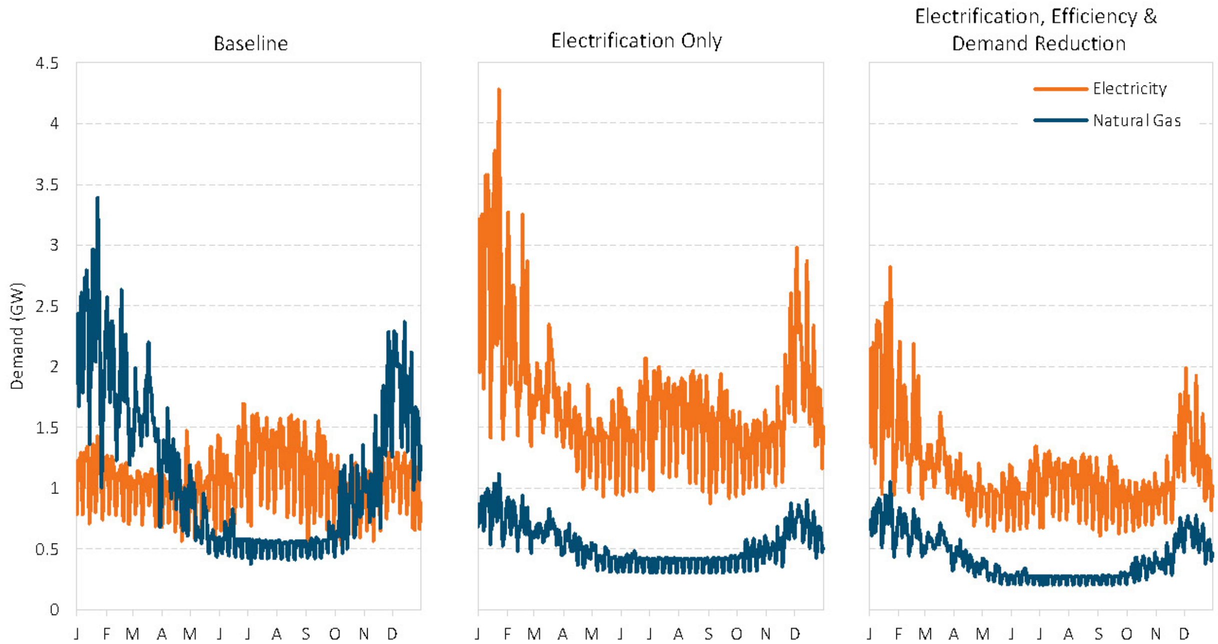

Figure 5.4.2. The impacts of energy efficiency and electrification (Hatchadorian et al., 2019).

Stimulus & Job Creation

In the short term, the policy roadmap proposed here would create millions of high-paying jobs particularly suited for those most adversely impacted by the COVID-19 era recession. Construction and property management jobs are uniquely incapable of being outsourced as they require the physical presence of workers at sites and are distributed across all regions of the U.S. During the first four years of implementation, the U.S. should budget two to three hundred billion in seed capital to catalyze the rapid, large scale decarbonization of public housing, low income housing, and public buildings (national, state, and local)—a portfolio that includes everything from military bases, embassies, public hospitals, universities, fire stations, and post offices. The building decarbonization programs should be designed to leverage private and public investments at the state and local level to create an overall investment of $1 trillion over 4 years.

The immediate impact to gross domestic product (GDP) will be prodigious. In 2019, construction contributed $1.46 trillion dollars to the GDP and every million in construction jobs will generate an additional 2.26 million jobs (indirect, and induced jobs).[4] Prior to the COVID-19 recession, energy efficiency jobs[i] were held by 2.3 million Americans.[5] That represents twice the number of jobs in the entire fossil fuels industry and jobs that were (until the first quarter of 2020) growing at twice the rate of the overall job market. Indeed, there have been huge energy efficiency job losses in 2020 - 18 percent of the entire sector and almost double the number of such jobs created since 2017.[6]

i Energy efficiency jobs include performing architectural and engineering work such as energy audits, retro-commissioning or designing new systems, and construction work such as installing new electrical, lighting or HVAC systems, replacing windows, or installing insulation.

As a result, there are a huge number of Americans with either the proven experience or capacity to take on new energy efficiency jobs right now. Decarbonization of the building sector thus has the potential to promote much-needed opportunities for economic revitalization.

Goal Setting and Multi-Jurisdictional Coordination

As set forth in Chapter 1, achieving economy wide carbon neutrality will require codification in federal law (as opposed to executive orders), the creation of a White House Office of Climate Change, and the creation of clear goals and plans. Likewise, success in decarbonizing the building sector will require an organizational structure that can coordinate the powerful but sprawling parts of the federal bureaucracy that impact buildings. To that end, the Federal Government should establish an Office of Buildings, led by an undersecretary or high level official that reports directly to the head of the department or White House Office of Climate Change. The Office of Buildings will be responsible for setting sector goals at regular intervals (such as 2030, 2040, and 2050), regularly updating plans, tracking progress, and coordinating the activities of the multiple federal agencies, the states, the territories, and the localities that impact the building sector.

The need for a clear organizational structure with sufficient clout and resources becomes apparent when considering that today, building sector related policies are advanced by a jumble of national and local programs with little coordination or sector-wide goal setting. Also, state and local governments have primary jurisdiction over building construction codes through a myriad of health and safety codes and programs that vary vastly across states, cities, territories, and tribal governments.

At the federal level, multiple departments are involved in the building portfolio. Most buildings owned or operated by the Federal Government (including offices, ports of entry, courthouses, laboratories, post offices, and data processing centers) are administered by the U.S. General Services Administration (GSA) while the individual services of the Department of Defense (DOD), the Department of State, the Department of Veterans Affairs, and a number of other agencies construct and or manage their own buildings.[7] Meanwhile, federal agencies and programs like the Federal Energy Management Program (FEMP) at the Department of Energy (DOE) advance higher performance of buildings across agencies.

The agencies that impact the private sector are even more complex. DOE has a myriad of programs to advance energy efficiency for public and private buildings of all kinds (e.g., a program for new single-family residences, programs for existing buildings, weatherization programs, and programs to support strategies and building codes at the state level). The Environmental Protection Agency (EPA) also has a fairly high-visibility efficiency program for existing commercial and multi-family buildings (ENERGY STAR for Buildings) and ENERGY STAR for appliances. The Department of Housing and Urban Development (HUD) has programs for low-income housing efficiency upgrades. Additionally, via various programs that “backup” residential mortgages (single family and multi-family), the Federal Government has a large impact on the shape of residential stock throughout the country including “green” or “energy efficient” mortgage programs.

Building related Research, Development, Demonstration and Deployment (RDD&D), education, and manufacturing also lacks a unified vision and leadership. RDD&D is advanced principally by DOE and the national labs, but there are other programs at Commerce (e.g., via the National Institute of Standards and Technology (NIST), the National Institute of Building Sciences (NIBS), and the National Science Foundation). Even the White House can play a role on RDD&D matters via the National Science and Technology Council's Buildings' Technology Research and Development Subcommittee. When it comes to education, deployment, and manufacturing, the Departments of Education, Labor, and Commerce all have roles to play. The approach laid out in this chapter recognizes that such a mosaic of governmental programs needs to be coordinated by a single entity in order to execute the national decarbonization goals. Such coordination will be essential for effective building sector policy and successful decarbonization of both new and old building stock.

5.4.2 Decarbonization of Buildings

Building Sector Emissions

The operation and construction of buildings are responsible for almost half of America's greenhouse gas (GHG) emissions.

The biggest chunk of the building sector's emissions come from building operations, which produce two streams of GHG emissions. The first is the fossil fuel combustion, typically natural gas or oil, that is burned onsite for space heating, domestic hot water[ii], cooking, and a variety of smaller end uses, such as clothes dryers, absorption chillers, and emergency power. This burning of fossil fuel accounts for 12 percent of national GHG emissions.[8] The second is electricity, which is typically produced at power plants, many of which are currently burning fossil fuel and thereby creating GHG emissions. This electricity is used for lighting, cooling, ventilation, fans and pumps, elevators, appliances, and to cover the "plug loads" of many small pieces of equipment, from computers to music systems. The electricity used in buildings contributes another 20 percent of national GHG emissions, for a total of 32 percent from building operations.

The second largest chunk is building construction, which is estimated to be responsible for 11 percent of global GHG emissions.[9] Known as "embodied carbon," these emissions result from the extraction, refinement, fabrication and transportation of building products and the energy used onsite by construction equipment such as backhoes, cranes, and a multitude of smaller electric tools. The steel and concrete used in buildings are especially carbon intensive. These construction related emissions are typically attributed to the industrial and transportation sectors rather than the building sector, but they bear mention here because they are so considerable and because building policies will be an important strategy in reining them in. A national carbon and energy code should be established, which in addition to driving efficiency and electrification, can also drive down emissions from construction. RDD&D to develop low-carbon materials, products, and construction methods will also be necessary.

An additional 1 to 2 percent of national GHG emissions is due to leaked refrigerants, fire suppression gases, and foam insulation used in buildings; these, too, can be addressed through building codes and appliance standards. Finally, the siting and design of buildings impact transportation emissions; where building policies can reduce such emissions, they are included.[10]

ii "Domestic hot water" is hot water that comes out of the tap as opposed to hot water that is used to heat spaces.

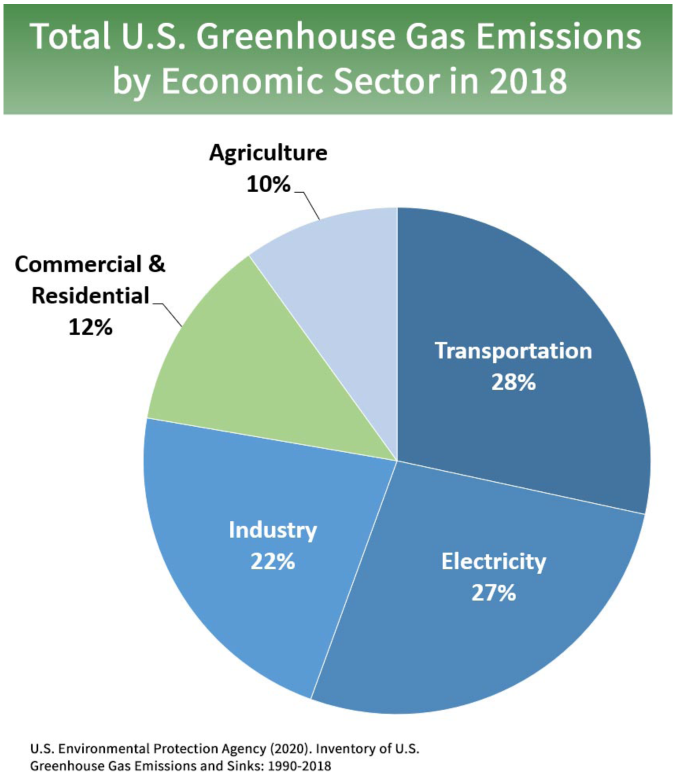

Figure 5.4.3. Total U.S. Greenhouse Gas Emissions by Economic Sector in 2018 ("Commercial and Residential Sector Emissions", 2020)

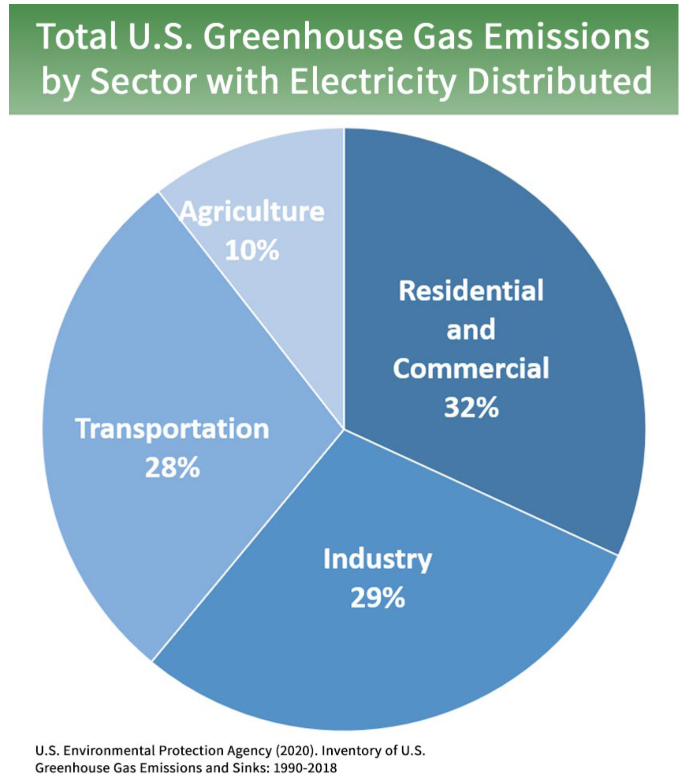

Figure 5.4.4. Total U.S. Greenhouse Gas Emissions by Sector with Electricity Distributed ("Electricity", 2020)

Reducing Building Sector Emissions

Reducing building sector emissions from energy use can be explained in a four-step process, although these steps will not happen sequentially.

- The first step is energy efficiency. Efficiency directly reduces the greenhouse gases emitted from fossil fuels burned onsite and in power plants, and reduces the amount of clean electricity that needs to be generated, transmitted, stored, and distributed as we transition to electric buildings and vehicles. To ensure reduced loads are aligned with periods of peak demand, demand response management will be key.
- The second step is transitioning from onsite fossil fuel burning equipment such as boilers and water heaters to efficient electrical equipment. The all-electric building is the stationary counterpart to the electric car. All-electric buildings have become feasible in most situations, except for certain older buildings in cold climates, because of new heat pump technologies, which supply heat much more efficiently than the inefficient electric resistive heaters of the 1970's and 1980's. Heat pumps are now so efficient that in many cases they cost less to run than gas-fired heaters. In addition, new technologies, such as induction stovetops and heat pump clothes dryers, make it feasible to phase out fossil fuel use for many secondary heating uses.

- To achieve the high levels of electrification that will be required, we propose phasing out fossil fuel for heating and domestic hot water in new buildings, limiting hot water heater replacements in existing buildings to electric units everywhere, and limiting space heating replacements to electric units in the warmer regions of the country. These strategies are discussed more fully in the next section.
- The third step is decarbonizing the electric grid, i.e., replacing fossil fuel power plants with carbon-neutral ones, such as solar or wind and supplementing these with on-site renewable electricity generation where appropriate. This will radically reduce the emissions from electricity used in buildings – both from traditionally electrified uses, such as lighting, and newly electrified uses, such as domestic hot water. The greening of the grid is addressed in Chapter 5.1 of this plan.
- The fourth step is to invest in RDD&D for the development of affordable carbon-neutral gas, such as synthetic hydrogen or methane, and for improved technologies for the electrification of the older national building stock. There are some buildings, especially older steam-heated buildings in the colder parts of the country, where it may be prohibitively expensive to replace the existing steam heating systems and to create an electrical grid that can support a massive winter peak due to heating loads. National resources should be allocated to developing the solutions that can enable these regions to decarbonize affordably.

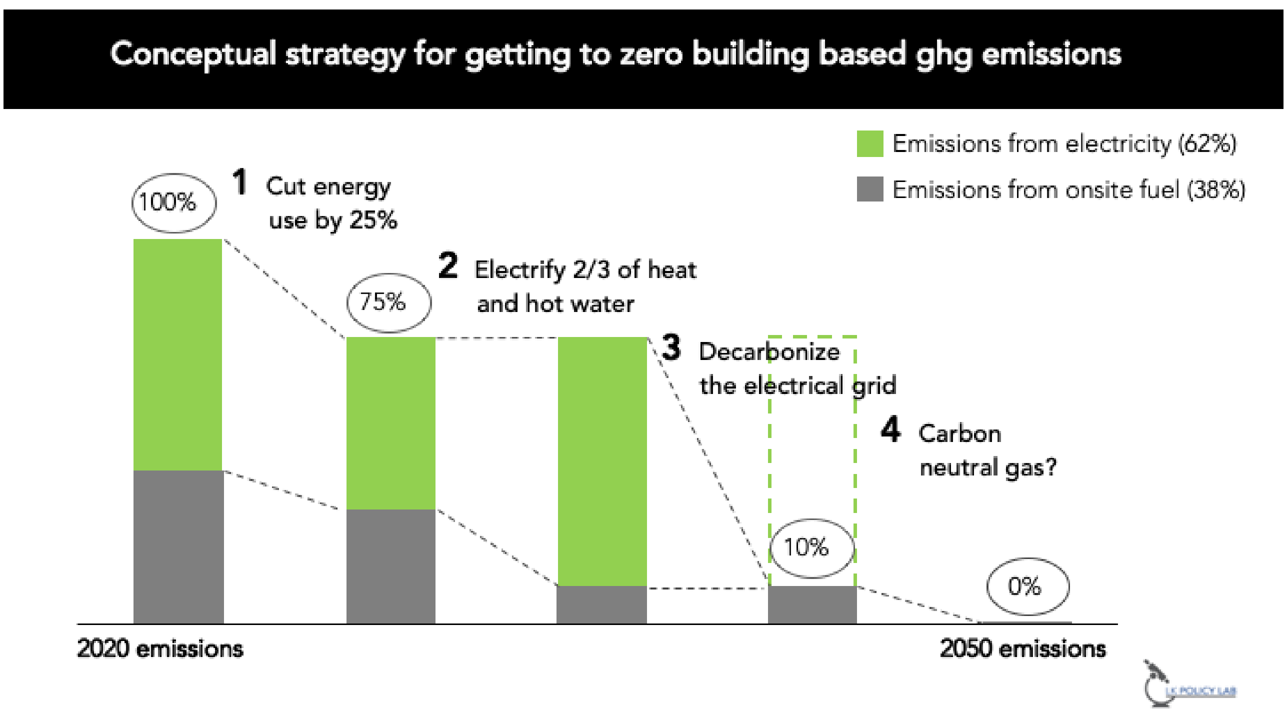

Figure 5.4.5. Conceptual strategy for getting to zero building based GHG emissions (LK Policy Lab, 2020).

The Strategy for New vs. Existing Buildings

Reducing GHG emissions from buildings requires a new building strategy and an existing building strategy. GHG emissions from new buildings represent a net increase in total emissions because the building stock is growing, with a relatively small amount being retired. Therefore, that increase must be kept as small as possible in order to reach zero carbon emissions. That will entail reducing GHG emissions from energy use, construction, and refrigerants.[iii]

Buildings that already exist today are the bigger piece of the puzzle—assuming a 1 percent annual growth rate in built area and a 0.2 percent demolition rate, by 2050 America's square footage will have increased by 35 percent, and roughly 70 percent of the built area will be in buildings that already exist today. Existing buildings present a more complex problem than new buildings because there are so many of them—over 150 million, of which roughly 95 million are single-family homes whose owners are unlikely to accept intrusive and/or expensive requirements. Effective building policy responds to the unique characteristics of new and existing buildings in order to efficiently target and reduce carbon emissions.

New Building Strategy

Energy use

Currently available technologies, such as heat pumps, and design strategies, such as the super-insulated, super-tight "Passive House" model, can enable new buildings to be built free of fossil fuels and highly efficient at a reasonable cost. Buildings that do not burn fossil fuel onsite will become carbon neutral as the grid is cleaned and as clean electricity via onsite or district-wide renewables becomes more available.

In many parts of the country, high electricity rates mean that all-electric buildings could pay more for heating if they are not efficient. Therefore, new buildings should be built to use minimal energy for heating and cooling—something that can be achieved reliably by building tight, well-insulated and well-ventilated buildings. This strategy will also diminish the peak summer and winter loads that would otherwise necessitate large and expensive expansions of the electrical grid. Therefore, as soon as possible, all new buildings will need to be fossil fuel free and hyper-efficient for heating and cooling, particularly as buildings built over the next 30 years cannot be expected to replace major equipment before 2050.

The phase out of natural gas for cooking could lag behind the phase out of fossil fuels for heating and hot water without incurring much of a penalty because cooking accounts for about 2 percent of fossil fuel use in buildings. Such a lag would enable the public to experience the benefits of electric induction cooking, which is cleaner, safer, and cooler than gas, and which is recommended by chefs because of its responsiveness.

Construction

Reducing the carbon emissions from construction is an emerging discipline, but there are already some very effective techniques, such as low-carbon concrete. Federal investments need to be made into RDD&D for low-carbon construction to help create carbon accounting tools and metrics for the industry and to develop increasingly low-carbon materials, equipment, and engineering strategies that builders can use. Requirements to reduce construction-related carbon emissions will need to be introduced into the carbon and energy code and made increasingly stringent as new strategies become viable.

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iii Emissions from construction are also addressed in the industrial and materials sections.

Chapter 5.3 also addresses the reduction of emissions from concrete.

Refrigerants and Fire Suppression Gases

As refrigerants with increasingly low greenhouse gas potential are developed, EPA regulations and codes will need to ensure that new buildings use them. As long as refrigerants with relatively high global warming potential are still being used, leak detection should be required.

Existing Building Strategy

The most cost-effective time to improve efficiency or electrify existing buildings is at the time of renovation and/or equipment replacements/upgrades, when work is already being done. If a perfectly operating gas hot water heater is replaced with a new heat pump, the full cost of the job would be roughly $2300 ($1500 for the heater and $800 for the installation). If the heater already needed to be replaced, a new gas one would cost $1600 ($1000 for the new gas heater and $600 for the installation).[iv] A new heat pump unit only costs $700 more than a gas one – which would be an incremental cost increase at the time of equipment replacement, and much less than the full $2,300.

The regulatory tools as applied to existing buildings (i.e., through energy codes and equipment standards) are well positioned to take advantage of equipment replacement cycles. They don't require that owners replace any equipment; rather they require that if a piece of equipment does need to be replaced, it must be replaced with one that meets certain standards. For this reason, carefully crafted codes and standards can garner widespread and fairly cost-effective efficiency improvements and electrification across the entire population of buildings over the decades. Since water heaters are replaced every 10 to 15 years and hydronic boilers and furnaces every 15 to 20 years, codes and standards could result in the vast majority of targeted equipment in pre-2020 buildings being replaced with more efficient, electric units between 2020 and 2050.

Determining Targets of Equipment Electrification and Decarbonization

In considering which types of equipment the codes should target to be electric or fossil free there are two issues: the impact on the grid and the cost of upgrading building systems.

The Grid

As buildings electrify, they will add load to the electric grid, as will electrifying vehicles. The cost of increasing the size of the grid to accommodate higher peak loads, including generation, transmission, and distribution within localities and within buildings, could be considerable – even astronomical in some regions if not enough efficiency is achieved and/or if too much heating is electrified.

Electrifying domestic hot water should not increase peak load significantly because the load is relatively small, evenly distributed throughout the year, and easy to move to times of day when loads are smaller. Thus, codes and standards should move aggressively to require new or replacement water heaters to be fossil fuel free.

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iv Costs for equipment and installation are hypothetical. In some cases, in fact, a new electric unit might cost less than a gas unit.

The same is not true for space heating. In the colder parts of the country, heating loads are very high, concentrated in the few colder months of the year, and they cannot be moved – you need heating when it's cold outside. Additionally, air source heat pumps, which are likely to be the type most commonly used, become less efficient and their heating capacity drops the colder it gets. The result could be a new winter peak load that is two to three times the current one in the colder parts of the country if too much heating is electrified and if too little efficiency is achieved. The more grid friendly solution in such areas would be to relieve the electric grid by using the current gas distribution system to distribute carbon neutral gas for heating, supposing such gas can become affordable.

Building Systems

Domestic hot water is typically generated by a central heater, stored in a tank, and distributed around the building through pipes.[v] That makes it fairly simple to electrify hot water in most situations: all that needs to be done is to replace the heating unit/tank combo, but the distribution pipes are unchanged.

The same is not true for some space heating systems. For most buildings that distribute space heat through hot air or hot water systems, an electrified source could be installed that could utilize the existing distribution system. But for most buildings that distribute heat via steam pipes and radiators, the distribution system would need to be replaced since heat pumps cannot deliver hot enough heat to create steam. (This is especially true for large urban buildings that cannot install multiple mini split condensing units on their facades.) This would be an extremely expensive and invasive proposition in most buildings, since it would entail work in every room, apartment, or office.

Steam heat was a widely used, extremely durable technology from the time James Watt invented it at the dawn of the Industrial Age through at least World War II. It remains common in the colder, older areas of the country—the mega-region of the Northeast and northern Midwest – areas of the country that use the most heat. Unfortunately, because this is a regional issue, there is little data on the prevalence of steam heating systems, with the exception of New York City. Here the city's audit data documents that roughly 75 percent of the square footage in buildings larger than 50k square feet (half the city's square footage) is heated with steam heat, and another analysis found that 86 percent of the multifamily buildings between 5k and 50k square feet (another 15 percent of the city's square footage) are heated with steam.[11] Steam heat is also quite prevalent in other large cities of the mega-region, such as Boston, Chicago, and Philadelphia.

5.4.3 Conclusions and Policy Recommendations

Policy Recommendations

Outlined below are specific policy recommendations for the decarbonization of the building sector. These federal policies would help to mobilize building decarbonization at city, state, and national levels while keeping costs as low as possible and capturing the associated benefits of the journey to zero carbon emissions. These recommendations include a national carbon and energy code for new and existing buildings, aggressive appliance standards, a federally funded stimulus program, leadership by example, and fiscal and tax incentives.

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v There are point of use hot water systems, wherein the hot water is locally generated for local use, say, within a bathroom or a kitchen. But those are fairly rare in the United States.

National Carbon and Energy Code

New Buildings

Status Quo: Today, local and state governments have exclusive jurisdiction over new building construction standards including energy performance and efficiency set out in local building codes. Lobbyists (including those representing construction companies and real estate developers) have resisted climate change mitigation precautions on the grounds that stricter codes would increase the price of housing. Consequently, many states and localities have energy efficiency standards well below those of other states and similar jurisdictions in other countries. As with (similarly criticized) requirements that cars be more efficient, in reality these codes have lowered fuel costs and any minimal upfront costs have quickly been recouped by the resulting cost savings.

Policy Recommendations: Develop a model National Energy Code for Buildings (NECB) that is updated triennially as per the current energy codes and that regulates carbon as well as energy. Require all states to adopt and enforce energy codes that are consistent with the national carbon goals or adopt the NECB. This departs from the current situation in three essential ways.

- First, to motivate the electrification necessary to achieve our goals, we need to transition from a building energy code to a carbon and energy code that, for example, would preclude the installation of new fossil fuel burning equipment under many conditions.
- Second, the current energy code structure does not allow for the regulation of carbon from construction or refrigerants, as will be necessary to reduce the non-energy related carbon from buildings.
- Third, there will be teeth in the requirement for states to adopt energy/carbon codes consistent with the national carbon goals.

A NECB is necessary because about half of the states lag in code adoption[vi] by at least a decade.[12] The current regulatory structure requires that DOE certify new energy codes for commercial and residential codes every three years, requiring the states to adopt the commercial code and to state whether they can adopt the residential codes within a few years of the promulgation of the new codes. Because DOE has no enforcement powers over the states and because of the loose language regarding residential buildings, state codes are often severely lagging, resulting in generation after generation of relatively inefficient new buildings that lock in high emissions for five decades or more.

The NECB should:

- Require that, no later than 2025, all new buildings be fossil fuel free and hyper-efficient, particularly with respect to heating and cooling, to avoid significant increases in winter peak and summer peak electrical use. The code for new and existing buildings should reduce heat loss through new or replacement windows by approximately 40 percent from current requirements for thermal resistance and air leakage by 2025.
- Include requirements for on-site or district generation, grid harmonization and peak load reduction capacity, and minimum levels of passive survivability and resilience.
- Include requirements that reduce the embodied carbon of new buildings, including requirements for low-carbon concrete, that become increasingly stringent as low-carbon building strategies emerge in this rapidly developing new expertise.

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vi In Nov. 2018, 19 states referenced a commercial code that was at least 11 years old and 27 states referenced a residential code that was at least 9 years old.

- Ban the use of refrigerants with high global warming potential and require that refrigerant leaks be monitored.
- Require a minimum percent of parking spaces to have Level 2 charging stations for electric vehicles.

Existing Buildings

Status Quo: Existing building energy performance issues are currently addressed as an afterthought in the energy codes. Otherwise, they are addressed principally through public and private sector investments, utility-funded programs, and increasingly by state or local mandatory energy performance standards (MEPs). These MEPS typically ratchet up stringent mandatory targets over time to achieve reductions in energy use and/or carbon intensity of energy use over the next thirty years.[13]

Federal programs – principally at DOE - support state, local, and private sector efforts via targeted programs that reach no more than 1 percent of existing buildings annually. Here the federal tools include carbon and energy codes, appliance standards, tax credits, recognition programs, and weatherization support programs. The weatherization program at DOE and some programs at HUD focus particular attention on low-income housing. If the Federal Government limits itself to moderate actions of the type we have seen in the past, even if combined with those undertaken in a few states with ambitious energy codes (e.g., California) or existing building programs (e.g., New York City, Washington, DC), carbon reductions in the building sector will likely be stuck in the 65 to 75 percent range by 2050.[14] That prediction assumes that the nation's grid achieves 90 percent decarbonization.

At the current rate of investments in home energy efficiency at the federal level – even when combined with the often more substantial investments at the state and local level – we are only creeping slowly toward a lower carbon economy. Per a recent study by the American Council for an Energy Efficient Economy (ACEEE), 2018 funding levels for the two main federal programs for whole home retrofits (DOE's Home Performance with Energy Star and the Weatherization Assistance Program) served just .09 percent of the 138.5M housing units in the U.S.[15]

Assuming that level of service comprises half of today's annual home retrofits in the U.S., it would take 500 years to retrofit the current stock of U.S. homes. Improvements to the commercial sector are somewhat less glacial but still inadequate. Commercial Buildings Energy Consumption Survey (CBECS) data shows 14 - 39 percent of commercial buildings have had an energy efficiency retrofit over the past 18 years, with those retrofits ranging from modest to deep.[16] At this same rate, it would take 67 years to retrofit the current commercial stock with even modest upgrades. In sum, according to the ACEEE analysis, to significantly retrofit 80 percent of current buildings by 2050, the current retrofit rate would need to increase for residential by 13X and the rate for commercial buildings by 2X, while also increasing the depth of the commercial retrofits.

Policy Recommendations: Ensure that the NECB is designed to accrue significant energy and GHG emissions reductions when existing buildings are renovated and/or equipment is replaced. The code should:

- Require that, no later than 2025, domestic water heaters cannot be replaced with heaters that use fossil fuel. Since domestic water heaters are replaced roughly every 15 years, this should ensure the electrification of hot water nationally by 2040 or 2050.

- Require that, no later than 2025, in climate Zones 1, 2, 3 and 4, boilers and furnaces cannot be replaced with fossil fuel burning units.
- By 2025, require 40 percent better performance for replacement windows above current standards.
- Complement the above requirements with federally funded rebates or tax cuts to reduce the economic burden, especially for low income households (see financial/tax section below).
- Begin to phase in low embodied carbon requirements for renovations and retrofits.
- For larger existing buildings, motivate the largest existing buildings to reduce their energy use and carbon emissions measurement and disclosure policies. Of the nation's 150 million buildings, 7 million, or less than 5 percent of them – the ones > 25k sq. ft. in size – account for roughly 1/3 of America's built square footage. Require that all properties > 25k sq. ft. be benchmarked annually, that their energy use and carbon emissions be publicly disclosed, and that by 2025 efficiency grades be posted in a highly visible place in the buildings. Create and maintain a national database of these large properties, including their energy use, carbon emissions, and available information about their energy systems.

Aggressive Appliance Standards

Status Quo: Prior to the 2016 Administration, the federal appliance standards promulgated by DOE have been very successful at delivering a more efficient economy and in decreasing the energy used by appliances, lighting, electronics, and other technologies used in buildings. However, more could be done. Striking gaps in the federal standards remain, such as computers and monitors. There are no overall goals, nor is there any regulatory authority over carbon. Finally, the upgrades for existing standards, which are required by the existing statute to be developed every six years, have fallen way behind schedule, and there is no consequence if DOE misses its deadlines.

If DOE adopted strong upgrades to the existing standards expeditiously, the cumulative impacts by 2050 would be enormous. Based on preliminary estimates by the Appliance Standards Assistance Project, even assuming a grid that is approaching carbon neutrality over the next 30 years, 1.5 billion tons of carbon would be avoided cumulatively—an amount equal to almost ¼ of America's current annual emissions. The impact on summer peak cooling loads by 2050 would be huge: a reduction of 93 Gigawatts or roughly the average available capacity of 120,000 windmills.[vii] These impacts would be even greater if the first round of upgrades were stronger, and of course the cumulative impact of more than one round of upgrades would be still larger. (There will be 5 six-year upgrade cycles between 2020 and 2050.)

Finally, there is another multiplying effect: as America upgrades its standards on many products, it drags the rest of the world along, as purchasers in other countries buy brands developed to meet American requirements and other economies adopt and upgrade standards. As the world's middle class grows and as global temperatures rise, the amount of installed air conditioning is predicted to quadruple by 2050.[17] The global impact of improved standards for air conditioners will therefore be quite significant.

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vii Predicted impacts are from a soon to be published report by the Appliance Standards Assistance Project (ASAP), and provided on a Zoom call August 28, 2020.

Policy Recommendations: Congress should amend the Energy Policy and Conservation Act (EPCA) to:

- Ensure that product standards are upgraded according to the mandated six-year schedule by removing the federal preemption of state standards when DOE misses its deadline, thereby allowing states to set requirements that are stronger than the federal ones.[viii]
- Enable DOE to address carbon impacts in addition to energy efficiency by allowing the standards to be fuel neutral and/or by allowing the standards to address carbon.
- Require DOE to establish an overall reduction goal across each six-year cycle that is in line with the country's overall carbon reduction plan.

In addition, Congress should impose taxes on gas fired appliances and further incentivize the purchase of electric options through tax policies or other incentive programs.

Making up for lost time:

- DOE should be directed to catch up on overdue upgrades on all existing appliance standards as expeditiously as possible, but no later than the end of 2022, including requirements for grid-flexibility functionality for key products, such as water heaters.
- By the end of 2021, DOE should create a goal that is at least 25 percent more stringent in aggregate than this first set of upgrades.
- By the end of 2021, DOE should implement the 45 lumen-per-Watt light bulb standards as required by the Energy Independence and Security Act of 2007.
- By the end of 2024, DOE should have set in motion a second set of upgrades, to be fully adopted by the end of 2028 and that meet the 25 percent reduction goal.

Including new products and addressing carbon emissions:

- By the end of 2023, DOE should set national standards for all appliances that had been regulated by California by 2020, such as computers and monitors, with such standards being at least as efficient at California's.
- As part of the second set of upgrades to be fully adopted by the end of 2028, phase out gas-fired appliances.

International:

- DOE, in partnership with the Department of State, should create an Office dedicated to working with other countries on appliance standards and providing assistance.

Federally Funded Stimulus Package

Status Quo: The 2008-2009 ARRA stimulus funding, created in response to the Great Recession, provides a model and lessons for the stimulus funding that will be required to recover from the Covid-19 Recession. The ARRA funding produced rapid economic benefits (often with full expenditures made within 2-3 years) and leveraged state and local spending by as much as 10X.

viii As proposed by the Appliance Standard Assistance Project.

For example, of the $3.1B in funds that went to the state energy program (SEP), each $1 leveraged $10.70 worth of local and state funds[ix] and resulted in measurable progress in states and localities developing building codes and standards, building retrofits, loans, grants, and incentives programs.[18] More than 62,900 direct, indirect, and induced jobs were created or retained as a result of this investment.[19]

The ARRA increase in low-income housing weatherization (via the Weatherization Assistance Program) to $5 billion (from prior year authorizations of $230 million per program year) ended up supporting the weatherization of over 800,000 sites over the 2009 to 2013 period with weatherization costs covered per site increasing from $2,500 to $6,500. The dollars were spent very quickly – $4.9B by May 2013 with the largest annual expenditures by 2010. Hundreds of thousands of units were weatherized when stimulus was most needed and with savings at an average of $444 per year for each weatherized site.

Policy Recommendations: Congress should provide sufficient funding, such that when it is leveraged with state and local funding and private funding, will provide $1 trillion for efficiency and electrification in buildings over the next 4 years. Improving existing buildings is guaranteed to provide a large number of well-paying construction-related jobs. Indeed, prior to the COVID-19 recession, 2 million out of the 3 million green economy jobs were building-related because building efficiency and electrification is labor intensive. Moreover, most of the work must be done onsite and therefore can't be outsourced. Additionally, because all areas of the country have existing buildings, this stimulus funding can be apportioned to all parts of the country – north and south, rural and urban.

In addition to the jobs benefits, the program should ensure that the American public and low income households benefit from this huge investment of public funds. Therefore the stimulus package should prioritize public buildings which serve everyone and on public housing and low income housing which serve the most vulnerable. Rules should ensure that jobs are equitably distributed among different demographic groups, in proportion to their regional numbers.

Buildings to receive such funding should include:

- Public buildings, federal, state and local (see Leading by Example below).
- Public housing and low-income housing, both urban and rural.
- Buildings that will reduce heating costs with electrification due to their high costs of fuel, notably buildings that use propane, oil or electric resistance heating.

The stimulus program as a whole will provide benefits that go well beyond its direct carbon reductions. Such a program stimulates demand for trained professionals and high performance products and helps advance the state of knowledge in the industry by providing experience to the design and construction communities and creating examples and data.

The stimulus program should also provide funding to train the supply chain on the use of new technologies and to financially incentivize suppliers, installers, contractors, and/or building owners to electrify heat and hot water and to upgrade buildings with better technologies, such as LED lights and high-performance windows. Local suppliers and installers are trusted sources who could be instrumental in promoting the clean energy transition in existing buildings.

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ix By contrast, for the Program Year 2008 prior to ARRA, State Energy Program funding was $33 million.

As to funding levels, significant increases should be made in the ARRA levels of funding for the SEP, Weatherization, and EECBG programs—increases at an order of magnitude of 3X to 10X depending on the cost-effectiveness of the programs. Unlike the ARRA approach, expansion of potential recipients should include weatherization subsidies from federal housing authorities and via block grants to low-income housing and state and local governments to all federal buildings (including military buildings), and all federally supported hospitals and medical facilities. In addition, the amount of the state and local government block grants should also be expanded to 10X the ARRA amounts (or $32B up from the $3.2B authorized in 2008 and spent over the next 7 years).

Leadership by Example

Status Quo: In the past, some Administrations and/or some individual departments (GSA and the DOD) have demonstrated real leadership in improving the standard for building performance. Existing law – including the Energy Independence and Security Act (EISA) of 2007, established additional environmental management goals. EISA requires new GSA buildings and major renovations to reduce fossil-fuel-generated energy consumption by 100 percent by 2030.[20]

Policy Recommendations: The Federal government should create a fully funded program to retrofit and substantially electrify the federal building portfolio on an accelerated schedule, achieving 90 percent decarbonization by 2035 or 2040.[x] The federal portion of the 4-year stimulus funding would provide the first installment toward achieving this deep decarbonization, with continued funding required over the next 10 to 15 years. Interim requirements should be set for the end of the 4-year stimulus funding, such as a minimum 25 percent carbon reduction per square foot when all the stimulus projects have been fully implemented. The federal portfolio includes military bases, court houses, federal office buildings, courthouses, post offices, embassies, public housing, museums, etc.

Local leadership by example programs should be funded, by federal block grants or the like, to retrofit and substantially electrify state and local government public portfolios. These portfolios include public universities, hospitals, and schools, office buildings, libraries, court houses, etc. Funds should be provided to state and local governments for staffing, knowledge sharing, and technical assistance for such programs along with funding for the retrofits themselves. As with the stimulus program, leadership by example programs have additional benefits beyond the direct carbon reduction benefits.

Fiscal and taxation policies, including those impacting residential mortgages

Status Quo: Fiscal and taxation policies at the federal level have, to date, had only a modest impact, on improving the energy performance of buildings. There are two areas that show some promise. The first are green banks, financial institutions that have begun to proliferate and to develop a proven track record of incentivizing and otherwise motivating energy efficiency and electrification projects. In recent years, green banks have led to $3,670,000,000 of investment in cost-effective clean energy projects across the United States, lowering energy costs for end-users, with the investment total composed of $1,079,000,000 in public funds and $2,591,000,000 in private and philanthropic capital.[21]

x The 90 percent decarbonization would be based on the anticipated 2050 grids.

The second relates to federal financial institutions, including federally chartered organizations such as Fannie Mae and Freddie Mac that are in a position to advance, at a greater scale than they are today, the decarbonization of single family and multi-family buildings.

Once the mandatory new and existing decarbonization requirements set out in this chapter gain momentum, banks will increasingly see real risk in real estate collateral that is not meeting (or not on its way to meeting) the technology and performance standards set out in our policy plan. They will begin to request (as part of their due diligence) documentation from borrowers regarding how they will meet these requirements. Once banks and other lenders take even minor steps toward including energy performance in their underwriting criteria, private sector investment toward our 2050 goals will accelerate rapidly. In England and the Netherlands, where existing buildings must meet certain energy performance goals or face grades (on a scale of D to A), banks are already beginning to veer away from lending on projects with grades below a certain level.[22]

Policy Recommendation: Legislation containing the key components of HR 5416 for a National Climate Bank (with a maximum liability of $70,000,000,000) should be adopted.

Federal programs that allow Americans unique levels of financing for new home acquisitions (such as those referred to above) should take steps to begin to align their underwriting policies so they are not exposed to the risk of "brown" collateral that is out of compliance now – or in the foreseeable future - with potential future local or national carbon or energy performance standards. Such institutions should begin to require disclosures or affirmative covenants on the part of prospective buyers that they are meeting certain minimum energy performance standards. Such policies will quickly be echoed by private sector banks.

Federal tax policies that encourage – and functionally subsidize – the financing of homes should also be refined as necessary to advance national climate goals. For example, homes with energy infrastructure that are becoming obsolete because they are clearly not on the path to electrification should not enjoy the full benefits of the residential mortgage tax deduction. Those that are making exemplary progress should be offered a superior deduction.

Federal Support for State and Local Programs and Policies to Advance Decarbonization of their Respective Building Sectors

Status Quo: The DOE's State Energy Program (SEP) should be expanded to assist states in meeting the new national building targets. As part of the Obama stimulus package, the SEP also provided training to those developing and implementing progressive code enforcement. Resources were also usefully invested in helping states on the cutting edge of code development. An area requiring greater attention is alignment of these local government programs with carbon emissions reductions. In addition, regulation of the siting of buildings and allowable uses key is entirely within the jurisdiction of local governments via their zoning and other land use authorities. Some have used these powers to create increasingly low-carbon communities while others have made little to no effort to advance that goal. Specifically, land-use policies that support compact and (mass) transit-oriented development patterns don't separate land uses in the way that "sprawling" zoning patterns do. Members of communities that are composed of more proximate mixes of (zoning code approved) uses including affordable housing at high densities do not need to make long and/or frequent trips between, for example, residential, retail, and commercial districts. As a result, their carbon footprints are measurably lower.

Policy Recommendations: Code adoption enforcement and training: Congress should provide significant funding over the long haul to states and localities for energy/carbon code adoption, enforcement, and training. Funding enforcement is one of the most cost-effective ways to achieve energy and carbon reductions dollar for dollar.

Leading edge policies: Provide funding to states and localities that seek to adopt decarbonization policies that go beyond the federal minimums, including funding for policy development, analytics, and staff and funding for knowledge transfer between localities. Advanced policies can include advanced energy codes, energy and or carbon reduction requirements for existing buildings, like those recently adopted by Washington, DC and New York City, or updated fire codes, building codes, or other policies that would reduce GHG emissions or increase resilience. Finally, state and local governments should be encouraged to adopt zoning and land use plans that produce more compact, and transit-friendly land use patterns as well as more affordable housing at higher densities.

Assistance for State and PUC Decarbonization Initiatives: Technical assistance, convening of key players for knowledge transfer, and targeted funding. States should be encouraged to explore proven or promising ideas including (i) renewable portfolio standards for natural gas serving the building sector, (ii) smart grids, and (iii) IOT management solutions.

RDD&D, Education, and American Manufacturing

Status Quo: In the U.S. and around the world, the construction industry typically invests less than 1 percent of net sales into RDD&D (3.5 to 4.5 percent for the auto and aerospace sectors.).[23] In the U.S., programs at the DOE and those undertaken by the national labs system have de-facto become the industry's RDD&D. However as a percentage of overall federal RDD&D, buildings-related programs are less than 1 percent. When the Federal Government has promoted technological improvement to meet major goals, such as space travel, the Internet, or the Human Genome Project, America has led the world. The U.S. has the opportunity to utilize the same approach for green building construction.

Policy Recommendations: Develop and fund a broad, unified strategy to support smarter, more effective strategies to decarbonize buildings. The strategy should include funding for RDD&D, incubators, and manufacturing, along with funding for vocational schools and college and university departments to develop programs that focus on research and training across the spectrum of energy professionals.

Commit 5 percent of the national RDD&D budget to the development of technologies and techniques that will help lower the cost of decarbonizing the building stock and create future jobs in the manufacturing sector by supporting:

- The development of new and/or improved low-carbon technology for building operations, such as batteries, heat pumps, including high temperature heat pumps that can create steam, high performance windows, advanced control systems, etc.
- The development of carbon-neutral fuels appropriate to buildings that can be used in existing gas lines; assist states in piloting renewable portfolio standards for gas.
- The development of low-carbon building products and construction techniques, accounting tools for embodied carbon, and data on embodied carbon in the national building stock.

- An integrated data system for the nation's 150 million buildings, including information at the building level on energy use and carbon emissions, energy systems, embodied carbon, refrigeration gases, etc. To include data from the annual benchmarking of existing buildings, as per the proposal in the Existing Building section.
- On-site and district microgrid solutions serving all building sectors.
- Smarter building design, and building siting and land use decisions that encourage more compact, low-carbon communities.
- Education must be enhanced for building and infrastructure architects and designers, civil engineers, trades people, building code regulators and everyone else involved with the building and infrastructure supply chain.

Decarbonizing America's building stock will not be just a matter of installing better widgets; it will require a much larger, more knowledgeable, and better trained building efficiency workforce. The Federal Government should invest in the creation of a network of departments, generally located within existing schools, that can train the next generation of energy efficiency professionals. The network should include everything from vocational schools and community colleges that can train installers, contractors, and auditors, to research institutions that will educate the PhDs who will develop the next cutting edge strategies. The national laboratories should partner with the research institutions and play an active role in this network.

Finally, the Federal Government should ensure that the benefits of nationally funded RDD&D benefit American workers and companies. The Federal Government should help support nascent technologies with incubators and pilot programs. And the Federal Government should provide seed funding and launch policies to support the development and long-term success of American manufacturing of clean technology (batteries, heat pumps, high-performance windows, components of products, low-carbon materials, low-to-no carbon gas, etc.). Planned deployments should be in the Rust Belt, in areas with abandoned factories such as the old mill towns of the Northeast, and in areas that would otherwise lose jobs in the clean energy transition.

Conclusions

Several of these proposed policies are likely to be controversial and resisted by affected industries, lobbies, and political interests—namely the creation of a NEBC, the adoption of aggressive appliance standards, and working to develop affordable low-carbon fuels for buildings. Since these may not be easy solutions to push forward, it is important to assess which policies will be necessary to achieving carbon neutrality by 2050.

For this plan we considered two scenarios - both with the same assumptions for the decarbonization of the electric grid and gas network (95 percent decarbonization for electric and 80 percent for gas); a massive stimulus efficiency program and the ramping up of federal incentives and assistance; but one including aggressive policies outlined above, while the other assumes the status quo for gradual progress on appliance standards and uneven state level action on efficiency and electrification - yield the following results.

- Aggressive scenario (see Figure 5.4.6): Without carbon neutral gas, the sector achieves an 86 percent reduction; with carbon neutral gas it achieves 94 percent reduction.
- Less aggressive scenario (see Figure 5.4.7): Without carbon neutral gas, the sector achieves slightly less than 70 percent reduction; with carbon neutral gas it achieves 90 percent reduction.

The less aggressive scenario gets a lot of mileage from the decarbonized grid, but it is not a robust solution; it sets things up poorly for the last mile of expensive reductions and it will necessitate building a larger and more expensive renewable network.

- Without the widespread deployment of affordable carbon neutral gas – as of yet, an unproven technology – the less aggressive scenario falls far short of carbon neutrality for the sector. Without such gas, it achieves slightly less than 70 percent carbon reductions in contrast to the 86 percent achieved in the aggressive scenario.
- Even with carbon neutral gas, the less aggressive scenario will need 60 percent more carbon capture and sequestration to achieve neutrality than the aggressive scenario.
- The amount of decarbonized electricity plus decarbonized gas in the less aggressive scenario is 22 percent more than the aggressive scenario. Since most carbon neutral gas will be created by renewable power generation, the less aggressive scenario will need 22 percent more renewable power than the aggressive scenario.

In conclusion, the aggressive approach is worth the potential political challenge. The less aggressive scenario misses the mark significantly, setting America up for potentially huge expenses and an unwise level of dependence on uncertain markets like carbon neutral fuels and carbon sequestration and capture. In contrast, the aggressive scenario gradually accrues decarbonization when it is least expensive: when new buildings are being built and when renovations are occurring. While it might seem at first like burdensome regulations, this path will be far less costly for most Americans, since it will gradually and inexorably deliver a low-carbon building sector at a fairly low increased incremental cost. This path will also bring sector emissions close enough to zero that emerging technologies could be expected to take us across the finish line.

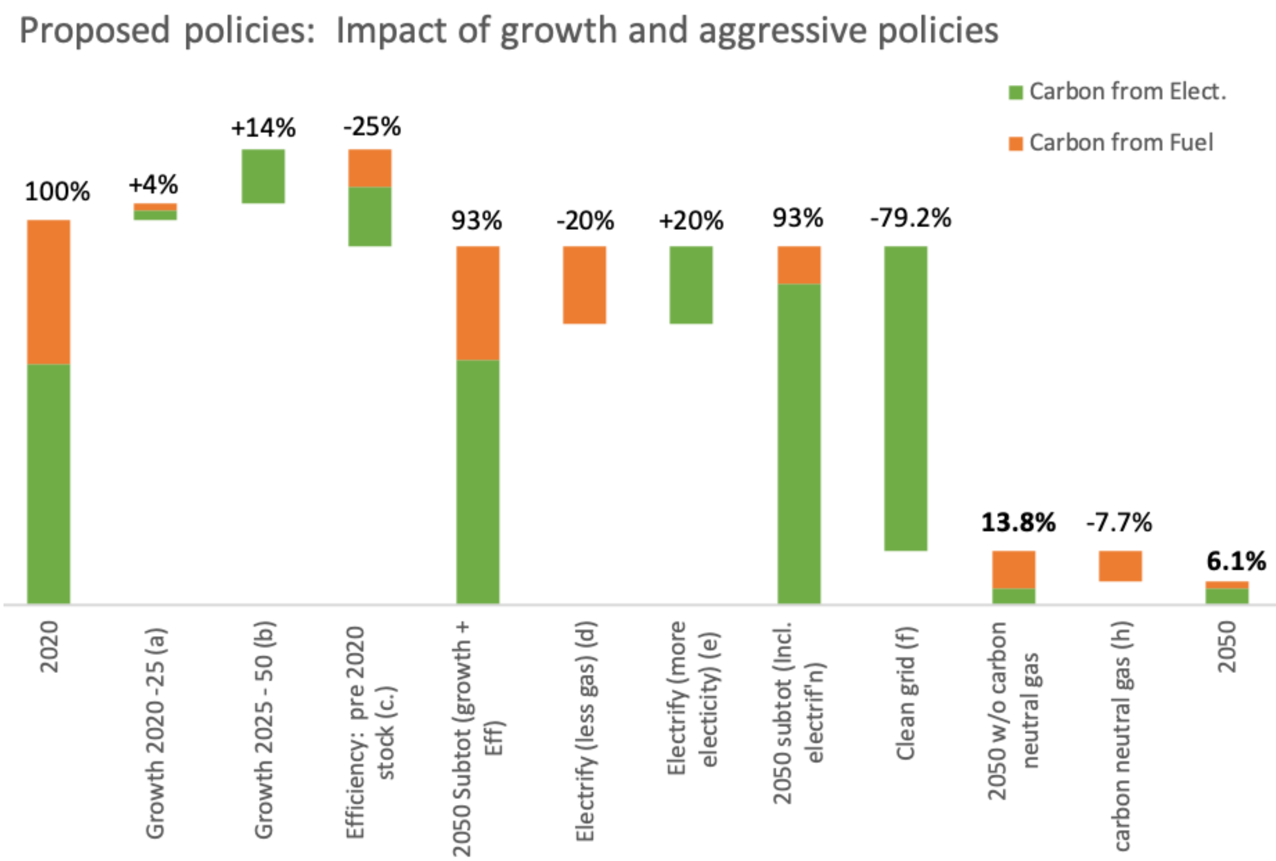

Figure 5.4.6. Aggressive scenario (LK Policy Lab, 2020).[xi]

xi Aggressive Scenario Assumptions:
(a) 2020 – 2025: 1% increase per year = 5%; Effic: 80% avg use compared to current stock; same percent elect vs fuel
(b) 2025 – 2050: 1% increase per year = 28%; Effic: 50% avg use compared to current stock; all electric
(c) Efficiency for pre-2020 stock: all electric and all gas reduced by 25%
(d) DHW electrified at 90% because of code; heat, cooking, dryers electrified at 60% because of code, tax, and appliance standards
(e) Assume transition before cleaning of the grid is 1:1 carbon from electricity: carbon from gas
(f) Decarbonize electric grid by 95%
(g) Decarbonize gas by 80%

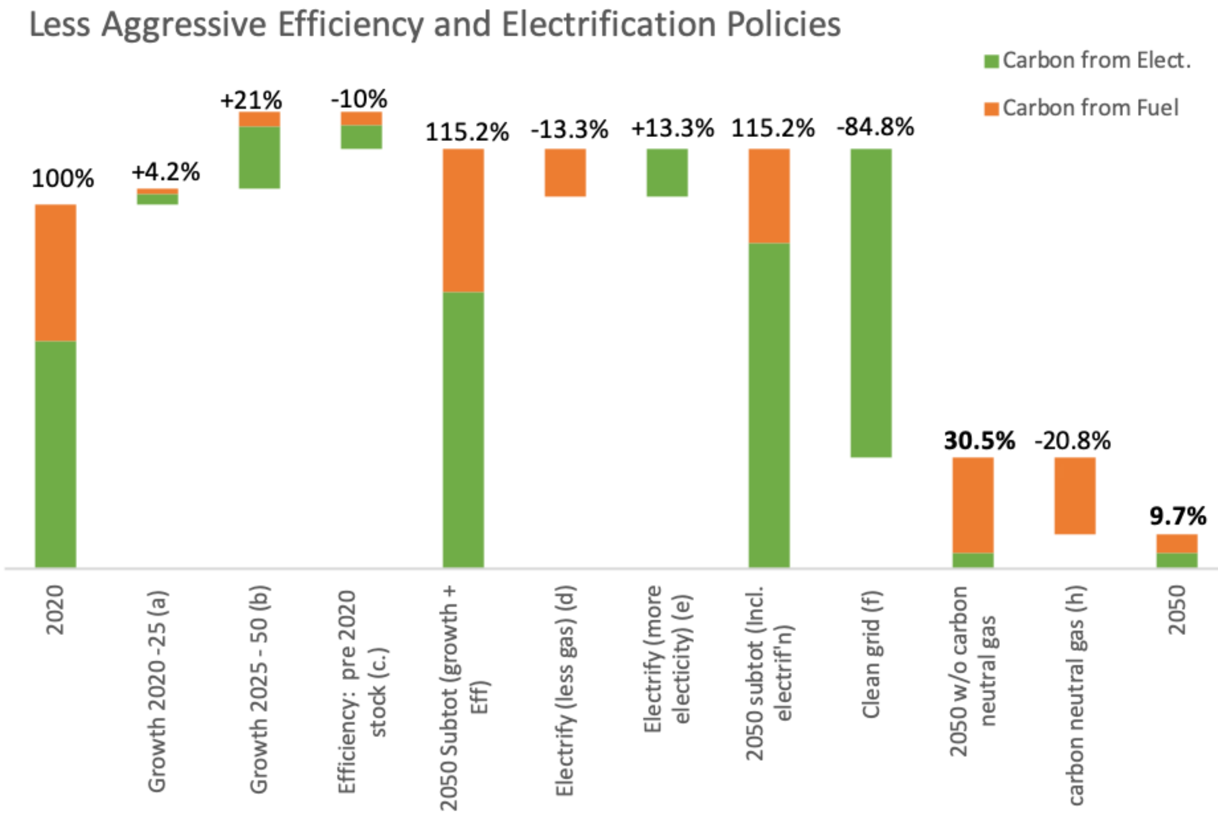

Figure 5.4.7. Less aggressive scenario (LK Policy Lab, 2020).[xii]

xii Less Aggressive Scenario Assumptions:
(a) 2020 – 2025: 1% increase per year = 5%; Effic: 85% avg use compared to current stock; same percent elect vs fuel
(b) 2025 – 2050: 1% increase per year = 28%; Effic: 75% avg use compared to current stock; 50% heat & hot water electrified.
(c) Efficiency for pre-2020 stock: all electric and all gas reduced by 10%
(d) DHW electrified at 45% because of code; heat, cooking, dryers electrified at 30% because of code, tax, and appliance standards
(e) Assume transition before cleaning of the grid is 1:1 carbon from electricity: carbon from gas
(f) Decarbonize electric grid by 95%
(g) Decarbonize gas by 80%

5.4.4 Costs and Jobs

What will be the impact of decarbonizing the building sector on economic activity, the federal budget and job growth? Below is a summary of impacts, as extracted from the chapter 2 “central case” scenario and the chapter 3 jobs analysis.

The average net increase in annual economic activity above the DOE BAU “reference case” scenario can be determined by aggregating the increases in construction, HVAC, appliances, refrigeration, and other commercial/ residential as per the chapter 2 analysis. The result comes to $64 billion per year, or $1.98 Trillion over the full 31-year period 2020 -2050. On average, this amounts to a modest 0.3 percent increase in GDP. But more to the point for our present discussion, it amounts to a 4.5 percent increase in annual spending on construction, which has important implications for blue-collar jobs, as discussed below. It will also represent a significant infrastructure investment in updating the nation’s aging building stock.

Assuming that the federal government will cover 25 percent of the overall costs, with the remainder being covered by state and local governments and the private sector, decarbonizing the building sector will add approximately $16 B to the Federal budget above the amount it currently spends on energy efficiency and R&D for the building sector. This would amount to an increase of approximately 0.4 percent to the federal budget. Taxes on the $64 billion in increased economic activity would likely cover most, if not all, of this budgetary increase. These federal funds would pay for the decarbonization of the federal portfolio, financial incentives for private buildings, development and enforcement of codes and standards, assistance to states and local governments, including block grants, subsidies to American manufacturing, research and development, education and training, and the overhead of developing and managing this vast program.

In estimating the number of direct and indirect jobs produced, we averaged over the different trades, and took a median between current manufacturing levels and full American manufacturing of equipment used in upgrades, to arrive at roughly 7.5 direct and indirect jobs per $1 million spent nationally. Consequently, the increased annual spending of $64 billion results in roughly 480,000 additional well-paid, construction-related jobs each year. The majority of the jobs would be in the construction trades, but others would be in architecture, engineering, manufacturing, retail, research, education, government, etc. These jobs would be spread across the country because buildings are everywhere, and most retrofit work must happen onsite. And because most of the jobs would be in the construction trades and the demand for work will be durable over 30 years, this job growth will be a boon to many blue-collar workers who have seen their opportunities and paychecks shrink over the past decades. Finally, if a chunk of the expenditure is front-loaded over the next four years, as this plan has proposed, the first steps toward decarbonizing the building sector will also help the nation recover from the Covid-19 recession.

References

1. "Plan for Climate Change and Environmental Justice | Joe Biden." 2020. Joe Biden for President: Official Campaign Website. Accessed August 13, 2020. https://joebiden.com/climate-plan/.;

House Select Committee On The Climate Crisis. 2020. *Solving the Climate Crisis: The Congressional Action Plan for a Clean Energy Economy and a Healthy, Resilient, and Just America*. 116th Cong., 2d sess. https://climatecrisis.house.gov/sites/climatecrisis.house.gov/files/Climate%20Crisis%20Action%20Plan.pdf.

2. Hatchadorian, R. et al. 2019. *Carbon Free Boston: Buildings Technical Report*. Boston: Boston University Institute for Sustainable Energy. http://sites.bu.edu/cfb/technical-reports.

3. Ibid.;

"Energy Department Announces Energy Efficiency and Conservation Block Grant Program National Evaluation Results." 2015. Energy.Gov. Accessed August 13, 2020. https://www.energy.gov/eere/articles/energy-department-announces-energy-efficiency-and-conservation-block-grant-program.

4. "U.S. Construction Spending: Public and Private Sectors 2019." n.d. Statista. Accessed August 13, 2020. https://www.statista.com/statistics/226355/us-public-and-private-sector-construction/;

"Updated Employment Multipliers for the U.S. Economy | Economic Policy Institute." n.d. Accessed August 13, 2020. https://www.epi.org/publication/updated-employment-multipliers-for-the-u-s-economy/.

5. "Energy Efficiency Jobs in America 2019 - 2.3 Million Americans Work in EE." n.d. *E2* (blog). Accessed August 13, 2020. https://e2.org/reports/energy-efficiency-jobs-in-america-2019/.

6. Ibid.

7. "Land Ports of Entry Overview." 2018. Accessed August 13, 2020. https://www.gsa.gov/real-estate/gsa-properties/land-ports-of-entry-overview; "Courthouse Program." 2018. Accessed August 13, 2020. https://www.gsa.gov/real-estate/gsa-properties/courthouse-program.

8. US EPA, OAR. 2015. "Sources of Greenhouse Gas Emissions." Overviews and Factsheets. US EPA. December 29, 2015. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.;

"Sources Of Greenhouse Gas Emissions: Commercial And Residential Sector Emissions". 2020. *US EPA*. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.;

"Sources Of Greenhouse Gas Emissions: Electricity". 2020. US EPA. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

9. "New Buildings: Embodied Carbon". 2020. Architecture2030.Org. https://architecture2030.org/new-buildings-embodied/.

10. Bond, Tami C., and Haolin Sun. 2005. "Can Reducing Black Carbon Emissions Counteract Global Warming?" Environmental Science & Technology 39 (16): 5921–26. https://doi.org/10.1021/es0480421.;

"Overview Of Greenhouse Gases". 2020. *US Environmental Protection Agency*. https://www.epa.gov/ghgemissions/overview-greenhouse-gases.

11. Urban Green Council. 2016. "New York City's Energy And Water Use 2013 Report". New York City: Urban Green Council. https://www.urbangreencouncil.org/sites/default/files/nyc_energy_water_use_report_2016.pdf.; Urban Green Council. 2019. "Demystifying Steam: Smaller Buildings". Research Brief. New York City: Urban Green Council. https://www.urbangreencouncil.org/sites/default/files/2019.10.15_demystifying_steam_smaller_buildings_final.pdf.

12. "Residential Building Codes". 2020. *BCAP*. http://bcapcodes.org/code-status/residential/.

13 Nadel, S., and A. Hinge. 2020. *Mandatory Building Performance Standards: A Key Policy for Achieving Climate Goals*. Washington D.C.: American Council for an Energy-Efficient Economy. https://www.aceee.org/sites/default/files/pdfs/buildings_standards_6.22.2020_0.pdf.

14. Ibid.

15. Ibid.

16. Ibid.

17. University of Birmingham. 2018. "A Cool World: Defining The Energy Conundrum Of Cooling For All". Birmingham, United Kingdom: Institute for Global Innovation and Birmingham Energy Institute, University of Birmingham. https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/2018-clean-cold-report.pdf.

18. Executive Office of the President of the United States. *A Retrospective Assessment of Clean Energy Investments in the Recovery Act*. 2016. Washington D.C.: GPO. https://obamawhitehouse.archives.gov/sites/default/files/page/files/20160225_cea_final_clean_energy_report.pdf.

19. "Energy Department Announces Energy Efficiency and Conservation Block Grant Program National Evaluation Results." November, 2015, https://www.energy.gov/eere/articles/energy-department-announces-energy-efficiency-and-conservation-block-grant-program.

20. *Energy Independence and Security Act of 2007*. U.S. Public Law 110-140. 110th Cong., 1st sess., 19 December 2007. https://www.govinfo.gov/content/pkg/PLAW-110publ140/pdf/PLAW-110publ140.pdf.

21. Calma, J. "Democrats Are Pushing a National Climate Bank." *The Verge*, January 29, 2020, https://www.theverge.com/2020/1/29/21113300/democrats-green-bank-national-climate-change-capital-greenhouse-gases.

22. Nadel and Hinge, *Mandatory Building Performance Standards*.

23. Agarwal R., S. Chandrasekaran, and M. Sridhar. "Imagining Construction's Digital Future." *McKinsey*, June 24, 2016, https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future.

5.5 Accelerating Sustainable Land Use Practices in the U.S.

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5.5.1 Introduction, Context, and Goals

While the focus of the Zero Carbon Action Plan (ZCAP) is on transformation in the energy, transport, and building sectors, achieving net-zero greenhouse gas (GHG) emissions for the United States by 2050 will require a concerted set of actions in land use. Infrastructure for renewable energy production and transmission will need to be sited, displacing some other productive uses. The energy sector modeling in chapter 2 shows that biofuels will be part of the energy mix by 2050, raising a number of sustainability challenges. Meanwhile, decarbonization will require reducing GHG emissions from agriculture and livestock, and managing soils to increase carbon storage. Reforestation and afforestation, together with best practices in forest management, can increase the carbon sink in U.S. forests significantly. Pressures on land use can be reduced if the population moves towards healthy, low-carbon diets, and if food loss and waste is reduced.

It is important to emphasize that sustainable land use management does not only strive to minimize GHG emissions. Land use must also accommodate urban areas and infrastructure, meet national commitments to water and biodiversity conservation and maintenance of ecosystem functions (including reduction of local pollutants to benefit human and ecosystem health), and provide enough food to satisfy human needs for the United States and the global food trade. The Food, Agriculture, Biodiversity, Land Use & Energy (FABLE) Consortium is developing a set of sustainable land use pathways for the United States to 2050 that optimize trade-offs between production (including food and biofuels), conservation, and GHG targets by 2050.[1]

This chapter does not offer an exhaustive set of policy prescriptions covering all issues related to sustainable land use. Instead, we discuss available policy instruments that would move the country towards land uses embedded in the energy modeling in chapter 2 and the FABLE sustainable pathways. Our focus, then, will be on challenges in siting renewable energy infrastructure and achieving the negative emissions in the land sector assumed by the energy sector pathway, while also satisfying the constraints imposed by the FABLE modeling exercise in terms of forest expansion, dietary changes, and reduction in food loss and waste. As the current state of the FABLE modeling does not cover reduction in emissions through nitrogen management or better livestock management, we do not consider them in this chapter, but point the reader to resources such as those from the U.S. Department of Agriculture (USDA).[2]

i We thank Peter Lehner (Earth Justice), Ritwick Ghosh (NYU) and Sonali McDermid (NYU) for their review of this chapter.

5.5.2 Siting Renewable Energy Infrastructure

As an example of the scale of the renewable energy siting challenge, chapter 2 examines pathways to achieve mid-century net-zero emissions from the energy and industrial sectors in the U.S., and finds that land area on the scale of Vermont plus New Hampshire will be needed for ground-mounted, utility-scale solar photovoltaic (PV) installations (or approx 1485 gigawatts), assuming a *central scenario* with lower fuel prices; this draws on the modeling work of "Spatial Planning for a Low-Carbon Future".[3] Total onshore wind installations needed to meet the model's GHG emissions targets under the same scenario assumptions will require land the size of New Mexico[ii] (or approx 990 GW).[4] Siting renewable energy facilities of this magnitude suggests that policies will need to address several key issues:

- Siting barriers due to environmental and social impacts pose increasingly important challenges for cost-effective and rapid renewable energy deployment.
- Environmental and land use impacts due to large-scale renewable energy development may be significant if they are unaccounted for.
- Both long distance and interconnection transmission corridors will be essential for achieving low-impact, cost-effective, and rapid renewable energy development, but transmission—particularly interstate transmission—historically has been difficult to site and permit. Interstate transmission is regulated by the Federal Energy Regulatory Commission (FERC), while local jurisdictions maintain responsibility for local siting. This split responsibility poses challenges for interstate transmission siting, due to divergent priorities regarding energy security and environmental concerns.

Policies need to address these considerations in an integrated manner by framing transparent siting processes and financing mechanisms for RDD&D, project development, and host community impacts.

Facilities Siting Processes

Integrated Planning

Policies at all levels should integrate land use siting constraints and impacts in low-carbon energy planning processes. A low-carbon energy planning framework that integrates land use and spatial considerations can directly address siting constraints as a key barrier to rapid and large-scale renewable energy deployment. Land-energy integration allows planners and policymakers to identify development opportunities that avoid downstream conflicts such as lengthy project delays or cancellations, negative ecological impacts, and backlash against renewable energy development by local communities leading to outright development bans. By incorporating conservation data into long-term energy planning, it is possible to establish the protection of natural lands and conservation as an objective of long-term energy planning. At the federal level, policies should mandate development of integrated spatial planning for interstate projects, as well as at state and local levels. These policies should include defined timelines for creation of such integrated plans in order to enable collaboration throughout the siting process, promote effective financial planning for renewable infrastructure investments, and avoid lock-in of infrastructure that may pose long-term, negative ecological consequences.

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ii Calculated using average land use factors, corresponding to the low fuel price scenarios.

Integrated land-energy planning also can help identify development strategies that address unavoidable anticipated impacts. For example, some of the best areas for wind power in the U.S. are located in the Great Plains, 80 percent of which is cropland, pastureland, or rangeland. And cropland—being sunny, flat, and accessible—is an ideal location for solar farms. Integrating wind and solar energy into agricultural landscapes in synergistic ways can spur needed economic development in rural communities while avoiding both conflicts over farmland conversion and natural habitat conversion and fragmentation. At the same time, addressing concerns over loss of cropland displaced by solar and wind requires a policy process that identifies win-win opportunities and balances trade-offs. How planners and policymakers manage the land use transition that must accompany a low-carbon transition can shape the perception of renewable energy infrastructure as either a threat or an opportunity. Inter-agency collaboration is needed to produce holistic environmental and social risk maps for energy modeling to help with both planning and siting of renewable energy facilities.

American Farmland Trust's Smart Solar Siting Partnership Project for New England offers some elements that could be incorporated into such integrated federal policy.[5] The project aims to accelerate expansion of solar energy while maintaining productive, resilient farmland and forest land by building an ongoing, multi-stakeholder coalition to advance smart solar siting policies and programs in New England states. Creation of a federally organized multi-stakeholder task force to advance renewables siting across the U.S. would provide a transparent structure to promote efficient siting decisions that incorporate local considerations. A federal policy that promotes dual goals of solar facility siting and farmland preservation can mitigate conflicts between land use, food systems, and decarbonized electricity production. Such a policy should include incentives that prioritize solar development on existing structures on agricultural land, as well as dual use arrays ("agrivoltaics") co-located with agriculture and livestock.

The Accelerated Renewable Energy Growth and Community Benefit Act, passed by the New York State legislature in April 2020, is another model for federal legislation to advance decarbonization while promoting sustainable land use.[6] For example, the Act authorizes the New York State Energy Research and Development Authority's (NYSERDA) Clean Energy Resources Development and Incentives Program to rapidly advance new "Build-Ready" projects and prioritize development of renewables projects on existing or abandoned commercial sites, brownfields, landfills, and otherwise underutilized sites.[7] Some examples include road medians, sand and gravel pits, industrial sites, and correctional facilities. This initiative also can be replicated and supported at the federal level.

Siting on Federal Lands

In addition to policies that facilitate siting on contaminated or underutilized lands, transparent, well-defined policies should enable renewable energy facility siting on federal lands while accounting for and addressing environmental effects. Federal policies should establish content and timing parameters for environmental impact assessments for siting of renewable energy facilities. Such parameters will promote consideration of land use trade-offs, transparency regarding challenges and their potential impacts, and timelines that can foster efficient and effective siting decisions. Federal policies should require local governments to make decisions on renewables facility siting in writing within a specified period of time.[8]

Since energy infrastructure for both generation and transmission involves long-term investments, integrated land-energy planning helps avoid long-term infrastructure lock-ins that lead to undesirable ecological outcomes. By identifying low-impact, high quality areas for wind and solar development, it is possible to coordinate the early planning of the transmission network needed to interconnect new low-impact renewable energy power plants to the grid.

Financing Mechanisms

Policies should include support for research on and promotion of small-scale siting and distributed generation, which can avoid some of the environmental and land use trade-offs associated with siting of large-scale renewables and transmission infrastructure. As previously mentioned, agrivoltaics offer an opportunity to co-locate small-scale renewable energy technologies with agricultural development, providing complementary benefits to food production, irrigation water requirements, and carbon-free energy production. Policies should include financing incentives to aid agricultural land owners with upfront costs of installing renewables such as solar PV on their properties. Several grant and loan programs already exist. For example, the Business Energy Investment Tax Credit, revised most recently in 2018, offers tax credits to eligible sectors, including the agricultural sector, for solar water heat, solar space heat, geothermal electric, solar thermal electric, solar thermal process heat, solar photovoltaics, wind, geothermal heat pumps, municipal solid waste, combined heat & power (CHP), tidal, wind, geothermal direct-use, fuel cells using renewable or non-renewable fuels, and microturbines. Expiration dates for tax credits for these technologies vary by technology and project start date. A framing policy is needed to expand and ensure longevity of this program to promote decarbonization goals.

Established in 2003, the U.S. Department of Agriculture's (USDA) Rural Energy for America Program (REAP) offers another example of an existing federal financing mechanism that can promote agrivoltaics by mitigating upfront installation costs. REAP provides financial assistance to agricultural producers and rural small businesses to:

- purchase, install and construct renewable energy systems, including small and large scale solar and wind, biomass, geothermal, hydrogen, small hydropower (less than 30 MW), and ocean/tidal technologies;
- make energy efficiency improvements to non-residential buildings and facilities;
- use renewable technologies that reduce energy consumption, including switching to electrically powered sprinklers and irrigation systems; and
- participate in energy audits & renewable energy development assistance.[9]

The grants for renewable energy systems, which can cover up to 25 percent of total eligible project costs, range from $2,500-$500,000. Loan guarantees, alone or in combination with grant funding, can cover loans up to 75 percent of total eligible project costs. The 2014 Farm Bill established a permanent funding baseline of $50 million per year for the program, reaffirmed in the 2018 Farm Bill. This program appears to be underutilized, based on an announcement from USDA in July 2019, which solicited applications and noted $400 million still remaining of its $565 million FY2019 budget.[10] The program would benefit from federal-state coordination to disseminate information to potential applicants, and it should be linked to other long-term policy initiatives to promote its use and longevity.

Transmission Siting

To support new renewables facilities, policies should address related transmission siting. Facilitating zoning of large-scale renewable energy development can help streamline transmission and generation planning and enable low-cost, low-impact renewable energy development. Despite the vast land area a low-carbon transition will require, it is possible to meet low-carbon electricity goals with minimal conservation and land use impacts. Studies show that sharing renewable energy resources across states can significantly reduce costs of achieving ambitious climate targets while also meeting land conservation goals.[11] Yet, regional energy solutions depend on early and proactive transmission planning. Interstate transmission lines will be needed to transmit low-impact, high quality renewable electricity to demand centers, yet interstate transmission lines take 10 or more years to permit and construct. We must begin planning essential transmission corridors now. Revising zoning regulations could include pre-approving permits for low impact sites, reducing land costs, and preemptively planning transmission for development on low-impact public sites, and expediting permitting of transmission upgrades or development of new lines on existing right-of-ways.

Regulations also must address jurisdictional overlaps among state and federal governments, regional transmission operators (RTOs), and the ability of one or a few states to veto an interstate expansion to balance regional and local interests. The Federal Government can establish RTOs and rule on interstate transmission disputes.

New York's legislation provides several models for policies to promote timely, cost-effective transmission siting that account for land use considerations. The Accelerated Renewable Energy Growth and Community Benefit Act creates a State Power Grid Study and Investment Program to identify investments in distribution and local and bulk transmission necessary to meet the State's requirements under the Climate Leadership and Community Protection Act. It also authorizes an expedited permitting process for transmission projects that are planned for existing rights-of-way. Federal policies should support this regional and local focus on transmission projects needed to support addition of renewables to the grid.

Where an economic incentive structure is not in place, policies must drive further transmission build-out. Such policies include federal regulations that fairly allocate costs for long distance transmission lines. A precedent for federal policy incentivizing transmission for renewable power delivery already exists. Section 1222 of the 2005 Energy Policy Act (42 U.S.C. 16421) enables the Federal Government to utilize non-federal funding to expand transmission infrastructure for delivery of power from renewables. It authorizes the Secretary of Energy, acting through the Southwestern Power Administration or the Western Area Power Administration, to "design, develop, construct, operate, own, or participate with other entities in designing, developing, constructing, operating, maintaining, or owning two types of projects".[12] The two project categories are "(1) electric power transmission facilities and related facilities needed to upgrade existing transmission facilities owned by Southwestern or Western (42 U.S.C 16421(a)), or (2) new electric power transmission facilities and related facilities located within any State in which Southwestern or Western operates (42 U.S.C. 16421(b))".[13] The policy specifically allows the Secretary of Energy to "accept and use funds contributed by another entity for the purpose of executing the Project (42 U.S.C 16421 (c))".[14] This policy thus enables partnerships between the Federal Government and private entities to finance and develop siting of transmission lines even without support from state utility commissions.[15]

The Federal Government has utilized Section 1222 only once since enactment of the Energy Policy Act of 2005; in 2016, for a partnership with Clean Line's Plains & Eastern Clean Line Project to develop transmission facilities from Oklahoma to the Arkansas-Tennessee border. Both parties terminated the agreement in 2018, eliminating federal funding for the project. To promote public-private partnerships on transmission siting to enable delivery of electricity from renewables, particularly from those sited in sparsely populated areas to areas of high electricity demand, the Department of Energy should develop new requests for proposals for new or upgraded transmission line projects under Section 1222. To promote effective implementation of such proposals, Section 1222 must be coupled with a transparent environmental impact assessment process and timeline to enable these public-private partnerships to accurately calculate costs and time for project development, as well as consideration of environmental effects associated with siting. Further, expansion of Section 1222 to include Bonneville and Southeastern Power Administrations would enable public-private partnerships to support transmission siting for renewables installation in Bonneville's territory, which includes Idaho, Oregon, Washington, California, Nevada, Utah, Wyoming, and parts of Montana, as well as Southeastern's territory, which includes West Virginia, Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Tennessee, and Kentucky.

Moving beyond policies such as Section 1222, federal policies should facilitate conversion of existing high-voltage alternating current (HVAC) transmission lines to high-voltage direct current (HVDC) lines. The Energy Information Administration used ICF to assess the potential for such conversion in a June 2018 report.[16] The report found that HVDC conversion can facilitate cost-effective movement of energy output from remotely located renewables to distant load centers.[17] By increasing the capacity of existing transmission corridors, such conversion would enable addition of renewables to the existing grid while reducing the need for new transmission lines, thus mitigating land use issues associated with transmission expansion. Policies should include support for RDD&D to address the technical challenges of HVAC to HVDC conversion, including control of power flow between terminals, construction of HVDC circuit breakers, and intermittency uncertainties.[18]

Addressing Impacted Communities

Without appropriate policies in place, energy projects sited in socially disadvantaged communities can impose long-term, negative environmental effects on these communities. Examples such as the Dakota Access Pipeline siting process and the more recent cancellation of the Atlantic Coast Pipeline highlight the need to incorporate community engagement formally into siting of energy facilities, including renewables. To avoid such effects and prevent social backlash, policies are needed to create frameworks that engage impacted communities in the siting process and decisions on compensation. Such policies and frameworks should:

- Enable regional planning (at the level of Western Interconnection, for example) to improve planning outcomes. Such planning should promote interstate and interagency coordination, including electricity demand modeling.
- Promote siting of clean energy technologies on already disturbed, degraded, or contaminated land, including brownfields. The National Renewable Energy Laboratory estimates that about 2,000 GW of solar PV potential exists on 20 million acres of landfills and other contaminated or disturbed sites.[19] This area exceeds the total land area of Vermont and New Hampshire combined, which amounts to approximately 12 million acres.

- Wind developers should utilize the U.S. Fish and Wildlife Service Land-Based Wind Energy Guidelines and best available science to identify appropriate measures to reduce impacts of development and operation.[20]

New York's legislation (Accelerated Renewable Energy Growth and Community Benefit Act) provides several models for policies to address communities impacted by renewables siting,[21] including:

Centralized, transparent siting decisions with community input: The Office of Renewable Energy Siting established under the Act will provide a centralized forum to promote predictability and timeliness of siting decisions, including opportunities for input from local communities. The Act requires all new, large-scale renewable energy projects of 25 megawatts (MW) or larger to seek a permit through the new office. The Act also requires all siting applications to provide proof of consultation with host communities regarding procedural and substantive requirements of applicable local laws. The permitting and pre-construction processes thus must engage landowners and local authorities. The new office must act on complete applications within one year, with a six-month deadline for certain former commercial and industrial sites. The Act stipulates that absence of a determination within the required timeframe will result in de facto approval of the draft permit and granting of a permit.

Efficient, effective environmental reviews: The new office will facilitate efficient timing and improve the effectiveness of environmental reviews of large renewable energy facilities by establishing regulations and uniform standards for environmental impacts common to large, renewable energy projects. The office will also identify mitigation measures to address these impacts.

Wildlife conservation: To protect wildlife from siting effects, the office will require that "uniform and site-specific standards and conditions shall achieve a net conservation benefit to any impacted endangered and threatened species".[22] The Act also establishes an endangered and threatened species mitigation bank fund to finance projects that facilitate such a "net conservation benefit to endangered and threatened species potentially impacted by a major renewable energy facility".[23]

Host community economic benefits: New York's legislation establishes mechanisms to provide incentives to property owners and communities that host major renewable energy facilities. The Act also tasks NYSERDA with assessing the need for green workforce training in host communities, with a particular focus on environmental justice. NYSERDA must create one or more job training programs based on its assessment.

This combination of regulations and financing mechanisms for community engagement can be replicated and supported at the federal level, particularly for facilities sited on federal lands. Such federal measures should include streamlined, transparent environmental impact assessments with defined timelines, as well as established funding mechanisms to address effects on endangered and threatened species. Federal policies should provide incentives for host communities, particularly when the facilities are providing interstate power. Policies also should require localities and states to create transparent processes for input from host communities. Finally, federal policies can allocate funding for green workforce training in host communities, and they should provide models and guidelines for such training programs.

5.5.3 Promoting Reforestation

The White House's United States Mid-Century Strategy for Deep Decarbonization suggests that 20 to 40 million ha of reforestation is needed to meet the land sector's contribution towards the goal of 80 percent reduction of GHG emissions below 1990 levels by 2050.[24] The report indicates that 40 million hectares (mHa) is equivalent to about one-third of 1850 U.S. forest cover. Other studies have shown a potential of over 60 mHa of reforestation.[25] Reforestation is defined as conversion from non-forest (<25 percent tree cover) to forest (>25 percent tree cover). Reforestation will occur on lands labeled 'natural ecosystems' which used to have trees.[26] Meeting a 40 mHa reforestation goal by 2050 implies approximately 1.3 mHa of forest need to be planted annually, which would sequester about 1.77 TG/ha/yr[iii] of CO_2 equivalent or a total of 53.2 Tg CO_2 equivalent over 30 years. Carbon removal benefits depend on geographic location and species planted.

Given that two-thirds of U.S. forest land is currently privately owned, most reforestation will likely occur on private lands. Private landowners will need incentives to reforest their land, and compensation for costs of reforestation including site preparation, planting material, labor, and maintenance for the first few years (an average cost of $900 per hectare).[iv]

The following recommendations can set the groundwork for an ambitious reforestation strategy to 2050:

Congress should mandate the development of a strategy to achieve a national reforestation goal by 2050. This will involve not only a spatially explicit plan mapping out potential areas of reforestation, but also quantifying the carbon removal benefits by location. This can build on existing management plans by the Bureau of Land Management (BLM) and the Forest Service, by reforming them to explicitly prioritize climate and reforestation. In addition, research will be needed to design optimal policies, in particular on the design of incentive payments to landowners. Payments need to be sufficient to cover opportunity costs, reforestation costs, and recurring costs conditional on a forest left standing. The recurring costs must be cost-effective in terms of the gains in carbon sequestration, perhaps dynamic to account for varying carbon sequestration rates in a forest over time, and designed to avoid perverse incentives (such as deforestation in order to capture future reforestation benefits). This research could be embedded in a broader effort to study the right amounts and structure of payments for ecosystem services across the U.S. Monitoring mechanisms to ensure compliance will also have to be developed. State governments should also articulate reforestation plans and policies to meet a national goal by 2050.

Where possible, the government can avoid the issue of annual incentive payments, monitoring, and enforcement by expanding the national forests by acquiring and reforesting private lands, as has been done before, or authorizing transfer of Bureau of Land Management (BLM) lands to the Forest System[v]. In the face of climate change, Congress could authorize the purchase of lands (and lesser property interests, such as conservation easements) specifically to strengthen the negative emissions provided by forests, as well as high quality grasslands. These purchases should be guided by credible scientific life cycle assessments that include externalities.

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iii Mean sequestration rate of 1.33 Mg C ha-1 yr-1.

iv Range $1.62b @ $600/ha to $2.97b @ $1,100/ha. Costs vary by region, species, and planting density.

v During the 1920s-1930s, the Federal Government used purchase authority under the National Industrial Recovery Act of 1933, the Emergency Relief Appropriation Act of 1935, and the Weeks Forestry Act of 1911 to purchase land rendered economically unproductive. Much of that land has since been restored and reforested (see Cheever et al. 2019).

To reduce concerns over taking productive lands out of local economies, and to heighten the likelihood of political palatability, Congress might focus these efforts on lands rendered economically unproductive by the effects of climate change, such as expanded floodplains, fires, and drought, as well as the retreat of northern permafrost in Alaska. Whether incorporated into the National Forest System or managed under the supervision of farm bill programs, such steps might be a boon to farmers eking crops out of marginal lands or considering farm transfers where children are not interested in continuing the family business.[27] State and local governments can also consider acquisition of land as part of a national reforestation policy goal.

Where outright acquisition is infeasible, Congress could create or extend existing conservation easement programs. Easement programs under the Forest Legacy Program, Migratory Bird Conservation Act, agriculture bills, and the Safe Drinking Water Act have offered much-needed supplemental income to landowners. They could also be targeted to places that show high forest carbon sequestration potential. Moreover, where servient landowners retain an interest, there exists a constituency for continued public appropriations to sustain a program.[28] The same program should be explored at state level.

Alternatively, landowners could be compensated for upfront reforestation costs and maintenance costs through incentives and subsidies. Four main sources of potential funding through existing programs include federal cost share programs, federal tax programs, state and local programs, and forest carbon programs.

Cost share programs under the Farm Bill

Numerous forest-related cost-share programs are administered by the Natural Resources Conservation Service (NRCS) and Farm Service Agency (FSA). Most of these originated in the farm bill, and although most are focused on agriculture some address forest conservation. None explicitly target reforestation or carbon sequestration goals. Programs include:

- EQIP: Environmental Quality Incentives Program
- CSP: Conservation Stewardship Program
- EFRP: Emergency Forest Restoration Program
- HFRP: Healthy Forests Reserve Program
- CRP: Conservation Reserve Program
- CREP: Conservation Reserve Enhancement Program
- FLP: Forest Legacy Program
- ACEP: Agricultural Conservation Easement Program

In addition, a handful of states administer state-level programs that encourage reforestation, for example the Virginia Reforestation of Timberlands program.

Each of these programs have different objectives and payment schemes. Some are one-time payments and others are annual (rental) payments for a specified number of years. Some cover only establishment costs and others cover maintenance costs. These programs are administered by state agencies and/or Federal agencies such as NRCS or FSA. Further increases are needed in their funding and staffing to meet an ambitious national reforestation goal.

A new, dedicated reforestation cost share program would play a key role in achieving 40 mHa of reforestation by 2050. Most of the programs mentioned above pay landowners on a per acre basis, but reforestation schemes can be developed that pay landowners for trees planted volume, tons of CO_2 sequestered, or pay-for-performance programs.

Federal Tax incentives

Various federal tax incentives are available for active forest management. The primary one is the Reforestation Tax Incentive Program, which provides up to a $10,000 per year deduction and any additional amount over $10,000 per year may be amortized over 84 months. Other Federal programs that may provide indirect tax incentives for landowners include:

- Cost Share exclusions - payments from government cost share programs
- Casualty loss provisions - indirect payments from disasters and other casualty losses
- Donating a conservation easement
- Estate planning strategies such as marital deduction, special use valuation, trusts, and more[vi]

In order to meet the target of 40 mHa of reforestation by 2050, better tax incentives should be implemented. For example, the current reforestation tax deduction could be changed to a tax credit, and the amount of credit increased. There are various ways the Treasury can allocate tax credit rates to meet these goals.

State and local level programs

State and local programs such as green growth policies, property tax incentives, zoning regulations, hunting and fishing licenses, and technical assistance for landowners can incentivize reforestation.

Property tax incentives, in particular, can serve to promote reforestation, if designed correctly. Every state provides in one way or another a preferential property tax to farm and forest land. These programs provide a deduction to the assessed fair market values of a property. Preferential assessed values vary by state and range from full or partial exemptions to percentage deductions or flat rates to current use valuation approaches. The intention of most of these programs is to encourage retention of open space and conservation of these lands from being developed. Programs could be enhanced to offer specific incentives for planting trees.

Forest carbon programs

Forest carbon programs are market-based approaches mainly implemented by non-governmental environmental and forestry organizations and associations. These programs incentivize private forest landowners to practice sustainable forestry and provide them payments for the amount of carbon sequestered from the land. Typically programs aggregate groups of private landowners to sign up. Carbon credits are verified and sold to companies willing to purchase the carbon credits as offsets.

In addition to reforestation, it is well-understood that improved forest management could increase carbon sequestration in U.S. forests. Importantly, any federal or state subsidies for harvesting trees should be eliminated in order to capture sequestration benefits of continued forest growth.

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vi See, for example, Estate Planning for Forest Landowners.

In order to allow the Forest Service to manage the National Forest System to sequester more carbon and encourage more resilience in the face of climate-driven disturbance, Congress should reduce the drain that wildfire suppression has placed in the Forest Service budget. To solve the problem, Congress should change the way the government of the United States pays for wildfire control. Instead of treating wildfire as an agency expense draining money away from forest management and land purchase, wildfires should be treated like other natural disasters—caused by climate change or not—and financed out of general funds. The Wildfire Disaster Funding Act, which provides a mechanism for achieving this goal, has been introduced in Congress.[29]

5.5.4 Increasing Soil Carbon Storage

Increasing the storage of carbon in agricultural soils could make a very significant contribution to U.S. deep decarbonization goals. One strategy alone—growing cover crops on the 40 percent of land used for the top five primary crops in the U.S. not already using them (88 million out of 230 million acres)—could store additional carbon equivalent to 100 million tons CO_2 per year at minimal cost.[30] Other measures include conservation tillage, efficient irrigation, sustainable grazing and improved nutrient management. Chapter 2 projects that the land sink needs to store 375 Mt CO_2 equivalent per year by 2050 to achieve economy-wide carbon neutrality, assuming net-zero emissions in the energy and industrial sectors. Using the FABLE sustainable pathway, 347 $MtCO_2e$ of that sequestration can come from ambitious reforestation, dietary shifts, changes in international trade of agricultural and forestry commodities, and agricultural productivity improvements, which leaves around 27 $MtCO_2e$ to be achieved through other land-based climate solutions not modeled in the FABLE pathways, including improved forest management and soil carbon sequestration. This would be a minimum target estimate for soil carbon (SOC) sequestration, as the FABLE pathway assumes ambitious changes across the food and land use sectors. Consequently, policy measures devoted to stimulating increased soil carbon storage should be an important plank of U.S. climate policy.

Policy in this area should be built around four pillars:

Pillar 1. Monitoring, reporting and verification (MRV): A key barrier to implementing programs to increase soil carbon at large scale is the need for credible and reliable monitoring, reporting, and verification (MRV) platforms, both for national reporting and for emissions trading. Without such platforms, investments could be considered risky.[31] While the modeling and measurement tools to enable such a platform exist, considerable funding is necessary to overcome high initialization costs and unequal monitoring capacity. Assuming \$20-\$50 for MRV from previous estimates derived from forestry projects over 410 million acres of U.S. agricultural land, we estimate the costs of an MRV program at \$250-\$650 million per year.[32] Costs would likely come down as MRV protocols are standardized and more cost-efficient monitoring technologies are developed and rolled out, a key research priority for the newly established Advanced Research Projects Agency (ARPA) Land, described in Section 5.5.8.

This platform should consist of a system of benchmark sites for long- and short-term soil carbon monitoring, representing a wide range of land use types, soil types, and management practices, supplemented by models of soil carbon change that can also simulate a range of scenarios of future change. If the models are deemed reliable, they could be used to derive region-specific emission or soil carbon stock change factors, or directly simulate regionally-disaggregated soil carbon change and GHG emissions.

Funding for these activities should also be made available to developing countries, including capacity building and technology transfer, given the high soil carbon storage potential in countries in Southeast Asia and Eastern Europe.[33]

Pillars 2 and 3, extension and financing, respond to the large transaction costs that farmers face to learn, invest, and durably adopt management practices and technologies that enhance soil carbon storage.

Pillar 2. Financing: Federal environment and conservation programs need to be expanded significantly to incentivize farmers to durably adopt a range of management practices that will enhance soil carbon storage. This includes increasing the annual budget of the US Department of Agriculture's Conservation Stewardship Program (CSP) from $1 billion to $5 billion. CSP provides financial assistance to farmers meeting threshold levels of conservation on their entire farm through a five-year contract. In return for annual payments, the producer agrees to maintain current conservation practices and increase or improve conservation across the farm during the five years of the contract. Another incentive measure that should be implemented is federal crop insurance reform, tying insurance premiums to the carbon intensity of farm management practices implemented; premiums would be reduced if carbon storage practices are adopted, while carbon intensive practices would increase premiums given the increased climate risk associated with their use. Similarly, building on the USDA's Sodbuster and Swampbuster programs, a suite of existing agricultural subsidies should be made conditional on the adoption of a range of management practices and technologies, akin to what is already done in the European Union.[34]

Pillar 3. Extension: In tandem with increased financial incentives, significant investments need to be made in the agricultural extension workforce, to increase the number of experts on the ground that can help farmers learn about, adopt, and adapt different management practices and technologies to enhance carbon storage, tailored to their unique environment. As a result, we recommend almost tripling the USDA NRCS staff capacity from 12,000 to 30,000, in line with Governor Inslee's Growing Rural Prosperity plan, which we estimate would cost approximately $1.5 billion per year. In addition, and in line with the 2020 Agriculture Resilience Act, we recommend setting aside 1 percent of Farm Bill conservation program funding to finance third party extension programs in conservation districts, land-grant universities, NGOs, and land trusts.

Pillar 4. Public-private partnerships: As explored in chapter 5.6, the Environmental Protection Agency's (EPA) Sustainable Materials Management (SMM) program fosters partnerships to reduce food waste in corporate supply chains and federal agency operations by supporting public-private partnerships to increase the recycling of food waste as agricultural soil amendments to stimulate soil carbon storage. If expanded and supported, this could have the co-benefit of reducing methane emissions from food waste decomposition in landfills.

5.5.5 Next Generation Biofuels

While the light-duty vehicle fleet will be largely electrified by 2035, biofuels will play an increasingly important role in other transport sub-sectors, including heavy-duty vehicles, aviation, and shipping. Chapter 2 projects that second generation biofuels, such as miscanthus (180 million tons) and switchgrass (135 million tons), will make up over 80 percent of biofuel production in the U.S. by 2050. This corresponds to approximately 4 million barrels of biofuel production per day, four times the current rate of fuel ethanol production and 10-20 percent of current U.S. petroleum refining capacity. We note that producing these crops for biofuels does not imply expanding cropland; the FABLE sustainable land use pathway shows that with dietary changes and productivity increases, these crops can be grown on land previously used for growing livestock feed.[35] We envisage a three-pronged approach to sparking this transformation: increased RDD&D funding, a new low-carbon fuel standard, and new federal procurement standards.

RDD&D funding: A central funding priority of the newly established ARPA-Land (as described in Section 5.5.8) should be the research, development, demonstration, and commercialization of next generation biofuels, particularly biofuels made from non-food (cellulosic and algae-based) resources. Funding should be made available for both private and public (including state research institutions) research initiatives via ARPA-Land, including competitive grant and cost-sharing programs. Increased private-sector RDD&D will also be stimulated by the strong market signal sent by a new low-carbon fuel standard, described below.

Low-carbon fuel standard: Post 2022, the Renewable Fuels Standard should be transformed into a low-carbon fuel standard that promotes low-carbon biofuels for vehicles that cannot be electrified cost-effectively, as well as planes and ships. This policy mechanism would support the ZCAP projections of increased miscanthus and switchgrass use as biofuel feedstocks by 2050. The new standard should set a technology- and feedstock-neutral benchmark for liquid and non-liquid fuels, tied to a lifecycle assessment of the carbon intensity of the fuels which takes into account land use implications. The carbon intensity standard should become more stringent over time—at least 80 percent below gasoline and diesel—and include guardrails to prevent conversion of non-agricultural lands into cropland, particularly sensitive lands with high carbon sequestration and biodiversity value.[36] The new standard should reward entities in the value chain, including farmers and producers, that use climate-smart practices that reduce carbon emissions, store soil carbon, and reduce nitrous oxide emissions, coordinating with policy efforts to improve farm-level management practices.[37]

Federal procurement standards: In order to rapidly ramp up demand for next generation biofuels, the Federal Government should use its authority under existing legislation, such as the Defense Production Act, to direct the USDA, Department of Defense, and other relevant departments to procure increasing levels of advanced low-carbon renewable fuels. From 2013-2017 the Department of Defense alone consumed approximately 90 million barrels of fuel per year, underlining the potential importance of a focused federal procurement strategy in changing market demand for next generation biofuels.[38]

5.5.6 Support Healthy Low-Carbon Diets

Pastureland dedicated to producing meat, especially beef, and cropland for animal feed together consume over 40 percent of land in the continental US. Integrated modeling suggests that dietary shifts are key to achieving net-zero GHG emissions in the land use sector by mid-century.[39] The U.S. FABLE sustainable land use pathway assumes that the American diet transitions towards a “healthy US-style pattern” as determined by the Dietary Guidelines for Americans by the USDA.[40] Compared to the EAT-LANCET recommendations, red meat, pork, milk, oils and fats, poultry, sugar, eggs, and animal fats are over-consumed in the current diet while cereals, fish, fruits and vegetables, pulses, and nuts are under-consumed. Moreover, fat intake per capita exceeds the dietary reference intake (DRI) due to high consumption of oils and fats and animals fats. Importantly, a diet that is more environmentally sustainable than the average U.S. diet can be achieved without excluding any food groups.

Several proven interventions can impact food preferences in order to foster a dietary shift towards a food system with lower GHG emissions.[41] The Federal Government can promote the shift with the following policies:

- Health and Human Services (HHS), in partnership with USDA, should ensure that dietary guidelines for Americans not only reflect the latest nutrition science, but also incorporate sustainability.[42] The Scientific Report of the 2015 Dietary Guidelines Advisory Committee already recommended incorporating sustainability into dietary recommendation guidelines. In 2021, HHS should take the next step and formally incorporate sustainability into the dietary guidelines for Americans.
- USDA should foster climate-friendly certification to encourage low-carbon agriculture and livestock production, following the success of organic certification in creating a price premium for organic products.
- Nutrition standards for food and beverages in schools have been shown to benefit diet and weight.[43] USDA should maintain the nutrition standards of school meals that were in effect prior to USDA’s interim final rule from November 2017, as well as current nutrition standards for school snacks. The USDA should align food nutrition standards for child nutrition programs (The Child and Adult Care Food Program (CACFP), The National School Lunch program, The School Breakfast Program, The Summer Food Service Program, The Fresh Fruit and Vegetable Program, and The Farm to School Program) with updated dietary guidelines for Americans that incorporate sustainability. In particular, child nutrition programs should increase the proportion of plant-based meat alternatives, fruits and vegetables in meals.
- USDA should continue to implement the Community Eligibility Provision that allows schools in high-poverty areas to serve free meals to all students, regardless of income. These meals should satisfy nutrition and low-carbon standards.
- Change the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) to include additional healthy foods, including more fish; increasing whole grains, fruits, and vegetables; and reducing sodium and saturated fat.[44] This has been shown to lead to healthier food purchases and intake by families using WIC.[45] WIC’s Farmer’s Market Nutrition Program provides fresh, locally-grown produce to participants and has been proven to increase fresh fruit and vegetable consumption.[46]
- Provide SNAP (Supplemental Nutrition Assistance Program) incentives for vegetables and fruits.[47] The Healthy Incentives Pilot in 2013 showed that certain SNAP recipients were successfully incentivized to purchase more fruits and vegetables.[48] SNAP-Ed,

educational programs that encourage participants to make healthy food choices, have been found to increase fruit and vegetable consumption among elementary school children and seniors in the program.[49] Successful Healthy Incentive and SNAP-Ed programs should be scaled up and continuously evaluated to improve impact.

- USDA's Food Insecurity Nutrition Incentive (FINI) program incentivizes SNAP participants to buy more fresh produce by lowering the cost of nutritious foods. FINI grants should add sustainability to the criteria of foods eligible for subsidies for SNAP recipients, generating incentives for recipients to purchase low-carbon produce and plant-based meat alternatives.
- Congress should prioritize climate change in procurement contracts. The 2008 Farm Bill, for example, directed USDA to pass regulations encouraging institutions participating in child nutrition programs to purchase local agricultural products. Congress should pass legislation prioritizing low-carbon agricultural products for all government bodies, including large-scale purchasers such as the U.S. Department of Defense as well as hospitals and prisons.

State and local governments can promote a more sustainable food system by policies such as:

- SNAP incentives for farmer's markets such as New York City's "Health Bucks" program, which increases access to and purchase of vegetables and fruits in low-income communities.[50]
- Offer healthy foods on government property

5.5.7 Reducing Food Loss and Food Waste

A key part of reducing pressure on agriculture systems and meeting sustainability goals for land is to reduce food loss and waste. The USDA Economic Research Service estimates that 31 percent of food produced in 2010 was wasted at the consumer or retail levels.[51] EPA and USDA have set a goal of reducing food loss and waste by 50 percent by 2030, and over the next year should put forward specific policies at federal level or guidance to states in pursuit of that goal.

An important first step is to standardize measurement and data analysis tools to measure and monitor progress towards the goal of reducing food loss and waste.[52]

Policy interventions in this area include:[53]

- Government-backed loans for on-farm harvest storage facilities to reduce post-harvest food loss
- Create and deliver effective and consistent messaging to the public about the importance of food stewardship and the need to address food loss and waste
- Establish clear food sell- and use-by-date guidelines that distinguish between quality versus safety concerns
- Streamline procedures and rules for food donation from traders, processors, and retailers

- Follow the food waste hierarchy of (1) reduce the amount of food at the source, (2) feed excess food to people, (3) feed left-over food to animals, (4) compost what remains, and (5) anaerobically digest if necessary (e.g.,: mandate businesses and institutions recover/recycle food scraps, and mandate private haulers and management facilities to construct and maintain infrastructure to properly manage these materials)
- Reduce food discards and increase edible food redistribution in food wholesale, retail, and food services through ambitious reduction goals and actions, including tracking software and other tools (e.g., Leanpath) to reduce over-purchasing, avoidable food waste, and redirect edible food to local charities (target larger generators first)
- Require public reporting of food waste and recycling rates by private actors in the food sector
- Provide tax incentives for research and development on new technologies for reducing food waste
- Develop incentives for the recovery and recycling of food waste as animal feed or centralized composting

5.5.8 Conclusions and Policy Recommendations

In addition to the specific recommendations detailed above, we outline three overarching policy recommendations that span the many issues that arise with respect to decarbonization of the U.S. economy and the role of U.S. lands.

ARPA-Land: The ARPA labs have proven to be invaluable assets to U.S. leadership in scientific discovery and the development of cutting-edge technologies. The Defense Advanced Research Projects Agency (DARPA) has a $3.5 billion annual budget and since its creation has helped fund many world-leading combat vehicles and information systems. ARPA-Energy has invested $2 billion in government RDD&D investment since its first round of funding in 2009, financing a variety of energy projects and generating over 300 patents. Given the range of technical challenges the U.S. faces with regard to the role of its land in economy-wide decarbonization, the U.S. government should create an ARPA lab with a singular focus on land-based activities. Specifically, ARPA-Land should have the following funding priorities:

- Monitoring technologies and tools to measure soil carbon sequestration from short- (days) to long-term (decades) over small- (fields) to large-scale (continents) areas. Given the importance of soil carbon sequestration in the overall carbon budget, improvements in measurement and monitoring technologies will be critical.
- Next-generation biofuels that can achieve the low-carbon fuel goals outlined in this plan, particularly biofuels made from non-food (cellulosic and algae-based) resources.
- Next-generation, low-carbon intensity animal protein substitutes that can be made widespread at low-cost.
- Technologies for reducing food loss and waste, including innovations in food packaging, storage, and transport.
- Renewable energy technologies that minimally impact agricultural production when integrated with agricultural lands

New inter-agency task force on land: Inter-agency task forces have been established to address a variety of issues throughout U.S. history that require coordination of activities and regulatory approaches of multiple departments and agencies, ranging from human trafficking to climate change. At the start of the next presidential term, the administration should create a new inter-agency task force on land to coordinate the multiple issues relevant to U.S. lands in the context of deep decarbonization. Renewable infrastructure siting, increased soil carbon sequestration, biofuel production, reforestation, and shifting away from animal agriculture all have positive and negative (and likely competing) implications for land use change and land-based activities, and authority over each of these activities is spread across several areas of the U.S. government, including the Department of Defense, Department of Energy, Department of the Interior, Department of Agriculture, and the Environmental Protection Agency. To minimize competition for land, whether it be for food, fiber, or energy, it is critical that federal departments and agencies coordinate and align their priorities to manage trade-offs and maximize synergies in land use decisions. Moreover, such a task-force should coordinate with relevant states, as state governments also have significant authority over land use decisions.

Integrated Spatial Planning: The U.S. needs to invest in developing targets and long-term pathways towards sustainable land use and food systems that consider agronomy, nutrition, ecology, hydrology, climatology, economics, infrastructure engineering, the social sciences, and of course local politics. To our knowledge, the federal and state governments lack both long-term targets to achieve sustainable food and land use systems as well as pathways (i.e., sets of policies, management strategies, and programs) to achieve those targets. An important first step is to support the development of analytical tools to understand the complex synergies and trade-offs across these areas and to determine which short-term measures must be undertaken in order to achieve long-term objectives. Just as it is impossible to design and implement economic policies without sound macroeconomic models, the U.S. will not be able to make its land use and food systems sustainable without robust tools to model the integrated impacts of policies.

Taken together, these policy recommendations would mark a transformative step forward in ensuring a meaningful, positive contribution of the land use sector—in all its forms—to deep decarbonization in the U.S. Moreover, the many links between land use and other environmental crises—from air and water pollution to biodiversity loss—means that ambitious action in this sector will enable the U.S. and the world to improve multiple elements of human and ecosystem wellbeing.

References

1. FABLE. 2020. *Pathways to Sustainable Land-Use and Food Systems: 2020 Report of the FABLE Consortium*. Laxenburg and Paris: International Institute for Applied Systems Analysis (IIASA) and Sustainable Development Solutions Network (SDSN).
2. USDA. 2014. Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. Technical Bulletin Number 1939. Office of the Chief Economist, U.S. Department of Agriculture, Washington, DC.
3. Wu, Grace C. 2020. *Spatial Planning of Low Carbon Transitions*. New York, NY: SDSN. https://irp-cdn.multiscreensite.com/be6d1d56/files/uploaded/SDSN_DDPP_SpatialPlanning_GraceWu_final.pdf.
4. Ibid.
5. "Smart Solar Siting Partnership Project for New England." n.d. *American Farmland Trust* (blog). Accessed August 18, 2020. https://farmland.org/project/smart-solar-siting-partnership-project-for-new-england.
6. "New York State Announces Passage of Accelerated Renewable Energy Growth and Community Benefit Act as Part of 2020-2021 Enacted State Budget - NYSERDA." April 3, 2020. Accessed August 18, 2020. https://www.nyserda.ny.gov/About/Newsroom/2020-Announcements/2020-04-03-NEW-YORK-STATE-ANNOUNCES-PASSAGE-OF-ACCELERATED-RENEWABLE-ENERGY-GROWTH-AND-COMMUNITY-BENEFIT-ACT-AS-PART-OF-2020-2021-ENACTED-STATE-BUDGET.
7. "Clean Energy Resources Development and Incentives 'Build-Ready' Program." n.d. NYSERDA. Accessed August 18, 2020. https://www.nyserda.ny.gov/All%20Programs/Programs/Clean%20Energy%20Standard/Renewable%20Generators%20and%20Developers/Build%20Ready%20Program.
8. Gerrard, Michael B. 2017. "Legal Pathways for a Massive Increase in Utility-Scale Renewable Generation Capacity," *Environmental Law Reporter* 47(7). https://climate.law.columbia.edu/sites/default/files/content/pics/homePage/Legal-Pathways-for-a-Massive-Increase-in-Utility-Scale-Renewable-Generation-Capacity.pdf.
9. "Rural Energy for America Program Renewable Energy Systems & Energy Efficiency Improvement Guaranteed Loans & Grants | Rural Development." n.d. Accessed August 18, 2020. https://www.rd.usda.gov/programs-services/rural-energy-america-program-renewable-energy-systems-energy-efficiency.
10. United States Department of Agriculture. 2019. "USDA Has More Than $400 Million Still Available For Renewable Energy System And Energy Efficiency Loan Guarantees". https://www.usda.gov/media/press-releases/2019/07/18/usda-has-more-400-million-still-available-renewable-energy-system.;

    United States Department of Agriculture. 2019. FY 2019 Budget Summary. Washington D.C.: United States Department of Agriculture. https://www.usda.gov/sites/default/files/documents/usda-fy19-budget-summary.pdf.
11. Wu, Grace C., Emily Leslie, Oluwafemi Sawyerr, D. Richard Cameron, Erica Brand, Brian Cohen, Douglas Allen, Marcela Ochoa and Arne Olson. 2020. "Low-impact land use pathways to deep decarbonization of electricity." *Environmental Research Letters* 15(7). https://doi.org/10.1088/1748-9326/ab87d1.
12. *Energy Policy Act Of 2005*. 2005. Vol. 1222. Department of Energy.
13. Ibid.
14. Ibid.
15. Perlman, David. 2018. "Boost for Renewables Transmission: DOE Transmission Siting Authority Upheld" *Energy Legal Blog*. https://www.energylegalblog.com/blog/2018/01/17/boost-renewables-transmission-doe-transmission-siting-authority-upheld.
16. U.S. Energy Information Administration. 2018. *Assessing HVDC Transmission for Impacts of Non–Dispatchable Generation*. Washington D.C.: U.S. Department of Energy. https://www.eia.gov/analysis/studies/electricity/hvdctransmission/pdf/transmission.pdf.
17. Reed, Liza, M. Granger Morgan, Parth Vaishnav, and Daniel Erian Armanios. 2019. "Converting Existing Transmission Corridors to HVDC Is an Overlooked Option for Increasing Transmission Capacity." *Proceedings of the National Academy of Sciences* 116 (28): 13879. https://doi.org/10.1073/pnas.1905656116.
18. U.S. Energy Information Administration. 2018. *Assessing HVDC Transmission for Impacts of Non–Dispatchable Generation*. Washington D.C.: U.S. Energy Information Administration. https://www.eia.gov/analysis/studies/electricity/hvdctransmission/pdf/transmission.pdf.

19. Macknick, Jordan, Courtney Lee, Gail Mosey, and Jenny Melius. 2013. "Solar Development on Contaminated and Disturbed Lands." NREL/TP--6A20-58485, 1260337. https://doi.org/10.2172/1260337.

20. U.S. Fish and Wildlife Service. 2012. U.S. Fish and Wildlife Service Land-Based Wind Energy Guidelines. *Washington D.C.: U.S. Fish and Wildlife Service*. https://www.fws.gov/ecological-services/es-library/pdfs/WEG_final.pdf.

21. N.Y. Senate. 2020. *Accelerated Renewable Energy Growth and Community Benefit Act.* 2nd sess., S7508B. https://www.nysenate.gov/legislation/bills/2019/s7508/amendment/b.

22. Ibid.

23. Ibid.

24. The White House. 2016. *United States Mid-Century Strategy for Deep Decarbonization*.

25. Monge, Juan J., Henry L. Bryant, Jianbang Gan, and James W. Richardson. 2016. Land use and equilibrium implications of a forest-based carbon sequestration policy in the United States. *Ecological Economics* 127, 102-120.;
Murray, Brian. C. et al. 2005. *Greenhouse gas mitigation potential in U.S. forestry and agriculture*. Washington, D.C.: U.S. Environmental Protection Agency.; Fargione, Joseph E., et al. 2018. Natural climate solutions for the United States. *Science Advances* 4(11). doi: 10.1126/sciadv.aat1869.

26. Fargione et al., Natural climate solutions.;

"Multi-Resolution Land Characteristics (MRLC) Consortium." Multi-Resolution Land Characteristics (MRLC) Consortium. Accessed August 19, 2020. https://www.mrlc.gov.

27. Cheever, Federico, Robert McKinstry and Robert Fischman. 2019. "Chapter 31: Forestry." In *Legal Pathways to Deep Decarbonization in the United States,* edited by Michael Gerrard and John C. Dernbach. Washington D.C.: Environmental Law Institute.

28. Ibid.

29. Ibid.

30. Fargione et al., Natural climate solutions.

31. Smith P, Soussana J-F, Angers D, Schipper L, Chenu C, Rasse DP, Batjes NH, van Egmond F, McNeill S, Kuhnert M, Arias-Navarro C, Olesen JE, Chirinda N, Fornara D, Wollenberg E., Álvaro-Fuentes J, Sanz-Cobeña A, Klumpp K. 2019. How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. Global Change Biology. DOI: 10.1111/gcb.14815.

32. Ibid.

33. Zomer, Robert J., Deborah A. Bossio, Rolf Sommer, and Louis V. Verchot. 2017. "Global Sequestration Potential Of Increased Organic Carbon In Cropland Soils". *Scientific Reports* 7 (1). doi:10.1038/s41598-017-15794-8.

34. Kanter, David R., et al. "Nitrogen pollution policy beyond the farm." *Nature Food* (2019): 1-6.

35. FABLE, *Pathways to Sustainable Land-Use and Food Systems.*

36. House Select Committee on the Climate Crisis. 2020. "Solving The Climate Crisis: The Congressional Action Plan For A Clean Energy Economy And A Healthy, Resilient, And Just America". Washington, D.C.: Select Committee on the Climate Crisis Majority Staff Report.;
Lehner, Peter, and Nathan A. Rosenberg. 2017. "Legal Pathways to Carbon-Neutral Agriculture." *Envtl. L. Rep*. News & Analysis 47: 10845.

37. Ibid.

38. Greenley, Heather L. 2019. "Department Of Defense Energy Management: Background And Issues For Congress". CRS Report 45832. Washington D.C.: Congressional Research Service.

39. FABLE, *Pathways to Sustainable Land-Use and Food Systems.*

40. U.S. Department of Health and Human Services, & U.S. Department of Agriculture. 2015. *2015-2020 Dietary Guidelines*. Health.gov. https://health.gov/dietaryguidelines/2015/guidelines.

41. Lehner and Rosenberg, "Legal Pathways to Carbon-Neutral Agriculture".;

Anderson, Cheryl A.M., Anne N. Thorndike, Alice H. Lichtenstein, Linda Van Horn, Penny M. Kris-Etherton, Randi Foraker, and Colleen Spees. 2019. "Innovation To Create A Healthy And Sustainable Food System: A Science Advisory From The American Heart Association". *Circulation* 139(23). doi:10.1161/cir.0000000000000686.

42. USDA & HHS. 2015. *Scientific Report of the 2015 Dietary Guidelines Advisory Committee, Part D. Chapter 5: Food Sustainability and Food Safety*. Washington D.C.: HHS.

43. Rosettie, KL, Micha R, Cudhea F, Peñalvo JL, O'Flaherty M, Pearson-Stuttard J, Economos CD, Whitsel LP, Mozaffarian D. 2018. Comparative risk assessment of school food environment policies and childhood diets, childhood obesity, and future cardiometabolic mortality in the United States. *PLoS One* 13:e0200378. doi: 10.1371/journal.pone.0200378.;

Welker E, Lott M, Story M. 2016. The school food environment and obesity prevention: progress over the last decade. *Curr Obes Rep.* 5:145–155. doi: 10.1007/s13679-016-0204-0.

44. National Academies of Sciences, Engineering, and Medicine. 2017. *Review of WIC food packages: improving balance and choice: final report*. National Academies Press. https://doi.org/10.17226/23655.

45. Chiasson MA, Findley SE, Sekhobo JP, Scheinmann R, Edmunds LS, Faly AS, McLeod NJ. 2013. Changing WIC changes what children eat. *Obesity* 21:1423–1429. doi: 10.1002/oby.20295.;

Kong A, Odoms-Young AM, Schiffer LA, Kim Y, Berbaum ML, Porter SJ, Blumstein LB, Bess SL, Fitzgibbon ML. 2014. The 18-month impact of Special Supplemental Nutrition Program for Women, Infants, and Children food package revisions on diets of recipient families. *Am J Prev Med*. 46:543–551. doi: 10.1016/j.amepre.2014.01.021; Odoms-Young AM, Kong A, Schiffer LA, Porter SJ, Blumstein L, Bess S, Berbaum ML, Fitzgibbon ML. 2014. Evaluating the initial impact of the revised Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) food packages on dietary intake and home food availability in African-American and Hispanic families. *Public Health Nutr*. 17:83–93. doi: 10.1017/S1368980013000761.

46. Wisconsin Department of Health Services. 2018. Executive Summary of the 2007 Wisconsin WIC Farmers' Market Nutrition Program. https://www.dhs.wisconsin.gov.

47. Olsho LE, Klerman JA, Wilde PE, Bartlett S. Financial incentives increase fruit and vegetable intake among Supplemental Nutrition Assistance Program participants: a randomized controlled trial of the USDA Healthy Incentives Pilot. *Am J Clin Nutr*. 2016;104:423–435. doi: 10.3945/ajcn.115.129320.

48. U.S. Department of Agriculture Food and Nutrition Service. "Healthy Incentives Pilot." June 2017. https://www.fns.usda.gov/hip/healthy-incentives-pilot (accessed July 16, 2018).

49. Supplemental Nutrition Assistance Program. "SNAP-Ed Education and Evaluation Study (Wave II)." U.S. Department of Agriculture. https://www.fns.usda.gov/snap/supplemental-nutrition-assistance-program-education-and-evaluation-study-wave-ii (accessed June 12, 2018).

50. Payne GH, Wethington H, Olsho L, Jernigan J, Farris R, Walker DK. Implementing a farmers' market incentive program: perspectives on the New York City Health Bucks Program. *Prev Chronic Dis*. 2013;10:E145. doi: 10.5888/pcd10.120285.

51. Buzby, J. C., Farah-Wells, H., & Hyman, J. 2014. *The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States*. U.S. Department of Agriculture, Economic Research Service. http://www.ssrn.com/abstract=2501659.

52. US EPA. 2020. A Call To Action By Stakeholders: United States Food Loss & Waste 2030 Reduction Goal. Washington D.C.: US EPA. https://www.epa.gov/sustainable-management-food/call-action-stakeholders-united-states-food-loss-waste-2030-reduction.

53. Kanter, David R., Fabio Bartolini, Susanna Kugelberg, Adrian Leip, Oene Oenema and Aimable Uwizeye. 2019. Nitrogen pollution policy beyond the farm. *Nature Food*: 1-6.;

Papargyropoulou, E., Lozano, R., Steinberger, J. K., Wright, N. & bin Ujang, Z. 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. *J Clean Prod* 76, 106-115. doi:10.1016/j.jclepro.2014.04.020;

Liu, C. et al. 2016. Food waste in Japan: Trends, current practices and key challenges. *J Clean Prod* 133, 557-564. doi:10.1016/j.jclepro.2016.06.026 (2016).; ReFED. 2018. Proposed Federal Food Waste Policy, https://doi.org/10.1016/j.jclepro.2016.06.026

5.6 Accelerating Sustainable Materials Management in the U.S.

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5.6.1 Introduction, Context, and Goals

Introduction and Context

In addition to other realities, the 2020 pandemic brought into sharp focus the startling consequences of human overuse and misuse of natural resources and related ecosystem stresses. As national and regional policies realign in order to respond to this threat, it is essential that opportunities are identified to shed old, costly, and carbon-inefficient materials (waste) management facilities, processes, and systems. This chapter of the Zero Carbon Action Plan (ZCAP) covers materials management. The primary focus is on the life cycle of consumer products packaging materials, currently and historically managed as waste after the end of their period of initial use. This group of materials is widely referred to as municipal solid waste (MSW), but this chapter also includes items from institutional, business/commercial, and residential sources. In addition to “traditional” materials like glass, metals, plastic, and paper, a few other materials are briefly addressed, such as construction, demolition, and disaster debris, food waste, and other organic material. Other ZCAP chapters, such as buildings (chapter 5.5) and land (chapter 5.3), touch on materials management as well. Coupled with “green” manufacturing initiatives, a progressive response to materials management will not only help to safeguard human and ecosystem health through significant greenhouse gas (GHG) reductions, but also provide economic stimulus for “clean” industries and job creation.

As Figure 5.6.1 depicts, one estimate has more than 40 percent of the climate impact in the U.S. comes from the materials and food consumed. This includes the entire supply chain, from manufacturing, transportation, and usage, to final disposition of the materials. This is called “consumption emissions.”[1]

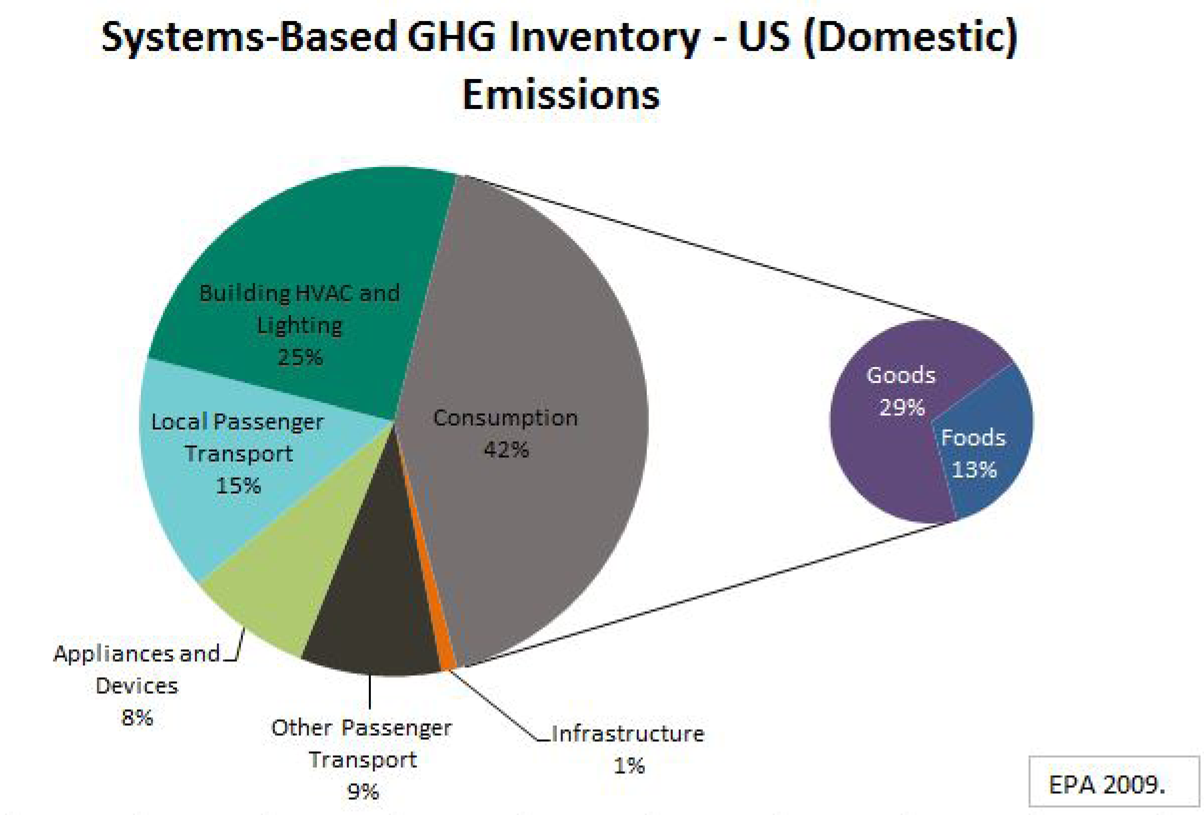

Figure 5.6.1. System-based GHG Inventory – U.S. (Domestic Emissions) ("Smokestacks", 2020).

Sustainable Materials Management (SMM) with associated and embedded zero waste and circular economy goals, provides a progressive response of deep decarbonization that is intrinsically linked to sustainable development. These combined concepts represent a valuable perspective for decoupling resource consumption from industrial growth and economic value creation, moving from extractive to regenerative processes, and reducing carbon use resulting in a commensurate decrease in GHGs. While industrialized societies have achieved gains in resource efficiency and materials recycling, total material throughput continues to rise. As the world's developing economies increase consumption rates, environmental pressures continue to accelerate.[2] This also includes increased GHG production.

A truly integrated materials management approach must recognize the physical, ecological, and economic implications of SMM policies, and assure that the burden is not shifted elsewhere. Policy integration should address SMM issues in a way that transcends traditional boundaries between substances, material categories, environmental media, and industry sectors. Fiscal tools are needed that help transition from subsidizing extractive industries to supporting circular economy activities. Focus should be on the entire life cycle of materials from extraction to end of life, and include externalities such as GHG production. An integrated approach toward SMM will provide a starting point for advancing a more sustainable global society, with significantly reduced GHG emissions, and increased environmental and social well-being.[3]

Integrating SMM principles and practices into everyday life will result in many positive externality-focused benefits. For example, sustainability, greenhouse gases, and decarbonization are intangible concepts to many people. The average person likely does not recognize the GHGs they emit on a daily, monthly, or yearly basis. These are difficult to track and hard to quantify. However, with some effort, a person can clearly see and measure the amount of material they produce over any given time span. SMM is tangible and can act as a gateway in creating a strong environmental ethic, leading people to take interest in additional decarbonization actions.

Goals of Chapter Recommendations

SMM, with associated and embedded zero waste, circular economy, and zero-carbon goals, should be embraced as U.S. national policy.

The U.S. needs to play a foundational role accelerating the global transition to a just, resource-efficient, circular, and climate-neutral economy, with zero-carbon as a primary objective. It cannot do this without addressing the current economic and consumption model and associated materials management schemes. To more rapidly reach zero-carbon objectives, the U.S. must also address a multitude of issues and challenges related to materials management, including, but not limited to:

- Implementation of product stewardship and extended producer responsibility initiatives
- Fragmentation and distributed policy authority
- Outdated federal policy
- Disassociation and distraction
- An unlevel playing field
- Difficult materials (such as plastics)
- “Chemical recycling”
- Waste-to-Energy impacts

To accelerate toward SMM, zero waste, and circular economy solutions, policy emphasis needs to be at, and change needs to emanate primarily from the Federal Government. While there are many successful state, local, private, and public-private accomplishments in the field of materials management, progress has been unacceptably slow, with discarded materials increasing in quantity and continuing to pose other environmental and public health impacts. The default with this chapter is on federal action, but some international, state, local, and private sector initiatives, and technology needs are addressed.

Federal action includes the need for the U.S. Congress to develop a comprehensive suite of policy changes and fiscal tools to move from subsidizing extractive industries to supporting circular economy activities and SMM; including, but not limited to: a national beverage container deposit act, material bans (such as single-use plastics), promotion of product stewardship, requiring comprehensive SMM plans for large organizations, and banning organic material from disposal facilities. Model SMM legislative initiatives and other progressive actions should be promoted that states and local governments could adopt from their peers. New technology opportunities and other strategies should be incentivized by the Federal Government to achieve zero-carbon through SMM at facilities and institutions, and new, related academic research and development activities should be supported.

In addition, the U.S. needs to play a leadership role on the international scene with zero-carbon as a core goal, attained in part through SMM and circular economic objectives included in free-trade agreements; bilateral, regional, and multilateral processes and agreements; and in U.S. external policy funding instruments.

The set of specific foreign, federal, and state and local policy recommendations included in this chapter form a foundation that will optimize material use and management with commensurate reduction in carbon use and GHG production.

5.6.2 Background

A Short History of U.S. Materials Management (Solid Waste Management)

Funding and the availability of resources at the local, state, regional, and federal levels for programs focused on education, new management infrastructure (e.g., recycling facilities), and research and development related to solid waste (materials) management experienced an exponential increase, particularly from 1990 to around 2010. This included efforts intended to change consumer buying habits – the goals being to encourage the choice of products with less packaging, higher-recycled content, and increased recyclability – and to affect behavior change regarding disposal habits (i.e., choose recycling and composting instead of disposal). During the last few decades, despite these investments and initiatives, and associated changes in packaging materials – such as lightweighting and the availability of new materials from the consumer products and materials industries – the total of discarded materials continued to increase.[i] In addition, the reliance on inefficient, polluting, and GHG generating disposal facilities, such as landfills, continued to be the method of management choice. Figure 5.6.2 depicts the most recent U.S. Environmental Protection Agency (EPA) data relating to MSW production[ii] and management.[4] In 1960, each person on average disposed of 2.68 pounds of solid waste per day. Since 2000, this rate fluctuated from 4.74 to 4.51 in 2017—one of the lowest since 1990; but still, unacceptably high (nearly one ton per person, per year).[5] As reported in *The Guardian* in July 2019:

> The U.S. produces far more garbage and recycles far less of it than [low- and middle-income] countries, according to a new analysis by the global risk consulting firm Verisk Maplecroft [Figure 5.6.2].[6] These figures emerge as the world faces an escalating waste crisis driven largely by plastics piling up in [low- and middle-income] countries and the oceans. The U.S. is at a crossroads as China and other [low- and middle-income] countries refuse to continue to accept its waste. The U.S. represents just 4 percent of the world's population, but it produces 12 percent of global MSW. In comparison, China and India make up more than 36 percent of the world's population and generate 27 percent of that waste. While [the U.S. recycles around 35 percent of its] municipal waste, Germany, the most efficient country, recycles 68 percent. [Verisk] estimates the U.S. produces about 234 pounds of plastic waste per person per year.[7]

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i Lightweighting refers to the design of lighter-weight packages and the purposeful reduction in materials in packaging, such as using thinner aluminum or plastic for beverage containers.

ii It is widely understood by materials management practitioners that EPA's waste generation numbers are underestimated, which means that all of the following assumptions about the potential GHG reductions from high levels of source reduction and recycling are also underestimated, and therefore conservative numbers.

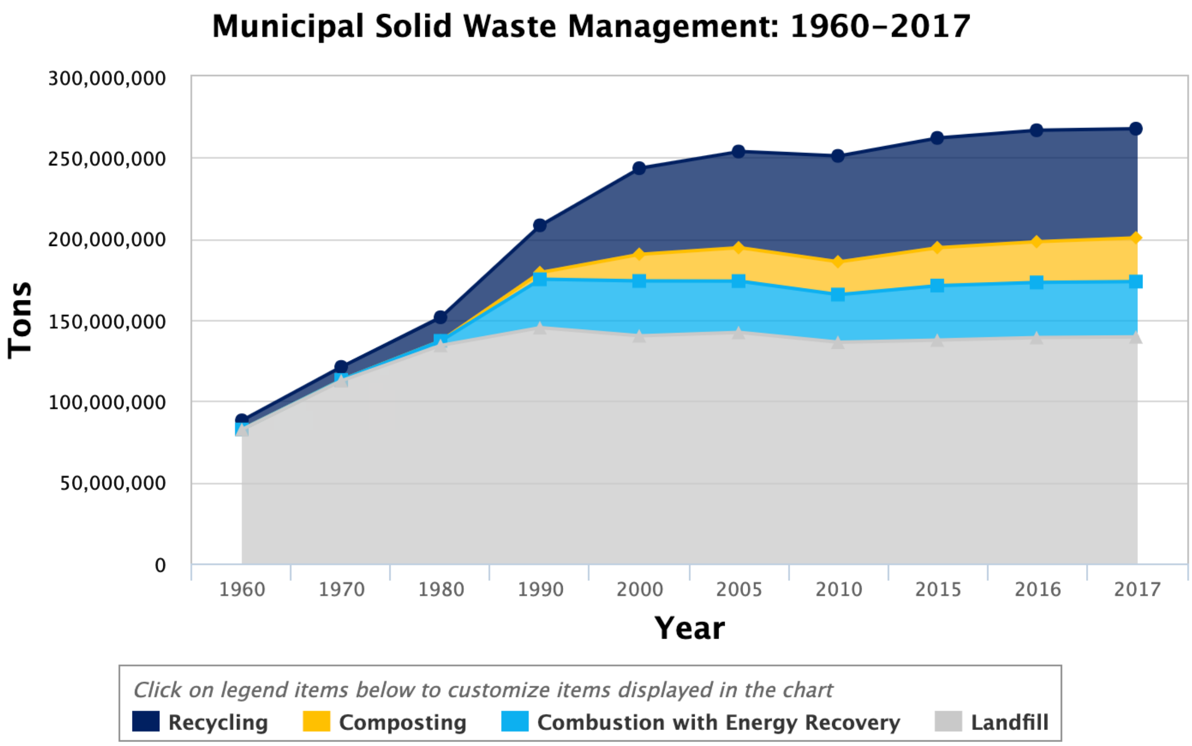

Figure 5.6.2. MSW management – 1960-2017 ("National Overview", 2020).

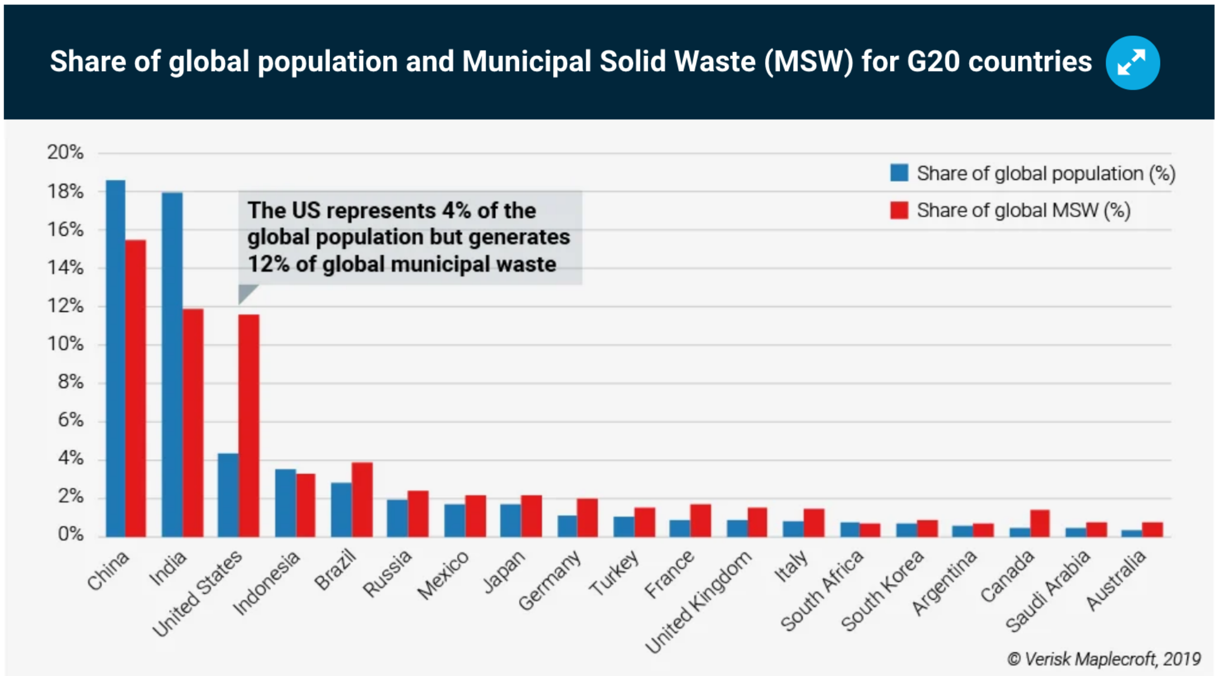

Figure 5.6.3. Share of Global Population and Municipal Solid Waste (MSW) for G20 Countries ("U.S. Tops Countries Fuelling the Mounting Waste Crisis", 2020).

Furthermore, recycling – a perceived panacea solution – has plateaued and seen minimal progress for nearly two decades.[8] Grassroots-recycling that swept the nation in the last generation made recycling and economic growth the focus of materials management. By 2000, the recycling sector comprised 56,000 companies, tens of thousands of government programs, 1.5 million jobs, and annual sales of $300 billion. In percentage of total MSW generation, recycling (including composting) did not exceed 15 percent until 1990. Growth in the recycling rate was significant over the next decade, but slowed and eventually stagnated by the 2000's. While some cities and towns have reached 50, 60, and even 70 percent recycling rates, most major U.S. cities recycle at 20 percent or less.[9] The national recycling rate in 2000 was about 29 percent, and grew to 35 percent in 2017.[10] However, it is expected that 2019 data will likely show a drop below 35 percent, "and [recycling] shows no signs of picking up steam again."[11]

Source, or waste reduction, has been at the top of the solid waste management hierarchy for decades. Some progress has been made with this "upstream" approach (eliminate the material before it enters the management system), but not at the levels needed to reverse the waste generation realities of the U.S. as noted in Figures 5.6.1 and 5.6.2. Over the last decade or so, a number of successful initiatives have advanced, including materials lightweighting, localized bans of unsustainable materials, like single-use plastics (e.g., plastic bags), and some product stewardship programs. In addition, there has been an uptick in consumer preference for multi-use product options over single-use. Society's "behavior of convenience," and individuals' need for expediency creates some challenges for source reduction. Nevertheless, the shift away from the disposable culture continues to expand with NGOs like the 5 Gyres Institute, Beyond Plastics, the Center for International Environmental Law, the Global Alliance for Incinerator Alternatives (GAIA), the National Recycling Coalition (NRC), the Plastics Pollution Coalition, the Post-Landfill Action Network (PLAN), The Story of Stuff Project, the Surfrider Foundation, the Upcycle Movement, Upstream, the U.S. Green Building Council (USGBC) TRUE Certification Program, Zero Waste International Alliance, Zero Waste USA, and others leading the way, but much more must be done.

U.S. Senator Tom Udall and U.S. Representative Alan Lowenthal, in an August 2020 memo to the National Caucus of Environmental Legislators, made the following observation:

> The current linear model of handling ... waste has only been exacerbated over time by increases in population and ever growing consumer appetite. In order to get it under control, we need to return to principles of product stewardship and circularity to ensure that we get a handle on our waste and address the environmental, economic, and health impacts that are straining our system.[12]

Greenhouse Gas Implications of Materials Management

The greenhouse gases (GHG) of concern in the materials management area include carbon dioxide (CO_2), mainly from energy use (e.g., manufacture and transportation, and processing of materials), and methane (CH_4), primarily from emissions (e.g., landfills). In September 2006, the EPA released the third edition of the report: *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks.*[13] While somewhat dated, the overall framework and premise of the report remains valid.

It outlines that:

> The materials in MSW largely represent what is left over after a long series of steps: (1) extraction and processing of raw materials, (2) manufacture of products, (3) transportation of materials and products to markets, (4) use by consumers, and (5) waste management. Virtually every step along this "life cycle" impacts GHG emissions. Solid waste management decisions can reduce GHGs by affecting one or more of the following: (1) Energy consumption (specifically, combustion of fossil fuels) associated with making, transporting, using, and disposing the product or material that becomes a waste; (2) Non Energy-related manufacturing emissions, such as the CO_2 released when limestone is converted to lime (e.g., steel manufacturing); [and] (3) CH_4 emissions from landfills where the waste is disposed. ... [These] mechanisms add GHGs to the atmosphere and contribute to global warming.[14]

However, different materials and materials management options have different implications for energy consumption (including associated CO_2 challenges) and CH_4 emissions. "Source reduction and recycling of paper products, for example, reduces energy consumption, and decreases combustion and landfill emissions."[15]

The EPA targeted the material constituents of MSW as those "most likely to have the greatest impact on GHGs."[16] The determination of what materials to include was "based on (1) the quantity generated, (2) the differences in energy use for manufacturing a product from virgin versus recycled inputs, and (3) the potential contribution of materials to CH_4 generation in landfills."[17] By this process, EPA limited the analysis to 21 single-material items. These include, but are not limited to aluminum and steel cans; glass; three types of plastic—HDPE (high-density polyethylene), LDPE (low-density polyethylene), and PET (polyethylene terephthalate); six categories of paper products, including corrugated cardboard, magazines/third-class mail, newspaper, and office paper; food discards; and, yard trimmings. The 21 materials constituted more than 65 percent of MSW by weight.[18] "In addition to the materials listed above, EPA examined the GHG implications of managing mixed plastics, mixed metals, mixed organics, mixed recyclables, mixed MSW, and three definitions of mixed paper."[19]

EPA developed:

> ... a streamlined life-cycle inventory for each of the selected materials. The analysis is streamlined in the sense that it examines GHG emissions only and is not a comprehensive environmental analysis of all emissions from municipal solid waste management options. EPA focused on those aspects of the life cycle that have the potential to emit GHGs as materials change from their raw states to products and then to waste. ... EPA examined the potential for these effects at the following points in a product's life cycle:
>
> - Raw material acquisition (fossil fuel energy and other emissions, and changes in forest carbon sequestration);
> - Manufacturing (fossil fuel energy emissions); and
> - Waste management (CO_2 emissions associated with composting, non-biogenic CO_2 and N_2O emissions from combustion, and CH_4 emissions from landfills); these emissions are offset to some degree by carbon storage in soil and landfills, as well as avoided utility emissions from energy recovery at combustors and landfills.

> At each point in the material life cycle, EPA also considered transportation-related energy emissions. Estimates of GHG emissions associated with electricity used in the raw materials acquisition and manufacturing steps are based on the nation's current mix of energy sources, including fossil fuels, hydropower, and nuclear power. However, when estimating GHG emission reductions attributable to utility emissions avoided, the electricity use displaced by waste management practices is assumed to be 100 percent fossil derived. EPA did not analyze the GHG emissions typically associated with consumer use of products because the primary concern of this report was end-of-life management. Also, with a fully decarbonized grid, the mitigation potential with materials occurs largely with their processing and disposal, not use. Furthermore, the energy consumed during use would be approximately the same whether the product was made from virgin or recycled inputs. To apply the GHG estimates developed in this report, one must compare a baseline scenario with an alternative scenario, on a life cycle basis. For example, one could compare a baseline scenario, where 10 tons of office paper are manufactured, used, and landfilled, to an alternative scenario, where 10 tons are manufactured, used, and recycled.[20]

In addition, EPA noted: "In order to support a broad portfolio of climate change mitigation activities covering a range of GHGs, various methodologies for estimating emissions are needed. The primary result of this research is the development of material-specific GHG emission factors that can be used to account for the climate change benefits of waste management practices."[21] To meet this challenge, EPA eventually created the Waste Reduction Model (WARM) to report and track GHG emissions reductions, energy savings, and economic impacts from different solid waste management practices. "WARM calculates and totals these impacts from baseline and alternative waste management practices—source reduction, recycling, anaerobic digestion, composting, combustion, composting, and landfilling."[22]

EPA concluded that sustainable "management of MSW presents many opportunities for GHG emission reductions. [For instance,] source reduction and recycling can reduce GHG emissions at the manufacturing stage, increase forest carbon sequestration, and avoid landfill CH_4 emissions."[23] "Source reduction, in general, represents an opportunity to reduce GHG emissions in a significant way. For many materials, the reduction in energy-related CO_2 emissions from the raw material acquisition and manufacturing process, and the absence of emissions from waste management, combine to reduce GHG emissions more than other options do.[24] "Through source reduction (for example, lightweighting a beverage can—using less aluminum for the same function), GHG emissions throughout the life cycle are avoided. In addition, when paper products are source reduced, additional carbon is sequestered in forests, through reduced tree harvesting.

"For most materials, recycling represents the second best opportunity to reduce GHG emissions. For these materials, recycling reduces energy-related CO_2 emissions in the manufacturing process (although not as dramatically as source reduction) and avoids emissions from waste management. Paper recycling [also] increases the sequestration of forest carbon."[25] Project Drawdown[iii] estimates that recycling could be responsible for 5.5-6.02 gigatons of CO_2E reduced or sequestered from 2020-2050.[26]

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iii Project Drawdown's mission "is to help the world reach 'Drawdown' – the point in the future when levels of greenhouse gases in the atmosphere stop climbing and start to steadily decline, thereby stopping catastrophic climate change – as quickly, safely, and equitably as possible." (See "Mission Statement", Project Drawdown).

Composting is a management option for food discards, yard trimmings, and other organic material. EPA concluded that: "The net GHG emissions from composting are lower than landfilling for food discards (composting avoids CH_4 emissions), and higher than landfilling for yard trimmings (landfilling is credited with the carbon storage that results from incomplete decomposition of yard trimmings)."[27] However, EPA did not look at all types of composting, such as an increase in backyard, or composting done by individual households and small businesses. In addition, "addressing the possible GHG emission reductions and other environmental benefits achievable by applying compost [to soil] instead of chemical fertilizers, fungicides, and pesticides was beyond the scope of [their analysis]. To the extent that compost may replace or reduce the need for these substances, composting may result in reduced energy-related GHG emissions."[28] EPA also evaluated the effect of compost application on soil carbon storage, concluding that "it is reasonable to expect that [compost is effective at storing] carbon."[29] If these additional considerations were included, the scale is tipped in favor of composting over landfilling, in regards to GHG emissions. Project Drawdown estimates that composting could be responsible for 2.14-3.13 gigatons of CO_2e reduced or sequestered from 2020-2050.[30]

Appendix 6.5 includes a comprehensive table that depicts per ton estimates of GHG emissions for baseline and alternative management scenarios (such as source reduction, recycling, landfilling, combustion, composting, and digestion) for 62 different materials. A few examples of the more common materials are depicted below, all which show sizable reductions in GHGs through source reduction, recycling, and composting versus landfilling and combustion.

- Corrugated Cardboard: 5.58 MtCO_2e reduced through source reduction and 3.14 MtCO_2e reduced through recycling, versus 0.49 MtCO_2e reduced through combustion and 0.26 MtCO_2e increased through landfilling[iv]
- Food Waste: 3.66 MtCO_2e reduced through source reduction and 0.18 MtCO_2e reduced through composting, versus 0.13 MtCO_2e reduced through combustion and 0.54 MtCO_2e increased through landfilling
- PET Plastic (beverage containers): 2.17 MtCO_2e reduced through source reduction and 1.15 MtCO_2e reduced through recycling, versus 1.24 MtCO_2e increased through combustion and 0.02 MtCO_2e increased through landfilling
- Aluminum Cans: 4.80 MtCO_2e reduced through source reduction and 9.13 MtCO_2e reduced through recycling, versus 0.03 MtCO_2e increased through combustion and 0.02 MtCO_2e increased through landfilling[v]

In 2009, the EPA undertook an effort to estimate potential GHG reductions through the implementation of a few aggressive SMM strategies. Table 5.6.1 shows the results for various SMM targets through source reduction, reuse, and recycling approaches. While this information is somewhat dated, it offers a glimpse at the potential reductions in GHGs that could be assumed through SMM practices.

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iv MtCO_2e: Million tons of carbon dioxide equivalents.

v It is widely understood by materials management practitioners that EPA's waste generation numbers are underestimated, which means that all of the assumptions about the potential GHG reductions from high levels of source reduction and recycling are also underestimated, and therefore, conservative numbers.

Table 5.6.1: Estimated GHG Reductions for Implementation of Some Aggressive SMM Strategies[31]

Source Reduction	Reduce packaging use by:	50% 25%	40-105 $MMtCO_2$ e/yr[vi] 20-50 $MMtCO_2$ e/yr
	Reduce use of non-packaging paper products by:	50% 25%	20-70 $MMtCO_2e$/yr 10-35 $MMtCO_2e$/yr
Reuse/Recycling	Increase recycling of construction and demolition debris to:	100% 50% 25%	150 $MMtCO_2e$/yr 75 $MMtCO_2e$/yr 40 $MMtCO_2e$/yr
	Increase national MSW recycling and composting rate from 2006 rate (32.5%) to:	100% 50%	300 $MMtCO_2e$/yr 70-80 $MMtCO_2e$/yr.
	Increase composting of food scraps from 2006 rate (2%) to:	100% 50% 25%	20 $MMtCO_2e$/yr 10 $MMtCO_2e$/yr 5 $MMtCO_2e$/yr

Also in 2009, Skumatz Economic Research Associates (SERA) published a paper comparing a few SMM alternatives to a variety of energy efficiency (EE) initiatives.

> [The intent was to show that although data from] the EPA indicates that electricity and energy use by buildings is responsible for the lion's share of [GHG] emissions, and solid waste / waste management is only responsible for about 3 percent of GHG emissions sources, [this] provides a misleading indication of the importance of [some] solid waste strategies in achieving reductions in GHGs. … For key program types, solid waste programs are a cheaper means of achieving GHG reductions than are typical EE programs. [The SERA study results] illustrate that, although a review of the sources of emissions would lead to the conclusion that EE programs are the largest source of GHG, that fact is only part of the picture. Typical recycling programs … may be the "low-hanging fruit," as they represent less expensive methods of achieving reductions in GHG.[32] … Key to SERA's computations is the fact that recycling achieves not only direct reductions from the landfills, but provides 'upstream' production savings.[33]

The study highlighted that curbside recycling, for example, represented 0.6 to 0.7 times the cost of commercial EE efforts—their baseline EE method. By way of example, and to put this in perspective, residential EE was three times as expensive as commercial EE; wind energy, 7-8 times as expensive; and photovoltaics, 18-25 times. Organic composting was four times as expensive. Job creating and economic development impacts for curbside recycling were identified by the study as the lowest of all the energy efficiency efforts they reviewed. As a result of their analysis, they recommend that when considering alternative strategies for reaching climate change goals, recycling should be included in the "first tier" of programs, "as a cost-effective, big-bang, and 'quick hit' set of strategies toward GHG reductions."[34]

vi $MMtCO_2e$/yr: Million metric tons of carbon dioxide equivalents per year.

5.6.3 A Refined Management Framework: Sustainable Materials Management, Zero Waste, and the Circular Economy

As supported by the data and conclusions above, a fundamentally refined and accelerated materials management approach must be part of a comprehensive zero-carbon plan. This includes more effectively reducing waste before it enters management systems, moving from single-use practices to the reuse of more materials, increasing the composting and anaerobic digestion of organic materials, and recycling, all with the intent to:

- Decrease the use of carbon and the generation of GHGs, particularly CO_2;
- Divert materials from disposal facilities that pose a plethora of environmental and societal ills; and
- Foster a circular economy, including the creation of jobs and wealth through a just transition, with environmental and social justice as guiding principles.

Embracing sustainable materials management (SMM), with the dual goals of achieving "zero waste" and developing a circular economy is the recommended framework to achieve these objectives.

Sustainable Materials Management

SMM is an integrated approach toward managing material life cycles to achieve economic efficiency, environmental viability, and social equity. Material life cycles include all human activities related to material selection, exploration, extraction, transportation, processing, consumption, recycling, and disposal.[35] SMM is a framework that strives to preserve natural capital by increasing resource productivity, reducing material throughputs, and reusing and recycling materials to such a degree that depletion of natural capital is minimized and ecosystem services maintained. The objective is to maximize positive, and minimize negative environmental, economic, and social outcomes across entire product life cycles, as well as at every stage of the cycle.

Strategies for SMM can generally be separated into two categories: *dematerialization* and *detoxification*.

Dematerialization refers to the reduction of material throughput in an economic system. It can include the following approaches: increase of material efficiency in the supply chain, thus reducing waste; eco-design of products to reduce mass, packaging, or life-cycle energy requirements; reduction of transport in the supply chain, thus reducing fuel and vehicle utilization; recovery and beneficial recycling of post-industrial or post-consumer wastes, or substitution of services for products.[36] This includes the combination of various conservation strategies, such as reducing the amount of materials needed to provide the function required (source reduction), extending the service life of products, developing more sustainable materials and materials management processes, and eliminating the concept of waste in part by ensuring that there are robust markets to reutilize post-industrial and post-consumer materials.

A goal of dematerialization is to recover more value out of the materials economy. This is related to the principle of optimal use of materials, including industrial symbiosis, where outputs from an industrial system become inputs for another. It is also related to the essential role SMM plays in establishing local and larger-scale circular economies, and reducing carbon use and GHG emissions. This concept is explored further in Chapter 4.3 (State and Cities for Climate Action).

Most recently, dematerialization is manifesting itself through a variety of deliberate and accelerated efforts to eliminate single-use products, primarily those made from plastic. It also includes a focus on changing the culture and behavior of convenience.

Detoxification refers to the prevention or reduction of adverse human or ecological effects associated with materials use, and includes approaches such as material substitution, cleaner technologies, and the reduction of fossil fuel combustion and GHG emissions associated with current production, logistics, and end-of-life systems. The key to SMM is to understand and mitigate the adverse impacts of material flows upon ecological and societal systems rather than simply constraining material flows.[37] Figure 5.6.4 below identifies the stages of SMM.[38]

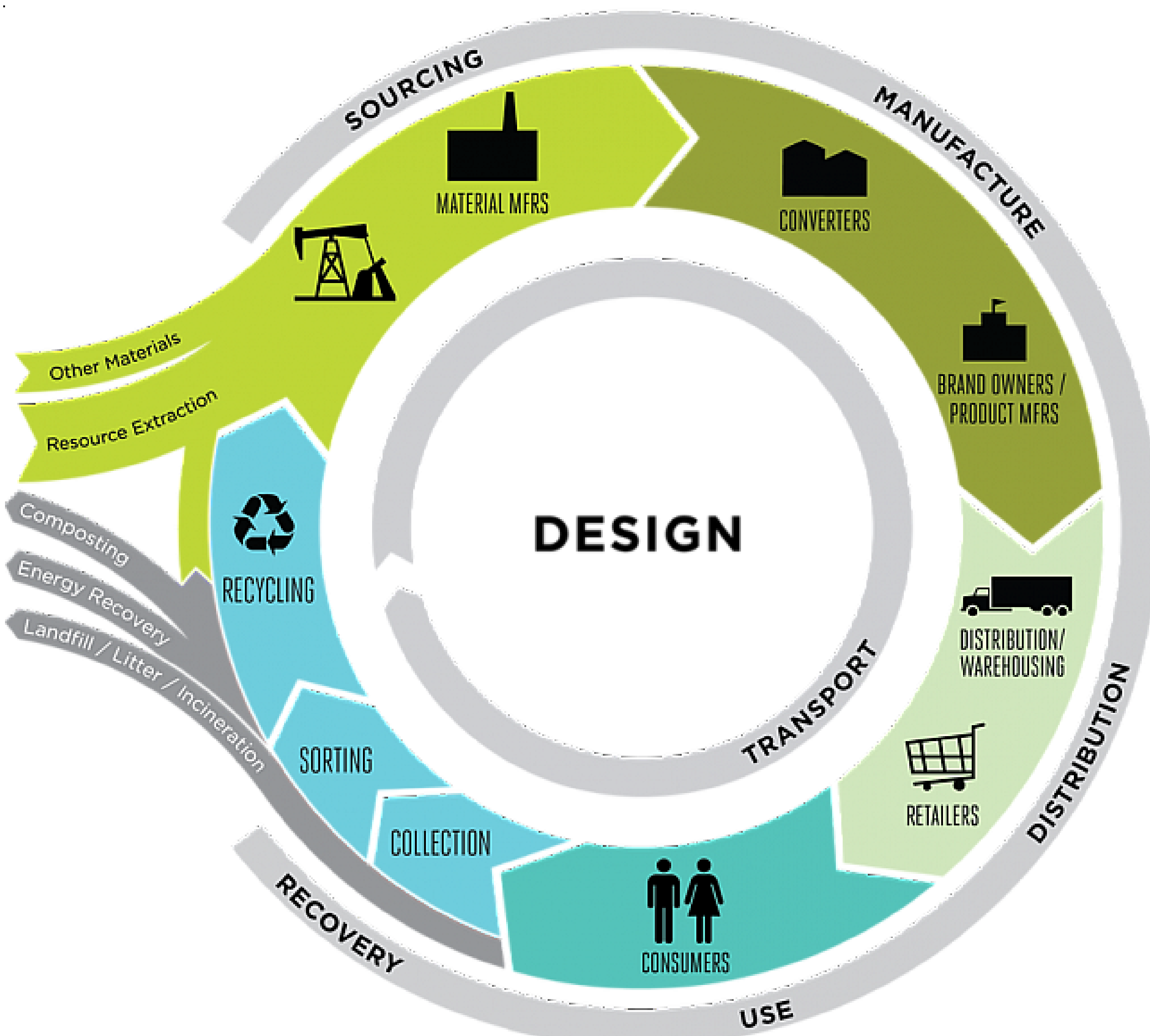

Figure 5.6.4. Sustainable Materials Management ("Sustainable Materials", 2015).

SMM prioritizes the need to ensure the recovery of valuable materials, provide consistent guidance to consumers about materials and materials management choices, progressively phase out materials for better alternatives, quantify the carbon footprint of manufacturing for specific materials, ethically/equitably source raw materials, and provide for security of materials supply. For the purposes of the ZCAP, the implicit focus is on the following items:

- Aluminum
- Construction and demolition debris
- Disaster debris
- Glass
- Marine debris
- Paper
- Plastics
- Organics, including food waste
- Single use items
- Steel

A summary of SMM prioritized approaches and a few select options:

Source Reduction, including:

- Providing incentives and subsidies for alternatives to extractive industries;
- Requiring product stewardship, closed-loop packaging, and identifying relevant producers of products and establishing policy, financial, and/or operational obligations for them to manage the waste stage of the product life cycle, including:
  - Reducing overpackaging and packaging waste,
  - Reducing the complexity of packaging materials (including the number of materials and polymers), and
  - Product redesign (including recycled content increases);
- Developing education, outreach, and marketing efforts targeting behavior change with the goal of decreasing the demand for wasteful materials, and resulting in decreased carbon consumption, thereby reducing GHG emissions.

Reuse, including:

- Providing incentives and subsidies to drive markets for "refurbished" goods (enabling used goods to more fully enter the marketplace and compete)—the longer-term outcome is to "normalize" used and refurbished goods;
- Realizing the benefit markets could receive from a marketplace for material sale and exchange (connect recycled, reused and refurbished as well as surplus goods to markets and organizations that are looking to sell or buy products and materials—an online marketplace);
- Encouraging repair and extending the lifespan of products through "right to repair" legislation, and reward systems to return old devices; and

- Support diversion providers that already have infrastructure in place and name recognition (Goodwill, Habitat for Humanity, Salvation Army, etc.), and successful and emerging reuse models, such as companies like GoBox, GoPak, Loop, and Vessel that are creating systems of reusable and returnable packaging (these business models are showing a way to deliver goods without wasteful packaging).

Recycling, including:

- Increased recognition of the varied societal and environmental benefits of recycling. To exemplify potential benefits of increased recycling for some traditionally collected materials, EPA's WARM tool was used in July 2020 to estimate impacts related to a five percent increase in the recovery of each of four materials nationwide: aluminum and glass, and HDPE and PET plastic containers. Factors such as GHG emissions, energy use, wages, taxes, and employment were analyzed, as follows:
  - Total decrease in GHG emissions ($MtCO_2e$) per each 5 percent increase: 960,484.38;
  - Total decrease in energy use (million BTU) per each 5 percent increase: 19,667,046.76;
  - Total increase in wages per each 5 percent increase: $628,544,091.98;
  - Total increase in taxes per each 5 percent increase: $100,078,654.82;
  - Total increase in employment (labor hours) per each 5 percent increase: 279,70213.27; and[vii]
- Incentivizing and providing technical assistance devoted to local market development and job creation.

Composting, and food discard and organics management, including[viii]:

- Changing laws which prohibit restaurant composting;
- Enabling access at all levels of society (all people/businesses should be able to access services/facilities);
- Following the food waste hierarchy of: (1) reduce the amount of food at the source, (2) feed excess food to people, (3) feed left-over food to animals, (4) compost what remains, and (5) anaerobically digest if necessary (e.g., mandate businesses and institutions recover/recycle food scraps, and mandate private haulers and management facilities to establish needed infrastructure to properly manage these materials);
- Reducing food discards and increasing edible food redistribution in food wholesale, retail, and food service through setting ambitious reduction goals and actions including: implementing tracking software and other tools (e.g., Leanpath—a creative food waste prevention and technology solution) to reduce over-purchasing, avoidable food waste, and redirect edible food to local charities to reduce food insecurity (target larger generators first); and

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vii It is widely understood by materials management practitioners that EPA's waste generation numbers are underestimated, which means that all of the assumptions about the potential GHG reductions from high levels of source reduction and recycling are also underestimated, and therefore conservative numbers.

viii This could reduce the single largest component of the waste stream. Food waste and yard debris account for 35 percent or more of the waste stream in most cities—more in cities with year-round plant growth. Composting leads to creation of good jobs and small businesses, healthier soils, and local food production. Composting has year-round and local markets. It also conserves water and reduces greenhouse gasses by sequestering carbon dioxide from the atmosphere (see Seldman, "Monopoly"). The goal should be no organics going to landfills/incinerators.

- Address the reality of food deserts (and associated environmental justice implications), which drive people to purchase highly-packaged staples from the "corner gas station," adding to the discard of single-use materials.

Zero Waste

The Zero Waste International Alliance (ZWIA) was established to develop standards intended to better define, and guide the development of zero waste efforts globally. ZWIA defines zero waste, as "the conservation of all resources by means of responsible production, consumption, reuse, and recovery of products, packaging, and materials without burning and with no discharges to land, water, or air that threaten the environment or human health."[39] Zero waste practitioners are striving to achieve at least a 90 percent reduction from a baseline year of all materials discarded in landfills and none in facilities using temperatures above 200 degrees F by a self-identified future date.

ZWIA articulated the Zero Waste Hierarchy and a set of Zero Waste Business Principles, as follows:

> All over the world, in some form or another, a pollution prevention hierarchy is incorporated into recycling regulations, solid waste management plans, and resource conservation programs that include recovery prior to landfill. Many organizations focused on this [3rd R, (materials recovery)] instead of the top of the hierarchy [source reduction and reuse] resulting in costly systems designed to destroy materials instead of systems designed to reduce environmental impact and properly manage resources. Because of this, along with other resource destruction systems that have been emerging over the past few decades, the Zero Waste International Alliance adopted the only internationally peer reviewed Zero Waste Hierarchy that focuses on the first 3 Rs: Reduce, Reuse and Recycle (including Composting).
>
> Purpose of Hierarchy:
>
> The Zero Waste Hierarchy describes a progression of policies and strategies to support the Zero Waste system, from highest and best, to lowest use of materials. It is designed to be applicable to all audiences, including policymakers, industry, and individuals. It aims to provide more depth to the internationally recognized 3 Rs (Reduce, Reuse, Recycle); to encourage policy, activity and investment at the top of the hierarchy; and to provide a guide for those who wish to develop systems or products that move us closer to zero waste. It enhances the zero waste definition by providing guidance for planning and a way to evaluate proposed solutions.[40]

Zero Waste Business Principles:

> The Zero Waste Business Principles serve as the basis for evaluating the commitment of companies to achieve zero waste.
>
> **Commitment to the triple bottom line** – We ensure that social, environmental and economic performance standards are met together. We maintain clear accounting and reporting systems and operate with the highest ethical standards for our investors and our customers. We produce annual environmental or sustainability reports that document how we implement these policies. We inform workers, customers and the community about life cycle environmental impacts of our production, products, or services.

Use Precautionary Principle – We apply the precautionary principle before introducing new products and processes, to avoid products and practices that are wasteful or toxic.[ix]

Zero waste to landfill or incineration – We divert more than 90 percent of the solid wastes we generate from landfill from all of our facilities. No more than 10 percent of our discards are landfilled. No solid wastes are processed in facilities that operate above ambient biological temperatures (more than 200 degrees F) to recover energy or materials.

Responsibility – Take back products and packaging. We take financial and/or physical responsibility for all the products and packaging we produce and/or market under our brand(s), and require our suppliers to do so as well. We support and work with existing reuse, recycling, and composting operators to productively use our products and packaging, or arrange for new systems to bring those back to our manufacturing facilities. We include the reuse, repairability, sustainable recycling, or composting of our products as a design criterion for all new products.

Buy reused, recycled and composted – We use recycled content and compost products in all aspects of our operations, including production facilities, offices and in the construction of new facilities. We use LEED-certified or equivalent architects to design new and remodeled facilities as green buildings. We buy reused products where they are available, and make our excess inventory of equipment and products available for reuse by others. We label our products and packaging with the amount of post-consumer recycled content and for papers. We label if chlorine-free and forest-friendly materials are used. Labels are printed with non-toxic inks—no heavy metals are used.

Prevent pollution and reduce waste – We redesign our supply, production and distribution systems to reduce the use of natural resources and eliminate waste. We prevent pollution and the waste of materials by continual assessment of our systems and revising procedures, policies, and payment policies. To the extent our products contain materials with known or suspected adverse human health or negative environmental impacts, we notify consumers of their content and how to safely manage the products at the end of their useful life according to the take-back systems we have established, and shall endeavor to design them out of the process.

Highest and best use – We continuously evaluate our markets and direct our discarded products and packaging to recover the highest value according to the following hierarchy: reuse of the product for its original purpose, reuse of the product for an alternate purpose, reuse of its parts, reuse of the materials, sustainable recycling of inorganic materials in closed loop systems, sustainable recycling of inorganic materials in single-use applications, composting of organic materials to sustain soils and avoid use of chemical fertilizers, and composting or mulching of organic materials to reduce erosion and litter and retain moisture.

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ix The precautionary principle refers to the need to exercise caution based on the potential for negative impacts, though extensive data on the issue might not yet be available.

Economic incentives for customers, workers and suppliers – We encourage our customers, workers and suppliers to eliminate waste and maximize the reuse, recycling, and composting of discarded materials through economic incentives and a holistic systems analysis. We lease our products to customers and provide bonuses or other rewards to workers, suppliers, and other stakeholders that eliminate waste. We use financial incentives to encourage our suppliers to adhere to zero waste principles. We evaluate our discards to determine how to develop other productive business opportunities from these assets, or to design them out of the process in the event they cannot be sustainably re-manufactured.

Products or services sold are not wasteful or toxic – We evaluate our products and services regularly to determine if they are wasteful or toxic and develop alternatives to eliminate those products which we find are wasteful or toxic. We do not use products with persistent organic pollutants (POPs), PVC, or polystyrene. We evaluate all our products and offer them as services if we can do so by our own company. We design products to be easily disassembled to encourage reuse and repair. We design our products to be durable, to last as long as the technology is in practice. We phase out the use of unsustainable materials, and develop the technology to do so. Our products can easily be re-made into the original product.

Use non-toxic production, reuse and recycling processes – We eliminate the use of hazardous materials in our production, reuse and recycling processes, particularly persistent bioaccumulative toxins. We eliminate the environmental, health and safety risks to our employees and the communities in which we operate. Any materials exported to other countries with lower environmental standards are managed according to the Best International Practice as recommended by ZWIA.[41]

Circular Economy

As has been depicted in the data and concepts already explored in this chapter, and as introduced in Chapter 5.3 (Accelerating Deep Decarbonization of U.S. Industry), the U.S. has an extractive industrial model based on a linear production system of "take-make-waste."[42] By contrast, a reimagined economy, such as a circular economy, is one that redefines growth and materials use, and focuses on positive, society-wide benefits, such as decarbonization and intergenerational interests.

The Ellen MacArthur Foundation recognizes a circular economy as one that "entails gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital. It is based on three principles: design-out waste and pollution, keep products and materials in use, and regenerate natural systems."[43]

GAIA, a leading voice in the zero waste and circular economy movements, also points-out that our current "linear economic model violates the principles of environmental justice and is dangerous for our health and our planet."[44] A complete transition of our extractive economy to a circular system is needed—one where all people can enjoy their right to a safe and healthy environment, and where no community bears the burden of these unsustainable patterns.[45]

The Sustainable Development Solutions Network sponsored a Global Solutions Forum in 2019: *Beyond Waste—Circular Resources Lab*. The Forum concluded:

> Current processes of production and consumption are deemed unsustainable [and] a transition is required to move towards a sustainable model, [one based on a circular economy, where] resources are kept in use for much longer and shared through distributive networks enabled by technology, products are designed never to become waste, and industrial activity aims to regenerate depleted natural capital.[46]

Michael Burger of the Columbia University Law School also acknowledges:

> [The circular economy is a] powerful new paradigm for materials consumption and solid waste management. Instead of beginning with extraction and ending with waste, the circular economy begins with material already in use, or else, material designed for iterative uses, moves through production and consumption, and into waste management, which secures a revived or altered source material, which in turn moves though production and consumption, and so on, over and over again. Achieving significant GHG reductions in this area requires widespread shifts in production and consumption ...[47]

William McDonough and Michael Braungart, in their seminal work, Cradle to Cradle, present elements of a circular economy, including an "integration of design and science that provides enduring benefits for society from safe materials, water, and energy, ... and eliminates the concept of waste..."[48] They also view important circular economy principles as "opportunities to improve quality, increase value, and spur innovation."[49]

A circular economy embraces local economies, the highest-and-best-use of materials, and a supply chain of circular or environmentally preferred products at the local and national level. This should be given priority when purchasing, by allowing sales at more competitive prices than international or non-environmental materials. (This can favor the use of local materials and motivate new startups to supply greener materials.) It is about internalizing externalities associated with extractive and polluting products and processes, leading to, and resulting in cost-effective environmentally-conscious products. A circular economy can be a zero-carbon economy.

In a circular economy, economic activity builds – and rebuilds – overall system health (see Figure 5.6.5).[50] The concept recognizes the importance of the economy needing to work effectively at all scales—for large and small businesses, and for organizations and individuals, globally and locally. Transitioning to a circular economy does not only amount to adjustments aimed at reducing the negative impacts of the linear economy, such as excessive GHG emissions. Rather, it represents a systemic shift that builds long-term resilience, generates business and economic opportunities, and provides holistic environmental and societal benefits.

The *Beyond Waste, Global Solutions Forum* concluded by pointing-out a challenge: "Shifting to this model will require a fundamental transformation of our cognitive models, of the [very] way we think about natural resources and the way we use them."[51] SMM strategies and zero waste approaches and principles underpin and provide essential inputs into a circular economy, and help to achieve the fundamental transformation discussed at the Forum.

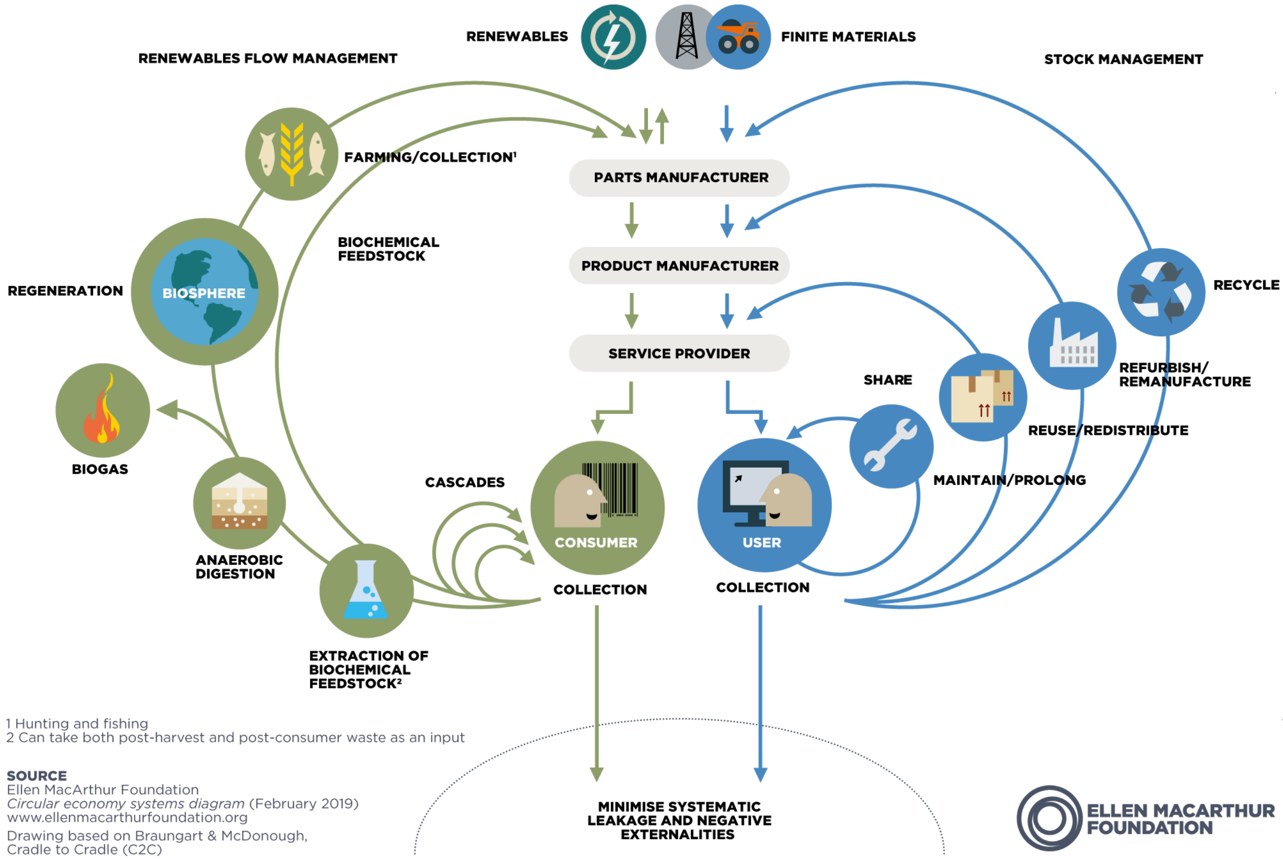

Figure 5.6.5. Circular economy ("Concept: What Is A Circular Economy?", 2020).

5.6.4 Challenges

There are a multitude of issues and challenges related to materials management that the U.S. must address to more rapidly reach zero-carbon objectives, including, but not limited to:

- Implementation of product stewardship and extended producer responsibility initiatives
- Fragmentation and distributed policy authority
- Outdated federal policy
- Disassociation and distraction
- An unlevel playing field
- Difficult materials (such as plastics)
- “Chemical recycling”
- Waste-to-Energy impacts

Implementation of Product Stewardship and Extended Producer Responsibility

A core element of successful SMM is the need for corporate *product stewardship* and *extended producer responsibility*.

> **Product stewardship** seeks to ensure that those who [extract materials for, and] design, manufacture, sell, and use consumer products take responsibility for reducing negative impacts to the economy, environment, public health, and worker safety. These impacts can occur throughout the lifecycle of a product and its packaging, and are associated with energy and materials consumption; waste generation; toxic substances; greenhouse gases; and other air and water emissions. In a product stewardship approach, manufacturers that design products and specify packaging have the greatest ability, and therefore greatest responsibility, to reduce these impacts by attempting to incorporate the full lifecycle costs into the cost of doing business. Product stewardship is the act of minimizing the health, safety, environmental, and social impacts of a product and its packaging throughout all lifecycle stages, while also maximizing economic benefits. The manufacturer, or producer, of the product has the greatest ability to minimize adverse impacts, but other stakeholders, such as suppliers, retailers, and consumers, also play a role. Stewardship can be either voluntary or required by law.
>
> **Extended producer responsibility (EPR)** is a mandatory type of product stewardship that includes, at a minimum, the requirement that the manufacturer's responsibility for its product extends to post-consumer management of that product and its packaging. There are two related features of EPR policy: (1) shifting financial and management responsibility, with government oversight, upstream to the manufacturer and away from the public sector; and (2) providing incentives to manufacturers to incorporate environmental considerations into the design of their products and packaging.[52]

EPR requires product and packaging companies to take responsibility for the end-of-life management of their products through a detailed EPR management system that supports recycling, reduces local government expenditures, prevents the release of toxins into the environment, promotes "green" redesign of products ("design for the environment"), and places a value on all environmental costs associated with the product throughout the product life cycle. One example of the great potential of EPR and product design working together is a change from fossil-fuel based plastic to a biological material substitution, which represents a shift away from technical to biologic materials, especially with single-use, throw-away packaging.[x]

The *Break Free From Plastic Pollution Act*, introduced in Congress in 2020, acknowledges producer responsibility by pointing out that by "producing overwhelming amounts of material with little to no end-of-life value for recycling, and designing products solely for the purpose of marketing and selling those items, producers have failed to make sustainable items that can be easily reused, recycled or efficiently disposed of. Items designed for a one-time use then become the responsibility of taxpayers and local governments to manage."[53] McDonough and Braungart recognize producer responsibility in another way: "[We] have a design problem. If [we] were to devise products … more intelligently from the start, [we] wouldn't even need to think in terms of waste.… Good design would allow for abundance, endless reuse, and pleasure."[54] They identify this as totally "eliminating the concept of waste."[55]

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x A fuller discussion of technical and biological materials is covered by the Ellen MacArthur Foundation ("Concept: What is A Circular Economy?").

Strong policy and policy initiatives surrounding product stewardship and EPR can be expected to garner stiff opposition (e.g., industry lobbying). This is particularly true for one approach to product stewardship: beverage container deposit systems. The beverage industry continues its long practice of aggressively opposing legislative initiatives intended to promote deposit systems. Nevertheless, product stewardship and EPR have had their successes, and adoption of this important approach needs to accelerate.

Fragmentation and Distributed Policy Authority

Policy frameworks that influence solid waste / materials management decisions emanate from the federal, state, and local levels. In addition, the private and NGO sectors play essential roles within the associated supply chains. The EPA regulates MSW under Subtitle D of the 1976 Resource Conservation and Recovery Act (RCRA), and delegates much solid waste management authority to state governments, who in large part do the same to local governments. Local governments have the added burden of public health and sanitation, which also drive their solid waste / materials management activities. Solid waste and materials management options vary greatly from one region to the next, based on many factors. Considering recycling, programs might differ greatly simply based on access to recyclable materials markets or existing long-term contracts.

This fragmentation inherently creates an extensive patchwork of policies and programs nationwide, leading to consumer confusion and process inefficiencies.

Outdated Federal Policy

RCRA, the nation's primary law governing MSW management, was enacted in 1976. The most recent amendment to RCRA was in 1996 (a minor amendment related to land disposal of certain wastes). The last substantial amendment was in 1984, nearly 40 years ago. There has been no substantive materials management-focused legislation from Congress since RCRA. Most federal policy in this regard has come from the executive branch. Recent attempts by Congress include the proposed *National Recycling Act* (2019), the *Break Free From Plastic Pollution Act* (2020), and the *Plastic Waste Reduction and Recycling Act* (2020) (all covered in more detail for information purposes only in Appendix B). Changes in consumer products and packaging, materials, management methods, and economic and social conditions dictate revisiting the federal policy framework.

Disassociation and Distraction

Disassociation in this context describes the state of individuals being "dissociated" or separated from the reality of the materials supply chain or the impacts of their choices as consumers and participants in end-of-life material (waste) decisions. This includes the lack of awareness of externality impacts of their actions and choices—of the non-value outputs of an economic process in which they are participating. Examples include the level of GHG emissions from single-use materials such as some plastics, excessive packaging, disposal technologies such as waste-to-energy facilities and landfills, and low-quality recyclable materials, explored further below.

The quality of recyclable materials directly impacts their marketability, and thus, recoverability. As introduced in Chapter 4.3 (State and Cities for Climate Action), an example of a process that has negatively impacted the quality of materials is "single-stream" recycling, in which all recyclables are put in a single container. According to the Institute for Local Self-Reliance:

> In 1995, only five cities in the U.S. had adopted single-stream recycling; by 2003, that number had risen to 94. Soon, single-stream became the norm, with 65 percent of the population using single-stream in 2010, up from 29 percent in 2005. The percentage of the U.S. using dual-stream systems (which keep paper separate from glass, plastic, and metal) plummeted from 70 to 34 percent. Cities were convinced that single-stream would increase recycling participation and rates, [and significantly lower-costs]. Instead, recycling rates stagnated, except in motivated cities, and most cities had to transport their materials long distances to centralized MRFs. Mixing together all recyclables led to high levels of contamination, which was not a problem because of China's insatiable demand for lower-cost recycled materials, and [where] low labor costs allowed for labor-intensive separation at their MRFs. Moreover, empty shipping containers returning from bringing finished goods to the U.S. market [facilitated] low-cost deadhead shipping rates. In 2013, this changed, as the cost of labor in China rose while contamination levels remained high. China [began] rejecting loads of contaminated U.S. shipments, [and] in 2018, imports were totally shut down.[56]

Another example of a process that impacts the quality of recyclables, and furthers the state of dissociation, is one promoted by some in the materials management arena: "mixed material processing facilities," also known as "Dirty MRFs." This is a technology that is the natural outcome of single-stream recycling.[57] The concept of a mixed material processing facility is that all recyclables and residential discards (a.k.a. trash) can be put into one container and then the so called "good" recyclables can then be separated out from the discards. The label of "Dirty MRF" references all the discards and recyclables mixed together in one container with the aspirational goal of producing marketable materials from the resulting heterogeneous mixture.

Dirty MRFs are presented to local communities as the panacea to solve all their solid waste problems, resulting in continued disassociation from more sustainable solutions. However, the materials generated from those facilities are often not usable in traditional recycling commodity markets. Paper, for example, once it has been exposed to MSW, can be either significantly deteriorated because of moisture, or worse yet, contaminated by food and animal wastes, rendering it unusable. In many respects, this seems to harken back to the days before consumers were encouraged to recycle materials; when, in fact, most materials ended up in a landfill. Today, the residue from Dirty MRFs inevitably go to an incinerator or waste-to-energy (WTE) facility.

Mixed-materials collection (Dirty MRFs) should be aggressively discouraged before these programs expand. Movement away from single- to multi-stream recycling is more complex (but not impossible), considering there has been significant investment in single-stream infrastructure throughout most of the supply chain from the curbside and with materials handling vehicles, to intermediate processing plants such as materials recovery facilities (MRFs).

Dissociation leads to distraction—distraction from the decision-making needed that would lead toward more sustainable choices. Increased focus on, and understanding and engagement in higher-level, tangible SMM practices reduces the phenomena of disassociation.

An Unlevel Playing Field

Higher-priority SMM strategies such as source (waste) reduction through producer responsibility, reuse, and materials recycling, have to compete with end-of-life options such as WTE and landfilling. Full-cost accounting is largely absent from these end-of-life disposal options. This includes valuation of externalities such as negative quality of life impacts (e.g., odor, increased truck traffic and infrastructure improvement needs, reduced property values), the costs of proper post-closure (in perpetuity), public health impacts of waste-to-energy emissions and ash, and the societal/global impacts of GHG emissions from transportation and WTE (CO_2), and from landfill operations (CH_4), to identify just a few.[xi]

Also, recycling markets for nearly all materials have had to compete with virgin raw materials producers who receive benefits such as measures to incentivize market demand, tax incentives, and other tools that create a pricing mechanism benefiting virgin materials. In regards to plastics:

> The elements that influence the pricing of recycled [plastics] material are completely different [than] virgin plastics. The collection, sorting, and cleaning of material sent for recycling, as well as the cost of energy and equipment required is unconnected to the cost of virgin plastic, but contributes to the discrepancy in pricing between virgin and recycled plastic. … Recycled content has been closely linked to brand sensitivity, and the inclusion of recycled material is still driven by consumer demand rather than legislation … The past few years have been particularly challenging, creating pricing fluctuation of such magnitude that recycling programs across the country have struggled to remain valid.[58]

The incentives mentioned also result in shortcuts being taken to avoid legitimate recovery options and opportunities further up the hierarchy. For example, heavy inert materials, like concrete from highways, bridges, and other large infrastructure projects, are managed by the construction and demolition processing industry. One-third of all the materials received is produced into alternative daily cover for landfills ADC is not a "highest-and-best-use" for recovered C&D materials. Some of the ADC use is legitimate, some of it is borderline, and some of it is sham recycling. There are facilities that use ADC as the easy cost-saving "out" instead of actually processing the material to be competitive in the marketplace. Residual coming off the end-of-the-line is often designated as ADC even though it was never processed into an ADC product, but instead is used simply as an opportunity to avoid calling it disposal. By processing material to a specification, a commodity value is created as well as opportunities to move the material into the marketplace, thus reducing the need for virgin, carbon-intensive materials inputs. In sum, standards need to be adopted and verified for materials to be used as ADC.[59]

Adopting ambitious goals (diversion, recycling, emissions, etc.) must be done intelligently with a focus on performance. If performance is not emphasized over goals, this also creates a barrier to leveling the playing field. For instance, government programs that have established recycling targets without fully understanding economic systems and markets, coupled with a lack of a verification element, can inadvertently incentivize recycling companies to misreport their recovery rates (inflated rates are common). In addition, an increasing number of local governments have shown reluctance to adopt a verification/validation program because they are afraid they may not like the numbers.

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xi "Post-closure" is also understood as the "custodial care period," based on the understanding that one can never completely leave an old landfill site.

Facilities sometimes don't want to certify because they are concerned they may get in trouble or possibly portrayed as cheaters.[60] The conflict between the recovery of increased quantity of materials versus a focus on quality of a marketable commodity "will always be present if rules and regulations demand higher recovery rates above all else, and this is even more important as the markets are increasingly sensitive to the quality of materials they receive from processors."[61]

A related challenge is what looks to be a "collective monopoly" in the solid waste management industry; more specifically, that the combined power of the relatively few large members of this industry unproportionally control end-of-life materials management schemes (landfills and WTE facilities). The industry's resources for lobbying are immense, and big waste management companies dominate nearly "every aspect of solid waste and recycling practice and policy. Consider that the top four consolidated companies earn $30 billion of the $70 billion economic sector. [These] companies own or control 75 percent of the permitted landfill capacity in major metropolitan areas, and control an estimated 50 percent of the national [waste] hauling market, with increased levels of domination in regional markets. Profits from operating landfills under [the control of these companies] typically are 60-70 percent…"[62] (All the figures just cited are from 2018.) The connection of single private sector ownership of landfills and hauling leads to further control of materials flow to landfills, where the commodity is "air space" (landfill space to fill with discarded materials). In many cases, the embedded costs are subsidized and actual risk unfairly limited (e.g., externality costs not included in the cost of operation).

A number of these companies included combustion/incineration as another way to vertically integrate operations (WTE facilities).

> [The Department of Energy (DOE) and EPA] were willing to adopt this antidote for managing the constantly growing waste stream due to [a] growing population and increased consumption of throw-away and single-use products. … [and] legislation in 1979 guaranteed sales for electricity produced by burning garbage. … Cities entered into "put or pay" contracts requiring minimum amounts of waste delivered to facilities, greatly limiting [waste reduction and] recycling efforts. [In a move that looked like industry's attempt] to stem the tide of recycling, [it] took action to protect its hauling and landfill market shares. It introduced single-stream recycling, [described earlier,] and started gobbling up materials processing capacity. … Consolidated companies now own 50 percent of the estimated 225 MRFs in the U.S.[63]

Implementing the higher-level of SMM strategies (source reduction, product stewardship, reuse) is a direct threat to this decades-long system of control by the private sector; as such, opposition can be expected from some business groups (and supported by others).

Difficult Materials

An anticipated result of robust product stewardship programs, is the development of a new generation of materials "designed for the environment." However, currently, there are a multitude of challenging materials in the stream of discarded materials—materials that are part of carbon-intensive manufacturing and supply chains. Plastic packaging is seen as a proxy for this problem.

It is important to consider the following:

- It is difficult to identify how much plastic is discarded each year. This is partly due to problems with government tracking. One estimate[xii] has the figure at 32 million tons, and another has it at 39.9 million tons.[64] In any case, either number represents an amount of discarded materials that burdens local government budgets, overwhelms management systems, and contaminates the environment (litter).[65] One analysis has 81.4 percent of this material being landfilled, and 13.4 percent incinerated, leaving 5.2 percent recycled.[66] However, it is important to note that this analysis does not account for plastic waste that becomes litter.
- The recycling system is broken. One source estimates domestic plastic recycling in 2020 at about 0.88 million tons.[67] And as reported above, another source has about 5 percent of plastic waste in the U.S. identified as sorted for recycling in 2019, a considerable drop from previous years.[68]
- Annual global production of plastic has reached 335 million tons and continues to rise, and global plastic production will triple by 2050, accounting for twenty percent of global oil consumption.[69]
- Plastic production facilities are super-polluters and a major contributor to climate change: Emissions linked to plastic will reach 1.3 billion tons by 2030, equal to 300 coal-fired power plants.[70]
- Of the 8.3 billion metric tons of plastic produced in the past 60 years, 6.3 billion metric tons have become plastic waste.[71]

In an August 10, 2020 memo to state leaders across the country, Senator Tom Udall and Representative Alan Lowenthal present this challenging picture in vivid detail:

> While plastic is an important material for building a variety of products like medical devices, lighter cars, and other advanced products, plastic producers have steadily designed unnecessary products that have flooded the market. These products have overwhelmed waste management systems, as many of them are not recyclable. Producers are not required to incorporate recycled content into their products and the cost of virgin plastic from cheap natural gas is far lower … Rather than reducing the waste they create or taking responsibility for its management, producers have shifted the responsibility for managing waste to government entities whose budgets are already stretched thin. Meanwhile, industry has promoted pollution reduction strategies that put even more burden on taxpayers instead of taking responsibility themselves—emphasizing their view that the government should invest in recycling infrastructure and accept plastic items in recycling bins that will never be recycled. All of this comes at the expense of U.S. taxpayers.
>
> We cannot recycle our way out of this crisis or rely solely on the government to clean it all up. … Consumers have been led to believe that everything they put in their blue bin will be magically turned into a new product somewhere because items are labeled recyclable. … The truth is that the recycling in our blue bins is often landfilled, incinerated, or shipped overseas to countries that are unable to manage this waste. … [China's shift in policy by reducing the importation of our recyclable materials] means that fewer plastic products have a recycling market.[72]

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xii Data cited is from the Break Free from Plastics Fact Sheet and Udall and Lowenthal, "Legislative Blueprints"; analysis and summary conclusions based on: 1) US EPA 2015 data (the EPA will next publish data in 2021 based on 2018 information), 2) US Census Bureau 2018 data, 3) estimates via mass balance analysis, and 4) incorporating an assumed 5 percent annual growth rate for single-use plastics based on increases in US bottled water sales, as reported in Dell, "Six Times More Plastic Waste is Burned in US than is Recycled".

> The oil and gas industries are investing in unprecedented plastic expansion. The industry announced $164 billion in investments for 264 new plastic facilities or expansion projects in the U.S. alone, many relying on state and local tax incentives. In just five years, these investments could increase global plastic production by a third. As a result, this wave of investment will increase pollution risks to frontline communities – communities closest to these facilities – throughout the plastics supply chain. They will also undermine efforts by cities, countries, and the global community to combat the growing plastics crisis, and exacerbate the growing climate crisis.[73] … In 2019 alone, the production and incineration of plastic will add more than 850 million metric tons of greenhouse gases to the atmosphere—equal to the pollution from 189 new 500-megawatt coal-fired power plants. If plastic production and use grow as currently planned, by 2030, these emissions could reach 1.34 billion tons per year—equivalent to the emissions released by more than 295 new 500-megawatt coal-fired power plants.[74]

Banning single-use plastics would be a major step toward holding manufacturers responsible, and transitioning the linear economy to a circular economy. In 2019, the European Parliament took similar action by approving a law banning single-use plastic items such as cotton swab sticks, cutlery, plates, and straws.[75]

Chemical Recycling

In 2019, the plastics industry embarked on an orchestrated campaign promoting what they erroneously refer to as "chemical recycling." "*Solving the Climate Crisis: The Congressional Action Plan For a Clean Energy Economy and a Healthy, Resilient, and Just America* by the House of Representatives' Select Committee on the Climate Crisis, unveiled on June 30, 2020, endorses 'chemical recycling,' using much of the same language also pushed by the American Chemistry Council and other players. Similar language made it into the Federal RECOVER Act [2019-20], and states across the country are passing or considering industry-backed bills that would pave the way for 'advanced recycling' to take root."[76] In reality, this is a plastics-to-fuel, or pyrolysis process. The plastics industry labels this as "advanced recycling," but it is largely the opposite—turning plastic into fuel to be burned.

> [There are] fatal inconsistencies in how the industry markets "chemical recycling" versus the reality: Millions of dollars have been invested in "chemical recycling" projects, yet based on public information, out of the 37 facilities proposed in the U.S. since 2000, only three are currently operational and none have been proven to successfully recover plastic to make new plastics on a commercial scale. … The technology is polluting, carbon intensive, and riddled with system failures, disqualifying it as a solution to the escalating plastic problem, especially at the scale needed.[77]

In a recent report, GAIA summarizes additional problems with the chemical recycling campaign:

- Plastic-derived fuels are fossil fuels that spend a very small portion of their lifecycle as plastic. This is not recycling. It is an expensive and complicated way to burn fossil fuels.
- This is an industry "greenwashing tactic," undermining real solutions to the plastics crisis. The fossil fuel industry is investing over $164 billion in expanding plastic production in the U.S., 35 times the amount that they claimed to invest in "chemical recycling."
- This is a bad investment. It's competing against, and losing to, virgin plastic production. The high likelihood of technical failure has also squandered investment.

- It is an environmental health risk, particularly to already overburdened communities. Every step of the process produces toxicants, from the sites themselves, where the product is burned, and at the facilities where the waste from the process goes, oftentimes in environmental justice communities. The chemical recycling industry is looking to expand into the same neighborhoods suffering from fossil fuel industry pollution.
- Importantly, especially for the ZCAP, it has a large carbon footprint, and poses a climate risk. Over half of the plastic that is processed in these facilities is released as CO_2. That's on top of the emissions from burning the resulting fuel.[78]

Dr. Andrew Neil Rollinson, chemical reactor engineer, specialist in alternative thermal conversion technologies, and author of a technical assessment of chemical recycling states, "Sound engineering practice and common sense shows that chemical recycling is not the answer to society's problem of plastic waste. It represents a dangerous distraction from the need for governments to ban single-use and unnecessary plastics, while simultaneously locking society into a 'business-as-usual' future of more oil and gas consumption."[79]

Judith Enck, President of Beyond Plastics and former EPA Regional Administrator in the Obama Administration, explains that "Industry-promoted 'chemical recycling' gives the false impression that we can chemically recycle our way out of this crisis, and detracts from what the U.S. should be doing: reducing the use of plastics. This technology has not worked in the past, cannot survive without significant taxpayer subsidies, creates few jobs, and brushes aside the serious climate change and air toxics issues associated with plastic production."[80]

Denise Patel, GAIA U.S./Canada Program Director, states, "Plastics are the new villain of the climate fight, and elected officials can't fall for industry's claims that they have a silver bullet solution, especially when the evidence does not back up those claims. With the rising crises of climate change, pollution, and economic insecurity under the backdrop of a global pandemic, we have no more time or money to waste on dangerous tech-fixes. Policymakers need to fight climate change at the source, by pursuing policies that place limits on production and support zero waste systems."[81]

Waste-to-Energy Impacts

Project Drawdown considers waste-to-energy (WTE) a "regrets solution." While they acknowledge that the social and environmental costs of WTE are "harmful and high," they argue that WTE can have a positive impact on carbon emissions. This argument is based on electricity generation from WTE facilities displacing electricity generation from fossil fuel plants, but does not take into consideration a host of other factors that will be explored here. Project Drawdown agrees that WTE can help transition away from fossil fuels in the near-term, but it is "not part of a clean energy future. Even when incineration facilities are state-of-the-art (and many are not), they are not truly clean and toxin-free."[82]

In 2018, there were 86 incinerators across 25 states burning about 29 million tons of MSW annually.[83] The Tishman Environment and Design Center at The New School in New York City completed (in 2018) a comprehensive study of the U.S. industry from the 1980's to 2018. It outlines an aging, costly, and polluting industry that is under increasing pressure from both economic and regulatory forces and citizen action. It frames a business model that relies on favorable regulations and enforcement, shifting the economic and human health burdens onto taxpayers, and capitalizing on renewable energy subsidies. In addition to being a public health threat, WTE facilities "are a bad investment."[84] As the Tishman study and other similar efforts over the years have shown, combusting MSW is one of the most expensive forms of generating energy, and these costs are often borne by the public in the form of public financing and fees. If the plant is unable to raise enough revenue through tipping fees or electricity sales to service the debt, local communities and taxpayers have ended-up paying the bill.[85]

The increasing fixed costs of maintaining and operating [these] incinerators together with competition for tipping fees [means] that the industry relies on energy sales to stay profitable. But burning trash is one of the most expensive forms of energy generation in the U.S., costing $8.33/MWh compared to $4.25/MWh for pulverized coal and $2.04/MWh for nuclear, the second and third most expensive forms of energy generation. Despite these costs and the fact that MSW incinerators produced a negligible 0.4 percent of total U.S. electricity generation (2015), two-thirds of all the incinerators in the U.S. today have access to renewable energy subsidies. These energy subsidies are coming under increased scrutiny as environmental advocates question the classification of waste burning, particularly non-biogenic waste, as renewable energy. The introduction of new carbon pricing policies in states like New York may mean that incinerators, which emit significant amounts of CO_2, will face new financial challenges.[86]

The entire WTE process has deleterious environmental and public health impacts emanating from each of its phases. Large, heavy-duty diesel sanitation trucks that collect and haul municipal solid waste release harmful substances. Host communities face health burdens and risks associated with chronic exposure to these diesel particulates. The actual incineration process releases various types of emissions including lead, mercury, dioxins and furans, particulate matter, carbon dioxide, carbon monoxide, nitrogen oxides, acidic gases, heavy metals, polychlorinated biphenyls (PCBs), brominated polyaromatic hydrocarbons (PAHS), and still to be understood further, a variety of nanoparticles.[87] By way of specific example, the EPA reports that combustion of plastics alone results in substantial net GHG emissions, estimated from 0.25 to 0.32 MtCe per ton of material.[88] "This is primarily because of the high content of non-biomass carbon in plastics. Also, when combustion of plastic results in electricity generation, the utility carbon emissions avoided (due to displaced utility fossil fuel combustion) are much lower than the carbon emissions from the combustion of plastic."[89]

Direct exposure to such toxins risks the health of facility workers and residents in nearby communities, and indirect exposure, through the food chain, poses global risks. While advanced air pollution control equipment removes some of the toxic pollutants, it concentrates them in other byproducts, such as ash, wastewater, and landfill leachate. Approximately 26-40 percent of waste becomes bottom ash. The more pollutants an air pollution control system removes, the more toxic its fly ash is. Incineration also generates toxic chemicals that can leach into soil and groundwater and accumulate in food chains. Ash residuals are mostly sent to landfills where the ash can spread via wind and air, leach toxic materials into the landfill leachate, and negatively impact operations (such as increased maintenance on equipment).[90]

The Tishman report further points out that "the people who have the least responsibility for the waste crisis in the U.S. – low income communities and communities of color – are forced to pay the highest price, both with their pocketbooks, and their health. These are communities "that are already overburdened by pollution from other industrial sources, causing cumulative impacts that regulators fail to take into account when setting emissions regulations."[91] "In the U.S., eight out of every 10 [WTE facilities] are located in low-income communities and communities of color. Residents face adverse environmental health impacts, public debt due to costly construction and maintenance of incinerators, and the stigma of being a dumping ground. Often, the communities are already overburdened with disproportionate amounts of pollution from a multitude of sources, such as coal power plants and petrochemical plants."[92] "Disproportionate siting of incinerators and waste facilities in communities of color and low-income communities was a key driver for the emergence of the environmental justice movement. In 1985, there were 200 proposed or existing incinerators online, but by 2015, fewer than 85 plants remained. Many U.S. communities effectively organized to defeat proposed plants, but poor, marginalized, and less-organized communities remained vulnerable."[93]

WTE facilities should not be considered as a renewable energy source, since an extremely large portion of the material burned is fossil-fuel based. Finally, combustion "solutions" like WTE, compete with, and deflect attention from more sustainable solutions, such as those embodied by SMM, including aggressive source reduction and reuse initiatives, product stewardship, redesigning products for recyclability, and eliminating toxic and hard-to-recycle plastics. Materials with higher BTUs (energy potential), such as plastics and paper are the prime target materials for combustion. It just so happens that these are the same materials that have priority for reduction and recycling. WTE is not symbiotic with, or complementary to SMM, zero waste, and circular economy solutions—instead, it competes.

5.6.5 Conclusion and Policy Recommendations

The U.S. needs to play a fundamental role accelerating the global transition to a just, resource-efficient, circular, and climate-neutral economy, with zero-carbon as a primary objective. It cannot do this without addressing the current economic and consumption model and associated materials management schemes. To more rapidly reach zero-carbon objectives, the U.S. must also address a multitude of issues and challenges related to sustainable materials management (SMM). To aggressively move toward SMM, zero waste, and circular economy solutions, policy emphasis and change needs to emanate primarily from the Federal Government. While there are many successful state, local, private, and public-private accomplishments in the field of materials management, progress has been unacceptably slow, with discarded materials increasing in quantity and continuing to pose other environmental and public health impacts. The default solutions included in this conclusion are on federal action, but some international, state, local, and private sector initiatives, and technology needs are addressed.

Legislative and Regulatory Needs and Broad Policy Pathways

Foreign Policy and International Leadership

The U.S. needs to assume a leadership role on the international scene with zero-carbon as a core goal attained in part through SMM and circular economic objectives.[94] To support this shift:

- Mainstream circular economy objectives should be included in free-trade agreements; bilateral, regional, and multilateral processes and agreements; and, in U.S. external policy funding instruments (similar to recommendations as articulated in the European Commission's *Circular Economy Action Plan*).[95]
- The U.S. needs to work with, and influence global consumer product companies to reshape their UN Sustainable Development Goal (SDG) commitments to include the phase-out of fossil-fuel-based plastics.
- Initiatives should be emphasized that reduce the adverse impacts of materials flow (e.g., eliminating burden-shifting between nations). For instance, to prevent plastic waste exports to developing countries in particular, the U.S. needs to join with the global community through the United Nations and become a party to (ratify) the Basel Convention, with the goal of controlling the transboundary movements of plastic waste. The U.S. has not joined with 186 states and the European Union in ratifying the Convention. Incidentally, the *Break Free From Plastic Pollution Act*, introduced in Congress in 2020, "prohibits plastic waste, plastic pairings, and plastic scrap from being exported to any country not a member of the Organization for Economic Cooperation and Development (OECD)."[96]

Federal Policy Targets and Recommendations

Federal action includes the need for the U.S. Congress to develop a comprehensive suite of policy changes and fiscal tools to move from subsidizing extractive industries to supporting circular economy activities and SMM. SMM, with associated and embedded zero waste, circular economy, and zero carbon goals, should be embraced as U.S. national policy. Congress should:

- Develop policy changes and fiscal tools to move from subsidizing extractive industries to supporting circular economy activities. Mandates should come with incentives and assistance connected to achievement targets and reasonable timelines to achieve the targets.
- Enact a mandatory national beverage container deposit act to substantially increase the recovery of aluminum, glass, plastic, and other containers; create new, domestic jobs; reduce litter; and decrease GHG emissions by nine $MtCO_2e$ per year[xiii] (equivalent to the annual emissions of 3.8 million cars).[97] The National Recycling Coalition (NRC) recently supported container deposits acknowledging a changing landscape and realization that the many promises of industry (e.g., single-stream recycling) never materialized, and that over the same period, container deposits continued to outperform all other systems and (as a form of EPR). The NRC also pointed out that container deposit systems remained effective at recovering more and higher quality material; thus, supporting and creating jobs and markets, and bolstering an ailing recycling industry.[98]

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xiii The amount noted (9 $MtCO_2e$) is the difference between avoided GHG emissions under current conditions (33.3% national overall beverage container recycling rate in 2018) and hypothetical recycling achieved by a national beverage container deposit law. Calculations assume that: 1) All beverages except for milk and dairy alternatives will be covered by deposit, and 2) the redemption rate for traditional containers (aluminum cans, glass, HDPE, and PET) will be 80%, and 57% for non-traditional containers (cartons and foil).

- Codify national material bans, including single-use plastics, with a related focus on incentivizing lower-carbon alternatives; thus, reducing the impact of these materials on the environment and public health.
- Create a national definition of recycling (similar to the European Union), discourage single-stream collection and Dirty MRFs and set ambitious national diversion goals – by material – resulting in substantial reductions in these products ending-up in WTE facilities and landfills.
- Develop policies that promote product stewardship, such as requiring Extended Producer Responsibility (EPR), life cycle assessment, and materials disclosure for a wide-range of materials and products, and funnel private sector investment to where it's needed.[xiv] This includes more effectively monitoring discarded materials that end up at landfills and WTE facilities, as well as litter. This data should be used as a measurement tool for EPR. Finally, support systems need to be developed, and in time, associated penalties imposed on industry and business not meeting EPR requirements. These policies would measurably reduce discarded materials.
- Require comprehensive SMM plans for large agencies, institutions, and businesses, and these should be tied to measurable actions, highest-and-best-use of materials, and require implementation and reporting on yearly performance metrics.
- Mandate consistent performance measurement and reporting, including the quantification and verification of GHG emissions associated with materials management practices; conversion metrics (carbon equivalencies, etc.); mechanisms for full cost accounting, adding a value to externalities like GHG emissions; minimum recycled content for targeted materials (e.g., rigid plastic packaging containers; and transparent and validated performance reporting.[xv] "What is needed is verification of materials throughout their lifecycle to establish a higher confidence level in the estimates [of diversion rates and GHG emissions]. We have nary a chance at informing, developing, and implementing sound policy if we do not have the best information to do so."[99]
- Ban yard debris, food waste, and other organic material from WTE facilities and landfills.[100] This would have the dual impact of reducing GHG creation, and realizing benefits of alternative management approaches (e.g., compost as soil amendment, food waste targeted to useful purposes).[xvi]
- Restrict built-in obsolescence designs for products, ban the destruction of unsold durable goods, enact "right to repair" policies, and develop reward systems to return old devices, reducing the need for end-of-life disposal options.
- Establish pay-as-you-throw (PAYT) or save-as-you-throw (SAYT) unit pricing programs, which will result in incentives to reduce, reuse, and recycle materials. Unit pricing, "can lead to a rapid increase in the recovery rate and reduce overall waste by up to 40 percent. Unit pricing has allowed cities to reduce their per capita waste generation to 1.5 lbs. per capita, down from the national average of 4.5 lbs. per capita."[101]
- Eliminate state preemption of local restrictions (e.g., plastic straw and plastic bag bans).

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xiv As noted by Burger, "Materials Consumption and Solid Waste", 21, and others.

xv As noted by Burger, "Materials Consumption and Solid Waste", 21, and others.

xvi "Food waste bans have only been implemented in a limited number of jurisdictions, but several other governments are contemplating adding mandatory food waste bans to existing landfill bans. While the methods and responsible agencies for implementation vary, most bans involve outreach and coordination with residences and businesses (as applicable), haulers, and the ability to perform waste audits to ensure compliance and identify areas for program reinforcement … almost half of the US states ban some form of yard trimmings from landfills".

- Abolish investment in WTE facilities, ensure that these facilities are not considered a form of recycling, or renewable or sustainable energy, and require plans for the phase-out of existing plants (the purposes noted in the Challenges section of this chapter).
- Foster regional coordination, with the goal of reducing fragmentation of policy initiatives, and ensuring coordination and consistency of measures adopted for implementation.
- Ensure that solid waste management facilities, such as landfills, are designed and operated with maximum GHG (CH_4) capture) (90%+) as a primary objective. Require strong emissions measurement systems, and GHG prevention measures, such as banning yard and food waste from landfills.
- Minimize the need for long-range, in-efficient transport of residual waste from recycling and WTE facilities, and justify this with GHG data.
- Mandate "green" public procurement criteria, targets, and standardized reporting with a focus on products and materials with lower carbon intensity and/or embodied carbon, and consistent with circular economy and zero-carbon goals.[xvii]
- Call for the Federal Trade Commission's (FTC) planned 2021-22 "Green Guide Rules" (16 CFR Part 260) update to be done in an inclusive and comprehensive manner, with the goal of strengthening these standards, and with a desired result of providing FTC more authority to enforce the intent of the Guides.[102] FTC should be required and held accountable for taking action against consumer product packaging companies who make false and deceptive claims about compostability, recyclability, and other environmental attributes. This includes better regulating the use of the chasing arrow symbol.[xviii]

Existing and Potential Federal Legislative Frameworks

There are a variety of policy framework mechanisms that could be utilized/actionalized, including but not limited to:

- Congress could amend RCRA Subtitle D, including articulating and codifying SMM as the new framework for solid waste / materials management, and keeping associated delegated authorities intact. This amendment could include most, if not all of the Policy Targets/Recommendations stated above.
- Congress could consider an amended *Break Free From Plastic Pollution Act (BFFPPA)* (HR 5845, S 3263), introduced in 2020. This proposed law also includes most of the Policy Targets/Recommendations stated above, and could be amended to address those not included.[xix]
- The *RECYCLE Act* (S 2941), introduced in the Senate in 2019, and the Plastic Waste Reduction and Recycling Act, introduced in the House in 2020, also include a few of the Policy Targets/Recommendations stated above; however, there is concern that neither do enough to eliminate the plastic packaging problem; namely, more of a focus on source reduction is needed.[xx]
- If additional pandemic-related stimulus bills are considered, funding for programs and initiatives discussed in this chapter could be included.

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xvii As noted by Burger, "Materials Consumption and Solid Waste", 21, and others.

xviii "The Green Guides were issued to help marketers ensure that the claims they are making are true and substantiated. The guidance they provide includes … general principles that apply to all environmental marketing claims…" (see *The Green Guides*).

xix See Appendix 6.6 for more information about *BFFPPA*.

xx See Appendix 6.6 for more information about the *RECYCLE Act* and the *Plastic Waste Reduction and Recycling Act*.

State and Local Policy Targets and Recommendations

Because the default with this chapter is on federal action, state and local initiatives are not explored extensively; nevertheless, there are some actions states and local governments could pursue.

- There are examples of model legislative initiatives and other progressive actions that states and local governments could adopt from their peers. [xxi]
- State and local governments could adopt laws with more ambitious goals (e.g., Zero Waste), intermediate targets and timetables for achieving these more ambitious goals, and means of achieving them.[xxii] Adopting ambitious goals must be done intelligently with a focus on performance and quality.

Technology Needs and Other Strategies to Achieve Zero Carbon through Materials Management

Facilities and Institutions

- Energy consumption protocols are needed for materials recovery (recycling) facilities (MRFs) and recycling production facilities, and there is a need for increased technological efficiency of materials processing.
- The creation of new composting facilities; centers for hard to recover materials, such as deconstruction / construction and demolition and disaster debris; reuse and recycling facilities; creative reuse centers; eco-industrial parks / drop-off centers; and Zero Waste transfer stations need to be encouraged and incentivized. “Industrial parks reserved for recycling, composting, and reuse companies [can] pass waste surcharges to generate investment capital for this sector of the local and regional economy. The model of companies like Road Runner (based in the Mid-Atlantic region), can be followed. The company requires extensive source separation, provides equipment and training for staff, uses deadhead loads from traditional local fleets instead of hydraulic equipped garbage trucks to deliver materials to end users and share revenue. This allows small businesses to actually benefit from reducing their waste streams.”[103]
- The construction industry / building sector should develop and utilize best practices for material conservation, reuse, and recovery (recycling), or highest-and-best-use of materials, including creating or expanding the building material reuse infrastructure and markets, valuing carbon already invested or embodied in buildings, encouraging adaptive reuse of buildings, encouraging or requiring deconstruction and reuse of materials, and integrating design for disassembly and buildings. The sector should be decarbonized by implementing material passports and building material libraries. A construction and demolition debris plan during the design phase should include material recovery strategies, and policies focused on using low-carbon materials should be followed.
- McDonough and Braungart – in their work, *Upcycle* – astutely point out that a regulation means something needs to be redesigned. “Although regulations are obviously a valuable signal or concern by society – even vital at certain moments in human history – we can also consider them at some point to be alerts to design failures. Or, to put it more positively, signs of design opportunities.”[104] In this case, as articulated in this chapter, federal policy (“regulations”) is needed to accelerate the decarbonization of the materials sectors, but the private sector can, to an extent, avoid being regulated.

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xxi As noted by Burger, “Materials Consumption and Solid Waste”, 22, and others.

xxii As noted by Burger, “Materials Consumption and Solid Waste”, 21, and others.

"Companies that operate at every stage of economic activity – from extraction to transportation to manufacture to retail to service – should consider mechanisms, including circular economy concepts, through which they can demonstrate leadership in materials and solid waste management and reduce the use and waste of embedded GHG emissions."[105] It is the companies producing large volumes of waste that may find themselves footing the bill if they do not find sustainable solutions to drive a more circular economy.

- Companies and institutions should commit to the Zero Waste International Alliance, Zero Waste Business Principles.
- Companies and institutions should participate in the US Green Building Council (USGBC) TRUE "Zero Waste"[xxiii] Certification Program.[106]

Research, Development, Demonstration & Deployment (RDD&D)

- Nonprofit/university-based product redesign institutes are needed that:
  - Promote green products and packaging innovation through the patent system, with research grants awarded from the Federal government; and
  - Develop the next generation of new materials.
- Associated with all the approaches defined in this chapter comes great opportunity for new jobs. This creates the need for related job training and placement programs.
- A national higher-education RDD&D consortium is required for SMM.
- Industry should invest a percentage of their RDD&D revenue into the development of alternative materials.
- The set of specific international, federal, state, and local policy recommendations and other strategies included above form a foundation that will optimize material use and management with commensurate reduction in carbon use and GHG production.

xxiii "The TRUE certification program enables facilities to define, pursue, and achieve their zero waste goals, cutting their carbon footprint and supporting public health. … TRUE is a whole systems approach aimed at changing how materials flow through society, resulting in no waste. TRUE encourages the redesign of resource life cycles so that all products are reused. TRUE promotes processes that consider the entire lifecycle of products used within a facility. With TRUE, [facilities] can demonstrate to the world what [they are] doing to minimize waste output. … By participating in TRUE certification, facilities commit to reducing materials, using recycled and more benign materials, longer product lives, reparability, and ease of disassembly at end of life. TRUE helps turn waste into savings. The TRUE certification program is used by facilities to define, pursue, and achieve their zero waste goals, cutting their carbon footprint and supporting public health. The certification goes beyond diversion numbers and focuses on the upstream policies and practices that make zero waste successful in any organization and beyond" (see "Less Waste, Higher Efficiency, Better Savings").

References

1. “Smokestacks, Tailpipes, and Trashcans,” Eco-cycle Solutions, Accessed July 30, 2020, https://www.ecocyclesolutionshub.org/about-zero-waste/climate-change/.
2. Fiksel, Joseph. 2006. “A Framework for Sustainable Materials Management,” *The Journal of the Minerals, Metals & Materials Society*, (January 2006): 15.
3. Fiksel, “A Framework”.
4. “National Overview: Facts And Figures On Materials, Wastes And Recycling”. 2020. *US EPA*. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials.
5. Ibid.
6. “US Tops List Of Countries Fuelling The Mounting Waste Crisis”. 2020. *Verisk Maplecroft*. https://www.maplecroft.com/insights/analysis/us-tops-list-of-countries-fuelling-the-mounting-waste-crisis/#:~:text=The%20highest%20risk%20countries%20in,%2C%20Germany%2C%20France%20and%20Australia.
7. “US Produces Far More Waste and Recycles Far Less of It than Other Developing Countries,” *The Guardian*, Accessed August 20, 2020, https://www.theguardian.com/us-news/2019/jul/02/us-plastic-waste-recycling.
8. “National Overview”.
9. Seldman, Neil. 2018. “Monopoly and the U.S. Waste Knot,” Institute for Local Self Reliance. Accessed July 26, 2020, https://ilsr.org/monopoly-and-the-us-waste-knot/.
10. “National Overview”.
11. Seldman, “Monopoly”.
12. Udall, Tom, and Alan Lowenthal. 2020. “Legislative Blueprints for Reducing Plastic and Packaging Pollution,” Memo to National Caucus of Environmental Legislators, August 10, 2020, 18.
13. US Environmental Protection Agency (EPA). 2006. *Solid Waste Management and Greenhouse Gases: A Lifecyle Assessment of Emissions and Sinks, 3rd Edition*, September 2006.
14. Ibid, 4-5.
15. Ibid, 5.
16. Ibid, 6.
17. Ibid, 6.
18. Ibid, 6-7.
19. Ibid, 7.
20. Ibid, 7-9.
21. Ibid, 13.
22. “Waste Reduction Model (WARM),” US Environmental Protection Agency (EPA), Accessed July 31, 2020, https://www.epa.gov/warm.
23. Ibid.
24. US EPA, *Solid Waste Management* ES 13.
25. Ibid, 13.
26. “Mission Statement,” Project Drawdown, Accessed August 14, 2020, https://drawdown.org/.;

Table of Solutions, Project Drawdown, Accessed August 14, 2020, https://drawdown.org/solutions/table-of-solutions.

27. US EPA, Solid Waste Management ES 13.
28. Ibid, 63.
29. Ibid, 51.
30. *Table of Solutions*.
31. US Environmental Protection Agency. 2009. Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices. US Environmental Protection Agency, Office of Solid Waste and Emergency Response: Washington, DC. https://www.epa.gov/sites/production/files/documents/ghg-land-materials-management.pdf.

32. Skumatz, Lisa. “Do Energy Efficiency Strategies Outperform Recycling in GHG Mitigation and Job Creation?” Presentation at: 2009 IEPEC Conference, Portland, Oregon, Skumatz Economic Research Associates, Inc. (SERA), https://serainc.com, 1, 11.
33. Ibid, 7.
34. Ibid, 11, 12.
35. Fiksel, “A Framework for Sustainable Materials Management,” 16.
36. Ibid, 18.
37. Ibid, 18.
38. “Sustainable Materials Management,” Northeast Recycling Council, Accessed July 13, 2020, https://nerc.org/news-and-updates/blog/nerc-blog/2015/03/10/sustainable-materials-management.
39. “Zero Waste Definition,” Zero Waste International Alliance, Accessed August 7, 2020, http://zwia.org/zero-waste-definition/.
40. Ibid.
41. “Zero Waste Business Principles,” Zero Waste International Alliance, Accessed August 8, 2020, http://zwia.org/zero-waste-business-principles/.
42. “Concept: What is A Circular Economy? A Framework for An Economy that Is Restorative and Regenerative By Design,” Ellen MacArthur Foundation, Accessed August 1, 2020, https://www.ellenmacarthurfoundation.org/circular-economy/concept.
43. Ibid.
44. Theory of Change, GAIA, Accessed August 4, 2020, https://www.no-burn.org/theory-of-change/.
45. Ibid.
46. Beyond Waste: Circular Resources Lab, Global Solutions Forum, Accessed August 15, 2020, https://www.circularresourceslab.ch.
47. Burger, Michael. “Materials Consumption and Solid Waste” (Chapter 7), *Legal Pathways to Deep Decarbonization in the United States: Summary and Key Recommendations,* edited by Michael B. Gerrard and John C. Dernbach, 20-22, Washington, DC: Environmental Law Institute, November 2018, 20.
48. McDonough, William, and Michael Braungart. 2002. *Cradle to Cradle: Remaking the Way We Make Things*. North Point Press: New York.
49. Ibid.
50. “Our Mission is to Accelerate the Transition to a Circular Economy,” Ellen MacArthur Foundation, Accessed July 14, 2020, https://www.ellenmacarthurfoundation.org.
51. Beyond Waste.
52. “What is Product Stewardship?” Product Stewardship Institute, Accessed July 28, 2020, https://www.productstewardship.us/page/Definitions.
53. *Break Free from Plastics Fact Sheet*, Beyond Plastics, Bennington College, Bennington, VT, 2020.
54. McDonough, William, and Michael Braungart, *The Upcycle: Beyond Sustainability—Designing for Abundance,* New York: Melcher Media, North Point Press, 2013, 7.
55. McDonough and Braungart, Cradle, 15.
56. Seldman, “Monopoly”.
57. McPoland, Fran. “Dirty MRFs Must Go.” Reprinted from *Resource Recycling*. April 2015. https://www.georgiarecycles.org/assets/Uploads/Presentations/2015-Semi-Meeting/2015-RRArticle-McPoland.pdf.
58. “Virgin Resin Price vs. Recycled Resin Price,” Vanden Knowledge Centre, Accessed August 8, 2020, https://blog.vandenrecycling.com/virgin-resin-price-vs.-recycled-resin-price.
59. Bantillo, Stephen, National Recycling Coalition Executive Vice President, and Policy Committee Co-chair, conversation with author, August 29, 2020.
60. Bantillo, conversation with author.
61. Bantillo, Stephen. “Quality vs Quantity,” Recycling Certification Institute, Accessed August 29, 2020, https://www.recyclingcertification.org/2020/05/quality-vs-quantity/.
62. Seldman, “Monopoly”.
63. Ibid.

64. Dell, Jan. "Six Times More Plastic Waste is Burned in US than is Recycled," Plastic Pollution Coalition (April 30, 2019), Accessed August 27, 2020, https://www.plasticpollutioncoalition.org/blog/2019/4/29/six-times-more-plastic-waste-is-burned-in-us-than-is-recycled.

65. Data cited.

66. Analysis and summary conclusions.

67. Analysis and summary conclusions.

68. Data cited.

69. Data cited.

70. Data cited.

71. Data cited.

72. Udall and Lowenthal, "Legislative Blueprint", 3.

73. Ibid, 4.

74 "Plastic and Climate: The Hidden Costs of a Plastic Planet," Center for International Environmental Law (2019), Accessed August 14, 2020, https://www.ciel.org/plasticandclimate/.

75. "Parliament Seals Ban on Throwaway Plastics by 2021." European Parliament (March 27, 2019). Accessed August 28, 2020. https://www.europarl.europa.eu/news/en/press-room/20190321IPR32111/parliament-seals-ban-on-throwaway-plastics-by-2021.

76. "House Democrats Fall for Fossil Fuel Industry Greenwashing Scheme, 'Chemical Recycling' in Climate Plan," Global Alliance for Incinerator Alternatives (GAIA), Accessed August 5, 2020, https://www.no-burn.org/house-democrats-fall-for-fossil-fuel-industry-greenwashing-scheme-chemical-recycling-in-climate-plan/.

77. Ibid.

78. Ibid.

79. Ibid.

80. Ibid.

81. Ibid.

82. *Table of Solutions*.

83. Babtista, Ana. "Garbage In, Garbage Out: Incinerating Trash is Not an Effective Way to Protect the Climate or Reduce Waste," *The Conversation* (February 27, 2018), Accessed July 28, 2020, https://theconversation.com/garbage-in-garbage-out-incinerating-trash-is-not-an-effective-way-to-protect-the-climate-or-reduce-waste-84182.

84. *US Municipal Solid Waste Incinerators: An Industry in Decline*, New York City: Tishman Environment and Design Center (The New School), May 2019, 13. https://static1.squarespace.com/static/5d14dab43967cc000179f3d2/t/5d5c4bea0d59ad00012d220e/1566329840732/CR_GaiaReportFinal_05.21.pdf.

85. Ibid.

86. Ibid, 5.

87. *Pollution and Health Impacts of Waste-to-Energy Incineration*, Fact Sheet. 2019. Global Alliance for Incinerator Alternatives (GAIA), Accessed August 5, 2020, www.no-burn.org.

88. "National Overview", 76.

89. Ibid.

90. *Pollution and Health Impacts of Waste-to-Energy Incineration*.

91. *US Municipal Solid Waste Incinerators*.

92. *Pollution and Health Impacts of Waste-to-Energy Incineration*.

93. Babtista, "Garbage In, Garbage Out".

94. European Commission. 2020. *Circular Economy Action Plan: For A Cleaner and More Competitive Europe*, European Commission, 22.

95. Ibid, 22.

96. Udall and Lowenthal, "Legislative Blueprint", 15.

97. Bantillo, Stephen, National Recycling Coalition Executive Vice President, and Policy Committee Co-chair, conversation with author, August 28, 2020.

98. The Container Recycling Institute. 2020. "2018 Beverage Market Data Analysis.".

99. Bantillo, Stephen, National Recycling Coalition Executive Vice President, and Policy Committee Co-chair, conversation with author, August 29, 2020.

100. Brown, Sally, Matthew Cotton, Steve Messner, Fiona Berry, and David Norem. 2009. *Methane Avoidance from Composting: An Issue Paper for the Climate Action Reserve*, SAIC, 37.

101. Seldman, "Monopoly".

102. The Green Guides – Statement of Basis and Purpose. Federal Trade Commission (FTC). Accessed August 14, 2020. https://www.ftc.gov/sites/default/files/attachments/press-releases/ftc-issues-revised-green-guides/greenguidesstatement.pdf.

103. Seldman, "Monopoly".

104. McDonough and Braungart, *The Upcycle: Beyond Sustainability*.

105. Burger, "Materials Consumption and Solid Waste", 22.

106. "Less Waste, Higher Efficiency, Better Savings," US Green Building Council (USGBC), Accessed August 14, 2020, https://true.gbci.org.

6. APPENDIX

This appendix presents supplementary information for the Jobs and Materials chapters, in order of the chapters' appearance in the report.

Appendix Table of Contents

6.1 Detailed Activities within Energy Supply Investment and Energy Demand Expenditure Categories Presented in Tables 3.1-3.4

6.1.1 Energy Supply Investment Categories

Clean Renewables

- Dispatchable Hydroelectric Power Plants
- Geothermal Power Plants
- Offshore Wind Fixed
- Offshore Wind Floating
- Onshore Wind
- Rooftop Solar PV
- Run of River Hydroelectric Power Plants
- Solar Thermal Power Plants
- Transmission-Sited Solar PV

Transmissions/storage

- Bulk Electricity Storage
- Electricity Distribution Grid
- Electricity Transmission Grid

Additional Supply Technologies

- Biomass Gasification Facilities
- Biomass Gasification Facilities w/CCU
- Biomass Hydrogen Production
- Biomass Power Plants
- Carbon Sequestration
- Direct Air Capture for Utilization - Conversion
- Ethanol Production Facilities
- Hydrogen Electrolysis - Central Station
- Hydrogen Gas Reformation Central Station
- Hydrogen Gas Reformation w/CCU
- Nuclear Power Plants
- Power-to-Gas Production Facilities
- Power-to-LPG Production Facilities
- Power-to-Liquids Production Facilities
- Renewable Diesel Production Facilities

- Renewable Diesel Production Facilities w/CCU
- Uranium Product
- Biomass pyrolysis
- Biomass pyrolysis w/ccu

Fossil Fuels

- Coal - End-Use Delivery
- Coal Power Plants
- Combined-Cycle Gas Turbines
- Combined-Cycle Gas Turbines with CCS
- Combustion Turbines
- Diesel End-Use Delivery
- Fossil Steam Turbines
- 1Gas Compression and Fueling Stations
- Gas Distribution Pipeline
- Liquefied Gas Fueling Station
- Motor Gasoline End-Use Delivery
- Natural Gas - International
- Pipeline Gas Liquefaction Facilities
- Residual Fuel-Oil End-Use Delivery

Other Investments

- Electric Boilers
- Hydrogen Blend
- Industrial CO_2 Capital
- Other Boilers
- Steam Production

6.1.2 Energy Demand Expenditure Categories

Vehicles

- Battery Electric Medium-Duty Vehicle
- CNG Light-Duty Auto
- CNG Light-Duty Truck
- CNG Transit bus
- Diesel - Electric Hybrid Light-Duty Auto

- Diesel Hybrid Heavy-Duty Vehicle
- Diesel Transit bus
- Electric - Diesel Hybrid Light-Duty Truck
- Electric - Gasoline Hybrid Light-Duty Truck
- Electric Heavy Duty Vehicle
- Electric Light-Duty Auto - 200 mile range
- Electric Light-Duty Auto - Long Range
- Electric Light-Duty Truck - 200 mile range
- Electric Light-Duty Truck - Long Range
- Electric Transit bus
- Gasoline Transit Bus
- Gasoline-Electric Hybrid Light-Duty Auto
- Hybrid Diesel Medium-Duty Vehicle
- Hybrid Gasoline Medium-Duty Vehicle
- Hybrid electric Transit bus
- Hydrogen FCV Heavy-Duty Vehicle
- Hydrogen Fuel Cell Medium-Duty Vehicle
- Hydrogen Fuel-Cell Light-Duty Auto
- Hydrogen Fuel-Cell Light-Duty Truck
- LNG Heavy-Duty Vehicle
- PHEV - 25 mile range - Light Duty Auto
- PHEV - 50 mile range - Light Duty Auto
- PHEV - Gasoline - 25 mile range - Light Duty Truck
- PHEV - Gasoline - 50 mile range - Light Duty Truck
- Propane ICE Light-Duty Auto
- Propane ICE Light-Duty Truck
- Reference Diesel Heavy-Duty Vehicle
- Reference Flex Fuel Light-Duty Auto
- Reference Flex-Fuel Light-Duty Truck
- Reference Gasoline Heavy-Duty Vehicle
- Reference Gasoline Light-Duty Auto
- Reference Gasoline Light-Duty Truck
- Reference LPG Medium-Duty Vehicle
- Reference Medium - Duty Diesel Vehicle
- Reference Medium-Duty CNG Vehicle
- Reference Medium-Duty Gasoline Vehicle
- Reference Propane Heavy-Duty Vehicle
- Reference TDI Light-Duty Auto
- Reference TDI Light-Duty Truck
- Aviation
- Transportation equipment

HVAC

- Commercial Electric Boiler
- Commercial Electric Resistance Storage Water Heater
- Commercial High Efficiency Gas Storage Water Heater
- Commercial High Efficiency Heat Pump Storage Water Heater
- Commercial Reference Gas Storage Water Heater
- Commercial Reference Heat Pump Storage Water Heater
- Commercial Reference Oil Water Heater
- Commercial Solar Water Heater with Electric Backup
- Cordwood Stoves
- Ductless Mini-Split Heat Pump - Cooling
- Ductless Mini-Split Heat Pump - Cooling (with flex cost)
- Ductless Mini-Split Heat Pump - Heating
- Electric Resistance Heat
- High Efficiency Air Source Heat Pump - Cooling
- High Efficiency Air Source Heat Pump - Cooling (with flex cost)
- High Efficiency Air Source Heat Pump - Heating
- High Efficiency Central Air Conditioner
- High Efficiency Centrifugal Chiller
- High Efficiency Commercial Air Source Heat Pump - Cooling
- High Efficiency Commercial Air Source Heat Pump - Cooling (with flex cost)
- High Efficiency Commercial Air Source Heat Pump - Heating
- High Efficiency Commercial Central Air Conditioner
- High Efficiency Commercial Ground Source Heat Pump - Cooling
- High Efficiency Commercial Ground Source Heat Pump - Cooling (with flex cost)
- High Efficiency Commercial Ground Source Heat Pump - Heating
- High Efficiency Constant Air Commercial Ventilation System
- High Efficiency Electric Heat Pump Water Heater
- High Efficiency Electric Resistance Water Heater
- High Efficiency Geothermal Heat Pump - Cooling
- High Efficiency Geothermal Heat Pump - Cooling (with flex cost)
- High Efficiency Geothermal Heat Pump - Heating
- High Efficiency Reciprocating Chiller
- High Efficiency Rooftop Air Conditioner
- High Efficiency Room Air Conditioner
- High Efficiency Screw Chiller
- High Efficiency Scroll Chiller
- High Efficiency Variable Air Commercial Ventilation System
- High Efficiency Wall/Room Air Conditioner

- Reference Air Source Heat Pump - Cooling
- Reference Air Source Heat Pump - Cooling (with flex cost)
- Reference Air Source Heat Pump - Heating
- Reference Central Air Conditioner
- Reference Centrifugal Chiller
- Reference Commercial Air Source Heat Pump - Cooling
- Reference Commercial Air Source Heat Pump - Cooling (with flex cost)
- Reference Commercial Air Source Heat Pump - Heating
- Reference Commercial Central Air Conditioner
- Reference Commercial Distillate Boiler
- Reference Commercial Distillate Furnace
- Reference Commercial Gas Boiler
- Reference Commercial Gas Engine-Driven Chiller
- Reference Commercial Gas Furnace
- Reference Commercial Gas Heat Pump - Cooling
- Reference Commercial Gas Heat Pump - Heating
- Reference Commercial Ground Source Heat Pump - Heating
- Reference Commercial Ground Source Heat Pump -Cooling
- Reference Commercial Ground Source Heat Pump -Cooling (with flex cost)
- Reference Constant Air Commercial Ventilation System
- Reference Distillate Boiler/Radiator
- Reference Distillate Furnace
- Reference Distillate Water Heater
- Reference Electric Furnace
- Reference Electric Heat Pump Water Heater
- Reference Electric Resistance Water Heater
- Reference Electric Unit Heaters
- Reference Gas Water Heater
- Reference Gas-Driven AC
- Reference Geothermal Heat Pump - Cooling
- Reference Geothermal Heat Pump - Cooling (with flex cost)
- Reference Geothermal Heat Pump - Heating
- Reference Kerosene Furnace
- Reference LPG Furnace
- Reference LPG Water Heater
- Reference Natural Gas Boiler/Radiator
- Reference Natural Gas Furnace
- Reference Natural Gas Heat Pump- Cooling
- Reference Natural Gas Heat Pump- Heating
- Reference Reciprocating Chiller

- Reference Rooftop Air Conditioner
- Reference Room Air Conditioner
- Reference Screw Chiller
- Reference Scroll Chiller
- Reference Variable Air Commercial Ventilation System
- Reference Wall/Room Air Conditioner
- Solar Water Heater with Electric Backup
- Through-the-wall Heat Pump - Cooling
- Through-the-wall Heat Pump - Cooling (with flex cost)
- Through-the-wall Heat Pump - Heating

Manufacturing

- balance of manufacturing - other
- aluminum industry
- cement
- computer and electronic products
- fabricated metal products
- food and kindred products
- glass and glass products
- machinery
- paper and allied products
- plastic and rubber products
- wood products

Other Commercial and Residential

- commercial – other
- residential - other

Construction

- Forty percent Res Building Shell
- PATH Res Building Shell
- Reference Res Building Shell
- construction

Appliances

- Electric Cooktop/Stove
- High Efficiency Clothes Washer - Front Loading
- High Efficiency Clothes Washer - Top Loading
- High Efficiency Dishwasher
- High Efficiency Electric Clothes Dryer
- Range, Electric, 4 burner, oven, 11 inch griddle
- Range, Electric-induction, 4 burner, oven, 11 inch griddle
- Range, Gas, 4 burner, oven, 11 inch griddle
- Range, Gas, 4 powered burners, convect. oven, 11 inch griddle
- Reference Clothes Washer - Front Loading
- Reference Clothes Washer - Top Loading
- Reference Dishwasher
- Reference Electric Clothes Dryer
- Reference Gas Clothes Dryer
- Reference Gas Cooktop/Stove
- Reference LPG Cooktop/Stove
- electrical equip., appliances, and components

Refrigeration

- High Efficiency Bottom Mount Refrigerator
- High Efficiency Chest Freezer
- High Efficiency Commercial Beverage Merchandisers
- High Efficiency Commercial Compressor Rack Systems
- High Efficiency Commercial Condensers
- High Efficiency Commercial Ice-Machines
- High Efficiency Commercial Reach-in Freezers
- High Efficiency Commercial Reach-in Refrigerators
- High Efficiency Commercial Refrigerated Vending Machines
- High Efficiency Commercial Walk-in Freezers
- High Efficiency Commercial Walk-in Refrigerators
- High Efficiency Side Mount Refrigerator
- High Efficiency Supermarket Display Cases
- High Efficiency Top Mount Refrigerator
- High Efficiency Upright Freezer
- Reference Bottom Mount Refrigerator
- Reference Chest Freezer
- Reference Commercial Beverage Merchandisers
- Reference Commercial Compressor Rack Systems

- Reference Commercial Condensers
- Reference Commercial Ice-Machines
- Reference Commercial Reach-in Freezers
- Reference Commercial Reach-in Refrigerators
- Reference Commercial Refrigerated Vending Machines
- Reference Commercial Walk-in Freezers
- Reference Commercial Walk-in Refrigerators
- Reference Side Mount Refrigerator
- Reference Supermarket Display Cases
- Reference Top Mount Refrigerator
- Reference Upright Freezer

Mining

- lime
- metal and other non-metallic mining

Agriculture

- Agriculture - other

Lighting

- 4ft LFL: LED Integrated Luminaire
- 4ft LFL: LED Integrated Luminaire - High Efficiency
- 4ft LFL: T5 F28
- 4ft LFL: T5 F28 2015 - High Efficiency
- 4ft LFL: T8 F32 Commodity
- 8ft LFL: LED Integrated Luminaire
- 8ft LFL: T8 F59
- 8ft LFL: T8 F59 - High Efficiency
- 8ft LFL: T8 F59 HE
- 8ft LFL: T8 F96 HO
- 8ft LFL: T8 F96 HO - High Efficiency
- CFL Exterior
- CFL GSL
- CFL Reflector
- HID Exterior
- Halogen Reflector
- High-Bay LFL: LED Integrated Luminaire
- High-Bay LFL: Sodium Vapor
- High-Bay LFL: T5 4xF54 HO High Bay

- Incandescent Exterior
- Incandescent GSL
- Incandescent Reflector
- LED Exterior
- LED GSL
- LED Linear Fluorescent
- LED Reflector
- Lamp: 100 Equivalent A19 Halogen
- Lamp: 100W A19 Incandescent
- Lamp: 100W Equivalent CFL Bare Spiral
- Lamp: 100W Equivalent LED A Lamp
- Lamp: Halogen Infrared Reflector (HIR)PAR38
- Lamp: Halogen Par 38
- Lamp: LED PAR 38
- Lamp: LED PAR 38 - High Efficiency
- Low-Bay LFL: LED Integrated Luminaire
- Low-Bay LFL: Mercury Vapor
- Low-Bay LFL: Metal Halide
- Low-Bay LFL: Sodium Vapor
- T-12 Linear Fluorescent
- T-8 Linear Fluorescent

6.2 Methodology for Estimating Job Creation and Job Quality

6.2.1 Employment Estimating Methodology

The employment estimates for the USA were developed using an input-output model. Here we used IMPLAN v3, an input-output model which uses data from the U.S. Department of Commerce as well as other public sources. The data set used for the estimates in this report is the 2018 USA National data. An input-output model traces linkage between all industries in the economy as well as institutional sources of final demand (such as households and government). A full discussion of the strengths and weaknesses of input-output (I-O) models and their application to estimating employment in the energy sector can be found in Appendix 6.4 of Pollin et al. (2014).

One important point to note here is that I-O models to date do not identify renewable energy industries such as wind, solar, or geothermal, or energy efficiency industries such as building retrofits, industrial efficiency, or grid upgrades.[i] However, all components that make up each of these industries are contained in existing industries within the models. For example, the hardware, glass production, and installation industries that are all activities within "solar" are each an existing industry in the I-O model. By identifying the relevant industries and assigning weights to each, we can create "synthetic" industries that represent each of the supply nodes and demand technology within the model. A full discussion of the methodology for creating synthetic industries can be found in Garrett-Peltier (2017).

In this estimation, we have estimated employment for all the supply nodes listed in Levelized Annual Investment section (tab 15) and all the demand technologies listed in the Demand Side Annual Costs (tab 21) of the William Jones et al. model, as summarized in Chapter 2 of this volume (Excel file; available upon request). Each supply node and demand technology were defined and weighted based on the available industries in the IMPLAN software. The weights were specified based on the cost aspects from the existing literature for each category. We focused on the central case and reference cases scenarios from the William/Jones model to select the various supply nodes and demand technologies for each category. For generating employment estimates, the expenditure figures that we utilized were annual flow amounts.

The various supply node cost groups modelled for the employment estimates are: biofuels production, carbon capture, electricity grid, electricity storage, hydrogen and synthetic fuels, natural gas infrastructure, nuclear power, renewable power plants and other sources. On the demand side, the various subsectors, and the different technologies modelled within them are: commercial and residential lighting, heavy-duty trucks, medium-duty trucks and autos, light-duty trucks and autos, transit buses, commercial and residential space heating, commercial and residential water heating, commercial and residential air conditioning, commercial and residential cooking, residential clothes washing and drying, residential cooking, commercial and residential refrigeration, commercial ventilation and several other sectors. We estimated employment numbers per million dollars of spending for each of these categories.

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i In recent data sets, IMPLAN has started reporting electricity generation from some renewable sources — biomass, solar, geothermal, hydro, etc., which primarily captures the operation and maintenance of the industry.

After estimating the employment numbers for million dollars of spending, we estimated the total employments generated in each category of the supply nodes and demand technologies. For the spending numbers in each category, we solely relied on the William/ Jones paper and the various estimations thereof. We took the difference in spending numbers between the Central case scenario and the Reference case scenario for both the categories of supply node and demand technologies. These figures for the 2020-2050 period gave the total from the existing literature spending (depending on positive or negative, respectively) in the Central case scenario vis-à-vis the Reference case scenario for each category. The annual average spending in each category was after that calculated by dividing the total spending with the total number of years. The total job numbers over the entire period are then calculated by multiplying the jobs per $1 million with the total spending (standardized to millions of dollars) in each category. When the spending figures for a particular category is more than zero, we get a net gain in jobs in the Central case scenario relative to the Reference case, while if the spending figures for some specific categories are less than zero, we report it as a net loss in the jobs. To arrive at the broader category numbers, we sum up across each category and report the total number of jobs generated over the study period. For the annual average job numbers, we divide it by the number of years in the study period.

6.2.2 Estimating Job Characteristics by Investment Area

Characteristics of Jobs Created by Energy Supply Investment and Energy Efficiency Spending Investments

Our strategy for identifying the types of jobs that would be added to the economy due to an investment in one of the energy supply or energy efficiency sectors involves two steps.

The first step is to calculate, for each specific investment program, the level of employment generated in each of 526 industries through our input-output model (IMPLAN) as explained above.

Next, we apply this information on the industry composition of the new employment created by an investment with data on workers currently employed in the same industrial mix of jobs. We use the characteristics of these workers to create a profile of the types of jobs and the types of workers that will likely hold the jobs created with each investment. These characteristics include types of occupations, gender, race/ethnicity, union status, credential requirements, and job-related benefits. Income data for these workers come directly from IMPLAN and are reported in 2020 dollars.

Our information about the workers currently employed in the industrial mix of jobs created by an investment comes from the Current Population Survey (CPS). The CPS is a household survey administered by the U.S. Census Bureau, on behalf of the Bureau of Labor Statistics of the U.S. Labor Department. The basic monthly survey of the CPS collects information from about 60,000 households every month on a wide range of topics including basic demographic characteristics, educational attainment, and employment status. Among a subset of its monthly sample—referred to as the outgoing rotation group (ORG)—respondents are asked more detailed employment-related questions, including about their wages and union status.

The CPS' survey in March includes a supplement, referred to as the Annual Social and Economic survey (ASEC) that asks additional questions, particularly about income, poverty status, and job-related health insurance and retirement benefits. We pool data from 2018-2019 for our analyses.[ii]

To create a profile of the types of jobs and the types of workers that will likely hold the jobs created with each investment, we weight the CPS worker data with the industry shares generated by IMPLAN. This creates a sample of workers with an industry composition that matches that of the jobs that we estimate will be added by investing in an energy supply or energy efficiency sector.

Specifically, we use the IMPLAN industry shares to adjust the sampling weights provided by the CPS. The CPS-provided sampling weights weight the survey sample so that it is representative at various geographic levels, including national and state. We adjust the CPS-provided sampling weights by multiplying each individual worker's sampling weight with the following:

$$S \text{ x } \frac{\text{IMPLAN's estimate of the share of new jobs in worker i's industry j}}{\sum \text{CPS sampling weights of all workers in industry j}}$$

where S is a scalar equal to the number of direct jobs produced overall by the level of investment being considered. For example, say the nation invests $100 billion in clean renewable energy sources and this generates 250,000 direct jobs, then S is equal to 250,000.

Some of the 526 IMPLAN industries had to be aggregated to match the industry variable in the CPS, which has 242 categories, and vice versa. For example, among IMPLAN's 526 sectors, there are 13 construction sectors while the CPS has only one construction industry. In the end, 194 industry sectors are common to both IMPLAN and the CPS.

We use these adjusted sampling weights to estimate the job-related health insurance and retirement benefits, and union membership among workers in the specific industrial mix of jobs associated with each type of investment. We also estimate demographic characteristics, such as percent female and percent non-white, as well as, workers' educational attainment. Finally, we determine what are the most prevalent occupations held by workers in the industrial mix of jobs associated with each type of investment.

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ii We use the CPS data files provided by IPUMS-CPS: "Integrated Public Use Microdata Series, Current Population Survey: Version 7.0, Minneapolis, MN: IPUMS, 2020," published by Sarah Flood, Miriam King, Renae Rodgers, Steven Ruggles and J. Robert Warren. https://doi.org/10.18128/D030.V7.0.

Characteristics of Jobs in Fossil Fuel and Related Industries

We use the same basic methodology for identifying fossil fuel and related jobs and worker characteristics. The only difference here is that IMPLAN's I-O models have well-defined sectors for the fossil fuel energy activities, i.e., we do not have to create "synthetic" industries. These sectors are listed in Table 3.11.

We can therefore use IMPLAN to model the industry distribution of the jobs that will be lost as the fossil fuel and related sectors contract. We use IMPLAN's estimates to create an industry profile of the types of jobs that will be lost as this combination of industries contract. As with the energy supply and energy demand jobs, we weight the CPS worker data with the industry shares generated by IMPLAN. This creates a sample of workers with an industry composition that matches that of the jobs that we estimate will be lost as fossil fuel sectors contract.

There are a couple industries that combine oil and gas related activities with coal related activities. These include fossil fuel electricity electric power generation, all other petroleum and coal products manufacturing. For these we assume that half of employment in these sectors are in oil and gas related activities and half of employment in these sectors are in coal related activities.

Definition of Jobs in IMPLAN

The employment figures in IMPLAN are based on the employment concept used by the Bureau of Economic Analysis. The BEA's concept of employment includes:

- wage and salaried workers
- self-employed workers in incorporated businesses, and
- proprietors employment which includes self-employed workers in unincorporated businesses.

The BEA's concept of employment is more expansive than what it typically used by the U.S. Labor Department's Bureau of Labor Statistics (BLS). Well-known BLS employer-based data on employment, such as from the Quarterly Census of Employment and Wages (QCEW), for example, do not include the unincorporated self-employed. The BLS' CPS data, on the other hand, does include the unincorporated self-employed. However, the CPS data on employment are based on household surveys and only counts the employment of the unincorporated self-employed if their self-employment is their primary job. Moreover, each person can only represent one job. The BEA's concept of proprietor's employment allows for the unincorporated self-employed to represent multiple units of employment. For example, if an individual has various different businesses operating during the year, each business would count as a unit of employment. To ensure that we use a consistent measure of employment effects in terms of both job creation from energy supply and energy efficiency investments, and job losses from the contraction of fossil fuel industry contractions, we use IMPLAN's (i.e., the BEA's) concept of employment throughout this report.

6.3 Detailed Prevalent Job Categories Generated through Energy Supply Investments and Energy Demand Expenditures

Table 6.3.1 Clean Renewables: Prevalent Job Types

(Job categories with 5 percent or more employment)

Job Category	Percentage of Total Industry Employment	Representative Occupations
Construction	28.2%	First-line supervisors, electricians, carpenters
Management	17.5%	Marketing managers, industrial production managers, chief executives
Production	16.1%	Testers, welding workers, metalworkers
Office and administrative support	7.3%	Stock clerks, customer service representatives, shipping clerks
Architecture and engineering	7.1%	Industrial engineers, electronics engineers, engineering technicians
Installation and maintenance	5.0%	Millwrights, truck mechanics, refractory machinery mechanics

Source: CPS 2018-2019

Table 6.3.2 Additional Supply Technologies: Prevalent Job Types

(Job categories with 5 percent or more employment)

Job Category	Percentage of Total Industry Employment	Representative Occupations
Construction	21.6%	Pipelayers, first-line supervisors, laborers
Farming, fishing, and forestry	18.8%	Graders and sorters, logging, forest workers
Management	16.9%	General managers, chief executives, farmers
Production	7.7%	Plastic workers, assemblers, brazing workers
Transportation and material movers	5.4%	Industrial tractor operators, packers, freight movers

Source: CPS 2018-2019

Table 6.3.3 Transmission/Storage: Prevalent Job Types

(Job categories with 5 percent or more employment)

Job Category	**Percentage of Total Industry Employment**	**Representative Occupations**
Installation and maintenance	17.9%	Industrial electrical repairers, first-line supervisors, electrical power-line repairers
Management	15.2%	Computer systems managers, chief executives, general managers
Architecture and engineering	12.2%	Civil engineers, mechanical engineers, drafters
Construction	12.1%	Plumbers, laborers, electricians
Production	10.5%	Welding workers, testers, power distributors
Office and administrative support	10.3%	Expediting clerks, general office clerks, secretaries
Computer and mathematics specialists	5.2%	Computer support specialists, computer programmers, software developers

Source: CPS 2018-2019

Table 6.3.4 Other: Prevalent Job Types

(Job categories with 5 percent or more employment)

Job Category	**Percentage of Total Industry Employment**	**Representative Occupations**
Construction	34.5%	Painters, carpenters, laborers
Production	19.2%	Fabricators, plastic workers, soldering workers
Management	16.2%	Marketing managers, industrial production managers, construction managers
Office and administrative support	6.8%	Bookkeeping clerks, shipping clerks, administrative assistants
Installation and maintenance	5.7%	Heavy vehicle mechanics, electrical power-line repairers, refrigeration mechanics

Source: CPS 2018-2019

Table 6.3.5 Vehicles: Prevalent Job Types

(Job categories with 5 percent or more employment)

Job Category	**Percentage of Total Industry Employment**	**Representative Occupations**
Production	44.4%	Electrical assemblers, inspectors, metalworkers
Management	10.9%	General managers, chief executives, industrial production managers
Architecture and engineering	10.8%	Electrical engineers, industrial engineers, engineering technicians
Transportation and material moving	9.1%	Truck drivers, industrial tractor operators, freight and stock movers
Office and administrative support	6.4%	Secretaries, production clerks, customer service representatives

Source: CPS 2018-2019

Table 6.3.6 HVAC: Prevalent Job Types

(Job categories with 5 percent or more employment)

Job Category	**Percentage of Total Industry Employment**	**Representative Occupations**
Construction	26.0%	Plumbers, electricians, carpenters
Production	24.1%	Plastic workers, first-line supervisors, machinists
Management	15.9%	Industrial production managers, marketing managers; construction managers
Office and administrative support	7.3%	First-line supervisors, bookkeeping clerks, shipping clerks
Architecture and engineering	6.4%	Electronics engineers, industrial health and safety engineers, mechanical engineers
Installation and maintenance	5.6%	Millwrights, mobile equipment service technicians, industrial machinery mechanics

Source: CPS 2018-2019

Table 6.3.7 Appliances: Prevalent Job Types

(Job categories with 5 percent or more employment)

Job Category	**Percentage of Total Industry Employment**	**Representative Occupations**
Production	27.1%	Metalworkers, brazing workers, fabricators
Construction	25.7%	Painters, electricians, carpenters
Management	12.3%	Operations managers; purchasing managers; sales managers
Office and administrative support	7.0%	Production clerks, order fillers, administrative assistants
Architecture and engineering	6.6%	Drafters, electronics engineers, engineering technicians
Installation and maintenance	5.3%	Millwrights, home appliance repairers, air conditioning mechanics

Source: CPS 2018-2019

Table 6.3.8 Refrigeration: Prevalent Job Types

(Job categories with 5 percent or more employment)

Job Category	**Percentage of Total Industry Employment**	**Representative Occupations**
Construction	43.7%	First-line supervisors, electricians, laborers
Management	17.1%	Operations managers, sales managers, construction managers
Production	13.0%	Inspectors, machinists, assemblers
Office and administrative support	6.1%	Shipping clerks, accounting clerks, administrative assistants
Installation and maintenance	5.5%	Telecommunications line installers, heavy vehicle mechanics, refrigeration mechanics

Source: CPS 2018-2019

Table 6.3.9 Lighting: Prevalent Job Types

(Job categories with 5 percent or more employment)

Job Category	Percentage of Total Industry Employment	Representative Occupations
Construction	38.3%	First-line supervisors, electricians, laborers
Management	17.5%	General managers, marketing managers; construction managers
Production	13.6%	Testers, fabricators, electrical assemblers
Architecture and engineering	6.2%	Civil engineers, industrial health and safety engineers, electrical engineers
Office and administrative support	6.1%	Shipping clerks, accounting clerks, stock clerks

Source: CPS 2018-2019

6.4 Detailed Cost Figures for Just Transition Program Costs

This appendix provides tables with the detailed cost figures that underlie the just transition program costs presented in Table 3.18, panels A and B.

TABLE 6.4.1 Total and Annual Average Costs for Just Transition Support for Displaced Fossil Fuel-Based Workers 2021 – 2030

Assumptions:

- Average compensation of workers in coal mining and related industries: $116,800[iii]
- Average compensation of workers in energy supply and energy efficiency: $84,000[iv]
- Annual wage insurance per worker: $32,800 ($116,800 - $84,000)
- Retraining cost per worker: $6,000[v]
- Relocation cost per worker: $75,000[vi]

iii Average compensation figures are employment weighted. Average compensation and employment figures for energy supply and energy efficiency investments are taken from IMPLAN 3.0 and presented in Table 3.2a, Table 3.4a, Table 3.6, and Table 3.8.

iv Average compensation figures are employment weighted. Average compensation figures and employment figures for contracting coal mining and related industries are taken from IMPLAN.

v See Table 3.17.

vi According to the 2020 article in Moneyzine "Job Relocation Expenses," these expenses for an average family range between $25,000 and $75,000 (https://www.money-zine.com/career-development/finding-a-job/job-relocation-expenses/). The costs include: selling and buying a home, including closing costs; moving furniture and other personal belongings; and renting a temporary home or apartment while house-hunting for a more permanent residence. For our calculations, we assume the upper-end figure of $75,000.

Year	**Income support** *(3 years of support for 12,087 coal workers)*	**Retraining support** *(2 years of support for 12,087 coal workers)*	**Relocation support** *(1 year of support for 6,044 coal workers)*	**Total (Cols. 1+2+3)**
2021	$396.4 million	$72.5 million	$453.3 million	$922.3 million
	(1 cohort)	(1 cohort)	(1 cohort)	
2022	$792.9 million	$145.0 million	$453.3 million	$1.4 billion
	(2 cohorts)	(2 cohorts)	(1 cohort)	
2023	$1.2 billion	$145.0 million	$453.3 million	$1.8 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2024	$1.2 billion	$145.0 million	$453.3 million	$1.8 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2025	$1.2 billion	$145.0 million	$453.3 million	$1.8 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2026	$1.2 billion	$145.0 million	$453.3 million	$1.8 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2027	$1.2 billion	$145.0 million	$453.3 million	$1.8 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2028	$1.2 billion	$145.0 million	$453.3 million	$1.8 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2029	$1.2 billion	$145.0 million	$453.3 million	$1.8 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2030	$1.2 billion	$145.0 million	$453.3 million	$1.8 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2031	$792.9 million	$72.5 million		$865.4 million
	(2 cohorts)	(1 cohort)		
2032	$396.4 million			$396.4 million
	(1 cohort)			
Total	$11.9 billion	$1.5 billion	$4.5 billion	$17.9 billion
Average Annual Costs	$991.1 million *(12 years of support)*	$131.9 million *(11 years of support*	$453.3 million *(10 years of support)*	$1.5 billion *(12 years of support)*

TABLE 6.4.2 Total and Annual Average Costs for Just Transition Support for Displaced Fossil Fuel-Based Workers 2031 – 2050

Assumptions:

- Average compensation of workers in oil and gas extraction and related industries: $107,900[vii]
- Average compensation of workers in energy supply and energy efficiency: $84,000
- Annual wage insurance per worker: $23,900 ($107,900 - $84,000)
- Retraining cost per worker: $6,000
- Relocation cost per worker: $75,000

Year	**Income support** *(3 years of support for 34,207 oil and gas workers)*	**Retraining support** *(2 years of support for 34,207 oil and gas workers)*	**Relocation support** *(1 year of support for 34,207 oil and gas workers)*	**Total (Cols. 1+2+3)**
2031	$817.5 million	$205.2 million	$1.3 billion	$2.3 billion
	(1 cohort)	(1 cohort)	(1 cohort)	
2032	$1.6 billion	$410.5 million	$1.3 billion	$3.3 billion
	(2 cohorts)	(2 cohorts)	(1 cohort)	
2033	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2034	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2035	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2036	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2037	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2038	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2039	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2040	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	

vii Average compensation figures are employment weighted. Average compensation figures and employment figures for contracting oil and gas extraction and related industries are taken from IMPLAN 3.0.

TABLE 6.4.3 Total and Annual Average Costs for Just Transition Support for Displaced Fossil Fuel-Based Workers 2031 – 2050 (continued)

Year	**Income support** *(3 years of support for 34,207 oil and gas workers)*	**Retraining support** *(2 years of support for 34,207 oil and gas workers)*	**Relocation support** *(1 year of support for 34,207 oil and gas workers)*	**Total (Cols. 1+2+3)**
2041	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2042	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2043	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2044	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2045	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2046	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2047	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2048	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2049	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2050	$2.5 billion	$410.5 million	$1.3 billion	$4.1 billion
	(3 cohorts)	(2 cohorts)	(1 cohort)	
2051	$1.6 billion	$205.2 million		$1.8 billion
	(2 cohorts)	(1 cohort)		
2052	$817.5 million			$817.5 million
	(1 cohort)			
Total	$49.0 billion	$8.2 billion	$25.7 billion	$82.9 billion
Average Annual Costs	$2.2 million *(22 years of support)*	$390.9 million *(21 years of support)*	$1.3 billion *(20 years of support)*	$3.8 billion *(22 years of support)*

Sources: See notes to Table 6.4.1.

6.5 Per Ton Estimates of GHG Emissions for Baseline and Alternative Management Scenarios[viii]

Material	GHG Emissions per Ton of Material:					
	Source Reduced ($MTCO_2E$)	**Recycled ($MTCO_2E$)**	**Landfilled ($MTCO_2E$)**	**Combusted ($MTCO_2E$)**	**Composted ($MTCO_2E$)**	**Anaerobically Digested ($MTCO_2E$)**
Corrugated Containers	(5.58)	(3.14)	0.26	(0.49)	NA	NA
Magazines/third-class mail	(8.57)	(3.07)	(0.39)	(0.35)	NA	NA
Newspaper	(4.68)	(2.71)	(0.82)	(0.56)	NA	NA
Office Paper	(7.95)	(2.86)	1.25	(0.47)	NA	NA
Phonebooks	(6.17)	(2.62)	(0.82)	(0.56)	NA	NA
Textbooks	(9.02)	(3.10)	1.25	(0.47)	NA	NA
Mixed Paper (general)	(6.07)	(3.55)	0.14	(0.49)	NA	NA
Mixed Paper (primarily residential)	(6.00)	(3.55)	0.08	(0.49)	NA	NA
Mixed Paper (primarily from offices)	(7.37)	(3.58)	0.18	(0.45)	NA	NA
Food Waste	(3.66)	NA	0.54	(0.13)	(0.18)	(0.04)
Food Waste (non-meat)	(0.76)	NA	0.54	(0.13)	(0.18)	(0.04)
Food Waste (meat only)	(15.10)	NA	0.54	(0.13)	(0.18)	(0.04)
Beef	(30.09)	NA	0.54	(0.13)	(0.18)	(0.04)
Poultry	(2.45)	NA	0.54	(0.13)	(0.18)	(0.04)
Grains	(0.62)	NA	0.54	(0.13)	(0.18)	(0.04)
Bread	(0.66)	NA	0.54	(0.13)	(0.18)	(0.04)
Fruits and Vegetables	(0.44)	NA	0.54	(0.13)	(0.18)	(0.04)
Dairy Products	(1.75)	NA	0.54	(0.13)	(0.18)	(0.04)
Yard Trimmings	NA	NA	(0.18)	(0.17)	(0.15)	(0.09)
Grass	NA	NA	0.13	(0.17)	(0.15)	0.00
Leaves	NA	NA	(0.52)	(0.17)	(0.15)	(0.14)
Branches	NA	NA	(0.50)	(0.17)	(0.15)	(0.22)
HDPE	(1.42)	(0.85)	0.02	1.29	NA	NA
LDPE	(1.80)	NA	0.02	1.29	NA	NA
PET	(2.17)	(1.15)	0.02	1.24	NA	NA
LLDPE	(1.58)	NA	0.02	1.29	NA	NA

viii US Environmental Protection Agency (EPA), "Versions of the Waste Reduction Model (WARM)," Accessed August 3, 2020, https://www.epa.gov/warm/versions-waste-reduction-model-warm#15.

PP	(1.54)	NA	0.02	1.29	NA	NA
PS	(2.50)	NA	0.02	1.65	NA	NA
PVC	(1.93)	NA	0.02	0.66	NA	NA
Mixed Plastics	(1.87)	(1.03)	0.02	1.26	NA	NA
PLA	(2.45)	NA	(1.64)	(0.63)	(0.15)	NA
Desktop CPUs	(20.86)	(1.49)	0.02	(0.66)	NA	NA
Portable Electronic Devices	(29.83)	(1.07)	0.02	0.65	NA	NA
Flat-Panel Displays	(24.19)	(1.00)	0.02	0.03	NA	NA
CRT Displays	NA	(0.57)	0.02	0.45	NA	NA
Electronic Peripherals	(10.32)	(0.37)	0.02	2.08	NA	NA
Hard-Copy Devices	(7.65)	(0.57)	0.02	1.20	NA	NA
Mixed Electronics	NA	(0.79)	0.02	0.39	NA	NA
Aluminum Cans	(4.80)	(9.13)	0.02	0.03	NA	NA
Aluminum Ingot	(7.48)	(7.20)	0.02	0.03	NA	NA
Steel Cans	(3.03)	(1.83)	0.02	(1.59)	NA	NA
Copper Wire	(6.72)	(4.49)	0.02	0.03	NA	NA
Mixed Metals	(3.65)	(4.39)	0.02	(1.02)	NA	NA
Glass	(0.53)	(0.28)	0.02	0.03	NA	NA
Asphalt Concrete	(0.11)	(0.08)	0.02	NA	NA	NA
Asphalt Shingles	(0.19)	(0.09)	0.02	(0.35)	NA	NA
Carpet	(3.68)	(2.38)	0.02	1.10	NA	NA
Clay Bricks	(0.27)	NA	0.02	NA	NA	NA
Concrete	NA	(0.01)	0.02	NA	NA	NA
Dimensional Lumber	(2.02)	(2.47)	(1.01)	(0.58)	NA	NA
Drywall	(0.22)	0.03	(0.06)	NA	NA	NA
Fiberglass Insulation	(0.38)	NA	0.02	NA	NA	NA
Fly Ash	NA	(0.87)	0.02	NA	NA	NA
Medium-density Fiberboard	(2.22)	(2.47)	(0.88)	(0.58)	NA	NA
Vinyl Flooring	(0.58)	NA	0.02	(0.31)	NA	NA
Wood Flooring	(4.03)	NA	(0.86)	(0.74)	NA	NA
Tires	(4.30)	(0.38)	0.02	0.50	NA	NA
Mixed Recyclables	NA	(2.85)	0.09	(0.42)	NA	NA
Mixed Organics	NA	NA	0.21	(0.15)	(0.16)	(0.06)
Mixed MSW	NA	NA	0.36	0.01	NA	NA

6.6 2019-2020 Federal Legislative Initiatives

6.6.1 The *Break Free From Plastics Pollution Act (BFFPPA)* (HR 5845, S 3263)[ix]

Sponsored by Senator Tom Udall and Representative Alan Lowenthal, *BFFPPA* was introduced in Congress in February 2020. It is intended to be a blueprint that requires:

- Product producers to take responsibility for collecting and recycling materials;
- Investment in US domestic recycling and composting infrastructure;
- Covering the costs of waste management and clean-up, and promoting awareness-raising measures to reduce waste;
- Creation of a nationwide beverage container deposit system;
- Promoting source reduction and phase-out major polluting products, such as single-use plastic products;
- Imposition of a fee on the distribution of carry-out bags;
- Creation of minimum recycled content requirements;
- Standardizing recycling and composting labels for products and receptacles to encourage proper sorting and disposal of items that can be recycled or composted;
- Reviewing the effects of plastic tobacco filters, electronic cigarettes, and derelict fishing gear;
- Preventing plastic waste from being shipped to developing countries that cannot manage it;
- Protection of existing state actions, such as the ability of state and local governments to enact more stringent standards, requirements, and additional product bans; and
- Temporarily pausing new plastic facilities.

BFFPPA shifts the responsibility to producers to finance, collect, and manage packaging (plastic, glass, metal) and paper product waste after consumer-use.[x] Additionally, *BFFPPA* sets out to require producers to design their products to minimize the impacts of extraction, manufacture, use, and end-of-life management. And to help with proper sortation and disposal, *BFFPPA* requires the EPA to develop guidelines for a national standardized recycling and composting labeling system for use in public places on recycling and composting receptacles.

BFFPPA includes and builds on plastic reduction policies that have been successfully demonstrated across the country: (1) a ban on plastic carry-out bags coupled with a fee on all other carry-out bags, and (2) a ban on expanded Polystyrene food and drinkware. In addition to bags, Polystyrene, and straws, *BFFPPA* targets other disposable plastic items for source reduction.

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ix Information from *Break Free from Plastics Fact Sheet*, Beyond Plastics, Bennington College, Bennington, VT, 2020, 5-6; and, Udall, 8-14.

x Udall, 8.

Importantly, *BFFPPA* defines what it means to be "recyclable" and does not classify waste-to-energy or other forms of fuel conversion as recycling. Products that are not recyclable shall not include confusing symbols, such as the universal chasing arrow symbol.[xi]

The act is a comprehensive tool-kit that tackles packaging waste issues and plastic pollution from extraction to disposal. The current linear model of handling this waste has only been exacerbated over time by increases in population and ever growing consumer appetite. In order to get it under control, we need to return to principles of product stewardship and circularity to ensure that we get a handle on our waste and address the environmental, economic and health impacts that are straining our system.[xii] A multi-pronged approach that focuses on limiting all aspects of plastic and packaging pollution and a transition to a truly circular economy is the only solution. It will require reducing unnecessary amounts of plastic and packaging, finding sustainable substitutes, promoting reusable items, improving recycling practices, and expanding waste collection services.[xiii] The act provides badly-needed national leadership by shifting the burden of cleanup to where it belongs: on the corporations that produce the waste.

6.6.2 *The RECYCLE ACT* (S 2941)[xiv]

Sponsored by Senators Rob Portman and Debbie Stabenow, the *Recycling Enhancements to Collection and Yield through Consumer Learning and Education (RECYCLE) Act*, intends to create a program within the EPA to bolster recycling education, proposing a fund of $75M for this purpose.

RECYCLE would authorize up to $15 million per year, over the course of five years, in grants to states, tribes, nonprofits, public partnerships, and local governments seeking to ramp up commercial and municipal recycling outreach and education. The legislation would also direct the EPA to develop a model recycling toolkit to bolster recycling participation and decrease contamination rates. Where appropriate, the bill would also task the EPA with more frequently updating guidelines for products containing recycled material, while recommending federal agencies purchase those items.

"The broad support for the *Recycle Act*, from industry, environmental groups, waste management, and all types of materials groups suggests that education and outreach is desperately needed to help improve our recycling systems. It shows that there are challenges with our nation's recycling that we can address today," said Emily Benavides, a spokesperson for Portman.

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xi Udall, 14.

xii Udall, 18.

xiii Udall, 4.

xiv Information from E. A. Crunden, "RECYCLE Act Proposes $75M for Education, with Widespread Industry Support," Waste Dive (November 16, 2019), Accessed August 19, 2020, https://www.wastedive.com/news/portman-recycle-act-swana-nwra-recycling-federal-trend/567899/.

The *Plastic Waste Reduction and Recycling Act* (HR 7228)[xv]

Representatives Haley Stevens and Anthony Gonzalez have introduced the Plastic Waste Reduction and Recycling Act as bipartisan legislation to reduce plastic waste and improve the global competitiveness of the US plastics recycling industry. This act directs the establishment of a plastic waste reduction and recycling research and development program, calls on the federal government to develop a strategic plan for plastic waste reduction and calls for the development of standards for plastics recycling technologies.

The proposed legislation would:

- Direct the director of the Office of Science and Technology Policy to establish a Plastic Waste Reduction and Recycling Program to improve the global competitiveness of the US plastics recycling industry;
- Direct the director of the Office of Science and Technology Policy to establish an interagency committee to coordinate the program and develop a strategic plan for plastic waste reduction and recycling and plastic waste remediation;
- Direct the National Institute of Standards and Technologies to carry out research and provide the metrology basis for standards development for plastics recycling and related technologies, and to develop a clearinghouse to support dissemination of the tools, guidelines, and standards supported by the program;
- Direct the National Science Foundation, Department of Energy, Environmental Protection Agency and National Oceanic and Atmospheric Administration to support research and other activities on advanced recycling technologies, plastic waste remediation and the public health impacts of microplastics, among other topics; and
- Authorize funding for five years and invest $85 million in 2021 for these activities.

xv Megan Smalley. "Legislators Introduce Plastic Waste Reduction, Recycling Act," Recycling Today, Accessed, August 21, 2020, https://www.recyclingtoday.com/article/haley-stevens-introduces-plastic-waste-reduction-recycling-act/.

BIBLIOGRAPHY

"3 Types of Measurement, Reporting, and Verification (MRV)." 2016. World Resources Institute. August 30, 2016. https://www.wri.org/resources/charts-graphs/3-types-measurement-reporting-and-verification-mrv.

"The 2017-18 Budget: Cap-and-Trade." n.d. Accessed August 10, 2020. https://lao.ca.gov/publications/report/3553#Conclusion.

2019 U.S. Energy and Employment Report." n.d. https://www.usenergyjobs.org/.

"2019 Was a Watershed Year for Clean Energy Commitments from U.S. States and Utilities." 2019. World Resources Institute. December 20, 2019. https://www.wri.org/blog/2019/12/2019-was-watershed-year-clean-energy-commitments-us-states-and-utilities.

A

"AB 32 Global Warming Solutions Act of 2006 | California Air Resources Board." n.d. Accessed August 10, 2020. https://ww2.arb.ca.gov/resources/fact-sheets/ab-32-global-warming-solutions-act-2006.

"About California Climate Investments – Background". California Climate Investments. http://www.caclimateinvestments.ca.gov/about-cci.

"Accelerating America's Pledge | Americas Pledge On Climate". 2020. Americas Pledge On Climate. https://www.americaspledgeonclimate.com/accelerating-americas-pledge-2/.

Agarwal R., S. Chandrasekaran, and M. Sridhar. "Imagining Construction's Digital Future." McKinsey, June 24, 2016, https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future.

Åhman, M., Nikoleris, A. & Nilsson, L. J. 2012. "Decarbonising Industry in Sweden - an Assessment of Possibilities and Policy Needs".

Åhman, Max, Lars J. Nilsson, and Bengt Johansson. 2016. "Global Climate Policy And Deep Decarbonization Of Energy-Intensive Industries". Climate Policy 17 (5): 634-649. doi:10.1080/14693062.2016.1167009.

Alaska Center for Energy and Power, and University of Alaska, Fairbanks. 2015. "Microgrids." http://acep.uaf.edu/media/158027/Microgrids-6-26-15.pdf.

Alaska Center for Energy and Power. 2020. "Microgrids". Fairbanks, AK: University of Alaska Fairbanks. Accessed September 3. http://acep.uaf.edu/media/158027/Microgrids-6-26-15.pdf.

"Alaska Heat Smart." n.d. Accessed September 6, 2020. https://akheatsmart.org/.

"Alaska Network For Energy Education And Employment | REAP". 2020. Alaskarenewableenergy.Org. https://alaskarenewableenergy.org/initiatives/alaska-network-for-energy-education-and-employment/.

Alemi, Farzad, & Caroline Rodier. 2020. "Ride-Hailing Holds Promise for Facilitating More Transit Use in the San Francisco Bay Area." UC Davis: National Center for Sustainable Transportation. http://dx.doi.org/10.7922/G2M043N5.

Allanore, A. 2015. "Features and challenges of molten oxide electrolytes for metal extraction". Journal of The Electrochemical Society 162, E13-E22.

Allanore, A., Yin, L. & Sadoway, D. R. 2013. "A new anode material for oxygen evolution in molten oxide electrolysis". Nature 497, 353-356.

Allwood, J. 2016. Bright Future for UK Steel: a Strategy for Innovation and Leadership through Up-cycling and Integration.

Allwood, J. M., Cullen, J. M. & Carruth, M. A. 2012. Sustainable Materials: with Both Eyes Open. UIT Cambridge.

Alston & Bird, Jamie Furst, and Andrew Howard. 2020. "The Moving America Forward Act: If Passed, Will Result in Increased Opportunities for Infrastructure Work and Contracting With the Federal Government." JD Supra. August 13, 2020. https://www.jdsupra.com/legalnews/the-moving-america-forward-act-if-66813/.

Alvarez, Alayna. 2020. "Denver Seeks Partner For National Western Center Redevelopment Project". Colorado Politics. https://www.coloradopolitics.com/denver/denver-seeks-partner-for-national-western-center-redevelopment-project/article_6f919320-211b-11ea-8ad7-077186c5adff.html.

Ambrose, Hanjiro, Alissa Kendall, Mark Lozano, Sadanand Wachche, and Lew Fulton. 2020. "Trends In Life Cycle Greenhouse Gas Emissions Of Future Light Duty Electric Vehicles". Transportation Research Part D: Transport And Environment 81: 102287. doi:10.1016/j.trd.2020.102287.

American Association of Community Colleges (AACC). 2020. "DataPoints: Tuition and Fees." June 18, 2020. https://www.aacc.nche.edu/2020/06/18/datapoints-tuition-and-fees/.

Anderson, Cheryl A.M., Anne N. Thorndike, Alice H. Lichtenstein, Linda Van Horn, Penny M. Kris-Etherton, Randi Foraker, and Colleen Spees. 2019. "Innovation To Create A Healthy And Sustainable Food System: A Science Advisory From The American Heart Association". Circulation 139(23). doi:10.1161/cir.0000000000000686.

Andrew, R. 2019. Global CO2 emissions from cement production. Earth Systems Science Data(11), 1675 - 1710.

Appalachian Citizens' Law Center, Appalachian Voices, Coalfield Development Corporation, Rural Action and Downstream Strategies. 2020. "A New Horizon: Innovative Reclamation For A Just Transition". Reclaiming Appalachia Coalition. https://reclaimingappalachia.org/new-2019-report-a-new-horizon/.

Arup-C40, 2015. Climate Action in Mega-Cities 3.0. http://cam3.c40.org/#/main/home

Aultman-Hall, Lisa. 2018. Incorporating Long-Distance Travel into Transportation Planning in the United States. UC Davis: National Center for Sustainable Transportation. https://escholarship.org/uc/item/0ft8b3b5.

B

Babtista, Ana. “Garbage In, Garbage Out: Incinerating Trash is Not an Effective Way to Protect the Climate or Reduce Waste,” The Conversation (February 27, 2018), Accessed July 28, 2020, https://theconversation.com/garbage-in-garbage-out-incinerating-trash-is-not-an-effective-way-to-protect-the-climate-or-reduce-waste-84182.

Bantillo, Stephen, National Recycling Coalition Executive Vice President, and Policy Committee Co-chair, conversation with author, August 28, 2020.

Bantillo, Stephen, National Recycling Coalition Executive Vice President, and Policy Committee Co-chair, conversation with author, August 29, 2020.

Bantillo, Stephen. “Quality vs Quantity,” Recycling Certification Institute, Accessed August 29, 2020, https://www.recyclingcertification.org/2020/05/quality-vs-quantity/.

Barbose, Galen. 2019. U.S. Renewables Portfolio Standards. Berkeley: Lawrence Berkeley National Laboratory and Office of Electricity Delivery and Energy Reliability. https://eta-publications.lbl.gov/sites/default/files/rps_annual_status_update-2019_edition.pdf.

Bataille, C. 2019. Physical and policy pathways to net-zero emissions industry. WIRES Wiley Interdisciplinary Reviews, 1-20, doi:10.1002/wcc.633.

Bataille, C. et al. 2018. “A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris Agreement”. Journal of Cleaner Production 187, 960–973, doi:10.1016/j.jclepro.2018.03.107.

Bataille, Chris, Max Åhman, Karsten Neuhoff, Lars J. Nilsson, Manfred Fischedick, Stefan Lechtenböhmer, and Baltazar Solano-Rodriquez et al. 2018. “A Review Of Technology And Policy Deep Decarbonization Pathway Options For Making Energy-Intensive Industry Production Consistent With The Paris Agreement”. Journal Of Cleaner Production 187: 960-973. doi:10.1016/j.jclepro.2018.03.107.

“Battery Pack Prices Fall As Market Ramps Up With Market Average At $156/KWh In 2019.” 2019. BloombergNEF (blog). December 3, 2019. https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/.

Bazzanella, A. M. & Ausfelder, F. 2017. Low carbon energy and feedstock for the European chemical industry. DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V.

Bedir, Abdulkadir, Noel Crisostomo, Jennifer Allen, Eric Wood, and Clément Rames. 2018. California Plug-In Electric Vehicle Infrastructure Projections: 2017-2025. California Energy Commission. Publication Number: CEC-600-2018-001.

"A Behind the Scenes Take on Lithium-Ion Battery Prices." 2019. BloombergNEF (blog). March 5, 2019. https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/.

Bentz, D. P., Irassar, E. F., Bucher, B. E., & Weiss, W. J.. 2009. Limestone Fillers Conserve Cement Part 1: An analysis based on Powers' model. Concrete International.

Berkeley Planning Associates and Social Policy Research Associates. 1994. "Evaluation Of The Defense Conversion Adjustment Demonstration: Interim Report On Implementation". Research And Evaluation Report Series. Office of Policy and Research, U.S. Department of Labor, Employment and Training. https://wdr.doleta.gov/opr/FULLTEXT/1994_12_NEW.pdf.

Best, Allen. 2020. "All-Electric Homes Offer A Prototype For Low-Carbon Housing In Colorado". Energy News Network. https://energynews.us/2019/10/17/west/all-electric-homes-offer-a-prototype-for-low-carbon-housing-in-colorado/.

Beyond Waste: Circular Resources Lab, Global Solutions Forum, Accessed August 15, 2020, https://www.circularresourceslab.ch.

Biven, Megan Milliken. 2020. "The Abandoned Well Administration: Putting Oil and Gas Workers Back to Work.

"Bloomberg - Are You A Robot?". 2020. Bloomberg.Com. https://www.bloomberg.com/news/articles/2019-08-05/the-problem-for-business-when-inventory-is-no-problem-justin-fox.

Bloomberg Philanthropies American Cities Challenge. 2019. "Climate Action Playbook Brief". Bloomberg Philanthropies. https://data.bloomberglp.com/dotorg/sites/2/2019/10/American-Cities-Climate-Challenge-Climate-Action-Playbook.pdf.

"BLS Data Finder". 2020. Beta.Bls.Gov. http://beta.bls.gov/dataQuery/find?st=240&r=20&fq=areaT:%5BCombined+areas%5D&more=0.

"BLS Data Finder Midland-Odessa, TX Combined Statistical Area". 2020. Beta.Bls.Gov. https://beta.bls.gov/dataQuery/find?st=0&r=20&q=midland-odessa&fq=areaT:[Combined+areas]&more=0&fq=survey:[la].

Bond, Tami C., and Haolin Sun. 2005. "Can Reducing Black Carbon Emissions Counteract Global Warming?" Environmental Science & Technology 39 (16): 5921–26. https://doi.org/10.1021/es0480421.

Boyce, James K. 2018. "Carbon Pricing: Effectiveness And Equity". Ecological Economics 150: 52-61. doi:10.1016/j.ecolecon.2018.03.030.

Break Free from Plastics Fact Sheet, Beyond Plastics, Bennington College, Bennington, VT, 2020.

Brown, Sally, Matthew Cotton, Steve Messner, Fiona Berry, and David Norem. 2009. Methane Avoidance from Composting: An Issue Paper for the Climate Action Reserve, SAIC, 37.

Bureau of Transportation Statistics. “National Household Travel Survey Daily Travel Quick Facts.” n.d. Accessed August 18, 2020. https://www.bts.gov/statistical-products/surveys/national-household-travel-survey-daily-travel-quick-facts

Burger, Michael, Materials Consumption and Solid Waste. 2018. Sabin Center for Climate Change Law, Columbia Law School, Chapter 7, Legal Pathways to Deep Decarbonization in the United States (Michael B. Gerrard and John Dernbach, eds.) (ELI Books, 2018 Forthcoming)., Columbia Public Law Research Paper No. 14-606, Available at SSRN: https://ssrn.com/abstract=3276245

Burke et al. 2020. Evaluation of the Economics of Battery-Electric and Fuel Cell Trucks and Buses. Davis, CA: UC Davis Sustainable Freight Program.

Buzby, J. C., Farah-Wells, H., & Hyman, J. 2014. The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States. U.S. Department of Agriculture, Economic Research Service. http://www.ssrn.com/abstract=2501659.

C

C40 Cities and Sustainia. 2015. “Cities 100”. C40 Cities; Sustainia. https://issuu.com/sustainia/docs/cities100/91?e=4517615/31305566.

“C40: One Year After Trump Decision To Withdraw From Paris Agreement, U.S. Cities Carry Clima…”. 2020. C40 Cities. https://www.c40.org/press_releases/one-year-after-trump-decision-to-withdraw-from-paris-agreement-u-s-cities-carry-climate-action-forward.

California Air Resources Board. 2019. California Greenhouse Gas Emissions for 2000 to 2017: Trends of Emissions and Other Indicators. California Air Resources Board.https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2017/ghg_inventory_trends_00-17.pdf.

California Air Resources Board, “Overview: Diesel Exhaust and Health,” 2019, https://ww2.arb.ca.gov/resources/overview-diesel-exhaust-and-health

“California Leads Fight to Curb Climate Change.” n.d. Environmental Defense Fund. Accessed August 10, 2020. https://www.edf.org/climate/california-leads-fight-curb-climate-change.

“California Sets Rules for Post-2020 Cap-and-Trade Program.” n.d. Environmental Defense Fund. Accessed August 10, 2020. https://www.edf.org/media/california-sets-rules-post-2020-cap-and-trade-program.

Calma, J. “Democrats Are Pushing a National Climate Bank.” The Verge, January 29, 2020, https://www.theverge.com/2020/1/29/21113300/democrats-green-bank-national-climate-change-capital-greenhouse-gases.

Cao, Z., Myers, R., Lupton, R., Duan, H., Sacchi, R., Zhou, N., Reed Miller, T., Cullen, J., Ge, Q. and Liu, G., 2020. The sponge effect and carbon emission mitigation potentials of the global cement cycle. Nature Communications, 11(1).

Carbó, Agustín and Amalia Saladrigas. 2020. “Resilience in the Eye of the Storm: How Puerto Rico Can Build a Stronger, More Sustainable Energy Future”. Environmental Defense Fund. http://blogs.edf.org/energyexchange/2020/06/30/resilience-in-the-eye-of-the-storm-how-puerto-rico-can-build-a-stronger-more-sustainable-energy-future/

“Carbon Smart Materials Palette.” n.d. Accessed August 11, 2020. https://materialspalette.org/palette/.

Carley, Sanya, and David M. Konisky. 2020. “The Justice and Equity Implications of the Clean Energy Transition.” Nature Energy 5 (8): 569–77. https://doi.org/10.1038/s41560-020-0641-6.

Cement Statistics And Information”. 2020. Usgs.Gov. https://www.usgs.gov/centers/nmic/cement-statistics-and-information.

Cheever, Federico, Robert McKinstry and Robert Fischman. 2019. “Chapter 31: Forestry.” In Legal Pathways to Deep Decarbonization in the United States, edited by Michael Gerrard and John C. Dernbach. Washington D.C.: Environmental Law Institute.

Chemical Industry Spotlight | Selectusa.Gov”. 2020. Selectusa.Gov. https://www.selectusa.gov/chemical-industry-united-states.

Chiasson MA, Findley SE, Sekhobo JP, Scheinmann R, Edmunds LS, Faly AS, McLeod NJ. 2013. Changing WIC changes what children eat. Obesity 21:1423–1429. doi: 10.1002/oby.20295.

Chow, Lorraine. 2017. “Germany Converts Coal Mine into Giant Battery Storage for Surplus Solar and Wind Power,” EcoWatch, March 20.

Cities of Oakland Park & Wilton Manors. 2019. Climate Action Plan: Two Cities. One Sustainable Future. Florida: Oakland Park & Wilton Manors. https://www.wiltonmanors.com/DocumentCenter/View/4747/OP-WM-Climate-Action-Plan-FINAL-February-2019.

“Clean Energy Resources Development and Incentives ‘Build-Ready’ Program.” n.d. NYSERDA. Accessed August 18, 2020. https://www.nyserda.ny.gov/All%20Programs/Programs/Clean%20Energy%20Standard/Renewable%20Generators%20and%20Developers/Build%20Ready%20Program.

Clift, Roland, and Angela Druckman, Eds. 2016. Taking Stock Of Industrial Ecology. Springer.

Climate Change 2007 - Mitigation Of Climate Change: Working Group III Contribution To The Fourth Assessment Report Of The IPCC. 2007. Cambridge University Press.

“Climate Action | City of Boise.” n.d. Accessed August 11, 2020. https://www.cityofboise.org/programs/climate-action/.

Coalition for Urban Transitions. 2019. Climate Emergency, Urban Opportunity: How National Governments Can Secure Economic Prosperity and Avert Climate Catastrophe by Transforming Cities. Washington DC: Coalition for Urban Transitions, C40 Cities Climate Leadership Group, WRI Ross Center for Sustainable Cities. https://urbantransitions.global/wp-content/uploads/2019/09/Climate-Emergency-Urban-Opportunity-report.pdf.

Coalition for Urban Transitions. 2019. Urban Opportunity: How National Governments Can Secure Economic Prosperity and Avert Climate Catastrophe By Transforming Cities. Washington D.C.: Coalition for Urban Transitions, C40 Cities Climate Leadership Group, WRI Ross Center for Sustainable Cities. https://urbantransitions.global/wp-content/uploads/2019/09/Climate-Emergency-Urban-Opportunity-report.pdf.

Cobo, Selene, Antonio Dominguez-Ramos, & Angel Irabien. 2018. "From linear to circular integrated waste management systems: A review of methodological approaches:. Resour. Conserv. Recycl. 135, 279–295.

"Colorado Gov Polis Unveils Roadmap to 100% Renewables by 2040, Signs 11 Clean Energy Bills." n.d. Utility Dive. Accessed August 10, 2020. https://www.utilitydive.com/news/colorado-gov-polis-unveils-roadmap-to-100-carbon-free-by-2040-signs-11-cl/555975/.

Colorado Just Transition Advisory Committee. 2020. "Draft Colorado Just Transition Plan". Denver, CO: Colorado Department of Labor and Employment.

Columbia University SIPA Center on Global Energy Policy, Energizing America: A Roadmap to Launch a National Energy Innovation Mission 43-50 (2020), https://www.energypolicy.columbia.edu/sites/default/files/file-uploads/EnergizingAmerica_FINAL_DIGITAL.pdf.

"Comstock". 2020. Comstock.Nrel.Gov. https://comstock.nrel.gov/.

"Concept: What is A Circular Economy? A Framework for An Economy that Is Restorative and Regenerative By Design," Ellen MacArthur Foundation, Accessed August 1, 2020, https://www.ellenmacarthurfoundation.org/circular-economy/concept.

Congressional Budget Office. 2018. "Public Spending on Transportation and Public Infrastructure, 1956 to 2017". CBO. October 2018. https://www.cbo.gov/system/files/2018-10/54539-Infrastructure.pdf.

The Container Recycling Institute. 2020. "2018 Beverage Market Data Analysis.".

"Coolclimate Calculator". 2020. Coolclimate.Org. https://coolclimate.org/calculator.

"Cool Climate Maps". 2020. Coolclimate.Berkeley.Edu. http://coolclimate.berkeley.edu/maps.

"Courthouse Program." 2018. Accessed August 13, 2020. https://www.gsa.gov/real-estate/gsa-properties/courthouse-program.

Cullenward, Danny, Mason Inman, and Michael D. Mastrandrea. 2019. "Tracking Banking in the Western Climate Initiative Cap-and-Trade Program." Environmental Research Letters 14 (12): 124037. https://doi.org/10.1088/1748-9326/ab50df.

"Crude Oil Production". 2020. Eia.Gov. https://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm.

Crunden, E.A. 2019. "RECYCLE Act Proposes $75M For Education, With Widespread Industry Support". Waste Dive. https://www.wastedive.com/news/portman-recycle-act-swana-nwra-recycling-federal-trend/567899/.

Cullenward, Danny. 2017. “California’s Foreign Climate Policy.” Global Summitry 3 (1): 1–26. https://doi.org/10.1093/global/gux007.

D

Darling, David, and Sara Hoff. 2020. “Investor-Owned Utilities Served 72% Of U.S. Electricity Customers In 2017”. Eia.Gov. https://www.eia.gov/todayinenergy/detail.php?id=40913.

“Databases, Tables & Calculators By Subject”. 2020. Bls.Gov. https://www.bls.gov/data/#employment.https://wdr.doleta.gov/opr/FULLTEXT/1994_12_NEW.pdf, pp. 4-3, 4-5

Davis, Stacy C. and Robert G. Boundy. “Transportation Carbon Dioxide Emissions by Mode, 1990–2017.” In Transportation Energy Data Book. 38th ed., 12-10. Oak Ridge, TN: Oak Ridge National Laboratory, 2020. https://tedb.ornl.gov/wp-content/uploads/2020/02/TEDB_Ed_38.pdf.

Davis, Steven J., Nathan S. Lewis, Matthew Shaner, Sonia Aggarwal, Doug Arent, Inês L. Azevedo, and Sally M. Benson et al. 2018. “Net-Zero Emissions Energy Systems”. Science 360 (6396): eaas9793. doi:10.1126/science.aas9793.

“Deadline 2020: How Cities Will Get The Job Done”. 2020. London: C40 Cities Climate Leadership Group

Dean, Charles C., Denis Dugwell, and Paul S. Fennell. 2011. “Investigation Into Potential Synergy Between Power Generation, Cement Manufacture And CO2 Abatement Using The Calcium Looping Cycle”. Energy & Environmental Science 4 (6): 2050. doi:10.1039/c1ee01282g.

Deep Decarbonization Pathways Project. 2015. Pathways to deep decarbonization 2015 report. SDSN and IDDRI

Dehghanian, Payman. 2017. “Power System Topology Control For Enhanced Resilience Of Smart Electricity Grids”. Doctor of Philosophy, Texas A&M University.

Deka, Deepjyoti, Scott Backhaus, and Michael Chertkov. 2016. “Learning Topology Of The Power Distribution Grid With And Without Missing Data”. In 2016 European Control Conference (ECC), Aalborg, 2016, 313-320. http://10.1109/ECC.2016.7810304.

Dell, Jan. “Six Times More Plastic Waste is Burned in US than is Recycled,” Plastic Pollution Coalition (April 30, 2019), Accessed August 27, 2020, https://www.plasticpollutioncoalition.org/blog/2019/4/29/six-times-more-plastic-waste-is-burned-in-us-than-is-recycled.

Deyette, Jeff. 2019. “States March Toward 100% Clean Energy - Who’s Next?”. Blog. Union Of Concerned Scientists. https://blog.ucsusa.org/jeff-deyette/states-march-toward-100-clean-energy-whos-next.

Dixon, Eric L., and Kendall Bilbrey. 2015. “Abandoned Mine Land Program: A Policy Analysis For Central Appalachia And The Nation”. Whitesburg, KY: Appalachian Citizens’ Law Center; Knoxville, TN: The Alliance for Appalachia. p. 13. https://appalachiancitizenslaw.files.wordpress.com/2015/07/abandoned-mine-reclamation-policy-analysis.pdf.

Dohmen, Frank, and Barbara Schmid. 2011. “Mining Green Energy: A Coal Region’s Quest to Switch to Renewables - DER SPIEGEL - International.” SPIEGEL International. September 11, 2011. https://www.spiegel.de/international/business/mining-green-energy-a-coal-region-s-quest-to-switch-to-renewables-a-796399.html.

Dowling, Jacqueline A., Katherine Z. Rinaldi, Tyler H. Ruggles, Steven J. Davis, Mengyao Yuan, Fan Tong, Nathan S. Lewis, and Ken Caldeira. 2020. “Role Of Long-Duration Energy Storage In Variable Renewable Electricity Systems”. Joule. doi:10.1016/j.joule.2020.07.007.

E

“Electrify America: U.S. EV Public Charging Network.” n.d. Electrify America. Accessed August 11, 2020. https://www.electrifyamerica.com/.

Electric Power Research Institute. 2014. “The Integrated Grid: Realizing The Full Value Of Central And Distributed Energy Resources”. Palo Alto, CA: Electric Power Research Institute. https://www.epri.com/research/products/000000003002002733.

The Ellen McArthur Foundation. 2012. Towards circular economy- Economic and Business Rationale for an Accelerated Transition, https://www.ellenmacarthurfoundation.org/assets/downloads/TCE_Ellen-MacArthur-Foundation_9-Dec-2015.pdf. (Accessed on January 21, 2019).

Energy Department Announces Energy Efficiency and Conservation Block Grant Program National Evaluation Results.” 2015. Energy.Gov. Accessed August 13, 2020. https://www.energy.gov/eere/articles/energy-department-announces-energy-efficiency-and-conservation-block-grant-program.

“Energy Efficiency Jobs in America 2019 - 2.3 Million Americans Work in EE.” n.d. E2 (blog). Accessed August 13, 2020. https://e2.org/reports/energy-efficiency-jobs-in-america-2019/.

Energy Independence and Security Act of 2007. U.S. Public Law 110-140. 110th Cong., 1st sess., 19 December 2007. https://www.govinfo.gov/content/pkg/PLAW-110publ140/pdf/PLAW-110publ140.pdf.

Energy Policy Act Of 2005. 2005. Vol. 1222. Department of Energy.

Environmental Integrity Project. 2020. “Greenhouse Gases From Oil, Gas, And Petrochemical Production”. Environmental Integrity Project. https://environmentalintegrity.org/wp-content/uploads/2020/01/Greenhouse-Gases-from-Oil-Gas-and-Petrochemical-Production.pdf.

"Establishment-Level Employment Shares: 1979-1992," American Economic Review, 86(2), 290-293.

European Commission. 2020. Circular Economy Action Plan: For A Cleaner and More Competitive Europe, European Commission, 22.

Evans, Melanie. 2017. "Two Months After Maria, Puerto Rico's Health System Struggles to Meet Needs". The Wall Street Journal, 2017. https://www.wsj.com/articles/two-months-after-maria-puerto-ricos-health-system-struggles-to-meet-needs-1510960587

Executive Office of the President of the United States. A Retrospective Assessment of Clean Energy Investments in the Recovery Act. 2016. Washington D.C.: GPO. https://obamawhitehouse.archives.gov/sites/default/files/page/files/20160225_cea_final_clean_energy_report.pdf.

F

FABLE. 2020. Pathways to Sustainable Land-Use and Food Systems: 2020 Report of the FABLE Consortium. Laxenburg and Paris: International Institute for Applied Systems Analysis (IIASA) and Sustainable Development Solutions Network (SDSN).

Farber, Daniel A. 2018. Beyond the Beltway: A Report on State Energy and Climate Policies. Berkeley: Berkeley Law University of California, Center for Law, Energy & the Environment. https://www.law.berkeley.edu/wp-content/uploads/2018/02/Beyond-the-Beltway.pdf.

Farbes, Jamil, Gabe Kwok, and Ryan Jones. 2020. "Low-Carbon Transition Strategies for the Midwest," 36. https://irp-cdn.multiscreensite.com/be6d1d56/files/uploaded/SDSN_Midwest%20Low%20Carbon%20Strategies_FINAL.20200713.pdf

Fargione, Joseph E., et al. 2018. Natural climate solutions for the United States. Science Advances 4(11). doi: 10.1126/sciadv.aat1869.

Federal Reserve Bank of Dallas. 2018. "At The Heart Of Texas: Cities' Industry Clusters Drive Growth". A Special Report Of The Federal Reserve Bank Of Dallas, Second Edition. Dallas, TX: Federal Reserve Bank of Dallas. https://www.dallasfed.org/research/heart/~/media/Documents/research/heart/heartoftexas.pdf.

Fennell and Ganzer. 2020. Literature review of Capital and Operating costs of Cement Plants with CCS. Final report to BEIS.

Fernandes, Orlando, Liana C. L. Portugal, Rita C. S. Alves, Rafaela R. Campagnoli, Izabela Mocaiber, Isabel P. A. David, Fátima C. S. Erthal, Eliane Volchan, Leticia de Oliveira, and Mirtes G. Pereira. 2013. "How You Perceive Threat Determines Your Behavior". Frontiers In Human Neuroscience 7. doi:10.3389/fnhum.2013.00632.

Fiksel, Joseph. 2006. "A Framework for Sustainable Materials Management," The Journal of the Minerals, Metals & Materials Society, (January 2006): 15.

Fischedick, M. et al. 2014. In Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change 739-810.

Fisher, Weston A. Fisher. 2020. Legal pathways to deep decarbonization in the United States, Impact Assessment and Project Appraisal, 38:4, 354-355, DOI: 10.1080/14615517.2020.1719651

Fitzgerald, B., Mazumdar & Lucintel, S. 2018. The new plastics economy - Catalysing action. Ellen MacArthur Foundation, 2018.

Flood, Sarah, Miriam King, Renae Rodgers, Steven Ruggles and J. Robert Warren. 2020. Integrated Public Use Microdata Series, Current Population Survey: Version 7.0 [dataset]. Minneapolis, MN: IPUMS. https://doi.org/10.18128/D030.V7.0

Fofrich, Robert, Dan Tong, Katherine Calvin, Harmen Sytze De Boer, Johannes Emmerling, Oliver Fricko, Shinichiro Fujimori, Gunnar Luderer, Joeri Rogelj, and Steven J Davis. 2020. “Early Retirement Of Power Plants In Climate Mitigation Scenarios”. Environmental Research Letters 15 (9): 094064. doi:10.1088/1748-9326/ab96d3.

Forrest, Kate E., Brian Tarroja, Li Zhang, Brendan Shaffer, and Scott Samuelsen. 2016. “Charging A Renewable Future: The Impact Of Electric Vehicle Charging Intelligence On Energy Storage Requirements To Meet Renewable Portfolio Standards”. Journal Of Power Sources 336: 63-74. doi:10.1016/j.jpowsour.2016.10.048.

“Fossil Fuels Continue To Account For The Largest Share Of U.S. Energy”. 2019. Eia.Gov. https://www.eia.gov/todayinenergy/detail.php?id=41353.

“Frequently Asked Questions (Faqs) - U.S. Energy Information Administration (EIA)”. 2020. Eia.Gov. https://www.eia.gov/tools/faqs/faq.php?id=75&t=11.

Friedmann, B. Y. S. J., Fan, Z. & Tang, K. E. 2019. Low-Carbon Heat Solutions for Heavy Industry : Sources , Options , and Costs Today.

Fulton, Lew, and Dan Sperling. 2020. “Zero Cost For Zero-Carbon Transportation?”. Blog. UC Davis Institute Of Transportation Studies. https://its.ucdavis.edu/blog-post/zero-cost-for-zero-carbon-transportation/.

Fulton, Lewis, Marshall Miller, Andrew Burke, Qian Wang, and Chris Yang. 2019. Technology and Fuel Transition Scenarios to Low Greenhouse Gas Futures for Cars and Trucks in California. Davis, CA: UC Davis, Institute of Transportation Studies. https://escholarship.org/uc/item/8wn8920p.

Funk, Cary, and Meg Hefferon. 2019. “U.S. Public Views on Climate and Energy.” Pew Research Center Science & Society (blog). November 25, 2019. https://www.pewresearch.org/science/2019/11/25/u-s-public-views-on-climate-and-energy/.

Furst, J. and Howard, A. 2020. “The Moving America Forward Act: If Passed, Will Result In Increased Opportunities For Infrastructure Work And Contracting With The Federal Government”. 2020. JD Supra. https://www.jdsupra.com/legalnews/the-moving-america-forward-act-if-66813/.

G

"Gainesville Feed In Tariff". 2020. Energy Democracy For All. https://energydemocracy.centerforsocialinclusion.org/gainesville-feed-in-tariff/.

Galgóczi, Béla. 2014. "The Long and Winding Road from Black to Green: Decades of Structural Change in the Ruhr Region." International Journal of Labour Research 6 (2): 217.

Gallagher, Kelly Sims, and Laura Diaz Anadon. 2020. DOE Budget Authority for Energy Research, Development, and Demonstration Database. Medford, MA: Fletcher School of Law and Diplomacy, Tufts University; Cambridge, England: Department of Land Economy, Center for Environment, Energy and Natural Resource Governance (C-EENRG), University of Cambridge; Cambridge, MA: Belfer Center for Science and International Affairs, Harvard Kennedy School. https://www.belfercenter.org/publication/database-us-department-energy-doe-budgets-energy-research-development-demonstration-1.

Garcia, Jeannette M., and Megan L. Robertson. 2017. "The Future Of Plastics Recycling". Science 358 (6365): 870-872. doi:10.1126/science.aaq0324.

Garrett-Peltier (2017). "Green versus Brown: Comparing the Employment Impacts of Energy Efficiency, Renewable Energy and Fossil Fuels Using an Input-Output Model," Economic Modeling, pp. 439 – 447.

"GDP (Current US$) - United States". 2020. Data.Worldbank.Org. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=US.

Gerrard, Michael B. 2017. "Legal Pathways for a Massive Increase in Utility-Scale Renewable Generation Capacity," Environmental Law Reporter 47(7). https://climate.law.columbia.edu/sites/default/files/content/pics/homePage/Legal-Pathways-for-a-Massive-Increase-in-Utility-Scale-Renewable-Generation-Capacity.pdf.

Geyer, R. in Taking stock of industrial ecology (eds R. Swift & A. Druckman) (Springer, 2016).

"GHG 1990 Emissions Level & 2020 Limit | California Air Resources Board." n.d. Accessed August 10, 2020. https://ww2.arb.ca.gov/ghg-2020-limit.

"GHG Current California Emission Inventory Data". 2020. Ww2.Arb.Ca.Gov. https://ww2.arb.ca.gov/ghg-inventory-data.

"GHG Protocol For Cities | Greenhouse Gas Protocol". 2020. Ghgprotocol.Org. https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities.

Gielen, D., 1999. Materialising Dematerialisation: Integrated Energy And Materials Systems Engineering For Greenhouse Gas Emission Mitigation. Ph.D. Delft University of Technology.

Gielen, Dolf, Deger Saygin, Emanuele Taibi, and Jean−Pierre Birat. 2020. "Renewables−Based Decarbonization And Relocation Of Iron And Steel Making: A Case Study". Journal Of Industrial Ecology. doi:10.1111/jiec.12997.

Gimon, E., M. O'Boyle, C. Clack, and S. McKee. 2019. The Coal Cost Crossover: Economic Viability of Existing Coal Compared to New Local Wind and Solar Resources. San Francisco: Energy Innovation; Boulder, CO: Vibrant Clean Energy.

Glaeser, Edward L., and Matthew E. Kahn. 2008. "The Greenness Of Cities: Carbon Dioxide Emissions And Urban Development". Cambridge, MA: Harvard Kennedy School Taubman Center for State and Local Government. https://www.hks.harvard.edu/sites/default/files/centers/taubman/files/glaeser_08_greencities.pdf.

Global Cement Directory. 2020. Epsom, UK: Pro Publications.

The Green Guides – Statement of Basis and Purpose. Federal Trade Commission (FTC). Accessed August 14, 2020. https://www.ftc.gov/sites/default/files/attachments/press-releases/ftc-issues-revised-green-guides/greenguidesstatement.pdf.

Greenberg, Michael, Karen Lowrie, Henry Mayer, K. Tyler Miller, and Laura Solitare. 2001. The Environmentalist 21 (2): 129-143. doi:10.1023/a:1010684411938..

Greenley, Heather L. 2019. "Department Of Defense Energy Management: Background And Issues For Congress". CRS Report 45832. Washington D.C.: Congressional Research Service.

Gross Output Of All Industries. 2020. Fred.Stlouisfed.Org. https://fred.stlouisfed.org/series/GOAI.

Grubert, Emily. 2020. "At Scale, Renewable Natural Gas Systems Could Be Climate Intensive: The Influence Of Methane Feedstock And Leakage Rates". Environmental Research Letters 15 (8): 084041. doi:10.1088/1748-9326/ab9335.

Guran, S. 2019. "Options to feed plastic waste back into the manufacturing industry to achieve circular carbon economy" AIMS Environmental Science, 6(5): 341-355. DOI: 10.3934/environsci.2019.5.34

H

Hannon, Jonathon, & Atiq U. Zaman. 2018. "Exploring the phenomenon of zero waste and future cities', Urban Science, 2, 90, 3-26, doi:10.3390/urbansci2030090.

Hansen, Chris, Morgan D. Bazilian, and Kenneth B. Medlock. 2019. "Energy Transitions And Local Action: The Case Of Colorado's Coal Transition." August 21, 2019. https://www.forbes.com/sites/thebakersinstitute/2019/08/21/energy-transitions-and-local-action-the-case-of-colorados-coal-transition/#780c41d03f23.

Hansen, J., et al. 2017. Young people's burden: Requirement of negative CO2 emissions. Earth Syst. Dynam., 8, 577-616, doi:10.5194/esd-8-577-2017.

Hasanbeigi, A., Arens, M. & Price, L. 2014. "Alternative emerging ironmaking technologies for energy-efficiency and carbon dioxide emissions reduction: a technical review". Renewable and Sustainable Energy Reviews 33, 645-658.

Hatchadorian, R. et al. 2019. Carbon Free Boston: Buildings Technical Report. Boston: Boston University Institute for Sustainable Energy. http://sites.bu.edu/cfb/technical-reports.

HCRI. n.d. “Hazard and Climate Resilience Institute.” HCRI. Accessed August 11, 2020. https://www.boisestate.edu/research-hcri/.

Hendren, Sam. 2020. “Slow Paced Clean Up Of Cold War Era Atomic Plant Frustrates Piketon Area Residents”. Radio.Wosu.Org. https://radio.wosu.org/post/slow-paced-clean-cold-war-era-atomic-plant-frustrates-piketon-area-residents#stream/0.

Henry, Matthew S., Morgan D. Bazilian, and Chris Markuson. 2020. “Just Transitions: Histories and Futures in a Post-COVID World.” Energy Research & Social Science 68 (October): 101668. https://doi.org/10.1016/j.erss.2020.101668.

Higdon, James. 2017. “The Obama Idea to Save Coal Country.” POLITICO Magazine, March 8, 2017. https://www.politico.com/magazine/story/2017/03/the-obama-administration-idea-to-save-coal-country-214885.

Hills, Thomas P., Mark Sceats, Daniel Rennie, and Paul Fennell. 2017. “LEILAC: Low Cost CO2 Capture For The Cement And Lime Industries”. Energy Procedia 114: 6166-6170. doi:10.1016/j.egypro.2017.03.1753.

Hobson, Kersty. 2016. “Closing the loop or squaring the circle? Locating generative spaces for the circular economy” Progress in Human Geography, 40(1), 88-104. https://doi.org/10.1177%2F0309132514566342.

Hoesly, Rachel M., Steven J. Smith, Leyang Feng, Zbigniew Klimont, Greet Janssens-Maenhout, Tyler Pitkanen, and Jonathan J. Seibert et al. 2018. “Historical (1750–2014) Anthropogenic Emissions Of Reactive Gases And Aerosols From The Community Emissions Data System (CEDS)”. Geoscientific Model Development 11 (1): 369-408. doi:10.5194/gmd-11-369-2018.

“Home | BEopt.” n.d. Accessed August 11, 2020. https://beopt.nrel.gov/home.; “OpenStudio.” n.d. Energy.Gov. Accessed August 11, 2020. https://www.energy.gov/eere/buildings/downloads/openstudio-0.

“Home | REAP”. 2020. Alaskarenewableenergy.Org. https://alaskarenewableenergy.org/.

Hoornweg, Daniel, Perinaz Bhada-Tata, and Chris Kennedy. 2013. “Environment: Waste Production Must Peak This Century”. Nature 502 (7473): 615-617. doi:10.1038/502615a.

“House Democrats Fall for Fossil Fuel Industry Greenwashing Scheme, ‘Chemical Recycling’ in Climate Plan,” Global Alliance for Incinerator Alternatives (GAIA), Accessed August 5, 2020, https://www.no-burn.org/house-democrats-fall-for-fossil-fuel-industry-greenwashing-scheme-chemical-recycling-in-climate-plan/.

House Select Committee On The Climate Crisis. 2020. Solving the Climate Crisis: The Congressional Action Plan for a Clean Energy Economy and a Healthy, Resilient, and Just America. 116th Cong., 2d sess. https://climatecrisis.house.gov/sites/climatecrisis.house.gov/files/Climate%20Crisis%20Action%20Plan.pdf.

Hughes, Erik-Logan. 2018. "Where Did the Green Jobs Go? : A Case Study of the Boston Metropolitan Region." Thesis, Massachusetts Institute of Technology. https://dspace.mit.edu/handle/1721.1/117827.

I

IEA. 2018. The Future of Petrochemicals : Towards more sustainable plastics and fertilisers. 1-66. Paris, France: International Energy Agency.

IEA. 2018. Technology Roadmap - Low-Carbon Transition in the Cement Industry. Paris, France: International Energy Agency. https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry.

IEA. 2019. The Future of Hydrogen. Paris, France: International Energy Agency.

IEA. 2019. Material efficiency in clean energy transitions. Paris, France: IEA. https://www.iea.org/reports/material-efficiency-in-clean-energy-transitions.

IEA. 2019. World energy balances. IEA World Energy Statistics and Balances 2018, doi:10.1787/data-00510-en.

IEA. 2019. World energy statistics. Paris, France: IEA. https://www.iea.org/reports/world-energy-statistics-2019.

"Impact Of Plastics Recycling On The Future Of Energy Transition". 2020. IHS Markit. https://ihsmarkit.com/research-analysis/impact-of-plastics-recycling-on-future-energy-transition.html?ite=988080&ito=1274&itq=13593fbb-6058-4a35-a1b3-ca38a2f9dab2&itx%5Bidio%5D=24716138.

IMPAQ International. 2012. "Green Jobs and Healthcare Implementation Study: Final Report." https://impaqint.com/work/project-reports/green-jobs-and-healthcare-implementation-study-final-report.

IMPLAN Group, LLC. 2019. "IMPLAN." Huntersville, NC. IMPLAN.com.

In Rosenzweig, C., W. Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, and S. Ali Ibrahim (eds.), Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. New York. 553–582

"Indiana Law Creates Carbon Sequestration Pilot Program," Environmental Law News, accessed July 31, 2020, https://www.indybar.org/index.cfm?pg=EnvironmentalLawNews&blAction=showEntry&blogEntry=8636

"Industry Statistics And Reports | American Public Power Association". 2020. Publicpower.Org. https://www.publicpower.org/public-power/stats-and-facts/industry-statistics-and-reports.

"Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2016". 2020. US EPA. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016.

"Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2018". 2020. US EPA. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018.

"Inventory Of U.S. Greenhouse Gas Emissions And Sinks | US EPA". 2020. US EPA. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC. 2018. Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways.

IRENA. 2014. Renewable Energy in Manufacturing, a Technology Roadmap for REmap 2030.

Iron And Steel Statistics And Information. 2020. Usgs.Gov. https://www.usgs.gov/centers/nmic/iron-and-steel-statistics-and-information?qt-science_support_page_related_con=0#qt-science_support_page_related_con.

J

Jaffe, Mark. 2020. "Environmentalists Worry Colorado Will See a Surge of Abandoned Oil and Gas Wells as Industry Tanks." The Colorado Sun, May 12, 2020. https://coloradosun.com/2020/05/12/fracking-oil-price-colorado-abandoned-wells/.

Jenkins, Jesse D., Max Luke, and Samuel Thernstrom. 2018. "Getting To Zero Carbon Emissions In The Electric Power Sector". Joule 2 (12): 2498-2510. doi:10.1016/j.joule.2018.11.013.

Jenn, Alan, Jae Hyun Lee, Scott Hardman, Gil Tal. 2019. An Examination of the Impact that Electric Vehicle Incentives Have on Consumer Purchase Decisions Over Time. Davis, CA: University of California Institute of Transportation Studies. https://doi.org/10.7922/G2S46Q51.

Job Relocation Expenses". 2020. Money-Zine.Com. https://www.money-zine.com/career-development/finding-a-job/job-relocation-expenses/.

John Dunham and Associates, Inc. 2018. "The Economic Impact Of The American Iron And Steel Industry". American Iron and Steel institute. https://www.steel.org/-/media/doc/steel/policy/reports/economicimpact/dunham-methodology.ashx?la=en&hash=143B7B196B37FEFED363FFC013E60E90D1ED9780.

Jones, Christopher M., and Daniel M. Kammen. "Spatial Distribution of U.S. Household Carbon Footprints Reveals Suburbanization Undermines Greenhouse Gas Benefits of Urban Population Density". Environ. Sci. Technol., 2013, dx.doi.org/10.1021/es4034364

K

Kanter, David R., Fabio Bartolini, Susanna Kugelberg, Adrian Leip, Oene Oenema and Aimable Uwizeye. 2019. Nitrogen pollution policy beyond the farm. Nature Food: 1-6.

Kassakian, J.G., R. Schmalensee, G. Desgroseilliers, T.D. Heidel, K. Afridi, A.M. Farid, J.M. Grochow, W.W. Hogan, H.D. Jacoby, J.L. Kirtley, H.G. Michaels, I. Perez-Arriaga, D.J. Perreault, N.L. Rose, G.L. Wilson. 2011. The Future of the Electric Grid: An Interdisciplinary MIT Study. Boston, MA: Massachusetts Institute of Technology, MIT Energy Initiative. http://energy.mit.edu/wp-content/uploads/2011/12/MITEI-The-Future-of-the-Electric-Grid.pdf.

Kavlak, Goksin, James McNerney, and Jessika E. Trancik. 2018. "Evaluating The Causes Of Cost Reduction In Photovoltaic Modules". Energy Policy123: 700-710. doi:10.1016/j.enpol.2018.08.015.

Keith, D. W., Holmes, G., St., A., D. & Heidel, K. 2018. "A process for capturing CO2 from the atmosphere. Joule 2, 1573–1594".

Kendall, Alissa, Hanjiro Ambrose, Erik Maroney. 2019. Brief: Life Cycle-Based Policies Are Required to Achieve Emissions Goals from Light-Duty Vehicles. Davis, CA: Institute of Transportation Studies, University of California, Davis. https://doi.org/10.7922/G2FB515B.

Kilhelmsson, Bodil; Kollberg, Claes; Larsson, Johan; Eriksson, Jan; Magnus, E. 2018. A Feasibility Study Evaluating Ways to Reach Sustainable Cement Production via the Use of Electricity. Cementa and Vattenfall.

Kiss, Benedek, Enikő Kácsor, and Zsuzsa Szalay. 2020. "Environmental Assessment Of Future Electricity Mix – Linking An Hourly Economic Model With LCA". Journal Of Cleaner Production 264: 121536. doi:10.1016/j.jclepro.2020.121536.

Kok, L., Wurpel, G., & Ten Wolde, A. 2013. "Unleashing the power of the circular economy", IMSA and Circle Economy, Amsterdam, Netherlands. https://mvonederland.nl/system/files/media/unleashing_the_power_of_the_circular_economy-circle_economy.pdf (accessed on 1/21/2019)

Kollmeyer, C. 2018. "Trade Union Decline, Deindustrialization, and Rising Income Inequality in the United States, 1947 to 2015". Research in Social Stratification and Mobility 57, 1–10, doi:10.1016/j.rssm.2018.07.002.

Komanoff, Charles, Ralph Cavanagh and Peter Miller. 2019. California Stars: Lighting the Way to a Clean Energy Future. New York: Natural Resources Defense Council. https://www.nrdc.org/sites/default/files/california-stars-clean-energy-future-report.pdf.

Kong A, Odoms-Young AM, Schiffer LA, Kim Y, Berbaum ML, Porter SJ, Blumstein LB, Bess SL, Fitzgibbon ML. 2014. The 18-month impact of Special Supplemental Nutrition Program for Women, Infants, and Children food package revisions on diets of recipient families. Am J Prev Med. 46:543–551. doi: 10.1016/j.amepre.2014.01.021

Kurani, Kenneth S. 2019. The State of Electric Vehicle Markets, 2017: Growth Faces an Attention Gap. Davis, CA: National Center for Sustainable Transportation, Institute of Transportation Studies, UC Davis. https://doi.org/10.7922/G2D50K51.

Kwok, Gabe, Jamil Farbes, and Ryan Jones. 2020. "Low-Carbon Transition Strategies for the Southeast," 38. https://irp-cdn.multiscreensite.com/be6d1d56/files/uploaded/SDSN_Southeast%20Report_FINAL.pdf

L

Lahti, Tom, Joakim Wincent, & Vinit Parida. 2018. "A definition and theoretical review of circular economy, value creation, and sustainable business models: where are we now and where should research move in the future?" Sustainability, 10, 2799-2817, doi:10.3390/su10082799.

LaMondia, Jeffrey J., Daniel J. Fagnant, Hongyang Qu, Jackson Barrett, and Kara Kockelman. "Shifts in Long-Distance Travel Mode Due to Automated Vehicles: Statewide Mode-Shift Simulation Experiment and Travel Survey Analysis', Transportation Research Record, 2566.1 (2016), 1–11 <https://doi.org/10.3141/2566-01>.

"Land Of Waste: American Landfills And Waste Production". 2020. Saveonenergy.Com. https://www.saveonenergy.com/land-of-waste/.

"Land Ports of Entry Overview." 2018. Accessed August 13, 2020. https://www.gsa.gov/real-estate/gsa-properties/land-ports-of-entry-overview.

Landau-Wells, Marika, and Rebecca Saxe. 2020. "Political Preferences And Threat Perception: Opportunities For Neuroimaging And Developmental Research". Current Opinion In Behavioral Sciences 34: 58-63. doi:10.1016/j.cobeha.2019.12.002.

Lazarus, Jessica, Jean Carpentier Pourquier, Frank Feng, Henry Hammel, and Susan Shaheen. 2020. "Micromobility Evolution And Expansion: Understanding How Docked And Dockless Bikesharing Models Complement And Compete – A Case Study Of San Francisco". Journal Of Transport Geography 84: 102620. doi:10.1016/j.jtrangeo.2019.102620.

Lechtenböhmer, S., Nilsson, L. J., Ahman, M. & Schneider, C. 2016. "Decarbonising the energy intensive basic materials industry through electrification – implications for future EU electricity demand". Energy 115, 1623–1631.

Leeson, D., Mac Dowell, N., Shah, N., Petit, C. & Fennell, P. 2017. "A Techno-Economic Analysis and Systematic Review of Carbon Capture and Storage (CCS) Applied to the Iron and Steel, Cement, Oil Refining and Pulp and Paper Industries, as Well as Other High Purity Sources". International Journal of Greenhouse Gas Control 61, 71–84.

Legal Pathways to Deep Decarbonization in the United States: Summary and Key Recommendations, edited by Michael B. Gerrard and John C. Dernbach, 20-22, Washington, DC: Environmental Law Institute, November 2018, 20.

Lehner, Peter, and Nathan A. Rosenberg. 2017. "Legal Pathways to Carbon-Neutral Agriculture." Envtl. L. Rep. News & Analysis 47: 10845.

Legislators Introduce Plastic Waste Reduction, Recycling Act". 2020. Recycling Today. https://www.recyclingtoday.com/article/haley-stevens-introduces-plastic-waste-reduction-recycling-act/

Leonard, Jonathan. 1984, "Employment and Occupational Advance Under Affirmative Action," Review of Economics and Statistics, 66(3).

Leonard, Jonathan. 1984. "The Impact of Affirmative Action on Employment," Journal of Labor Economics, 3(3), 439-463.

Leseur, Alexia, Vivian Dépoues, Cécile Bordier, Cynthia Rosenzweig, Chantal Pacteau, Luc Abbadie, and Somayya Ali Ibrahim. 2020. "LPAA Focus On Cities & Regions Climate Action, 2015 December The 8Th". Paris: Institute for Climate Economics; New York: Urban Climate Change Research Network. Accessed October 16. https://unfccc.int/sites/default/files/scientific-brief-cop21-lpaa.pdf.

Leskinen, Pekka, Giuseppe Cardellini, Sara González-García, Elias Hurmekoski, Roger Sathre, Jyri Seppälä, Carolyn Smyth, Tobias Stern and Pieter Johannes Verkerk. 2018. Substitution effects of wood-based products in climate change mitigation. From Science to Policy 7. European Forest Institute.

"Less Waste, Higher Efficiency, Better Savings," US Green Building Council (USGBC), Accessed August 14, 2020, https://true.gbci.org.

Levi, P. and Cullen, J., 2018. Mapping Global Flows of Chemicals: From Fossil Fuel Feedstocks to Chemical Products. Environmental Science & Technology, 52(4), pp.1725-1734.

Liu, C. et al. 2016. Food waste in Japan: Trends, current practices and key challenges. J Clean Prod 133, 557-564. doi:10.1016/j.jclepro.2016.06.026 (2016).

Lonergan, Tim, and Gary Resnick, "Why Two South Florida Cities Are Partnering to Face Climate Change | Opinion," South Florida SunSentinel, August 24, 2018, https://www.sun-sentinel.com/opinion/fl-op-viewpoint-cities-climate-change-partnership-20180823-story.html.

Lopez-Cantu, Tania, and Constantine Samaras. 2018. "Temporal And Spatial Evaluation Of Stormwater Engineering Standards Reveals Risks And Priorities Across The United States". Environmental Research Letters 13 (7): 074006. doi:10.1088/1748-9326/aac696.

Lovins, Amory B., Diana Ürge-Vorsatz, Luis Mundaca, Daniel M Kammen & Jacob W Glassman. 2019. "Recalibrating climate prospects". Environ. Res. Lett. 14, 120201. doi:10.1088/1748-9326/ab55ab.

Lowrie, Karen, Michael Greenberg, and Michael Frisch. 1999. "Economic Fallout." Forum for Applied Research and Public Policy; Knoxville 14 (2): 119–25.

Luna, P. D. et al. 2019. "What would it take for renewably powered electrosynthesis to displace petrochemical processes?" Science 364, 350.

Lynch, A., A. LoPresti,, and C. Fox. 2019. The 2019 US Cities Sustainable Development Report. New York: Sustainable Development Solutions Network (SDSN). https://www.sustainabledevelopment.report/reports/2019-us-cities-sustainable-development-report/.

Lynch, John, Kirshenberg, Seth. 2000. Economic Transition by the Energy-Impacted Communities. Sacramento: California Energy Commission.

M

Macknick, Jordan, Courtney Lee, Gail Mosey, and Jenny Melius. 2013. "Solar Development on Contaminated and Disturbed Lands." NREL/TP--6A20-58485, 1260337. https://doi.org/10.2172/1260337.

Mai, Trieu, Paige Jadun, Jeffrey Logan, Colin McMillan, Matteo Muratori, Daniel Steinberg, Laura Vimmerstedt, Ryan Jones, Benjamin Haley, and Brent Nelson. 2018. Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71500. https://www.nrel.gov/docs/fy18osti/71500.pdf.

Maier, H.R., J.H.A. Guillaume, H. van Delden, G.A. Riddell, M. Haasnoot, and J.H. Kwakkel. 2016. "An Uncertain Future, Deep Uncertainty, Scenarios, Robustness And Adaptation: How Do They Fit Together?". Environmental Modelling & Software 81: 154-164. doi:10.1016/j.envsoft.2016.03.014.

Majcher, Kristen. 2015. "What Happened To Green Concrete?". MIT Technology Review. https://www.technologyreview.com/2015/03/19/73210/what-happened-to-green-concrete/.

Marcotullio, P. J., Sarzynski, A. Sperling, J., Chavez, A., Estiri, H., Pathak, M., and Zimmerman, R. (2018). Energy transformation in cities. In Rosenzweig, C., W. Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, and S. Ali Ibrahim (eds.), Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. New York. 443–490

Marinova, S., Deetman, S., van der Voet, E. and Daioglou, V., 2020. Global construction materials database and stock analysis of residential buildings between 1970-2050. Journal of Cleaner Production, 247, p.119146.

Material Economics. 2019. Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry. Cambridge, England: University of Cambridge Institute for Sustainable Leadership.

Mattauch, Linus, Felix Creutzig, and Ottmar Edenhofer. 2015. Avoiding Carbon Lock-In." Economic Modelling 50 (November 2015): 49-63. https://doi.org/10.1016/j.econmod.2015.06.002.

McConnell, Virginia, and Benjamin Leard. 2019. "The California ZEV Program: A Long And Bumpy Road, But Finally Some Success". Resources, December 2, 2019. https://www.resourcesmag.org/common-resources/california-zev-program-long-and-bumpy-road-finally-some-success/.

McDonough, William, and Michael Braungart, The Upcycle: Beyond Sustainability—Designing for Abundance, New York: Melcher Media, North Point Press, 2013, 7.

McDonough, William, and Michael Braungart. 2002. Cradle to Cradle: Remaking the Way We Make Things. North Point Press: New York.

McMillan, C. et al. 2016. "Generation and Use of Thermal Energy in the U. S. Industrial Sector and Opportunities to Reduce its Carbon Emissions".

McPoland, Fran. "Dirty MRFs Must Go." Reprinted from Resource Recycling. April 2015. https://www.georgiarecycles.org/assets/Uploads/Presentations/2015-Semi-Meeting/2015-RRArticle-McPoland.pdf.

Mehling, Michael A., Harro van Asselt, Kasturi Das, Susanne Droege, and Cleo Verkuijl. 2019. "Designing Border Carbon Adjustments For Enhanced Climate Action". American Journal Of International Law 113 (3): 433-481. doi:10.1017/ajil.2019.22.

Meijden, C. M., van der Rabou, L. P. L. M., Vreugdenhil, B. J. & Smit, R. 2011. "Large scale production of bio methane from wood". The International Gas Union Research Conference IGRC.

"Members List". 2020. Eei.Org. https://www.eei.org/about/members/uselectriccompanies/Documents/memberlist_print.pdf.

MetroNews Staff. 2019. "Boone County Commission Asking for 20 Percent Spending Cut." MetroNews, August 28, 2019. https://wvmetronews.com/2019/08/28/boone-county-commission-asking-for-20-percent-spending-cut/.

Michelini, Gustavo, Renato N. Moraes, Renata N. Cunha, Janaina M. H. Costa, Aldo R. Ometto. 2017. "From linear to circular economy: PSS conducting the transition" Procedia CIRP, 2-6 doi: 10.1016/j.procir.2017.03.012.

Mineral Products Association, Cinar Ltd., and VDZ gGmbH. 2019. "Options For Switching UK Cement Production Sites To Near Zero CO2 Emission Fuel: Technical And Financial Feasibility.". SBRI Competition. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866365/Phase_2_-_MPA_-_Cement_Production_Fuel_Switching.pdf.

"Mission Statement," Project Drawdown, Accessed August 14, 2020, https://drawdown.org/.

Monge, Juan J., Henry L. Bryant, Jianbang Gan, and James W. Richardson. 2016. Land use and equilibrium implications of a forest-based carbon sequestration policy in the United States. Ecological Economics 127, 102-120.

"Monthly Energy Review September 2020 203". 2020. U. S. Energy Information Administration. https://www.eia.gov/totalenergy/data/monthly/pdf/sec11_9.pdf/.

Moran, Daniel, et al. 2018. Environ. Res. Lett. 13 064041

Morfeldt, J., Nijs, W. & Silveira, S. 2015. "The impact of climate targets on future steel production - an analysis based on a global energy system model". Journal of Cleaner Production 103, 469-482.

"Multi-Resolution Land Characteristics (MRLC) Consortium." Multi-Resolution Land Characteristics (MRLC) Consortium. Accessed August 19, 2020. https://www.mrlc.gov.

Mundaca, Luis, and Jessika Luth Richter. 2015. "Assessing 'Green Energy Economy' Stimulus Packages: Evidence From The U.S. Programs Targeting Renewable Energy". Renewable And Sustainable Energy Reviews 42: 1174-1186. doi:10.1016/j.rser.2014.10.060.

Murray, Brian. C. et al. 2005. Greenhouse gas mitigation potential in U.S. forestry and agriculture. Washington, D.C.: U.S. Environmental Protection Agency.

N

Nadel, S., and A. Hinge. 2020. Mandatory Building Performance Standards: A Key Policy for Achieving Climate Goals. Washington D.C.: American Council for an Energy-Efficient Economy. https://www.aceee.org/sites/default/files/pdfs/buildings_standards_6.22.2020_0.pdf.

"NAHB: Cost Of Constructing A Home". 2020. Nahbclassic.Org. https://www.nahbclassic.org/generic.aspx?genericContentID=260013#:~:text=On%20average%20in%20the%202017,to%20marketing%20costs%2C%20leaving%2010.7.

Naqi, A. & Jang, J. G. 2019. "Recent Progress in Green Cement Technology Utilizing Low-Carbon Emission Fuels and Raw Materials: A Review". Sustainability 11, 1-18.

NASA."How to Find and Visualize Nitrogen Dioxide Satellite Data | Earthdata." Earthdata NASA. March 26, 2020. Accessed August 11, 2020. https://earthdata.nasa.gov/learn/articles/feature-articles/health-and-air-quality-articles/find-no2-data/.

NASEO and EFI. 2019. "The 2019 U.S. Energy And Employment Report". Arlington, VA: National Association of State Energy Officials; Washington D.C.: Energy Futures Initiative. http://www.naseo.org/data/sites/1/documents/publications/USEER-2019-US-Energy-Employment-Report1.pdf.

National Academies of Sciences, Engineering, and Medicine. 2017. Review of WIC food packages: improving balance and choice: final report. National Academies Press. https://doi.org/10.17226/23655.

"National Overview: Facts And Figures On Materials, Wastes And Recycling". 2020. US EPA. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials.

National Renewable Energy Laboratory (NREL). 2018. Celebrating 10 Years of Success: Hawaii Clean Energy Initiative. Golden, Colorado: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy18osti/70709.pdf.

"National Western Center". 2020. National Western Center. https://nationalwesterncenter.com/.

"Natural Gas Dry Production (Annual Supply & Disposition)". 2020. Eia.Gov. https://www.eia.gov/dnav/ng/ng_sum_snd_a_EPG0_FPD_Mmcf_a.htm.https://www.eia.gov/dnav/ng/ng_sum_snd_a_EPG0_FPD_Mmcf_a.htm

Nealer, Rachael, David Reichmuth, and Don Anair. 2015. "Cleaner Cars From Cradle To Grave". Union of Concerned Scientists. https://www.ucsusa.org/sites/default/files/attach/2015/11/Cleaner-Cars-from-Cradle-to-Grave-full-report.pdf.

Nelson, Austin, Adarsh Nagarajan, Kumar Prabakar, Vahan Gevorgian, Blake Lundstrom, Shaili Nepal, Anderson Hoke, Marc Asano, Reid Ueda, Jon Shindo, Kandice Kubojiri, Riley Ceria and Earle Ifuku. 2016. Hawaiian Electric Advanced Inverter Grid Support Function Laboratory Validation and Analysis. Golden, Colorado: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy17osti/67485.pdf.

"New Buildings: Embodied Carbon". 2020. Architecture2030.Org. https://architecture2030.org/new-buildings-embodied/.

The New Plastics Economy – Rethinking the future of plastics, http://www3.weforum.org/docs/WEF_The_New_Plastics_Economy.

"New York State Announces Passage of Accelerated Renewable Energy Growth and Community Benefit Act as Part of 2020-2021 Enacted State Budget - NYSERDA." April 3, 2020. Accessed August 18, 2020. https://www.nyserda.ny.gov/About/Newsroom/2020-Announcements/2020-04-03-NEW-YORK-STATE-ANNOUNCES-PASSAGE-OF-ACCELERATED-RENEWABLE-ENERGY-GROWTH-AND-COMMUNITY-BENEFIT-ACT-AS-PART-OF-2020-2021-ENACTED-STATE-BUDGET.

Neuhoff, K. et al. 2014. "Carbon Control and Competitiveness Post 2020: the Steel Report".

New York State Assembly, Bill No. S2992B, "New York state climate leadership and community protection act," https://legislation.nysenate.gov/pdf/bills/2019/s2992b.

"NRECA Fact Sheet". 2020. NRECA. https://www.electric.coop/wp-content/uploads/2020/05/NRECA-Fact-Sheet-%205-2020-1.pdf.

NREL.gov. 2020. NREL Evaluates Advanced Solar Inverter Performance For Hawaiian Electric Companies. https://www.nrel.gov/workingwithus/partners/partnerships-heco-solar-inverter.html.

N.Y. Senate. 2020. Accelerated Renewable Energy Growth and Community Benefit Act. 2nd sess., S7508B. https://www.nysenate.gov/legislation/bills/2019/s7508/amendment/b.

O

The Obama White House. 2015. "FACT SHEET: The Partnerships For Opportunity And Workforce And Economic Revitalization (POWER) Initiative". https://obamawhitehouse.archives.gov/the-press-office/2015/03/27/fact-sheet-partnerships-opportunity-and-workforce-and-economic-revitaliz.

Oda, Tomohiro, Rostyslav Bun, Vitaliy Kinakh, Petro Topylko, Mariia Halushchak, Gregg Marland, and Thomas Lauvaux et al. 2019. "Errors And Uncertainties In A Gridded Carbon Dioxide Emissions Inventory". Mitigation And Adaptation Strategies For Global Change 24 (6): 1007-1050. doi:10.1007/s11027-019-09877-2.

Odoms-Young AM, Kong A, Schiffer LA, Porter SJ, Blumstein L, Bess S, Berbaum ML, Fitzgibbon ML. 2014. Evaluating the initial impact of the revised Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) food packages on dietary intake and home food availability in African-American and Hispanic families. Public Health Nutr. 17:83–93. doi: 10.1017/S1368980013000761.

Office of Surface Mining Reclamation and Enforcement (OSMRE). n.d. "Reclaiming Abandoned Mine Lands." Accessed September 6, 2020. https://www.osmre.gov/programs/aml.shtm.

"Offshore Wind Accelerator (OWA)". 2020. Carbon Trust. https://www.carbontrust.com/our-projects/offshore-wind-accelerator-owa.

Olade, Mark. 2020. "Support Grows for Taxpayer-Funded Oil Well Cleanup as an Economic Stimulus." Energy News Network, June 23, 2020. https://energynews.us/2020/06/23/national/support-grows-for-taxpayer-funded-oil-well-cleanup-as-an-economic-stimulus/.

Olsho LE, Klerman JA, Wilde PE, Bartlett S. Financial incentives increase fruit and vegetable intake among Supplemental Nutrition Assistance Program participants: a randomized controlled trial of the USDA Healthy Incentives Pilot. Am J Clin Nutr. 2016;104:423–435. doi: 10.3945/ajcn.115.129320.

"One-Screen Data Search". 2020. Data.Bls.Gov. https://data.bls.gov/PDQWeb/en.

"OSMRE Reclaiming Abandoned Mine Lands". 2020. Osmre.Gov. https://www.osmre.gov/programs/aml.shtm.

Oteng-Ababio, M., Annepu, R., Bourtsalas, A., Intharathirat, R., and Charoenkit, S. 2018. Urban solid waste management.

"Our Mission is to Accelerate the Transition to a Circular Economy," Ellen MacArthur Foundation, Accessed July 14, 2020, https://www.ellenmacarthurfoundation.org.

"Overview Of Greenhouse Gases". 2020. US Environmental Protection Agency. https://www.epa.gov/ghgemissions/overview-greenhouse-gases.

P

Papargyropoulou, E., Lozano, R., Steinberger, J. K., Wright, N. & bin Ujang, Z. 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. J Clean Prod 76, 106-115. doi:10.1016/j.jclepro.2014.04.020

"Parliament Seals Ban on Throwaway Plastics by 2021." European Parliament (March 27, 2019). Accessed August 28, 2020. https://www.europarl.europa.eu/news/en/press-room/20190321IPR32111/parliament-seals-ban-on-throwaway-plastics-by-2021.

Pauliuk, S., Milford, R. L., Müller, D. B. & Allwood, J. M. 2013."The Steel Scrap Age". Environmental Science & Technology 47.

Payne GH, Wethington H, Olsho L, Jernigan J, Farris R, Walker DK. Implementing a farmers' market incentive program: perspectives on the New York City Health Bucks Program. Prev Chronic Dis. 2013;10:E145. doi: 10.5888/pcd10.120285.

Pendergrass, John, Mike Italiano, John A. "Skip" Laitner, Elizabeth Richardson, and Meagan Weiland. 2018. "American Waste: Paradigm Shifting Toward A Circular Economy". Presentation, Washington D.C.

Perlman, David. 2018. "Boost for Renewables Transmission: DOE Transmission Siting Authority Upheld" Energy Legal Blog. https://www.energylegalblog.com/blog/2018/01/17/boost-renewables-transmission-doe-transmission-siting-authority-upheld.

Philibert, C. 2017. Producing ammonia and fertilizers: new opportunities from renewables. Paris, France: International Energy Agency.

Philips, Peter. 2014. "Environmental and Economic Benefits of Building Solar in California: Quality Careers -- Cleaner Lives," 52.

Phillips, Amber. 2019. "Why Puerto Rico's Governor Is Resigning". The Washington Post, 2019. https://www.washingtonpost.com/politics/2019/07/19/why-puerto-rico-is-crisis/

Piketty, M.-G., Wichert, M., Fallot, A. & Aimola, L. 2009. "Assessing land availability to produce biomass for energy: The case of Brazilian charcoal for steel making". Biomass and Bioenergy 33, 180-190.

"Plan for Climate Change and Environmental Justice | Joe Biden." 2020. Joe Biden for President: Official Campaign Website. Accessed August 13, 2020. https://joebiden.com/climate-plan/.

"A Plan To Strengthen Puerto Rico's Electric Grid". 2020. Environmental Defense Fund. Accessed October 16. https://www.edf.org/sites/default/files/content/PuertoRicoFactSheet01.29.20.pdf.

"Planet Blue". 2020. Planet Blue. http://sustainability.umich.edu/.

"Plastic and Climate: The Hidden Costs of a Plastic Planet," Center for International Environmental Law (2019), Accessed August 14, 2020, https://www.ciel.org/plasticandclimate/.

Pollin, Robert. 2015. Greening The Global Economy. Cambridge, MA: The MIT Press.

Pollin, Robert. 2019. "Green Economics And Decent Work: A Viable Unified Framework". Development And Change 51 (2): 711-726. doi:10.1111/dech.12559.

Pollin, Robert, and Brian Callaci. 2018. "The Economics Of Just Transition: A Framework For Supporting Fossil Fuel–Dependent Workers And Communities In The United States". Labor Studies Journal 44 (2): 93-138. doi:10.1177/0160449x18787051.

Pollin, Robert, and Brian Callaci. 2019. "The Economics of Just Transition: A Framework for Supporting Fossil Fuel–Dependent Workers and Communities in the United States." Labor Studies Journal 44 (2): 93–138. https://doi.org/10.1177/0160449X18787051.

Pollin, Robert, Heidi Garrett-Peltier, James Heintz, and Shouvik Chakraborty. 2015. "Global Green Growth: Clean Energy Industrial Investments and Expanding Job Opportunities." https://www.peri.umass.edu/publication/item/689-global-green-growth-clean-energy-industrial-investments-and-expanding-job-opportunities.

Pollin, Robert, Jeannette Wicks-Lim, Shouvik Chakraborty, and Tyler Hansen. 2019. "A Green Growth Program for Colorado." https://www.peri.umass.edu/publication/item/1168-a-green-growth-program-for-colorado.

Pollution and Health Impacts of Waste-to-Energy Incineration, Fact Sheet. 2019. Global Alliance for Incinerator Alternatives (GAIA), Accessed August 5, 2020, www.no-burn.org.

"Population, Total - United States | Data". 2020. Data.Worldbank.Org. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=US.

Portman, Senator Rob. 2016. "Senate Passes Portman Priority to Fund Cleanup of Portsmouth Gaseous Diffusion Plant." May 12, 2016. https://www.portman.senate.gov/newsroom/press-releases/senate-passes-portman-priority-fund-cleanup-portsmouth-gaseous-diffusion.

Powers, Laura, and Ann Markusen. 1999. "A Just Transition? Lessons From Defense Worker Adjustment In The 1990S". Washington D.C.: Economic Policy Institute. https://www.epi.org/publication/technicalpapers_justtransition/.

President's Commission on Carbon Neutrality. 2020. "Spring 2020 Interim Progress Report". Ann Arbor, Michigan: University of Michigan. http://sustainability.umich.edu/media/files/U-M-Carbon-Neutrality-Spring-2020-Report.pdf.

Proske, T., Hainer, S., Rezvani, M. and Graubner, C., 2013. Eco-friendly concretes with reduced water and cement contents — Mix design principles and laboratory tests. Cement and Concrete Research, 51, pp.38-46.

Protecting American Communities. In Progress Manuscript, August.

"Puerto Rico Monthly Electricity Sales By Sector". 2020. https://upload.wikimedia.org/wikipedia/commons/5/55/Puerto_Rico_monthly_electricity_sales_by_sector%2C_January_2016_through_May_2018_%2843165035474%29.png.

Q

Quader, M. A., Ahmed, S., Ghazilla, R. A. R., Ahmed, S. & Dahari, M. 2015. "A comprehensive review on energy efficient CO2 breakthrough technologies for sustainable green iron and steel manufacturing". Renewable and Sustainable Energy Reviews 50, 594-614.

Queiroz et al., 2017. Implementation and Results of Solar Feed-In-Tariff in Gainesville, Florida. Journal of Energy Engineering.

R

Rapoport, Elizabeth, Michele Acuto, and Lenora Grcheva. 2019. Leading Cities: A Global Review of City Leadership. JSTOR Open Access Monographs. UCL Press. https://books.google.com/books?id=xvWNDwAAQBAJ.

Raven, J., Stone, B., Mills, G., Towers, J., Katzschner, L., Leone, M., Gaborit, P., Georgescu, M., and Hariri, M. (2018). Urban planning and design. In Rosenzweig, C., W. Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, and S. Ali Ibrahim (eds.), Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. New York. 139-172

Ray, Douglas. 2019. "Lazard's Levelized Cost of Energy Analysis—Version 13.0," 20. https://www.lazard.com/media/451086/lazards-levelized-cost-of-energy-version-130-vf.pdf.

Reclaiming Appalachia Coalition. 2019. "New 2019 Report – A New Horizon." https://reclaimingappalachia.org/new-2019-report-a-new-horizon/.

Reed, Liza, M. Granger Morgan, Parth Vaishnav, and Daniel Erian Armanios. 2019. "Converting Existing Transmission Corridors to HVDC Is an Overlooked Option for Increasing Transmission Capacity." Proceedings of the National Academy of Sciences 116 (28): 13879. https://doi.org/10.1073/pnas.1905656116.

ReFED. 2018. Proposed Federal Food Waste Policy. http://www.refed.com/tools/food-waste-policy-finder/federal-policy-proposed347federal-food-waste-policy

Reich, Robert B., Doug Ross, and Raymond J. Uhalde. 1994. "Evaluation of the Defense Conversion Adjustment Demonstration: Interim Report on Implementation."

"Remembering FDR's Commencement Speech At Oglethorpe - The Source". 2020. The Source. https://source.oglethorpe.edu/2012/05/22/remembering-fdrs-commencement-speech-at-oglethorpe/.

Renewable Energy Alaska Project (REAP). 2020. "Alaska Network for Energy Education and Employment." March 17, 2020. https://alaskarenewableenergy.org/initiatives/alaska-network-for-energy-education-and-employment/.

"Renewable Juneau". 2020. Renewable Juneau. https://renewablejuneau.org/.

"Residential Building Codes". 2020. BCAP. http://bcapcodes.org/code-status/residential/.

"Restock". 2020. Restock.Nrel.Gov. https://restock.nrel.gov/.

Ritzen, Sofia, & Gunilla Ölundh Sandstrom. 2017. "Barriers to the circular economy-integration of perspectives and domains", Procedia CIRP 64, 7-12. Doi:10.1016/j.procir.2017.03.005.

Robles, Frances and Jess Bidgood. 2017. "Three Months After Maria, Roughly Half of Puerto Ricans Still Without Power". The New York Times, 2017. https://www.nytimes.com/2017/12/29/us/puerto-rico-power-outage.html

Robles, Frances, and Jugal K. Patel. 2018. "On Hurricane Maria Anniversary, Puerto Rico Is Still In Ruins". The New York Times, September 20, 2018. https://www.nytimes.com/interactive/2018/09/20/us/puerto-rico-hurricane-maria-housing.html?action=click&module=RelatedCoverage&pgtype=Article&region=Footer.

Rodgers, William M., and William E. Spriggs. "The Effect of Federal Contractor Status on Racial Differences in Establishment-Level Employment Shares: 1979-1992." The American Economic Review 86, no. 2 (1996): 290-93. Accessed October 23, 2020. http://www.jstor.org/stable/2118139.

Rosettie, KL, Micha R, Cudhea F, Peñalvo JL, O'Flaherty M, Pearson-Stuttard J, Economos CD, Whitsel LP, Mozaffarian D. 2018. Comparative risk assessment of school food environment policies and childhood diets, childhood obesity, and future cardiometabolic mortality in the United States. PLoS One 13:e0200378. doi: 10.1371/journal.pone.0200378.

"Rural Energy for America Program Renewable Energy Systems & Energy Efficiency Improvement Guaranteed Loans & Grants | Rural Development." n.d. Accessed August 18, 2020. https://www.rd.usda.gov/programs-services/rural-energy-america-program-renewable-energy-systems-energy-efficiency.

S

Sartor, Olivier & Chris Bataille. 2019. Decarbonising basic materials in Europe : How Carbon Contracts-for-Difference could help bring breakthrough technologies to market. IDDRI Policy Brief. Paris, France: IDDRI.

"Scale-Up Of Solar And Wind Puts Existing Coal, Gas At Risk". 2020. BNEF. https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk/.

Schleifstein, Mark. 2020. "Number Of "Orphaned" Wells Increased By 50 Percent, Could Cost State Millions: Audit". The Times-Picayune, The New Orleans Advocate, 2020. https://www.nola.com/news/business/article_313d8dd2-7a9d-11ea-b4a4-e7675d1484f7.html#:~:text=Mark%20Schleifstein,-Author%20email&text=The%20Louisiana%20agency%20overseeing%20oil,the%20Louisiana%20Legislative%20Auditor's%20Office.

Scrivener, Karen & John, Vanderley & Gartner, Ellis. 2018. Eco-efficient cements: Potential economically viable solutions for a low-CO2 cement-based materials industry. UN Environment.

Scully-Russ, Ellen. 2018. "The Dual Promise of Green Jobs: Sustainability and Economic Equity." In The Palgrave Handbook of Sustainability: Case Studies and Practical Solutions, edited by Robert Brinkmann and Sandra J. Garren, 503–21. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-71389-2_27.

Seldman, Neil. 2020. "Monopoly And The U.S. Waste Knot – Institute For Local Self-Reliance". Ilsr.Org. https://ilsr.org/monopoly-and-the-us-waste-knot/.

"Senate Passes Portman Priority To Fund Cleanup Of Portsmouth Gaseous Diffusion Plant". 2020. Senator Rob Portman. https://www.portman.senate.gov/newsroom/press-releases/senate-passes-portman-priority-fund-cleanup-portsmouth-gaseous-diffusion.

Sepulveda, Nestor A., Jesse D. Jenkins, Fernando J. de Sisternes, and Richard K. Lester. 2018. "The Role Of Firm Low-Carbon Electricity Resources In Deep Decarbonization Of Power Generation". Joule 2 (11): 2403-2420. doi:10.1016/j.joule.2018.08.006.

Seto, Karen C., Steven J. Davis, Ronald B. Mitchell, Eleanor C. Stokes, Gregory Unruh, and Diana Ürge-Vorsatz. 2016. "Carbon Lock-In: Types, Causes, And Policy Implications". Annual Review Of Environment And Resources 41 (1): 425-452. doi:10.1146/annurev-environ-110615-085934.

Shaner, Matthew R., Steven J. Davis, Nathan S. Lewis, and Ken Caldeira. 2018. "Geophysical Constraints On The Reliability Of Solar And Wind Power In The United States". Energy & Environmental Science 11 (4): 914-925. doi:10.1039/c7ee03029k.

Simon, Ruth. 2016. "Oil Bust Forces West Texas To Adjust". The Wall Street Journal, 2016. https://www.wsj.com/articles/oil-bust-forces-west-texas-to-adjust-1456950453.

"Sizing Up The Carbon Footprint Of Cities". 2020. Earthobservatory.Nasa.Gov. https://earthobservatory.nasa.gov/images/144807/sizing-up-the-carbon-footprint-of-cities.

Skumatz, Lisa. "Do Energy Efficiency Strategies Outperform Recycling in GHG Mitigation and Job Creation?" Presentation at: 2009 IEPEC Conference, Portland, Oregon, Skumatz Economic Research Associates, Inc. (SERA), https://serainc.com, 1, 11.

Smart Growth America. 2011. "Recent Lessons from the Stimulus: Transportation Funding and Job Creation". Smart Growth America. February 2011. https://smartgrowthamerica.org/app/legacy/documents/lessons-from-the-stimulus.pdf.

"Smart Solar Siting Partnership Project for New England." n.d. American Farmland Trust (blog). Accessed August 18, 2020. https://farmland.org/project/smart-solar-siting-partnership-project-for-new-england.

Smil, V. 2014. Making the Modern World: Materials and Dematerialization. John Wiley & Sons, 2014.

Smith P, Soussana J-F, Angers D, Schipper L, Chenu C, Rasse DP, Batjes NH, van Egmond F, McNeill S, Kuhnert M, Arias-Navarro C, Olesen JE, Chirinda N, Fornara D, Wollenberg E., Álvaro-Fuentes J, Sanz-Cobeña A, Klumpp K. 2019. How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. Global Change Biology. DOI: 10.1111/gcb.14815.

"Smokestacks, Tailpipes, and Trashcans," Eco-cycle Solutions, Accessed July 30, 2020, https://www.ecocyclesolutionshub.org/about-zero-waste/climate-change/.

Sonter, L. J., Barrett, D. J., Moran, C. J. & Soares-Filho, B. S. 2015. "Carbon emissions due to deforestation for the production of charcoal used in Brazil's steel industry". Nature Climate Change 5, 359-363.

"Sources Of Greenhouse Gas Emissions: Commercial And Residential Sector Emissions". 2020. US EPA. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

"Sources Of Greenhouse Gas Emissions: Electricity". 2020. US EPA. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

"Sources Of Greenhouse Gas Emissions | US EPA". 2020. US EPA. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

"State Actions". 2020. Price On Carbon. https://priceoncarbon.org/business-society/state-actions/.

"State Electric Vehicle Mandate | Alliance of Automobile Manufacturers." n.d. Accessed August 14, 2020. https://autoalliance.org/energy-environment/state-electric-vehicle-mandate/.

"State Renewable Portfolio Standards And Goals". 2020. National Conference Of State Legislatures. https://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx.

Supplemental Nutrition Assistance Program. "SNAP-Ed Education and Evaluation Study (Wave II)." U.S. Department of Agriculture. https://www.fns.usda.gov/snap/supplemental-nutrition-assistance-program-education-and-evaluation-study-wave-ii (accessed June 12, 2018).

Sustainable Development Solutions Network. 2020. Conceptualizing Employment Pathways to Decarbonize the U.S. Economy. New York: Sustainable Development Solutions Network (SDSN).

"Sustainable Materials Management," Northeast Recycling Council, Accessed July 13, 2020, https://nerc.org/news-and-updates/blog/nerc-blog/2015/03/10/sustainable-materials-management.

T

Table of Solutions, Project Drawdown, Accessed August 14, 2020, https://drawdown.org/solutions/table-of-solutions.

"Tackling The Fly Ash Supply Issue". 2020. Materials That Perform: Building Materials Suppliers. https://www.materialsthatperform.com/tackling-fly-ash-supply-issue.

Taft, JD, and A Becker-Dippman. 2015. "Grid Architecture". Prepared For The U.S. Department Of Energy. Richland, WA: Pacific Northwest National Laboratory. https://gridarchitecture.pnnl.gov/media/white-papers/Grid%20Architecture%20%20-%20DOE%20QER.pdf.

Teger, A., 2015. The Minimal Cement Content Of Workable Concrete. MSc. Israel Institute of Technology.

Theory of Change, GAIA, Accessed August 4, 2020, https://www.no-burn.org/theory-of-change/.

Tong, D, Qiang Zhang, Yixuan Zheng, Ken Caldeira, Christine Shearer, Chaopeng Hong, Yue Qin and Steven J. Davis. 2019."Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target". Nature 572, 373-377, doi:10.1038/s41586-019-1364-3.

"Total U.S. Chemical Import Value 2019". 2020. Statista. https://www.statista.com/statistics/258904/us-chemical-imports-since-2001/.

U

Udall, Tom, and Alan Lowenthal. 2020. "Legislative Blueprints for Reducing Plastic and Packaging Pollution," Memo to National Caucus of Environmental Legislators, August 10, 2020, 18.

United Nations Environment Programme (UNEP) and International Solid Waste Association (ISWA). 2015. Global Waste Management Outlook. UNEP International Environment Technology Centre: Osaka. http://web.unep.org/ourplanet/september-2015/unep-publications

"United States Climate Alliance 2019 State Factsheets: Puerto Rico". 2019. https://static1.squarespace.com/static/5a4cfbfe18b27d4da21c9361/t/5d8e533c9ef9643a4472975f/1569608509328/USCA_2019+State+Factsheet-PR_20190924.pdf.

University of Birmingham. 2018. "A Cool World: Defining The Energy Conundrum Of Cooling For All". Birmingham, United Kingdom: Institute for Global Innovation and Birmingham Energy Institute, University of Birmingham. https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/2018-clean-cold-report.pdf.

"University Launches Commission On Carbon Neutrality". 2019. The University Of Michigan Record. https://record.umich.edu/articles/university-launches-commission-carbon-neutrality/.

"Updated Employment Multipliers for the U.S. Economy | Economic Policy Institute." n.d. Accessed August 13, 2020. https://www.epi.org/publication/updated-employment-multipliers-for-the-u-s-economy/.

Urban Climate Change Research Network (UCCRN). 2015. Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network.

Urban Green Council. 2016. "New York City's Energy And Water Use 2013 Report". New York City: Urban Green Council. https://www.urbangreencouncil.org/sites/default/files/nyc_energy_water_use_report_2016.pdf.

Urban Green Council. 2019. "Demystifying Steam: Smaller Buildings". Research Brief. New York City: Urban Green Council. https://www.urbangreencouncil.org/sites/default/files/2019.10.15_demystifying_steam_smaller_buildings_final.pdf.

Ürge-Vorsatz, Diana, Cynthia Rosenzweig, Richard J. Dawson, Roberto Sanchez Rodriguez, Xuemei Bai, Aliyu Salisu Barau, Karen C. Seto, and Shobhakar Dhakal. 2018. "Locking In Positive Climate Responses In Cities". Nature Climate Change 8 (3): 174-177. doi:10.1038/s41558-018-0100-6.

U.S. Bureau of Labor Statistics. 2020. "Employment Projections — 2019-2029." https://www.bls.gov/news.release/pdf/ecopro.pdf.

U.S. Bureau of Labor Statistics. n.d. "Employment Status of the Civilian Noninstitutional Population by Age, Sex, and Race." Accessed September 3, 2020a. https://www.bls.gov/cps/cpsaat03.htm.

U.S. Bureau of Labor Statistics. n.d. "Quarterly Census of Employment and Wages." Accessed September 3, 2020b. https://www.bls.gov/cew/.

U.S. Census Bureau. 2015. "Manufacturing: Subject Series: Concentration Ratios: Share of Value of Shipments Accounted for by the 4, 8, 20, and 50 Largest Companies for Industries: 2012".

"U.S. Census Bureau | Usagov". 2020. Usa.Gov. https://www.usa.gov/federal-agencies/u-s-census-bureau.

"U.S. Construction Spending: Public and Private Sectors 2019." n.d. Statista. Accessed August 13, 2020. https://www.statista.com/statistics/226355/us-public-and-private-sector-construction/

U.S. Department of Agriculture. 2014. Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry Methods for Entity-Scale Inventory. Technical Bulletin Number 1939. Office of the Chief Economist, U.S. Department of Agriculture, Washington, DC.

U.S. Department of Agriculture. 2019. FY 2019 Budget Summary. Washington D.C.: United States Department of Agriculture. https://www.usda.gov/sites/default/files/documents/usda-fy19-budget-summary.pdf.

U.S. Department of Agriculture. 2019. "USDA Has More Than $400 Million Still Available For Renewable Energy System And Energy Efficiency Loan Guarantees". https://www.usda.gov/media/press-releases/2019/07/18/usda-has-more-400-million-still-available-renewable-energy-system.

U.S. Department of Agriculture Food and Nutrition Service. "Healthy Incentives Pilot." June 2017. https://www.fns.usda.gov/hip/healthy-incentives-pilot (accessed July 16, 2018).

U.S. Department of Agriculture & Health and Human Services. 2015. Scientific Report of the 2015 Dietary Guidelines Advisory Committee, Part D. Chapter 5: Food Sustainability and Food Safety. Washington D.C.: HHS.

U.S. Department of Energy. 2016. "2016 Billion-Ton Report". U.S. Department of Energy. https://www.energy.gov/sites/prod/files/2016/12/f34/2016_billion_ton_report_12.2.16_0.pdf.

U.S. Department of Energy Office of Electric Transmission and Distribution. 2003. "'Grid 2030': A National Vision For Electricity's Second 100 Years". Washington D.C.: U.S. Department of Energy

U.S. Department of Health and Human Services, & U.S. Department of Agriculture. 2015. 2015-2020 Dietary Guidelines. Health.gov. https://health.gov/dietaryguidelines/2015/guidelines.

U.S. Department of Energy. "U.S. Departments of Energy and Interior Announce Site for Solar Energy Demonstration Projects in the Nevada Desert," Press release, 7/8/10, http://energy.gov/ articles/us-departments-energy-and-interior-announce-site-solar-energy-demonstration-projects-nevada.

U.S. Department of Labor. 2012. “Green Jobs Program: Limited Success in Meeting Employment and Retention Goals as of June 30, 2012.”

U.S. Department of Transportation, Bureau of Transportation Statistics. 2017. “Freight Facts and Figures”. https://www.bts.dot.gov/sites/bts.dot.gov/files/docs/FFF_2017.pdf.

U.S. Energy Information Administration. 2018. Assessing HVDC Transmission for Impacts of Non−Dispatchable Generation. Washington D.C.: U.S. Department of Energy. https://www.eia.gov/analysis/studies/electricity/hvdctransmission/pdf/transmission.pdf.

U.S. Energy Information Administration. “Electric Power Monthly”. 2020. Eia.Gov. https://www.eia.gov/electricity/monthly/.

U.S. Energy Information Administration (EIA). n.d. “Crude Oil Production.” Accessed September 6, 2020a. https://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm.

U.S. Energy Information Administration. n.d. “Fossil Fuels Continue to Account for the Largest Share of U.S. Energy - Today in Energy.” Accessed September 5, 2020b. https://www.eia.gov/todayinenergy/detail.php?id=41353.

U.S. Energy Information Administration. n.d. “Natural Gas Dry Production (Annual Supply & Disposition).” Accessed September 6, 2020c. https://www.eia.gov/dnav/ng/ng_sum_snd_a_EPG0_FPD_Mmcf_a.htm.

U.S. Environmental Protection Agency (EPA). 2006. Solid Waste Management and Greenhouse Gases: A Lifecyle Assessment of Emissions and Sinks, 3rd Edition, September 2006.

U.S. Environmental Protection Agency. 2009. Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices. US Environmental Protection Agency, Office of Solid Waste and Emergency Response: Washington, DC. https://www.epa.gov/sites/production/files/documents/ghg-land-materials-management.pdf.

U.S. Environmental Protection Agency. 2014. “Protecting Communities-Restoring Land-Conserving Resources: RCRA’s Critical Mission & The Path Forward”, https://www.epa.gov/sites/production/files/2015-09/documents/rcras_critical_mission_and_the_path_forward.pdf.

U.S. Environmental Protection Agency. 2018. “Advancing Sustainable Materials Management: (2015) Fact Sheet- Assessing Trends in Material Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling in the United States”.

U.S. Environmental Protection Agency. 2018. “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016.” Reports and Assessments. January 30, 2018. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016.

U.S. Environmental Protection Agency. 2020. A Call To Action By Stakeholders: United States Food Loss & Waste 2030 Reduction Goal.Washington D.C.: US EPA. https://www.epa.gov/sustainable-management-food/call-action-stakeholders-united-states-food-loss-waste-2030-reduction.

U.S. Environmental Protection Agency. 2020. Fast Facts U.S. Transportation Sector Greenhouse Gas Emissions 1990-2018. Washington D.C.: Office of Transportation and Air Quality, Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100ZK4P.pdf.

US Environmental Protection Agency, OAR. 2015. "Fast Facts on Transportation Greenhouse Gas Emissions." Overviews and Factsheets. US EPA. August 25, 2015. https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

U.S. Environmental Protection Agency, OAR. 2015. "Smog, Soot, and Other Air Pollution from Transportation." Overviews and Factsheets. US EPA. September 10, 2015. https://www.epa.gov/transportation-air-pollution-and-climate-change/smog-soot-and-local-air-pollution.

U.S. Environmental Protection Agency, OAR. 2015. "Sources of Greenhouse Gas Emissions." Overviews and Factsheets. US EPA. December 29, 2015. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

U.S. Fish and Wildlife Service. 2012. U.S. Fish and Wildlife Service Land-Based Wind Energy Guidelines. Washington D.C.: U.S. Fish and Wildlife Service. https://www.fws.gov/ecological-services/es-library/pdfs/WEG_final.pdf.

U. S. Government Accountability Office (GAO). 2013. "Employment and Training: Labor's Green Jobs Efforts Highlight Challenges of Targeted Training Programs for Emerging Industries," no. GAO-13-555 (July). https://www.gao.gov/products/GAO-13-555.

US Municipal Solid Waste Incinerators: An Industry in Decline, New York City: Tishman Environment and Design Center (The New School), May 2019, 13. https://static1.squarespace.com/static/5d14dab43967cc000179f3d2/t/5d5c4bea0d59ad00012d220e/1566329840732/CR_GaiaReportFinal_05.21.pdf.

"US Produces Far More Waste and Recycles Far Less of It than Other Developing Countries," The Guardian, Accessed August 20, 2020, https://www.theguardian.com/us-news/2019/jul/02/us-plastic-waste-recycling.

"U.S. Public Views On Climate And Energy". 2020. Pew Research Center Science & Society. https://www.pewresearch.org/science/2019/11/25/u-s-public-views-on-climate-and-energy/.

"US Tops List Of Countries Fuelling The Mounting Waste Crisis". 2020. Verisk Maplecroft. https://www.maplecroft.com/insights/analysis/us-tops-list-of-countries-fuelling-the-mounting-waste-crisis/#:~:text=The%20highest%20risk%20countries%20in,%2C%20Germany%2C%20France%20and%20Australia.

V

Vattenfall. 2017. "Fossil Free Within One Generation". Annual And Sustainability Report 2017. Solna, Sweden: Vattenfall. https://group.vattenfall.com/siteassets/corporate/investors/annual-reports/2017/vattenfall_annual_and_sustainability_report_2017_eng.pdf.

Versions Of The Waste Reduction Model (WARM)". 2020. US EPA. https://www.epa.gov/warm/versions-waste-reduction-model-warm#15.

“Virgin Resin Price vs. Recycled Resin Price,” Vanden Knowledge Centre, Accessed August 8, 2020, https://blog.vandenrecycling.com/virgin-resin-price-vs.-recycled-resin-price.

Vogl, Valentin, Max Åhman, and Lars J. Nilsson. 2018. “Assessment Of Hydrogen Direct Reduction For Fossil-Free Steelmaking”. Journal Of Cleaner Production 203: 736-745. doi:10.1016/j.jclepro.2018.08.279.

W

Wabash Valley Resources. “The Largest US Carbon Capture and Sequestration Project to Be Developed by Wabash Valley Resources with Funding Support from OGCI Climate Investments.” PR Newswire: news distribution, targeting and monitoring. May 20, 2019. https://www.prnewswire.com/news-releases/the-largest-us-carbon-capture-and-sequestration-project-to-be-developed-by-wabash-valley-resources-with-funding-support-from-ogci-climate-investments-300852906.html.

Wagner, Gernot, Tomas Kåberger, Susanna Olai, Michael Oppenheimer, Katherine Rittenhouse, and Thomas Sterner. 2015. “Energy Policy: Push Renewables To Spur Carbon Pricing”. Nature 525 (7567): 27-29. doi:10.1038/525027a.

Wang, P., L. Goel, X. Liu, and F. H. Choo. 2013. “Harmonizing AC And DC: A Hybrid AC/DC Future Grid Solution”. IEEE Power And Energy Magazine 11 (3): 76-83. doi:10.1109/mpe.2013.2245587.

Wang, Seaver. 2020. “We Need To Plan Ahead For The Narwhal Slope”. The Breakthrough Institute. https://thebreakthrough.org/issues/energy/narwhal-slope.

Wara, Michael. 2014. “California’s Energy and Climate Policy: A Full Plate, but Perhaps Not a Model Policy.” Bulletin of the Atomic Scientists 70 (5): 26–34. https://doi.org/10.1177/0096340214546832.

“Waste Reduction Model (WARM),” US Environmental Protection Agency (EPA), Accessed July 31, 2020, https://www.epa.gov/warm.

Weigel, M., Fischedick, M., Marzinkowski, J. & Winzer, P. 2016. “Multicriteria analysis of primary steelmaking technologies”. Journal of Cleaner Production 112, 1064-1076.

Weiss, Martin, Andreas Zerfass and Eckard Helmers. 2019. “Fully electric and plug-in hybrid cars - An analysis of learning rates, user costs, and costs for mitigating CO2 and air pollutant emissions”. Journal of Cleaner Production 212, 1478-1489. https://doi.org/10.1016/j.jclepro.2018.12.019.

Welker E, Lott M, Story M. 2016. The school food environment and obesity prevention: progress over the last decade. Curr Obes Rep. 5:145–155. doi: 10.1007/s13679-016-0204-0.

Wesseling, J.H., S. Lechtenböhmer, M. Åhman, L.J. Nilsson, E. Worrell, and L. Coenen. 2017. "The Transition Of Energy Intensive Processing Industries Towards Deep Decarbonization: Characteristics And Implications For Future Research". Renewable And Sustainable Energy Reviews 79: 1303-1313. doi:10.1016/j.rser.2017.05.156.

"What Climate Change Means For Puerto Rico". 2016. 19January2017snapshot.Epa.Gov. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-pr.pdf.

"What is Product Stewardship?" Product Stewardship Institute, Accessed July 28, 2020, https://www.productstewardship.us/page/Definitions.

"What We Do — Our Climate Voices". 2020. Our Climate Voices. https://www.ourclimatevoices.org/what-we-do.

"Whisper Valley, Austin's First EcoSmart, ZeroEnergy Community." 2020. Whisper Valley. Accessed August 10, 2020. https://www.whispervalleyaustin.com/.

The White House. 2016. United States Mid-Century Strategy for Deep Decarbonization.

Whitney, Erin. 2017. "Preface: Technology And Cost Reviews For Renewable Energy In Alaska: Sharing Our Experience And Know-How". Journal Of Renewable And Sustainable Energy 9 (6): 061501. doi:10.1063/1.5017516.

Whittle, Daniel. 2020. "The Federal Government and PREPA Must do Better for Puerto Rico". Environmental Defense Fund. https://www.edf.org/media/federal-government-and-prepa-must-do-better-puerto-rico

Wicks-Lim, Jeannette. 2013. "A Stimulus for Affirmative Action? The Impact of the American Recovery and Reinvestment Act on Women and Minority Workers in Construction," In Capitalism on Trial: Explorations in the Tradition of Thomas E. Weisskopf, edited by Jeannette Wicks-Lim and Robert Pollin (Northampton, MA: Edward Elgar Publishing, Inc.).

Williams, J.H., B. Haley, F. Kahrl, J. Moore, A.D. Jones, M.S. Torn, H. McJeon. 2014. Pathways to deep decarbonization in the United States. The U.S. report of the Deep Decarbonization Pathways Project of the Sustainable Development Solutions Network and the Institute for Sustainable Development and International Relations. Revision with technical supplement, Nov 16, 2015.

Williams, J.H., B. Haley, R. Jones. 2015. Policy implications of deep decarbonization in the United States. A report of the Deep Decarbonization Pathways Project of the Sustainable Development Solutions Network and the Institute for Sustainable Development and International Relations. Nov 17, 2015.

Williams, J.H. et al. 2012. The technology path to deep greenhouse gas emissions cuts by 2050: the pivotal role of electricity. Science 335.6064, 53-59

Wilson, David C., & Costas Velis. 2015. "Waste management –still a global challenge in the 21st century: an evidence based call for an action", Waste Management & Research, 33(12), 1049-1051.

Wisconsin Department of Health Services. 2018. Executive Summary of the 2007 Wisconsin WIC Farmers' Market Nutrition Program. https://www.dhs.wisconsin.gov.

Wiser, Ryan H., Galen L. Barbose, Jenny Heeter, Trieu Mai, Lori Bird, Mark Bolinger, and Alberta Carpenter et al. 2016. "A Retrospective Analysis Of The Benefits And Impacts Of U.S. Renewable Portfolio Standards". Berkeley, CA: Lawrence Berkeley National Laboratory. https://emp.lbl.gov/publications/retrospective-analysis-benefits-and.

"World Resources Institute - America's New Climate Economy - GPSEN". 2020. GPSEN. https://gpsen.org/project/world-resources-institute-americas-new-climate-economy/.

Wu, Grace C. 2020. Spatial Planning of Low Carbon Transitions. New York, NY: SDSN. https://irp-cdn.multiscreensite.com/be6d1d56/files/uploaded/SDSN_DDPP_SpatialPlanning_GraceWu_final.pdf.

Wu, Grace C., Emily Leslie, Oluwafemi Sawyerr, D. Richard Cameron, Erica Brand, Brian Cohen, Douglas Allen, Marcela Ochoa and Arne Olson. 2020. "Low-impact land use pathways to deep decarbonization of electricity." Environmental Research Letters 15(7). https://doi.org/10.1088/1748-9326/ab87d1.

Wyns, T., Khandekar, G., Axelson, M., Sartor, O. & Neuhoff, K. 2019. Industrial Transformation 2050: Towards an industrial strategy for a climate neutral Europe. Brussels, Belgium: Institute for European Studies.

X

Xi, F., Davis, S., Ciais, P., Crawford-Brown, D., Guan, D., Pade, C., Shi, T., Syddall, M., Lv, J., Ji, L., Bing, L., Wang, J., Wei, W., Yang, K., Lagerblad, B., Galan, I., Andrade, C., Zhang, Y. and Liu, Z., 2016. Substantial global carbon uptake by cement carbonation. Nature Geoscience, 9(12), pp.880-883.

Z

"Zero Waste Business Principles," Zero Waste International Alliance, Accessed August 8, 2020, http://zwia.org/zero-waste-business-principles/.

"Zero Waste Definition," Zero Waste International Alliance, Accessed August 7, 2020, http://zwia.org/zero-waste-definition/.

Zomer, Robert J., Deborah A. Bossio, Rolf Sommer, and Louis V. Verchot. 2017. "Global Sequestration Potential Of Increased Organic Carbon In Cropland Soils". Scientific Reports 7 (1). doi:10.1038/s41598-017-15794-8.

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