Accelerating Decarbonization of the U.S. Energy System (2021)

Chapter:4 How to Achieve Deep Decarbonization

« Previous: 3 To What End: Societal Goals for Deep Decarbonization

Page 163

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CHAPTER FOUR

How to Achieve Deep Decarbonization

INTRODUCTION

This chapter addresses the policy package needed to achieve the first 10 years of the energy transition. These policies would accomplish the five quantitative technical objectives identified in Chapter 2 (targeting efficiency, electrification, zero-carbon power, infrastructure, and innovation), and place the nation on a 30-year path to net zero, while retaining optionality about the nature of the midcentury system. The package would also address the four societal goals developed in Chapter 3: enhanced U.S. economic leadership, an equitable transition and net-zero energy system, protected regional interests and sustained local communities, and cost-effectiveness.

To tackle both the technical and social needs, four overarching policy priorities are identified, each comprising a portfolio of specific proposals:

Establish the U.S.’ commitment to a rapid, just, and equitable transition to a net-zero carbon economy.

Set rules and standards to accelerate the formation of markets for clean energy that work for all.

Invest in the research, technology, people, and infrastructure for a U.S. net-zero carbon future.

Assist families, businesses, communities, cities, and states in accelerating an equitable transition, ensuring that disadvantaged and at-risk communities do not suffer disproportionate burdens.

Table 4.1 summarizes how the specific policies support the technical and societal objectives. The combination of policies in this diverse portfolio shown in Table 4.1 is required to achieve all of the technical objectives while addressing multiple societal goals. There is no silver-bullet policy any more than there is a silver-bullet technology. Equally important, the policy portfolio in the table would greatly reduce climate disruption risks, increase long-term climate resilience, reduce air pollution and related health burdens, increase energy security, and support a clean energy industry and workforce.

Page 164

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

TABLE 4.1 Summary of Policies Designed to Meet Net-Zero Carbon Emissions Goal and How the Policies Support the Technical and Societal Objectives

Policy Technological Goals Socioeconomic Goals Government Entities Appropriation, if Any Notes

Establish U.S. commitment to a rapid, just, equitable transition to a net-zero carbon economy.

U.S. CO2 and other GHG emissions budget reaching net zero by 2050.

Executive and Congress $5 million per year. Budget is central for imposing emissions discipline, although any consequences for missing the target must be implemented through other policies. Funds are primarily for administration of the budget and data collection and management.

Economy-wide price on carbon.

Congress None. Revenue of $40/tCO2 rising 5% per year, which totals approximately $2 trillion from 2020 to 2030. Carbon price level not designed to directly achieve net-zero emissions.

Additional programs will be necessary to protect the competitiveness of import/export exposed businesses.

Establish 2-year federal National Transition Task Force to assess vulnerability of labor sectors and communities to the transition of the U.S. economy to carbon neutrality.

Congress $5 million per year. Task force responsible for design of an ongoing triennial national assessment on transition impacts and opportunities to be conducted by the Office of Equitable Energy Transitions.

Page 165

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Establish White House Office of Equitable Energy Transitions.

Establish criteria to ensure equitable and effective energy transition funding.

Sponsor external research to support development and evaluation of equity indicators and public engagement.

Report annually on energy equity indicators and triennially on transition impacts and opportunities.

Congressional appropriation $25 million per year, rising to $100 million per year starting in 2025. Federal office establishes targets and monitors and advances progress of federal programs aimed at a just transition.

Establish an independent National Transition Corporation to ensure coordination and funding in the areas of job losses, critical location infrastructure, and equitable access to economic opportunities and wealth, and to create public energy equity indicators.

Congressional appropriation $20 billion in funding over 10 years. Primary means to mediate harms that occur during transition, including support for communities that lose a critical employer, support for displaced workers, abandoned site remediation, and opportunities for communities to invest in a wide range of clean energy projects.

Page 166

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Policy Technological Goals Socioeconomic Goals Government Entities Appropriation, if Any Notes

Set rules/standards to accelerate the formation of markets for clean energy that work for all.

Set clean energy standard for electricity generation, designed to reach 75% zero-emissions electricity by 2030 and decline in emissions intensity to net-zero emissions by 2050.

Congress None.

Set national standards for light-, medium-, and heavy-duty zero-emissions vehicles, and extend and strengthen stringency of Corporate Average Fuel Economy (CAFE) standards. Light-duty zero-emission vehicle (ZEV) standard ramps to 50% of sales in 2030; medium- and heavy-duty to 30% of sales in 2030.

Congress None.

Set manufacturing standards for zero-emissions appliances, including hot water, cooking, and space heating. Department of Energy (DOE) continues to establish appliance minimum efficiency standards. Standard ramps down to achieve close to 100% all-electric in 2050.

Congress None.

Page 167

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Enact three near-term actions on new and existing building energy efficiency, two by DOE/Environmental Protection Agency (EPA)a and one by the General Services Administration (GSA).

DOE, GSA None. GSA to set a cap on existing and new federal buildings that declines by 3% per year.

Enact five federal actions to advance clean electricity markets, and to improve their regulation, design, and functioning.b

Congress $8 million per year for Federal Energy Regulatory Commission (FERC) Office of Public Participation and Consumer Advocacy. Two of these actions involve FERC utilizing existing authorities and three involve congressional actions, two directed to FERC and one to DOE.

Deploy advanced electricity meters for the retail market, and support the ability of state regulators to review proposals for time/location-varying retail electricity prices.

Congressional appropriation for DOE $4 billion over 10 years.

Recipients of federal funds and their contractors must meet labor standards, including Davis-Bacon Act prevailing wage requirements; sign Project Labor Agreements (PLAs) where relevant; and negotiate Community Benefits (or Workforce) Agreements (CBAs) where relevant.

Congress None.

Page 168

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

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Report and assess financial and other risks associated with the net-zero transition and climate change by private companies, government agencies, and the Federal Reserve. Private companies receiving federal funds must also report their clean energy research and development (R&D) by category (wind, solar, etc.).

Congress None. Risk disclosures to be included in annual SEC reports for private companies. Federal Reserve to use climate-related risks in financial stress tests. Federal agencies to include climate-related risks in all benefit cost analyses.

All banks to report on comparative financial investments in all energy sources.

Ensure that Buy America and Buy American provisions are applied and enforced for key materials and products in federally funded projects.

Congress None.

Establish an environmental product declaration library to create the accounting and reporting infrastructure to support the development of a comprehensive Buy Clean policy.

Congressional appropriation for EPA and DOE $5 million per year.

Page 169

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Invest (research, technology, people, and infrastructure) in a U.S. net-zero carbon future.

Establish a federal Green Bank to finance low- or zero-carbon technology, business creation, and infrastructure.

Congressional authorization and appropriation Capitalized with $30 billion, plus $3 billion per year until 2030. Additional requirements include public reporting of both energy equity analyses of investment and leadership diversity of firms receiving funds.

Amend the Federal Power Act and Energy Policy Act by making changes to facilitate needed new transmission infrastructure.c

Congress None.

Plan, fund, permit, and build additional electrical transmission, including long-distance high-voltage, direct current (HVDC). Require fair public participation measures to ensure meaningful community input.d

Congressional authorization and appropriation for DOE and FERC $25 million per year to DOE for planning; $50 million per year for DOE and FERC to facilitate use of existing rights-of-way; finance build through Green Bank; $10 million per year to DOE for distribution system innovations. Funds provide support for technical assistance to states, communities, and tribes to enable meaningful participation in regional transmission planning and siting activities. Funds to distribution utilities to invest in automation and control technologies.

Page 170

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Policy Technological Goals Socioeconomic Goals Government Entities Appropriation, if Any Notes

Expand electric vehicle (EV) charging network for interstate highway system.e

Congressional directive to Federal Highway Administration (FHWA) and National Institute of Standards and Technology (NIST); congressional appropriations to DOE $5 billion over 10 years to expand changing infrastructure. FHWA to expand its “alternative fuels corridor” program. NIST to develop interoperability standards for level 2 and fast chargers.

DOE to fund expansion of interstate charging to support long-distance travel and make investments for EV charging for low-income businesses and residential areas.

Expand broadband for rural and low-income customers to support advanced metering.

Congress to authorize and fund rural electric cooperatives and private companies to offer broadband $0.5 billion for rural electric cooperatives and $1.5 billion for private companies. 10% of investment costs to expand capabilities of smart grid to underserved areas. Grants or loans to rural electric providers and investment tax incentives to companies, both focused on rural and low-income communities.

Page 171

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Plan and assess the requirements for national CO2 transport network, characterize geologic storage reservoirs, and establish permitting rules.f

Require fair public participation measures to ensure meaningful community input.

Congressional authorization and appropriation to multiple agencies $50 million to Department of Transportation (DOT) with other agencies involved for 5-year planning plus $50 million for block grants for community and stakeholder engagement. $10 billion to $15 billion total during the 2020s to DOE, United States Geological Survey (USGS), and Department of the Interior (DOI) to characterize reservoirs. Extend 45Q and increase to $70/tCO2—$2 billion per year. Modeling studies and other analysis indicate that significant amounts of negative emissions will be needed to meet net-zero emissions. The CO2 pipeline network is needed even with 100% non-fossil electric power to enable carbon capture at cement and other industrial facilities with direct process emissions of greenhouse gases and to enable capture of CO2 from biomass or via direct air capture for use in production of carbon-neutral liquid and gaseous fuels.

Page 172

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Establish educational and training programs to train the net-zero workforce, with reporting on diversity of participants and job placement success.g

Congressional appropriations to Department of Education, DOE, and National Science Foundation (NSF) $5 billion per year for GI Bill-like program. $100 million per year for new undergraduate programs. $50 million per year for use-inspired and $375 million per year for other doctoral and postdoctoral fellowships. Eliminate visa restrictions for net-zero students. $7 million over 2020–2025 for the Energy Jobs Strategy Council. Fields covered include science, engineering, policy, and social sciences, for students researching and innovating in low-carbon technologies, sustainable design, and the energy transition.

Revitalize clean energy manufacturing.h

Congressional appropriation and direction of Green Bank and U.S. Export-Import Bank Manufacturing subsidies for low-carbon products starting at $1 billion per year and phased out over 10 years. No additional appropriation required for loans and loan guarantees from Green Bank and Export-Import Bank. Export-Import Bank should make available at least $500 million per year in low-carbon product and clean-tech export financing and eliminate support for fossil technology exports.

Page 173

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Increase clean energy and net-zero transition RD&D that integrates equity indicators.i

Congressional appropriation for and directions to DOE and NSF DOE clean energy RD&D triples from $6.8 billion per year to $20 billion per year over 10 years. DOE funds studies of policy evaluation at $25 million per year and regional innovation hubs at $10 million per year; DOE- and NSF-funded studies of social dimensions of the transition should be supported by an appropriation of $25 million per year. Establish criteria for receiving funds on equity analysis, appropriate community input, and leadership diversity of companies applying for public investments. DOE to report on equity impacts and diversity of entities receiving public funds.

Increase funds for low-income households for energy expenses, home electrification, and weatherization.

Congressional appropriation Increase Weatherization Assistance Program (WAP) funding to $1.2 billion per year from $305 million per year. Direct Department of Health and Human Services (HHS) to increase state’s share of Low Income Home Energy Assistance Program (LIHEAP) funds for home electrification and efficiency.

Page 174

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Policy Technological Goals Socioeconomic Goals Government Entities Appropriation, if Any Notes

Increase electrification of tribal lands

Congressional appropriation to DOE and U.S. Department of Agriculture (USDA) $20 million per year for assessment and planning through DOE Office of Indian Energy Policy (DOE-IE) and USDA Rural Utilities Service (USDA-RUS); expand DOE-IE to $200 million per year. Increase direct financial assistance for the build-out of electricity infrastructure through DOE-IE grant programs.

Assist families, businesses, communities, cities, and states in an equitable transition, ensuring that the disadvantaged and at-risk do not suffer disproportionate burdens.

Please note that the primary policies targeting fairness, diversity, and inclusion during the transition are the establishment of the Office of Equitable Energy Transitions and the National Transition Corporation, which are the fourth and fifth policies in this table.

Establish National Laboratory support to subnational entities for planning and implementation of net-zero transition.

Congressional appropriation Additional funding to national laboratories’ annual funding commencing at the level of $200 million per year, rising to $500 million per year by 2025, and $1 billion per year by 2030. To establish a coordinated, multi-laboratory capability to provide energy modeling, data, and analytic and technical support to cities, states, and regions to complete a just, equitable, effective, and rapid transition to net zero.

Page 175

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Establish 10 regional centers to manage socioeconomic dimensions of the net-zero transition.j

Congressional authorization and appropriations to DOE $5 million per year for each center; $25 million per year for external research budget to provide data, models, and decision support to the region. Coordinated by the Office of Equitable Energy Transitions.

Establish net-zero transition office in each state capital.

Congressional appropriations $1 million per year in matching funds for each state. Coordinate state’s effort with federal and regional efforts.

Establish local community block grants for planning and to help identify especially at-risk communities. Greatly improve environmental justice (EJ) mapping and screening tool and reporting to guide investments.

Congressional appropriations to DOE $1 billion per year in grants administered by regional centers. Required to qualify for funding from the National Transition Corporation. Block grant funding requires inclusive participation and engagement by historically marginalized and low-income groups.

Page 176

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

KEY TO ICONS

DARK GREEN icon indicates that the policy is highest priority and indispensable to achieve the objective.

MEDIUM GREEN icon indicates that the policy is important to achieve the objective.

LIGHT GREEN icon indicates that the policy would play a supporting role.

No icon indicates that the policy would have at most a small positive role in achieving the objective (and might in, some cases, have a small negative impact on the objective).

Technological Goals

Invest in energy efficiency and productivity. Examples include accelerating the rate of increase of industrial energy productivity (dollars of economic output per energy consumed) from the historic 1% per year to 3% per year.

Electrify energy services in transportation, buildings, and industry. Examples include, by 2030, moving half of vehicle sales (all classes combined) to EVs, and deploying heat pumps in one-quarter of residences.

Produce carbon-free electricity. Roughly double the share of electricity generated by carbon-free sources from 37% to 75%.

Plan, permit, and build critical infrastructure. Build critical infrastructure needed for the transition to net zero, including new transmission lines, an EV charging station network, and a CO2 pipeline network.

Expand the innovation toolkit. Triple federal support for net-zero RD&D.

Socioeconomic Goals

Strengthen the U.S. economy. Use the energy transition to accelerate U.S. innovation, reestablish U.S. manufacturing, increase the nation’s global economic competitiveness, and increase the availability of high-quality jobs.

Promote equity and inclusion. Ensure equitable distribution of benefits, risks, and costs of the transition to net zero. Integrate historically marginalized groups into decision making by ensuring adherence to best-practice public participation laws. Require that entities receiving public funds report on leadership diversity to ensure nondiscrimination.

Support communities, businesses, and workers. Ensure support for those directly and adversely affected by the transition.

Maximize the cost-effectiveness of the transition to net zero.

Page 177

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

a Direct DOE/EPA to expand their outreach of and support for adoption of benchmarking and transparency standards by state and local government through the expansion of Portfolio Manager. Direct DOE/EPA to further investigate the development of model carbon-neutral standards for new and existing buildings that, in turn, could be adopted by states and local authorities. Policies targeting retrofits of existing buildings will be in the final report.

b FERC should work with regional transmission organizations (RTOs) and independent system operators (ISOs) to ensure that markets in all parts of the country are designed to accommodate the shift to 100% clean electricity on the relevant timetable. Congress should clarify that the Federal Power Act does not limit the ability of states to use policies (e.g., long-term contracting with zero-carbon resources procured through market-based mechanisms) to support entry of zero-carbon resources into electric utility portfolios and wholesale power markets. Congress should further direct FERC to exercise its rate-making authority over wholesale prices in ways that accommodate state action to shape the timing and character of the transitions in their electric resource mixes. Congress should reauthorize the FERC Office of Public Participation and Consumer Advocacy to provide grants and other assistance to support greater public participation in FERC proceedings. FERC should direct North American Electric Reliability Corporation (NERC) to establish and implement standards to ensure that grid operators have sufficient flexible resources to maintain operational reliability of electric systems. Congress should direct and fund DOE to provide federal grants to support the deployment of advanced meters for retail electricity customers as well as the capabilities of state regulatory agencies and energy offices to review proposals for time/location-varying retail electricity prices, while also ensuring that low-income consumers have access to affordable basic electricity service.

c (1) Establish National Transmission Policy to rely on the high-voltage transmission system to support the nation’s (and states’) goals to achieve net-zero carbon emissions in the power sector. (2) Authorize and direct FERC to require transmission companies and regional transmission organizations to analyze and plan for economically attractive opportunities to build out the interstate electric system to connect regions that are rich in renewable resources with high-demand regions; this is in addition to the traditional planning goals of reliability and economic efficiency in the electric system. (3) Amend the Energy Policy Act of 2005 to assign to FERC the responsibility to designate any new National Interest Electric Transmission Corridors and to clarify that it is in the national interest for the United States to achieve net-zero climate goals as part of any such designations. (4) Authorize FERC to issue certificates of public need and convenience for interstate transmission lines (along the lines now in place for certification of gas pipelines), with clear direction to FERC that it should consider the location of renewable and other resources to support climate-mitigation objectives, as well as community impacts and state policies as part of the need determination (i.e., in addition to cost and reliability issues) and that FERC should broadly allocate the costs of transmission enhancements designed to expand regional energy systems in support of decarbonizing the electric system.

d (1) Congress should authorize and appropriate funding for DOE to provide support for technical assistance and planning grants to states, communities, and tribal nations to enable meaningful participation in regional transmission planning and siting activities. (2) Congress should authorize and appropriate funding for DOE and FERC to encourage and facilitate use of existing rights-of-way (e.g., railroad; roads and highways; electric transmission corridors) for expansion of electric transmission systems. (3) Congress should authorize and appropriate funding for DOE to analyze, plan for, and develop workable business model/regulatory structures, and provide financial incentives (through the Green Bank) for development of transmission systems to support development of offshore wind and for development, permitting, and construction of high-voltage transmission lines, including high-voltage direct-current lines.

Page 178

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e (1) Congress should direct the Federal Highway Administration (a) to continue to expand its “alternative fuels corridor” program, which supports planning for EV charging infrastructure on the nation’s interstate highways, and (b) to update its assessment of the ability and plans of the private sector to build out the EV charging infrastructure consistent with the pace of EV deployment needed for vehicle electrification anticipated for deep decarbonization, the need for vehicles on interstate highways and in public locations or high-density workplaces, and to identify gaps in funding and financial incentives as needed. In coordination with FHWA, DOE should provide funding for additional EV infrastructure that would cover gaps in interstate charging to support long-distance travel and make investments for EV charging for low-income businesses and residential areas. (2) NIST should develop communications and technology interoperability standards for all EV level 2 and fast charging infrastructure.

f Extend 45Q tax credit for carbon capture, use, and sequestration for projects that begin substantial construction prior to 2030 and make tax credit fully refundable for projects that commence construction prior to December 31, 2022. Set the 45Q subsidy rate for use equal to $35/tCO2 less whatever explicit carbon price is established and the subsidy rate for permanent sequestration to be equal to $70/tCO2 less whatever explicit carbon price is established. A hydrogen pipeline network will ultimately also be needed, but, as indicated in Chapter 2, the time pressure to build a national hydrogen pipeline network is less severe than for CO2. This is because hydrogen production facilities can be located close to industrial hydrogen consumers, unlike CO2 pipelines, which must terminate in geologic storage reservoirs. Also, hydrogen can be blended into natural gas and transported in existing gas pipelines, and gas pipelines could ultimately be converted to 100% hydrogen.

g (1) Congress should establish a 10-year GI Bill-type program for anyone who wants a vocational, undergraduate, or master’s degree related to clean energy, energy efficiency, building electrification, sustainable design, or low-carbon technology. Such a program would ensure that the U.S. workforce transitions along the physical infrastructure of our energy, transportation, and economic systems. (2) Congress should support the creation of innovative new degree programs in community colleges and colleges and universities focused uniquely on the knowledge and skills necessary for a low-carbon economic and energy transformation. (3) Congress should provide funds to create interdisciplinary doctoral and postdoctoral training programs, similar to those funded by the National Institutes of Health (NIH), which place an emphasis on training students to pursue interdisciplinary, use-inspired research in collaboration with external stakeholders that can guide research and put it to use in improving practical actions to support decarbonization and energy justice. (4) Congress should provide support for doctoral and postdoctoral fellowships in science and engineering, policy, and social sciences for students researching and innovating in low-carbon technologies, sustainable design, and energy transitions, with at least 25 fellowships per state to ensure regional equity and build skills and knowledge throughout the United States. (5) The Department of Homeland Security (DHS) should eliminate or ease visa restrictions for international students who want to study climate change and clean energy at the undergraduate and graduate levels, where appropriate. (6) Congress should pass the Promoting American Energy Jobs Act of 2019 to reestablish the Energy Jobs Strategy Council under DOE, require energy and employment data collection and analysis, and provide a public report on energy and employment in the United States.

Page 179

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

h (1) Congress should establish predictable and broad-based market-formation policies that create demand for low-carbon goods and services, improve access to finance, create performance-based manufacturing incentives, and promote exports. Specifically, Congress should provide manufacturing incentive through loans, loan guarantees, tax credits, grants, and other policy tools to firms that are matched with corresponding performance requirements. Subsidies provided directly to manufacturers must be tied to the meeting of performance metrics, such as production of products with lower embodied carbon or adoption of low-carbon technologies and approaches. Specific items could include expanding the scope of the energy audits in the DOE Better Plants program and expanded technical assistance to focus on energy use and GHG emissions reductions at the 1,500 largest carbon-emitting manufacturing plants; supporting the hiring of industrial plant energy managers by having DOE provide manufacturers with matching funds for 3 years to hire new plant energy managers; enabling the development of agile and resilient domestic supply chains through DOE research, technical assistance, and grants to assist manufacturing facilities in addressing supply chain disruptions resulting from COVID-19 and future crises. (2) Congress should provide loans and loan guarantees to manufacturers to produce low-carbon products, ideally through a Green Bank (see Chapter 4). (3) Congress should require the U.S. Export-Import Bank to phase out support for fossil fuels and make support for clean energy technologies a top priority with a minimum of $500 million per year. (4) Congress should create a new Assistant Secretary for Carbon Smart Manufacturing and Industry within DOE.

i (1) Congress should triple the DOE’s investments in low- or zero-carbon RD&D over the next 10 years, in part by eliminating investments in fossil-fuel RD&D. These investments should include renewables, efficiency, storage, transmission and distribution (T&D), carbon capture, utilization, and storage (CCUS), advanced nuclear, and negative emissions technologies and increase the agency’s funding of large-scale demonstration projects. By eliminating investments in non-carbon capture and storage (CCS) fossil-fuel RD&D, the net increase to the energy RD&D budget will be partially offset. (2) Congress should direct DOE to fund energy innovation policy evaluation studies to determine the extent to which policies implemented (both RD&D investment and market-formation policies) are working. (3) Congress should direct DOE and the NSF to create a joint program to fund studies of the social, economic, ethical, and organizational drivers, dynamics, and outcomes of the transition to a carbon-neutral economy, as well as studies of effective public engagement strategies for strengthening the U.S. social contract for decarbonization. (4) Congress should direct DOE to establish regional innovation hubs where they do not exist or are critically needed using funds appropriated under item 1 above. (5) Congress should direct DOE to enhance public-private partnerships for low-carbon energy.

j (1) Congress should coordinate federal agency actions at the regional scale through the deployment of federal agency staff to regional offices. (2) Congress should host a coordinating council of regional governors and mayors that meets annually to establish high-level policy goals for the transition. (3) Congress should establish mechanisms for ensuring the effective participation of low-income communities, communities of color, and other disadvantaged communities in regional dialogue and decision making about the transition to a carbon-neutral economy. (4) Congress should provide information annually to the White House Office of Equitable Energy Transitions detailing regional progress toward decarbonization goals and benchmarks for equity.

Page 180

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

When introduced in Congress, most policies are assigned an “appropriations cost,” which is an estimate of the dollar amount of federal appropriation required to implement the policy, if any. This cost is neither the capital investment required to achieve a technical objective, as reported in Chapter 2, nor is it the “social cost” used by economists to capture the consumption forgone by households and obtained from a general equilibrium economic model of the global economy.

Until recently, most of the legislative approaches proposed in Congress have been built around a single, overarching carbon pricing policy, such as cap-and-trade or a carbon tax (S. 2877, 111th Cong., 2009; Baker III et al., 2017). Broad carbon pricing policies are typically designed to satisfy an efficiency or cost-effectiveness test based on long-standing economic arguments (Hahn and Stavins, 1992). Under the assumption that the carbon price completely addresses climate-related externalities, other policies are justified only to the extent that they address other market failures, including information gaps, spillovers, other externalities, and market power (Jaffe et al., 2004, 2005; Driscoll et al., 2015; Newbery, 2008; Cohen, 1995). Equity and justice concerns, if addressed at all in a carbon pricing policy, have tended to be accomplished through the allocation of revenue from carbon taxes or auction of emissions allowances (S. 2877, 111th Cong., 2009; Baker III et al., 2017; RGGI, Inc., 2020; Green and Knittel, 2020).

While an economy-wide carbon price plays an important role in the presented policy roadmap, it does not do all the heavy lifting for several reasons. The existence of other market failures justifies a range of complementary interventions (Doris et al., 2009). These include federal emissions standards (e.g., Corporate Average Fuel Economy [CAFE]/ greenhouse gas [GHG] emissions standards for light-duty vehicles); state standards and other state policies (e.g., California Zero Emissions Vehicle [CA ZEV] standards, Northeast (NE) states Regional Greenhouse Gas Initiative emissions allowance scheme); local standards (e.g., New York City Carbon Challenge); and corporate initiatives (e.g., Mars and WalMart’s climate action plans). Equity and justice concerns are also placed alongside cost-effectiveness as equal if not more important goals. The direct effect of carbon pricing on gasoline, fuel oil, natural gas, and electricity is particularly regressive (Metcalf, 2008; Rausch et al., 2011; Williams et al., 2015; Green and Knittel, 2020), although this is true of other emissions-mitigation policies. Meanwhile, high carbon prices can affect competitiveness of U.S. industries exposed to international competition and trade (Aldy and Pizer, 2015). Carbon revenue allocation can attenuate these impacts at carbon prices up to $40 per ton, which is why carbon pricing proposals in the United States almost always include them. However, the committee is unaware of any studies examining whether this is possible at the higher prices necessary for deep decarbonization.

A number of recent approaches move the idea of carbon pricing to the side and focus directly on equity and justice through a larger set of more targeted policies (H. Res.109,

Page 181

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

116th Cong., 2019; U.S. Congress, House, 2020a). One challenge in these proposals is to identify, mechanically, how all the pieces fit together to achieve the emissions goal.

The approach recommended here combines an overarching but insufficient (to achieve net-zero emissions) economy-wide carbon price and greenhouse gas budget with an additional set of policies that are all essential to address equity and justice considerations and to drive decarbonization in key sectors. The sector-by-sector approach presented here is consistent with emerging legislative text, which has pivoted from economy-wide solutions to sector-specific climate interventions (H.R.2486, 116th Cong., 2019; S.2300, 116th Cong., 2019; U.S. Congress, House, 2020a). Just as reaching net-zero emissions requires a full toolkit of low-carbon technologies (see Chapter 2), driving the net-zero transition requires the use of the full toolkit of policy levers. Also included is a mechanism to provide feedback if the policies need to be strengthened to meet the net-zero emission goal. The committee notes that this approach can be motivated either as a necessary deviation from cost-effectiveness and a heavy emphasis on carbon pricing (an economist framing) or as a logical consequence of addressing a fundamental system problem and transformation (Rosenbloom et al., 2020). Others have argued this approach is likely to promote public support (Bergquist et al., 2020; Brückman and Bernauer, 2020; Cullenward and Victor, 2020).

Beyond suggesting an extremely high carbon tax, there has been little research on a policy mix that can achieve net-zero emissions. The committee found no research on how to achieve the reductions needed as well as meet the diverse societal goals the committee lays out in Chapter 3. Rather than proposing more research to develop an “optimal” climate policy from the ground up, the committee has chosen to make recommendations that build on existing ideas where possible. This has the added benefit of stakeholder coalitions that have arisen around such proposals both in the United States and internationally. Moreover, the committee has sought to put them together to form a coherent pathway that puts the energy system on a trajectory to a net-zero economy by 2050.

This chapter explains the policy package needed to achieve net-zero emissions. Policies are organized thematically. The first set of policies, including a carbon price, is meant to establish the overall tenor and direction of the U.S. commitment to reducing GHG emissions through a small number of policies, including a carbon price and with equity, social justice, and engagement front and center. The second set defines the rules and regulations necessary to further align private incentives with overarching goals, including flexible, sector-specific zero-emissions performance standards. The third set of policies clarifies priorities for government investment along with incentives for private-sector investment. The last set rounds out additional policies necessary to assist in a fair and equitable transition to a net-zero emissions economy.

Page 182

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

The following presents the rationale for each policy area, followed by evidence and implementation details related to each item within the area.

ESTABLISHING THE U.S. COMMITMENT TO A RAPID, JUST, AND EQUITABLE TRANSITION TO A NET-ZERO CARBON ECONOMY

This first policy domain emphasizes the policies that together establish the direction and tone of climate-change policy going forward. These policies include:

An economy-wide CO2 and other greenhouse gas budget;

A price on carbon with appropriate measures to address competitiveness, equity, and environmental justice;

A framework and specific actions and commitments for justice and equity as integral elements of the low-carbon transition; and

A new social contract to connect public values to energy-system design.

A Greenhouse Gas Budget for the U.S. Economy

The starting point for decarbonization is to establish an overarching, economy-wide, cumulative GHG emission budget for the next several decades that produces an emissions trajectory leading to zero net emissions by midcentury. As discussed in prior chapters, net zero means that any remaining emissions at midcentury must be offset by negative emissions technologies such as afforestation, carbon capture and sequestration at electricity or industrial facilities, or direct ambient air capture and sequestration. (See Figure 2.2.)

For the United States, a net-zero target means that its net GHG emission budget between 2020 and 2050 is about 86 Gt CO2e assuming a linear phase down from emissions of net 5.7 Gt CO2e in 2020 to near zero in 2050.

A national emissions budget provides an unambiguous metric to assess whether policies are on track. The United Kingdom adopted a carbon budget in its Climate Change Act of 2009, where, in order to reach 80 percent emissions reduction by 2050, the government set up budgets for 5-year periods to serve as mileposts along the way to the 2050 target. The package of policies described in this report results in a robust suite of actions, incentives, investments, and transition-support programs, but these alone may not be enough, or their stringency may need to be tightened periodically. In particular, industrial emissions sources and a number of others, such as existing building equipment and nonroad transportation, face the economy-wide carbon price but are not otherwise directly regulated in our package. If, over time, the cumulative

Page 183

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

emissions budget is not achieved, these sectors may need direct regulation, the economy-wide carbon price may need to be raised, or zero-emission investment and/or technology incentives may need to be increased.

In this way, the policy provides the short- and medium-term price certainty of a carbon tax along with longer-term emissions certainty. That is, the budget provides a look-back mechanism as discussed in the referenced papers to make policy adjustments—including the tax level—depending on observed cumulative emissions. Unlike an ordinary cap-and-trade, which provides greater emission certainty and leaves cost uncertain, fixing a carbon price (through a carbon tax or a cap-and-trade with a price collar) leaves emissions uncertain (Weitzman, 1974; Burtraw et al., 2010; Fell et al., 2011). Therefore, other measures such as those discussed in the following sections may be needed to meet the cumulative emissions path and address adverse impacts on low-income communities and communities of color. Metcalf (2009) first proposed such measures. More recent discussions include two symposium discussions in the Harvard Environmental Law Review (2017) and Review of Environmental Economics and Policy (2020) (Aldy et al., 2017; Murray et al., 2017; Aldy, 2017; Hafstead et al., 2016; Brooks and Keohane, 2020; Aldy, 2020; Hafstead and Williams, 2020; Metcalf, 2020).

The committee recommends:

Congress should enact a national, cumulative, greenhouse gas emission budget, similar to Figure 2.2, that goes to net-zero in 2050 and that establishes separate sectoral benchmarks for net CO2 emissions from all sectors (industry, buildings, transportation, electricity, agricultural operations, net emissions from bio-energy with carbon capture and sequestration, and negative emissions from direct air capture, mineralization, forestry and agricultural soils, methane, nitrous oxide, and other non-CO2 greenhouse gases). With critical funding for the mandate, the Environmental Protection Agency (EPA) should report annually on current and projected progress against the budget and for key technological benchmarks in the industry, buildings, transportation, and electricity sectors. For strategic action in the building sector, EPA’s Portfolio Manager database that tracks measured energy use for U.S. buildings should enable prioritized actions for investing in building energy efficiency. Congress should further authorize and direct EPA to develop and report environmental indicators for areas where localized emissions and poverty pose environmental justice concerns.

Cost: $5 million/year.

Page 184

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

A Price on Carbon with Appropriate Measures to Address Competitiveness and Equity

As noted above, economy-wide carbon pricing is important to encourage emission reductions and to achieve net-zero emissions at the lowest cost. Carbon pricing is widely acknowledged by economists to be the key ingredient to achieve cost-effectiveness based on its ability to create consistent incentives throughout the economy to reduce emissions (Mufson, 2020). This is true along a pathway to zero emissions as well (Wigley et al., 1996).

But these same discussions also note that such a policy will need to include expenditures and programs, in particular, to avoid or mitigate inequities that will otherwise accompany such a policy, including impacts on low-income households and communities of color long exposed to the local air pollution that accompanies fossil-fuel combustion in power plants, buildings, vehicles, and industrial facilities. Additionally, carbon price policy should be designed in ways to avoid considerable disruption to trade flows in energy intensive industries highly exposed to import and export conditions.

The committee is not suggesting a carbon price do all the work, far from it. The regressive effects of carbon pricing on poor households is well documented (Metcalf, 2008; Rausch et al., 2011; Williams et al., 2015). Within income groups, Black households have higher residential energy expenditures than white households in the United States (Lyubich, 2020), so such a policy would have disproportionate effects on people of color. More generally, data show that even with very detailed socioeconomic information, there are considerable unexplained and irremediable differences in impacts across households (Pizer and Sexton, 2019; Rausch et al., 2011; Cronin et al., 2017; Fischer and Pizer, 2018; Green and Knittel, 2020). Thus, the typical response to addressing equity concerns with carbon pricing—directing payments to those adversely affected (Stavins, 2009)—only works to address broad regressivity or other easily targeted differences.

Distinct from equity concerns, there is the risk that carbon pricing will simply shift emissions and economic activity to jurisdictions with weaker regulation. This leads to both environmental (leakage) and economic (competitiveness) concerns (Jaffe et al., 1995; Frankel, 2008; Aldy and Pizer, 2015; Fischer and Fox, 2011). One way to address competitiveness is to design “border adjustments” for carbon pricing so that imports to the United States, and perhaps exports from the United States, are made competitive despite differences in carbon pricing. This is a complicated issue with distinct economic, political, legal, and practical issues (CBO, 2013; Kortum and Weisbach, 2017).

Another approach to address competitiveness impacts and some equity concerns has been to use carbon value to subsidize product prices (EPA, 2009; H.R. 2454,

Page 185

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

111th Cong., 2009). That is, rather than giving revenue to those adversely affected by higher prices or foreign trade, revenue from carbon pricing is used to lower the price of emission/energy intensive industrial products facing trade competition and reduce electricity bill impacts. Electricity and industrial producers would still have the incentive to reduce emissions. End users, however, may lose their incentive to consume less.1

These discussions of equity and competitiveness concerns and the ability to ameliorate them hinge on the level of the carbon price itself. Most analyses and experiences concern relatively modest prices, ranging up to perhaps $30–40t/CO2 (Cronin et al., 2017; EPA, 2009). The recent Climate Leadership Council proposes a price of $40t/CO2 in 2021, rising at 5 percent per year (Climate Leadership Council, 2020). An exception is several recent carbon pricing proposals in the 116th Congress, some of which could reach between $75t/CO2 by 2025 (C2ES, 2020a), which have not been analyzed for equity and trade impacts. Meanwhile, estimates of the price that would by itself drive to net-zero emissions by midcentury would be closer to at least $100t/CO2 over the next decade and perhaps much higher in the future (Kaufman et al., 2020). Even these higher prices assume that certain “market failures” are addressed through complementary policies, including those that encourage electric vehicle adoption and improve vehicle fuel economy, and assumptions related to lower electricity demand, additional coal plant closures, and faster innovation (Kaufman et al., 2020). At these carbon prices, less is known about the effectiveness of policies to address equity and competitiveness concerns. It should be noted that the amount of revenue generated from prices of about $40t/CO2 is approximately $2 trillion over a 10-year period (Horowitz et al., 2017; C2ES, 2019; Pomerleau and Asen, 2019). This revenue could be used for the funding of rebates and other activities to address the regressive nature of this policy and funding of clean energy investments.

With this in mind, the committee proposes not to select a carbon price designed to directly achieve net-zero emissions. Rather, it recommends that Congress adopt a policy meeting all of these objectives:

Implement a carbon price of $40t/CO2 in 2021 rising at 5 percent per year, targeting emissions from all uses of fossil fuels and industrial processes with GHG emissions. At these levels, existing research suggests equity and competitiveness concerns can be ameliorated. This would generate roughly $200 billion per year over the next decade, prior to any revenue use.

Cost: Negative cost/positive revenue of approximately $200 billion/year.

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1 To address competitiveness and leakage, it is important to use allocation to lower product prices and encourage more domestic production. This contrasts with efforts to simply compensate affected industries.

Page 186

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Address equity and fairness through both rebates and through funding of programs described in later sections within this chapter.

Address competitiveness through a combination of output-based allocations and carbon border adjustments. These should target energy-intensive, trade-exposed industries. Output-based allocations should be designed to mitigate trade effects entirely, and carbon border adjustments should be implemented only if the output-based allocations prove insufficient. This may require additional research and data collection around the carbon dioxide embedded in traded goods and relevant carbon pricing along the value chain.

As described in the remainder of this chapter, this carbon price will then be combined with additional, harmonized companion policies to achieve net-zero emissions (Burtraw et al., 2018) in ways that address equity and competitiveness imperatives. While recognizing this may raise the overall monetary cost to society compared to an approach that uses carbon pricing as the primary tool to drive mitigation,2 the committee’s approach has the advantage of focusing on equity, fairness, and trade, as well as cost-effectiveness. Moreover, it is not clear from existing research whether the standard equity and competitiveness mechanisms will be effective under a pure carbon pricing approach designed to achieve net-zero emissions by 2050. At the same time, the proposed carbon price and companion policies do not alone ensure net-zero emissions. This requires the budget and look-back mechanism to raise the carbon price, strengthen existing policies, or enact additional policies in the future if cumulative emissions exceed the net-zero path.

An Equity and Social Justice Framework

As is clear from earlier in the report, the committee believes that however critically important and urgent it is to reduce GHG emissions, it must be done in ways that support a just and equitable transition. As discussed in Chapter 3, the costs and benefits of the current energy system are unequally distributed and create disproportionately negative impacts for disadvantaged populations, and, absent targeted policies and policy reform, this situation risks being repeated in a future energy system.

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2 To the extent the committee’s companion policies simply correct other market failures (e.g., address innovation spillovers), they will not raise costs. However, the companion policies in the electricity, electric vehicle, and electric appliance market are designed to put an additional price on carbon emissions in these sectors. For example, one recent study suggests that a $150 per ton price might be needed to achieve 70 percent clean energy (implying an $85 per ton price for the clean energy standard). That same study also found only 41 percent of new car sales were electric vehicles even with a $150 per ton price (Larsen et al., 2020). Generally, this is not the most cost-effective way to address such additional market failures (Fischer and Newell, 2008).

Page 187

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

An effective approach to address equity and social justice dimensions in national energy policy requires oversight and coordination, the establishment of key criteria and programs to monitor them, and mandated commitments to seek out and provide resources to enable and assimilate the perspectives of historically marginalized stakeholders and groups into energy system design. Running across these threads is the imperative to develop strategies that are both top-down and bottom-up—for example, by coordinating the development of tools and processes for vulnerability assessment at a national scale while meaningfully including local stakeholders in the deployment of such tools and interpretation of their findings.

The following federal actions are necessary to build and implement an equity and social justice framework as part of the energy transition:

Congressional authorization of and appropriations for the convening of a 2-year National Transition Task Force comprised of nongovernmental community and expert stakeholders, with a directive for the Task Force to report to the White House Office of Equitable Energy Transitions, Congress, and the public on:

The vulnerabilities of U.S. labor sectors and communities to the transition of the U.S. economy to carbon neutrality;

The needs of diverse communities experiencing transition impacts and inequitable energy burdens, as well as research priorities to address these needs and the design of standards for an equitable and just transition;

A draft Presidential Policy Directive that would require relevant federal agencies to integrate equitable energy transition objectives into agencies’ policies, programs, procurement decisions, project reviews, grants, and other administrative decisions, and to do so on an expedited and cooperative basis while also ensuring inclusion of meaningful participation by relevant agency staff (no additional cost);

The history of successes and failures in prior U.S. efforts to support distressed communities and regions facing diverse economic challenges, lessons to be learned for efforts to address equity concerns in decarbonization policy, and strategies for integrating equity responses with wider U.S. efforts to address inequality in society as a whole; the provision of greater opportunities for the labor force and stakeholders in vulnerable communities to derive value from the energy, including through enabling them to have access to investments in low-/no-carbon infrastructures and buildings;

The adequacy of existing federal programs and support for vulnerable communities affected by the energy transitions (e.g., those related to abandoned-mine lands, coal ash sites, brownfields redevelopment

Page 188

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

programs), as well as recommendations for any needed changes in those programs or for any new programs to support equitable and just outcomes;

Analysis, insights, and recommendations to the EPA with regard to establishing cumulative air-emission limits, targets for local emissions reductions, and other environmental improvements (e.g., water quality, exposure to hazardous wastes) specific to local environmental justice communities;

Barriers and opportunities to successful and equitable public engagement processes for the planning of low-carbon energy systems;

Social, public health, and environmental risks of infrastructure abandonment from bankruptcies;

Federal decommissioning and remediation regulations, and the policy reforms needed, focusing on retired and retiring fossil-fueled generating plants and abandoned oil wells, natural gas wells, and coal mines while recommending a time frame to expand the analysis to other fossil fuel infrastructure; and

The design of a federal program for an ongoing triennial national assessment on transition impacts and opportunities with attention to the equity dimensions described above, with that assessment to be conducted by the Office of Equitable Energy Transitions (described below).

Cost: $5 million/year for Transition Task Force.

Congressional authorization of and appropriations for the establishment of an independent Office of Equitable Energy Transitions within the Executive Office of the President responsible for interagency coordination and assessment, analysis, and evaluation of the nation’s energy transitions. The functions of this Office would be to:

Establish criteria to ensure equitable and effective allocation of energy transition funding;

Establish targets for key indicators, annually evaluate progress toward those goals, and conduct the triennial national assessment on transition impacts and opportunities;

Ensure that appropriate equity standards and assessments are incorporated into implementation of all federal energy and environmental programs and regulatory decisions;

Assess and make recommendations to rectify the lack of representation of affected groups and stakeholders on the Secretary of Energy’s Advisory Board and other federal advisory committees (e.g., DOE’s Electricity Advisory Committee and EPA’s Clean Air Act Advisory Committee);

Page 189

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Oversee and coordinate federal agencies’ implementation of programmatic reforms in response to the public engagement evaluation conducted by the Task Force; and

Sponsor external research to support its work in establishing equity criteria, developing and assessing key targets for tracking equity and effectiveness indicators, and implementing improvements in federal agencies’ public engagement on the energy transition.

Cost: The annual cost to staff and fund the research, reporting, assessment, and other responsibilities of the Office of Equitable Energy Transitions will begin at $25 million per year, rising to $100 million/year starting in 2025.

A New Social Contract to Mitigate Harm and Expand Economic Opportunities for Impacted Communities

Chapter 3 recommends that any sustainable decarbonization strategy must build on a strong new social contract that commits to innovative and novel forms of public engagement and new pathways for creating public value from energy transitions. As indicated in Table 3.3.1 a wide range of communities either currently struggle or expect to be struggling with the impacts of climate change and of the energy transitions in diverse and sometimes multiple ways.

Building a social contract depends on ensuring equitable access to wealth generated by the transition, mitigating harms to vulnerable populations and geographies, pursuing new approaches to include diverse American voices in designing and creating low-carbon energy futures, and realigning how the public realizes value from and contributes to value in national energy policies and investments. Policy must also address socioeconomic and racial inequalities resulting from energy system architectures.

To these ends, the committee recommends that Congress:

Establish a new federally chartered, independent National Transition Corporation (NTC) to complement the functions of the White House Office of Equitable Energy Transitions, to ensure coordination and funding in the areas of job losses, critical infrastructure, and equitable access to economic opportunities and wealth creation. The NTC would be tasked with the following objectives:

Coordinate and leverage existing federal programs and agencies to deliver employment, housing, small business assistance, and other critical social services through temporary initiatives focused on decarbonization impacts and opportunities;

Page 190

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Deliver funding and implementation support for reclamation and remediation in the case of gaps caused by bankruptcies and asset orphaning;

Provide opportunities for low-income communities to develop projects that ensure low-income communities have a direct stake in the clean energy transition;

Demonstrate local commitment and provide direct distributions to replace critical public revenue shortfalls—including debt maintenance—based on eligibility and credit criteria; and

Effectively engage diverse, broad-based stakeholder groups in oversight and implementation of NTC programs.

The NTC would also have the responsibility to:

Recommend changes to laws or regulations to expand the notification requirements and thresholds in the Worker Adjustment and Retraining Act to give vulnerable communities and labor sectors adequate time to plan for and secure resources for retraining;

Establish an Energy Transition Jobs Initiative as a joint effort of the National Transition Task Force and Office of Equitable Energy Transitions, to aggregate and streamline delivery of support packages to transition frontline workers. This can be accomplished by updating the triggers and qualifying standards of economic adjustment programs to recognize the unique circumstances of transition frontline workers and to enable proactive planning and by extending support beyond the coal industry to extraction, processing, and distribution of other carbon-intensive energy resources;

Fund major community-based demonstration projects that strengthen equity outcomes and further NTC objectives to support activities such as fund reclamation and remediation in the case of orphaned infrastructure and unfavorable bankruptcy proceedings; fund the implementation and enforcement of existing laws to accomplish reclamation and remediation; direct distributions to replace critical revenue shortfalls; fund development opportunities for low-income communities to invest in a wide range of clean energy projects, including distributed renewable energy, energy storage, microgrids, and transportation.

The value of a federally chartered corporation model is that it can be endowed with dedicated funding and empowered to act strategically in the interest of its charter, giving it the necessary autonomy to act both quickly and continuously. Stable sources of funding that can be used for relevant governmental purposes are essential to provide predictability and secure success of transition initiatives. The NTC will be governed by five members who are Senate-confirmed presidential appointees, with staggered 4-year terms and with no

Page 191

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

more than three members of the same party. That Board will select and hire a chief executive officer who reports directly to a Board of Directors. The members of the Board shall have relevant experience in working with economic development, communities in transition, persistent poverty geographies, and Black, Indigenous, people of color (BIPOC) communities.

The NTC will provide funding in the form of grants and other direct distributions to provide subsidies for certain private investments. The NTC will be directed to establish a formula to distribute the transition funds directly to local governments. The NTC formula should also include a cost share requirement for recipients. The NTC’s distribution formula will prioritize locations currently experiencing an acute fiscal crisis associated with the actual or expected loss of revenue resulting from the closure of energy-generating or energy-refining facilities or from the decline or closure of resource extraction activities (e.g., coal, oil, and natural gas). Eligibility will also consider community characteristics including social and economic measures of income, poverty, education, geographic isolation, and others identified by the White House Office of Equitable Energy Transitions in the interest of identifying cases of past energy injustices.

Cost: $20 billion in funding over 10 years. This is based on $3 billion for the Energy Transition Jobs Initiative, up to $2 billion for reclamation work, and $15 billion to support communities through grants, loans, loan guarantees, and/or subsidies for development projects and direct distributions. Congress should provide an initial no-year appropriation (which can be held until it is used up) of $10 billion at the outset, with $1 billion a year in additional annual funding.

SETTING RULES AND STANDARDS TO ACCELERATE THE FORMATION OF MARKETS FOR CLEAN ENERGY THAT WORK FOR ALL

Because the carbon price recommended in this report will not be sufficient to drive decarbonization to net zero, specific sets of rules and standards are needed to guide private-sector decisions so that they are aligned with achieving decarbonization while realizing social goals. The first of these is a zero-emission standard for the power sector (also known as a clean energy standard). Others include energy-efficiency standards for appliances; energy efficiency standards for new and existing buildings; CAFE/GHG emissions standards for vehicle fleets; standards for the design of zero-carbon electricity markets; standards for labor engaged in clean-energy work; standards for corporate reporting of climate risk; and standards for U.S. government procurement.

Page 192

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

The committee will address additional standards for other sectors of the economy—rail and air transportation, industrial energy use, and existing (versus new) buildings and vehicles—in its final report.

A Clean Energy Standard for Electricity

A clean energy standard for electricity is a relatively cost-effective way to eliminate emissions in the power sector that also mitigates some equity and competitiveness concerns. Simple carbon-pricing raises electricity prices for two reasons: the technological cost of producing electricity with less CO2 (Palmer et al., 2018; Larson et al., 2018), and charges for the remaining CO2 emissions (Fischer and Pizer, 2018). This “carbon charge” is a rent or payment that accrues to someone in the form of allowance value (if allowances are freely allocated under cap-and-trade) or to the government (if allowances are auctioned or under a carbon tax). It is generally paid by end users of electricity, and serves as an appropriate incentive to conserve electricity in order to reduce emissions further (Ho et al., 2008).

Many policies, proposed and implemented, suggest ways to use carbon revenue to depress adverse effects on electricity end users, including equity and competitiveness effects (California Climate Investments, 2020; H.R. 2454, 111th Cong., 2009; Tierney and Hibbard, 2019). Other carbon pricing programs in the electric sector—for example, the multistate Regional Greenhouse Gas Initiative—auction the allowances and then reinvest the proceeds in consumers’ bill reductions or energy efficiency measures (which further reduce consumers’ electricity bills; see Hibbard and Tierney, 2011; Hibbard et al., 2018). Others propose to give allowances to local utilities, who are instructed to use the allowance value to protect end-users (e.g., H.R. 2454, 111th Cong., 2009).

There is conflicting evidence if California’s cap-and-trade program has yielded improvements in environmental equity with respect to health-damaging co-pollutant emissions. Cushing et al. (2018) presents evidence from California’s cap-and-trade program showing emissions of co-pollutants associated with ambient air quality and human health effects (particulate matter, nitrogen oxides, sulfur oxides, volatile organic compounds, and air toxics) increasing in socioeconomically disadvantaged communities. However, in a recent study, Hernandez-Cortes and Meng (2020) suggest that the program has reduced the pollution exposure gap between disadvantaged and other communities.

An alternative approach is a clean energy standard (CES) in the power sector (Aldy, 2011). Such a policy addresses some equity and competitiveness concerns by depressing the price effects on end users relative to simple carbon pricing. This policy still involves the potential for certain justice concerns, particularly if credit trading leads to

Page 193

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

more emissions in disadvantaged communities. Moreover, the committee still recommends additional competitiveness and especially equity-related policies elsewhere in this report. In one design, allowances would still be required for GHG emissions from electric generators, as under carbon pricing. Allocation, however, would be based on the volume of electricity generation and the established standard “performance rate” (this is sometimes called a rate-based approach). Individual generators are typically credited or debited based on their performance relative to the standard.3 Generators buy and sell credits in a market, which establishes a transparent price. A policy to achieve carbon neutrality in the power sector would gradually ramp the performance rate to zero. For example, with the U.S. power sector currently emitting roughly 0.45 tons of CO2 per megawatt hour (EIA, 2020), a policy that started with a performance rate of 0.45 and declined to zero by 2050, would fully decarbonize the power sector. There are a number of additional design options and nuances in this type of policy that are discussed in the literature (e.g., Aldy, 2011; C2ES and RAP, 2011; Fitzpatrick et al., 2018; Cleary et al., 2019).

A second approach to the design of a CES would focus on requiring sellers of retail electricity to rely on an increasing share of zero-carbon sources. This approach would operate along the lines of the current renewable portfolio standards (RPS) that have been adopted by 30 states and the District of Columbia, or like the CES adopted in 4 states (DSIRE, 2019). Under a similarly designed national CES, the policy could call for increasing amounts of zero-carbon supply, expressed as a percent or share of total sales, with a target year for reaching a 100 percent. Each year, retail sellers of electricity need to demonstrate that they have a power supply portfolio that satisfies the required percentage of zero-carbon resources. Retail sellers with excess zero-carbon generation can sell credits to sellers with deficits, such that the overall national system hits the target. This approach would help to pull zero-carbon resources into the system while increasingly restricting fossil generation that does not include carbon capture (Cleary et al., 2019; U.S. Congress, House, 2020b). It is generally criticized, however, in not discriminating among higher and lower emitting fossil fuel sources on the pathway to zero emissions (Aldy, 2011).

It should be noted that Congress has recently introduced multiple CES bills (S.1359, 116th Cong., 2019; S.1974, 116th Cong., 2019; H.R.7516, 116th Cong., 2020) and the House Climate Crisis Committee Report released in June 2020 also featured CES, indicating existing political support and momentum for this approach.

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3 For example, if a coal plant emits 1 ton per megawatt-hour as it produces 100 megawatt hours, and the standard is 0.2 tons/MWh, it will owe the regulator (1 ton/MWh—0.2 tons/MWh) × 100 MWh = 80 tons worth of credit. Meanwhile, low carbon electric generators, including zero-emitting sources, earn credits based on the amount they beat the standard and the amount of electricity that they sell. A zero emitting source facing the same 0.2 tons/MWh standard, and generated 100 megawatt hours, would earn 20 credits (denominated in tons of carbon dioxide).

Page 194

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Note that a power-sector standard policy would operate alongside the economy-wide carbon price that would also cover the electricity sector. To the extent that the economy-wide price is sufficient to decarbonize the power sector, the CES will have little effect. However, it is anticipated that the chosen economy-wide price will not be sufficient. The CES will provide the necessary additional incentives to drive the sector to zero emissions.

The committee recommends that Congress:

Adopt a clean energy standard for electricity along the lines of Aldy (2011) designed to reach roughly 75 percent clean electricity share by 2030 and a declining emissions intensity reaching zero net emissions in 2050.

Electrification and Efficiency Standards for Vehicles, Appliances, and Buildings

As noted earlier in this report, reaching a net-zero economy will require significantly and rapidly reducing power sector emissions and the electrification of a substantial portion of vehicles, buildings, and appliances. Moreover, it is critical to pursue substantially increased energy efficiency in order to reduce the total amount of electric capacity needed to meet demand and to help control energy costs. The overarching carbon-pricing policy described in the earlier section will likely be insufficient to drive demand reduction as a critical step in effective low-carbon electrification.

Minimum energy efficiency standards for appliances, building efficiency standards, and average vehicle fuel-economy standards have been long used to drive increased energy efficiency and energy productivity (Alliance Commission, 2013; Nadel et al., 2015). There is a long-running debate in economics about the role of these types of standards, and whether decisions regarding the purchase of energy efficient equipment are subject to various market failures (Hausman and Joskow, 1982; Fischer, 2004; Jaffe et al., 2004; Gillingham et al., 2004, 2006; Houde and Spurlock, 2016). There has also been discussion of shifting the minimum standards for appliances to average standards, similar to those for vehicles, to increase cost-effectiveness (USG, 2017). There have been pro and con arguments for such changes, with some asserting that the added flexibility would reduce compliance costs for manufacturers and prices for consumers and others arguing it would add undue levels of complexity to program administration and allow standards to backslide (Blonz et al., 2018; Urbanek, 2017). Nonetheless, there is general recognition that these standards have been shown to drive increased efficiency (Doris et al., 2009), to avoid fuel consumption, and to reduce GHG emissions (Greene et al., 2020).

Energy use in buildings accounts for approximately 28 percent of total U.S. energy consumption, taking into account both buildings’ direct use of energy and their use of

Page 195

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

electricity (DOE, 2020a). One approach that has been shown to help achieve efficiency improvements is to measure a building’s energy use, benchmark it (e.g., relative to its own past use or to comparable buildings or to an advanced “stretch” building code), and then provide the information to the building’s owner, manager or occupant (EPA, 2012; Palmer and Walls, 2015; Meng et al., 2016). Such benchmarking helps to drive the market for efficiency services and reduction in buildings’ energy use. Policies relating to building codes and standards have typically been the domain of states and local government. The DOE has supported policy assessments and the provision of information to stakeholders, but even so, as of January 2020, only 35 U.S. localities and 3 states had adopted benchmarking and transparency policies that require reporting of energy consumption for public and privately owned commercial and/or multifamily buildings (IMT, 2020). The federal government should expand its outreach of and support for adoption of benchmarking and transparency standards by state and local government.

Given its status as the largest landlord in the United States (Jungclaus et al., 2017), the federal government also has a more direct role to play in making its buildings more energy efficient and less carbon intensive. The federal government should set an emissions cap for existing and new federally owned buildings, with the cap declining at 3 percent per year (Architecture 2030, 2014) and with emissions reductions accomplished through energy efficiency upgrades, switching to electric or district systems, and/or generating/procuring carbon-free renewable energy. These federal-building emissions caps would be models for states and municipalities to set standards for buildings with public and private sector ownership (such as has already occurred in New York City, whose 2019 Local Law No 97 requires large existing buildings to reduce their emissions by 40 percent by 2030 and 80 percent by 2050, from a 2005 baseline; see NYC, 2019).

In order to drive further energy efficiency for appliances, buildings, and transportation, existing programs and policies will need to be adapted and strengthened in the future. Existing laws allow DOE to set appliance standards to levels “technologically feasible and economically justified,” but regulatory action has varied over time (Clark, 2019). Vehicle standards are focused on increasing miles-per-gallon and reducing emissions for gasoline and diesel vehicles, not improving efficiency of future electric vehicles (C2ES, 2020b). Resources exist for states to continue to improve building regulations (DOE, 2020b; California, 2020a). Further work is necessary to strengthen these standards in preparation for increases in electrification.

There is less experience with direct electrification regulation itself. California has mandated a certain fraction of passenger vehicle sales to be zero-emission vehicles (ZEVs) since 1998, although this standard was modified frequently in its early stages as vehicle batteries lagged in their development (NRC, 2006; Collantes and Sperling, 2008).

Page 196

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

The current requirement will reach 22 percent by 2025 (California, 2020b) and California’s governor has recently issued an executive order requiring sales of all new passenger vehicles to be zero emission by 2035 (Office of the Governor, 2020). Ten other states (Colorado, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont) have adopted California’s ZEV requirements for their own vehicle fleets (EDF, 2019). EV policies could be extended and expanded to require increased vehicle electrification at the national level for the ground transportation sector. Policies should expand the current focus beyond light-duty vehicles, to include medium- and heavy-duty vehicles.

To further electrify household and commercial appliances (heating, hot water, and cooking) will require additional policies. Appliance electrification policies could mirror the EV mandates, requiring manufacturers to sell an increasing fraction of electric products with the flexibility to trade among manufacturers. Alternatively, the policies could be focused on emissions per product to be reduced over time to zero, similar to the clean energy standard for electricity described above.

Distinct from increasing restrictions on fossil fuel equipment, a number of jurisdictions have recently adopted building codes to encourage electrification. This includes policies to reduce access to natural gas (Margolies, 2020) or require all-electric appliances through “reach” codes (DiChristopher, 2020). The California Energy Commission is preparing a modification to its Building Energy Efficiency Standards to mandate new construction to be all electric starting in 2023. The Rocky Mountain Institute found that delaying an all-electric construction requirement to the 2025 code cycle would result in 3 million additional tons of carbon emissions by 2030 and more than $1 billion of spending on new gas infrastructure (Grab and Shah, 2020). Building codes to drive electrification could be encouraged at the federal level but would be implemented at the state level in the United States, given state-level authority (Vaughan and Turner, 2013).

The committee recommends that Congress:

Direct EPA to establish a national zero-emission vehicle standards. They should be set on a timetable to achieve 50 percent of new sales of light-duty vehicles and 30 percent of sales of medium- and heavy-duty vehicles by 2030 (either EVs or fuel-cell vehicles).

Direct EPA/DOT to continue tightening light-duty vehicle fuel economy/greenhouse gas emissions standards beyond model year 2026.

Direct DOE to establish a national zero-emission appliance manufacturing standard covering all fossil-emitting building uses (space heating/cooling, hot water, and cooking). This should be modeled after the ZEV vehicle standards and achieve full electrification by 2050.

Page 197

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Reaffirm that the DOE continue to establish minimum efficiency standards for appliances, particularly targeting electric appliances.

Direct DOE/EPA to expand their outreach of and support for adoption of benchmarking and transparency standards by state and local government through the expansion of Portfolio Manager.

Direct DOE/EPA to further investigate the development of model carbon neutral standards for new and existing buildings that, in turn, could be adopted by states and local authorities.

Direct the General Services Administration (GSA) to set an aggregate emissions cap for existing and new federal buildings, with the cap declining at 3 percent per year. GSA should prioritize high-reduction, low-cost actions.

Cost: None of these actions would require an additional appropriation by Congress beyond the program management resources.

Improved Regulation and Design of Power Markets for Clean Electricity

Given the outsized role that the electric sector will need to play in a low-carbon energy economy, electric systems need to operate efficiently and reliably, to attract capital for significant new infrastructure investment in a timely way, and to provide economically accessible power for all Americans. In conjunction with the overarching market-based policies to explicitly price and directly drive down power-sector CO2 emissions to net zero, the structure and design of retail utility regulation and wholesale electricity markets together need to support such investment, operations, and reliability. Wholesale market design, combined with state and federal policies, will play key roles in enabling new zero-carbon resources to enter the market as rapidly as possible (and for others to remain in operation, where current power market conditions do not support continued operations of certain existing zero-carbon resources in the absence of carbon prices).

It is well understood that tomorrow’s electric system will depend increasingly on low-carbon resources with high upfront capital costs and very low operating costs (Aggarwal et al., 2019; Bielen et al., 2017; Corneli, 2018; Ela et al., 2014; Pierpont and Nelson, 2017.) This is a different set of conditions than those in place when many regions of the United States adopted centrally organized energy and capacity markets for electric power (Clements, 2017; Joskow and Schmalensee, 2020). Even with a national policy that prices carbon emissions into electricity markets and requires the share of zero-emission generation to rise to 100 percent, conditions in the future will tend to produce very low electric-energy prices during more and more hours of the year. In turn, revenues in wholesale energy markets alone are not likely to be sufficient to support accelerated entry (and maintenance) of zero-carbon technologies in many regions of the county.

Page 198

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Distinct from designing wholesale markets that work with increasing and eventually 100 percent zero-carbon sources, many states are interested in pursuing their own efforts. The federal government should encourage rather than discourage those efforts. Wholesale markets will need to allow for states’ policy-driven market-based instruments (such as competitive power procurements leading to long-term contracts for off-shore wind, storage, carbon capture, utilization and storage, and other technologies), and this may require Congress to direct the Federal Energy Regulatory Commission (FERC) to accommodate such state-supported approaches. (This might be akin to the provisions of the amended Federal Power Act that state that “no wholesale transmission order may be issued that is inconsistent with any state law governing retail marketing areas of electric utilities” [16 U.S.C. 824k(g)], which was intended to harmonize states’ decisions regarding the structure of the electric industry in their states with FERC’s role in encouraging open access to transmission.)

Although today’s wholesale market designs vary across these regions, all of the Regional Transmission Organizations (RTOs)/Independent System Operators (ISOs) that operate the markets use bid-based markets for wholesale electricity with security-constrained economic dispatch and locational-marginal pricing mechanisms. Such markets are the gold standard for efficient operations of a portfolio of resources in place at any point in time (Fox-Penner, 2020; Joskow and Schmalensee, 2020; Hogan, 2014, 2017). Some argue that energy-only wholesale markets (e.g., without capacity markets) with opportunity-cost pricing and bilateral contracting will perform well in the future (Hogan, 2017; Gramlich and Hogan, 2019). Stakeholders in many regions of the United States, however, may not support such an approach. Analysis also suggests that such designs are not likely to support entry of clean energy resources on a fast-enough time frame consistent with the nation’s decarbonization needs (Fox-Penner, 2020; Joskow and Schmalensee, 2020). Also, it is not clear that the centralized capacity markets in several RTOs are sustainable as they are currently configured, because there is so much tension in states’ efforts to support contracts that retain or pull zero-carbon resources into the market.

Those parts of the United States with traditional utilities and no retail competition may be better positioned for investment in zero-carbon technologies in light of rate-base treatment of fixed costs and the ability for utilities to sign long-term contracts with third-party suppliers (Joskow and Schmalensee, 2020; Corneli et al., 2019; Fox-Penner, 2020.) In these markets, states already can use mechanisms such as least-cost planning, competitive power procurements, and utility investments to shape their supply portfolios. (Many of the committee’s recommendations for federal action aim at encouraging these and other states to take more aggressive action to reduce carbon emissions from their power sector and elsewhere in local economies.)

Page 199

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

In all parts of the United States, most electricity consumers will need to be exposed to real-time, locational pricing in order to provide flexible demand and to avoid the large capacity additions that would otherwise be needed in its absence. FERC has supported adoption of market rules in RTO wholesale markets to accommodate supply from distributed energy resources (FERC Order 2222; [FERC, 2020]), including specifically addressing energy storage (FERC Order 841; [FERC, 2018]) and demand response (FERC Order 745; [FERC, 2011]). Presumably at the retail level, there will be utilities and third-party intermediaries to provide different pricing and service-delivery options to consumers, but the former will need to be able to see real-time pricing. In parallel, there will need to be advanced meters to open up access to flexible demand and demand management strategies. The federal American Recovery and Reinvestment Act (ARRA) stimulus package provided approximately $3.4 billion to accelerate electric utilities’ deployment of advanced meters and related infrastructure, and led to roughly 16 million meters being installed around the United States (DOE, 2015, 2016). As of 2018, however, nearly half of the nation’s electricity meters—43 percent of residential meters, 46 percent of commercial meters, and 49 percent of industrial meters—did not have advanced two-way communications capability enabling visibility on real-time prices and supporting flexible demand (EIA, 2019).

The committee recommends that:

FERC work with RTO/ISOs to ensure that markets in all parts of the country are designed to accommodate the shift to 100 percent clean electricity on the relevant timetable.

Congress clarify that the Federal Power Act does not limit the ability of states to use policies (e.g., long-term contracting with zero-carbon resources procured through market-based mechanisms) to support entry of zero-carbon resources into electric utility portfolios and wholesale power markets. Congress should further direct FERC to exercise its rate-making authority over wholesale prices in ways that accommodate state action to shape the timing and character of the transitions in their electric resource mixes.

Congress reauthorize FERC’s Office of Public Participation and Consumer Advocacy to provide grants and other assistance to support greater public participation in FERC proceedings.

Cost: $8 million/year.

FERC direct the North American Electric Reliability Corporation (NERC) to establish and implement standards to ensure that grid operators have sufficient flexible resources to maintain operational reliability of electric systems.

Congress direct and fund the Department of Energy to provide federal grants to support the deployment of advanced meters for retail electricity customers as

Page 200

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

well as the capabilities of state regulatory agencies and energy offices to review proposals for time/location-varying retail electricity prices while also assuring that low-income consumers have access to affordable basic electricity service.

Cost: $4 billion over 10 years.

Labor Standards for Clean Energy Work

The transition to clean energy presents enormous opportunities for job growth in clean energy sectors, which is already occurring. In 2019, there were 3.6 million workers in clean energy jobs in the United States, including energy efficiency, electric and alternative fuel vehicles, solar energy, wind energy, biofuels, and battery storage (NASEO and EFI, 2019).

Clean energy jobs have higher wages than the national average and tend to have lower educational requirements, making them more accessible (Muro et al., 2019). However, the reality is that the energy transition thus far has largely displaced good-paying, stable, and high-benefits jobs and has not created jobs with comparable wages, benefits, locations, and hours (see Partridge and Steigauf, 2020, for example). An illustrative 2015 analysis of the Clean Power Plan, which would have mandated emissions reductions in existing power plants, showed that while net jobs were created, the jobs lost were less likely to be low wage and less likely to require a 4-year degree (Bivens, 2015). As stationary fossil fuel plants are retired and replaced by distributed wind and solar, this imbalance between the quality of jobs lost and the jobs gained can be mitigated with federal assistance, complementary policies, and the cooperation of organized labor. Additionally, ensuring that jobs created in clean energy are high-wage, safe, family-supporting jobs that enable communities and workers to capture the benefits of clean energy will maintain the social contract.

To ensure that such jobs are created in the transition, labor standards should be attached to federal funding and support for clean energy projects. The Davis-Bacon Act may be referenced as an existing standard that has an accepted framework for its use. The use of Department of Transportation and Department of Housing and Urban Development funds and their pass-through programs such as the Community Development Block all require compliance with the Davis-Bacon Act. Bids for utility-scale wind and solar development projects, which contain these types of policies, are already cost-competitive in many areas (such as California, for example), and good wages and benefits lead to a safer and more productive construction workforce that is highly skilled and trained (Jones et al., 2016). Even if labor standards increase the cost of labor, the cost of labor for installation of utility-scale wind and solar projects is less than 10 percent of the total development costs (Fu et al., 2018; Stehly and Beiter, 2019).

Page 201

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

There are a number of pathways to increase wages. Historically, labor unions have been a pathway to the middle class and economic prosperity for Americans and a way to improve workers’ wages (Voos, 2009; Ahlquist, 2017; Bivens et al., 2017; Farber et al., 2018). Although politically contentious, they have also proven to increase worker safety and reduce income inequality. Other ways to increase income include earned income tax credits and a minimum wage. For the past several decades, however, American workers have faced wage stagnation, rising income inequality, and coordinated efforts to remove their right to organize (Horowitz et al., 2020; Shierholz, 2019). To maintain the social contract for a transition to net zero, workers must be assured that the clean energy economy can work for them and that their rights will be protected.

The committee recommends that:

Federal grants, loans, tax incentives, and other support for projects should be conditioned on recipients and their contractors meeting strong labor standards (including Davis-Bacon Act prevailing wage requirements, compliance with all labor, safety, environmental, and civil rights statutes), requiring that federally funded construction and infrastructure project developers sign Project Labor Agreements (PLAs) where relevant, and requiring recipients of federal incentives negotiate Community Benefits (or Workforce) Agreements (CBAs), where relevant.

Cost: No direct additional costs to federal government.

Standards for Corporate Reporting

The financial performance of countless and quite-different American companies—which account for 88 percent of U.S. economic activity4—and the interests of both shareholders and workers will be affected by climate change. Many firms’ assets, operations, and/or supply chains will be physically and financially impacted by a changing climate (e.g., from extreme weather events and temperature change). Others’ business models are vulnerable to reputational risk or market competition. Many businesses will grow in a transition to a low-carbon economy. Others will be challenged because their operations and those of their suppliers face the possibility that public policy or litigation will require deep reductions in GHG emissions in the future. This is true for companies that are directly involved in the energy industries as well as companies in the larger economy whose businesses will be affected by incremental and fundamental changes in energy markets.

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4 This metric reflects 2018 value added by private industries as a percentage of gross domestic product (BEA, 2018).

Page 202

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Although the magnitude, timing, location, character, distribution, and costs of such climate-related risks (and opportunities) are uncertain (Weitzman, 2009), they are systemic and may lead to significant disruptions in markets, financial institutions, the economy, communities, and workers (Ramani, 2020).

Investors depend on well-functioning financial markets with transparent information. “Open economies of sound macroeconomic policies, good legal systems, and shareholder protection attract capital and therefore have larger financial markets” (World Bank, 2020).

Financial markets play an essential role in the economy by pricing risk “to support informed, efficient capital-allocation decisions,” but many companies do not provide sufficient information to show that they adequately factor in climate-related risks. “More effective, clear, and consistent climate-related disclosure is needed from companies around the world” (TCFD, 2017).

Many financial risk-management experts observe that climate risk still is poorly priced into financial markets, in part because there is inadequate transparency in corporate financial statements and because it is difficult to assign probabilities on government action (Litterman, 2020a,b). Even recognizing growing investor interest in companies with positive environmental, social, and governance (ESG) practices and outcomes (Fink, 2020; Eccles and Klimenko, 2019), many companies have not integrated climate risk into their governance and fiduciary responsibilities (Zaidi, 2020).

Many investors, financial fiduciaries and other fund managers, and others have called for reforms in financial markets to address and internalize climate risk into companies’ information disclosures (Vizcarra, 2020), and in their internal financial, economic and risk analyses, systems, metrics (TFCD, 2017). Several bills have been introduced in Congress to accomplish such objectives, and the House Select Committee on the Climate Crisis has recommended several legislative actions to “expose climate-related risks to private capital to shift assets toward climate-smart investments” (U.S. Congress, House, 2020b).

The committee recommends that Congress:

Direct the Securities and Exchange Commission (SEC) to require public companies to formally disclose their risks from adverse impacts of climate change mitigation policies and climate change as part of their annual filings to the SEC.

Direct the Federal Reserve to identify climate-related financial risks, including by applying climate change policy and impact scenarios to financial stress tests.

Page 203

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Direct federal agencies (e.g., EPA, Department of Energy [DOE], Department of Transportation [DOT], House and Urban Development [HUD], FERC, SEC) to incorporate risks and costs from climate policies and climate change into the benefit-cost analyses required prior to the adoption of regulations or standards, or approval of public or private infrastructure investments).

Require private firms to report their energy-related research and development investments by category (e.g., fossil, solar, wind) annually to the Department of Energy.

Cost: No cost beyond administrative.

In additional the committee recommends:

The Commodities Future Trading Commission should build on the recommendations of the report Managing Climate Risk in the U.S. Financial System (Climate-Related Market Risk Subcommittee, 2020) to ensure that climate risk is better reflected in the commission’s and other federal financial agencies’ oversight of commodities and derivative markets.

U.S. Government Procurement Policy and Domestic Clean Energy Markets

Even with increasing deployment of clean technology, the U.S.’ ability to manufacture such technologies is not keeping pace. In some instances, the United States depends on imports from other countries for materials and components critical to a clean economy. “Under current government procurement policies and trade rules, much of the public spending for infrastructure and clean energy systems would leak away to foreign providers, in the form of increased imports” (Scott, 2020).

Failure to produce these technologies domestically puts the United States at risk and threatens future jobs and the economy. Making these products in the United States is critical to leadership in the clean economy and necessary for innovation and global competitiveness. Developing solutions to the economics and foreign competition conundrum is an important part of developing a domestic clean energy market. However, while the United States needs to be able to produce final products like wind turbines and solar panels domestically, the majority of manufacturing jobs in many energy-related sectors are at supplier companies, not the end assembler or original equipment manufacturers. In the auto industry, for example, three out of every four manufacturing jobs are parts workers (Ruckelshaus and Leberstein, 2014). A robust domestic supply chain for these products is critical for innovation but also for resilience and to withstand disruption, which has become evident during the COVID-19 global pandemic.

Page 204

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

“Buy American” or “Buy America” provisions require that projects funded directly or indirectly with federal dollars use specified products such as iron and steel made in the United States, ensuring that the United States maintains the ability to produce critical materials and products (Morgan, 2019). These provisions have been added to federal infrastructure bills and passed with bipartisan support: the bipartisan American Water Infrastructure Act (AWIA) of 2018 was passed with a Buy America provision requiring that drinking water infrastructure supported by funds from the Drinking Water State Revolving Fund is built with U.S.-made iron and steel (see American Iron and Steel provision in CRS, 2018). The ARRA of 2009 included a Buy American provision that required domestic sourcing of iron, steel, and manufactured goods for projects funded by the stimulus (DOE, n.d.).

Many industrial materials such as iron, steel, chemicals, cement, and concrete have high levels of embodied carbon emissions (see, e.g., Fischedick et al., 2014). To meet the goal of net-zero emissions by 2050, embodied carbon emissions in materials must decrease. A Buy Clean procurement policy will drive down embodied carbon emissions within products by establishing a baseline level of emissions intensity for key input materials and requiring that a percentage of materials procured achieve that baseline or lower. Focusing on federal, state, and local government procurements—which, according to expert testimony, account for the purchase of 90 percent of the cement and concrete and 50 percent of the steel used in the United States (Friedmann, 2019)—could create significant demand for cleaner materials and create a high-achievers market. Further, investments in innovation in materials and assemblies that reduce embodied carbon, including the development of alternative high-performance products that can be manufactured in the United States, could be achieved through dedicated National Science Foundation and DOE programs.

Deep decarbonization also means that the United States should have policies that help to avoid the leakage of emissions overseas, which occurs when the U.S. imports materials with high embodied carbon emissions. A recent report estimates that 25 percent of the world’s total emissions pass through a carbon accounting loophole by not including embodied carbon emissions of imported products in the consuming country (Moran et al., 2018). While these emissions are being debited at the producer side, it can allow countries that import products with high embodied carbon emissions, such as steel and cement, to avoid fully accounting for this portion of their carbon footprint. A Buy Clean procurement policy would reduce the offshoring of U.S. emissions while strengthening clean U.S. manufacturing and increasing global competitiveness of U.S. industry.

Developing a Buy Clean standard will require a number of elements: deciding products for which Buy Clean applies; defining a standardized life cycle emissions

Page 205

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

accounting system (such as Environmental Product Declarations [EPDs]) so that emission intensity can be compared for those products; and setting a maximum emission intensity for each product. This accounting system should build on existing certification programs such as Energy Star. Stakeholder engagement with industry, academia, workers, and community groups to determine the products and materials covered and set the benchmarks should be undertaken to ensure a transparent decision-making process.

The State of California passed the Buy Clean California Act in 2017, which covers concrete-steel rebar, flat glass, structural steel, and mineral-wool board insulation and uses EPDs for emission intensity reporting. The Department of General Services is tasked with establishing the maximum emission intensity for products by January 2021 (CA DGS, 2018). The CLEAN Futures Act introduced in January 2020 would establish a similar Buy Clean program nationally (U.S. Congress, House, 2020a,c).

A comprehensive Buy Clean policy might include an additional requirement that a portion of procurements meet higher emissions standards, creating a high achievers’ market to drive down emission intensity and cost. It would likely also include direct support for manufacturers to conduct life cycle analysis and report emission intensity of their products (the CLEAN Futures Act includes technical assistance for this) as well as make efficiency and technology improvements to lower their emissions. A “Buy Fair” component added to a Buy Clean standard would ensure that labor standards are met as well.

Establishing comprehensive policy and generating a set of standards will require a stakeholder engagement process and development of accounting and reporting infrastructure. An initial, immediate step is to begin to build the accounting and reporting infrastructure.

The committee recommends that Congress:

Ensure that Buy American and Buy America provisions are appropriately applied and enforced to cover key materials and products on federally funded projects.

Cost: No direct cost.

Direct EPA and DOE to establish an EPD library to create the accounting and reporting infrastructure to support the development of a comprehensive Buy Clean policy.

Cost: $5 million/year for EPA and DOE to cover information requirements and administrative needs.

Page 206

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

INVESTING IN A NET-ZERO U.S. ENERGY FUTURE

Policies aimed at unleashing public and private investment will be required during the first 10 years of the energy transition. The necessary investments take many forms: investment in long-distance transmission of renewable energy or in EV-charging networks; investment in education and training to build a talented workforce that is fit for service in a low-carbon economy; investment in domestic manufacturing of clean energy technologies; investment in R&D for technology innovation and deployment; investment in understanding and mitigating the impacts of decarbonization on communities; and investment in building resilient communities in a low-carbon economy. The committee thus proposes a number of institutions and policy instruments designed to mobilize public and private investment in and financing of the energy transition.

Creation of a Green Bank

Although the transition might be achieved while spending only a fraction of gross domestic product (GDP) that the nation currently allocates to its energy system, the transition will be much more capital intensive than business-as-usual (Chapter 2). Private sources are unlikely to provide the needed capital, especially during the 2020s when the effort is new. To ensure industrial competitiveness and quality of life, the United States should establish a Green Bank to mobilize finance for low-carbon infrastructure and business in America. Partial financing by a Green Bank would reduce risk for private investors and encourage rapid expansion of private source capital. Such a bank would underpin the broad economic and social transitions required to achieve net-zero emissions by midcentury. The new bank should lend, provide loan guarantees, make equity investments, cooperate with community banks to increase the availability of finance at the local level, and leverage private finance consistent with a national strategy to compete internationally in low-carbon industries and transform the U.S. economy. It should make particular effort be a source of credit for innovative small and medium-size enterprises that may be locked out of commercial markets owing to their size. The Green Bank can be a lead investor on big decarbonization projects that serve the public good, de-risking and leveraging larger commercial investors. It should address inequities in the financing system, working with local banks, co-ops, and rural and other marginalized communities. It can also play a countercyclical role by scaling up lending operations when private banks contract (Luna-Martinez and Vicente, 2012), which is essential to sustained and uninterrupted access to finance during the low-carbon transition.

U.S. companies have to compete globally with German, British, Indian, and Chinese firms, among others, all supported by government-backed financial institutions

Page 207

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

that have a specific public policy mandate. The German KfW, UK Green Investment Bank, China Development Bank, and Industrial Development Bank of India are a few examples. The German KfW is one of the largest development banks in the world, with assets exceeding €500 billion. It was initially the sole lender in Germany to solar companies, prior to financing from private banks. The China Development Bank holds assets exceeding $1 trillion and likewise has invested heavily in renewable energy and low-carbon infrastructure (Griffith-Jones and Ocampo, 2018). The UK established the world’s first green investment bank in 2012, which financed more than £12 billion of UK green infrastructure projects between 2012 and 2017. This bank backed the construction of the Rampion offshore wind farm and invested in four other offshore wind farms. In 2017, the UK government privatized the bank in order to access additional capital and pay off public debt. It was acquired by an Australian firm, Macquarie, and it now operates as the Green Investment Group. All of the taxpayer money was returned with a gain of £186 million, but the UK government announced in 2020 that it would create a new state-backed Green Bank in the UK.

The United States currently has no domestic independent development, investment, or Green Bank at the federal level, but it has periodically used them in the past. The War Finance Corporation was established during World War I to mobilize finance for the war effort, and in 1932, President Hoover created the Reconstruction Finance Corporation, which later became the capital bank for the New Deal (Omarova, 2020). However, federal agencies including DOE and U.S. Department of Agriculture (USDA) do have substantial programs to invest in domestic development through loans and loan guarantees, research grants, and loan and grant assistance. At the USDA for example, the Rural Energy for America Program administered by the Rural Business and Cooperative Service offers loans and grants to rural businesses and agriculture producers to adopt renewable and energy efficiency measures in their farm operations. At the subnational level, at least nine states have established Green Banks or funds, ranging from the Connecticut Green Bank to the Colorado Clean Energy Fund. There are also a number of local funds that serve specific communities, such as the Solar and Energy Loan Fund (SELF) in Florida. These investments also mobilize private sector investment into a project by reportedly three to six times the amount of public sector dollars at work (NREL, 2017). Legislation has been introduced into Congress for a National Climate Bank with an initial capitalization of $10 billion and an additional $5 billion per year for 5 years to reach $35 billion. The Coalition for Green Capital (2019) suggests this could mobilize up to $1 trillion in investment.

While an initial multi-billion-dollar capitalization for the Green Bank would be a significant investment of federal resources, it should be financially self-sustaining and assets should grow over time. There is no magic number for initial capitalization, but

Page 208

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

to enable the green recovery that is needed in the United States, it needs to be large enough to be adequate to the task and to compete with its counterparts. The China Development Bank’s current assets equal $1 trillion, Germany’s KfW’s are $575 billion, and Brazil’s National Development Bank is worth $145 billion. A recent proposal for an American Development Bank called for an initial capitalization of $100 billion (Griffith-Jones, 2020). The recent establishment of the U.S. Development Finance Corporation came with authorization of $60 billion, so an initial capitalization of $30 billion in a U.S. Green Bank, rising to $60 billion, may be politically realistic. Equal authorizations would establish that the government cares just as much about domestic investments in green economic development as it does in overseas investments.

The committee recommends that a federal Green Bank be established with a specific public mission to finance low- or zero-carbon technology, business creation, and infrastructure. The rationale for an independent Green Bank as opposed to an entity like a Clean Energy Deployment Administration is to allow it to operate more nimbly than would be the case if the Green Bank was a federal entity. An independent Green Bank formed by the federal government and capitalized with federal funds could forgive loans, something that most governmental entities cannot do. Its remit could be broader, encompassing the financing of other green industries and sectors (e.g., climate adaptation and resilience, fresh water supply), but it must devote at least two-thirds of its financing for the energy transition to achieve net-zero emissions by midcentury. Its objectives within the energy transition space would include fostering long-term domestic manufacturing capacity in clean energy and energy efficiency.

The committee recommends:

Establishment of a federal Green Bank with a specific public mission to finance low- or zero-carbon buildings and technologies, business creation, and infrastructure.

Congress should provide an initial capitalization of a minimum of $30 billion, followed by an additional $3 billion per year through 2030, resulting in a minimum capitalization of $60 billion by 2030.

Cost: $60 billion.

The bank must adopt good governance procedures and practices, including being transparent and abiding by environment and social safeguards and incorporating labor standards (and Buy American) requirements.

The staff of the bank must be trained not only in finance but also in engineering, science, technology, and policy so that the bank can make well-informed investment decisions.

Page 209

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

The bank must devote at least two-thirds of its financing to the social, economic, and infrastructural energy transition to achieve net-zero emissions by midcentury.

The bank must report annually to Congress on its investments and their impacts, including total financing, firms supported, infrastructure created, jobs created, value added, and reduced or avoided GHG emissions.

Invest in New Infrastructure

Like today’s energy systems, a net-zero energy economy will require numerous energy-delivery systems and networks to connect energy sources with energy consumers. Some of these systems—like the high-voltage electric grid—will build on the current interconnected interstate transmission network. Others—such as an expansive body of EV charging stations that are as accessible as today’s gasoline filling stations—will need to be developed from the relatively nascent stage that exists today. This policy cluster involves recommendations related to electric transmission, EV charging, deployment of broadband to underserved areas, and CO2 pipelines. The committee’s final report will discuss other infrastructure needs for the later decades, including transport of hydrogen.

Electric Transmission and Distribution Infrastructure

A net-zero energy economy that depends on both a decarbonized electric system and electrification of many building, vehicle, and industrial energy uses will require expansion of today’s high-voltage electric grid and local distribution-system infrastructure. Even assuming significant deployment of distributed energy resources (e.g., solar panels, microgrids, energy efficiency, and flexible demand), the nation will also need an expanded high-voltage grid to connect regions with high-quality renewables to locations where people live and work (U.S. Congress, House, 2020b; MacDonald et al., 2016). The distribution system will need to be expanded to accommodate greater capacity requirements associated with electric vehicles, heat pumps, and distributed energy resources. It will also require investment in expanded automation and controls to handle more complicated power flows and to enable such things as greater demand response of EV charging and space and water heating loads, as well as cooling energy storage for air conditioning buildings.

With regard to the bulk power system, two persistent conditions threaten to undermine the ability of the country to scale up access to and development of high-quality renewables: First, a chicken-and-egg problem currently exists with respect to the

Page 210

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

development of high-quality renewable projects in remote areas (e.g., offshore wind, wind in the Prairie states) and access to transmission to ensure that that renewable power can be delivered to distant load centers. Second, the current federal/state jurisdictional split, in which FERC regulates transmission planning/access and the states determine whether to approve transmission facilities, has proven to stand in the way of building out the kind of high-voltage transmission system needed for deployment of renewables at scale (NASEM, 2017b; Reed et al., 2019). The approach approved by Congress in 2005 to designate National Interest Electric Transmission Corridors proved unsuccessful (Swanstrom and Jolivert, 2009; CRS, 2010).

An enhanced interstate transmission grid will require long-term national and regional electric-system planning. The current planning paradigm—for example, long-term transmission planning conducted by regional grid operators and transmission companies under FERC authority; DOE’s analysis of congested transmission corridors; separation of planning for generation from planning for transmission in many if not most parts of the country—is not up to the task of what is needed to open up large regional markets for development of high-quality renewable resources. In the large portions of the country with RTOs/ISOs, such planning is designed to inform decisions of market participants on various potential wires/generation/demand-side solutions. While designed to support efficient outcomes, these approaches are insufficient to put in place, in a timely fashion, the kind of high-voltage interstate transmission system that is needed for deep decarbonization.

Planning for and siting of transmission requires many improvements: a national statement of the important role of transmission in supporting the nation’s, regions’, and states’ achievement of GHG-emission reduction targets (U.S. Congress, House, 2020b); provision of “side-payments” or other economic incentives for states that need to host transmission enhancements for national and regional purposes (Reed et al., 2020; Eto, 2016); greater use of existing rights of way to site new transmission (Reed et al., 2020, 2019); financial support for state and local governments to analyze transmission projects and to provide meaningful analyses of barriers to local economic development through transmission, such as poorly designed incentive schemes (Haggerty et al., 2014); and support for authentic engagement of stakeholders, with community groups supported by resources so that they can meaningfully participate in regional planning processes (Eto, 2016). In the upcoming section on strengthening the capacity to effectively and equitably transition to a clean energy future, the committee recommends various policies and actions to support participation in regional energy/transmission plans.

With regard to the local distribution system, the committee anticipates that electric utilities will make customer-funded investments over time in response to and in

Page 211

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

anticipation of changes in demand and power flows on the local system. The committee believes, however, that the needed acceleration of electrification of building end uses and vehicles, combined with continuing requirements for reliable and affordable electricity supply, also warrants the availability of near-term federal incentives for investment in automation and control technologies on distribution systems.

The committee recommends that Congress:

Amend the Federal Power Act to:

Establish a U.S. National Transmission Policy to enable a high-voltage transmission system to support the nation’s (and states’) goals to achieve net-zero carbon emissions in the power sector.

Authorize and direct FERC to require transmission companies and regional transmission organizations to analyze and plan for economically attractive opportunities to build out the interstate electric system to connect regions that are rich in renewable resources with high-demand regions; this is in addition to the traditional planning goals of reliability and economic efficiency in the electric system.

Amend the Energy Policy Act of 2005 to assign to FERC the responsibility to designate any new National Interest Electric Transmission Corridors and to clarify that it is in the national interest for the U.S. to achieve net-zero climate goals as part of any such designations.

Authorize FERC to issue certificates of public need and convenience for interstate transmission lines (along the lines now in place for certification of gas pipelines), with clear direction to FERC that it should consider the location of renewable and other resources to support climate-mitigation objectives, as well as community impacts and state policies as part of the need determination (i.e., in addition to cost and reliability issues) and that FERC should broadly allocate the costs of transmission enhancements designed to expand regional energy systems in support of decarbonizing the electric system.

Authorize and direct FERC to approve compensation to states and tribes to compensate for lands traversed by existing and new transmission projects that support regional clean energy objectives.

Authorize and appropriate funding for:

DOE to provide support for technical assistance and planning grants to states, communities, and tribes to enable meaningful participation in regional transmission planning and siting activities.

Cost: $25 million/year.

Page 212

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

DOE and FERC to encourage and facilitate use of existing rights-of-way (e.g., railroad; roads and highways; electric transmission corridors) for expansion of electric transmission systems.

DOE to analyze, plan for, develop workable business model/regulatory structures, and provide financial incentives (through the Green Bank) for development of transmission systems to support development of offshore wind and for development, permitting, and construction of high-voltage transmission lines, including high-voltage direct-current lines.

Cost: $50 million/year for analysis and planning, and for technical assistance to states, tribes, localities. No incremental cost for the transmission lines (included in Green Bank).

DOE to provide grants to local distribution utilities for innovative projects to encourage investment in automation and control technologies on distribution systems.

Cost: $10 million/year.

Electric Vehicle Charging Infrastructure

Decarbonizing the nation’s energy economy will depend on rapid electrification of the vehicle fleet, which will, in turn, require the build-out of electric vehicle (EV) charging infrastructure.

Americans have come to expect that refueling their vehicles is convenient, given the near ubiquitous nature of the fuel-filling infrastructure. Today’s filling stations are typically available within relatively close distances to homes, offices, and major thoroughfares, and the act of filling up a tank with gasoline or diesel fuel takes little time. Drivers’ willingness to purchase and depend on EVs for their mobility needs depends upon their expectations that they will be able to charge their vehicles conveniently and relatively quickly. Broad adoption of EVs will be frustrated if consumers and workers lack access to EV charging infrastructure—whether at home, in parking lots, at office buildings, at local service stations, and at stops on interstate highways. Less than half of U.S. households have access to off-street parking and adequate electric service (Traut, 2013).

Planning for EV charging infrastructure has been undertaken in various localities and regions of the country, and the federal government and governors in many regions are cooperating with efforts to coordinate such planning on interstate routes (e.g., FHWA, 2020). Many private companies have invested in commercial charging facilities,

Page 213

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

and states have used a variety of approaches (e.g., use of the Volkswagen settlement funds; tax incentives) to create incentives for infrastructure development.

The National Governors Association reports that “many states are exploring the role of their electric utilities in building the EV charging network needed. State public utility commissions have already approved roughly $1 billion in utility EV infrastructure investments, with another $1.5 billion in additional utility investments already proposed” (NGA, 2019). In some states (e.g., Minnesota), where utilities have exclusive franchises to sell electricity to consumers, legislatures and utility regulators have established carve-outs where third parties may own EV charging stations that sell power to vehicle operators.

In spite of considerable work under way to support development of EV charging infrastructure, significant gaps may exist between the scope of EV charging infrastructure that is on the ground or on drawing boards, and the vast network of EV charging stations that will be needed to provide consumer confidence. In Chapter 2, the committee identified the goals of (1) 60 million light-duty EVs and trucks and 1 million medium-duty and heavy-duty vehicles, including buses, to be on the roads by 2030; and (2) 3 million public Level 2 charging units and 120,000 DC fast-charging units. As of May 2019, there were an estimated 58,000 Level 2 and 10,800 DC charging units throughout the United States (DOE, 2019). The Breakthrough Institute estimated the need for up to 9.6 million EV chargers by 2030 and calls for a federal investment of $5 billion (Olson, 2020). Like an earlier National Academies report (TRB and NRC, 2015) on barriers to electric vehicles, the Breakthrough Institute highlighted fast charging on interstate highway corridors as a particular area for investment.

Much more planning and investment for EV infrastructure development is needed, by the public and private sectors. Fleet operators could be leaders in this effort. To spur EV deployment and use, the federal government and states should accelerate planning and deepen financial incentives for EV charging infrastructure build-out. Particular attention must be paid to how future building designs and community planning accommodates access to convenient EV charging. Creating the opportunity for home-based charging to the roughly half of U.S. households that do not have a garage or at-home off-street parking will be essential. Also, the federal government should work with stakeholders to establish interoperability standards for the EV Level 2 and fast-charging infrastructure.

The committee recommends that Congress direct:

The FHWA to

Continue to expand its “alternative fuels corridor” program, which supports planning for EV charging infrastructure on the nation’s interstate highways.

Page 214

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Update its assessment of the ability and plans of the private sector to build out the EV charging infrastructure consistent with the pace of EV deployment needed for vehicle electrification anticipated for deep decarbonization, and the need for vehicles on interstate highways and in public locations or high-density workplaces, and to identify gaps in funding and financial incentives as needed.

DOE, in coordination with FHWA, to provide funding for additional EV infrastructure that would: cover gaps in interstate charging to support long-distance travel and make investments for EV charging for low-income businesses and residential areas.

Cost: $5 billion.

The National Institute of Standards and Technology (NIST) to develop communications and technology interoperability standards for all EV Level 2 and DC fast-charging infrastructure.

Broadband

The operational performance and affordability of the low-carbon electricity system will depend on both low-carbon resources as well as flexible demand, with the latter particularly important in an electric system dominated by intermittent generating resources (like solar and wind). Flexible demand, in turn, will depend on the ability of households, businesses, and others to communicate with wholesale and local power markets in real time.

Vast geographic segments of the United States, notably in rural areas and in low-income urban areas, lack access to broadband (Anderson and Kumar, 2019; Perrin, 2019). According to the Federal Communication Commission’s (FCC’s) most recent report, over 21 million Americans did not have access to high-speed broadband as of the end of 2017 (FCC, 2019), and economic barriers prevent private broadband companies from reaching these communities and inhibit states from providing financial incentives to overcome these barriers. This situation poses countless challenges for millions of households. From the point of view of decarbonizing the nation’s energy system, individual electricity customers without broadband cannot effectively respond to price and demand management signals to allow them to play a part in flexible demand strategies. The deployment of advanced meters (addressed earlier) must be accompanied by deployment of broadband to enable that capability. Further, a Brookings Institution analysis indicates that although the FCC provides subsidies to assist rural areas (e.g., $186 million in 2018; see Conexon, 2018), it would take in the

Page 215

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

range of $14 billion to $28 billion to provide universal broadband access (Levin, 2019). Investment tax credits (or grants to publicly owned utilities for 10 percent of that cost would help the private sector and others to accelerate such deployment.

The committee recommends that Congress enact:

Statutory changes to enable rural electric cooperatives to invest in broadband technology and projects and to provide communications services to their customer base, with appropriations that would provide for grants and/or loans to public power entities equal to 10 percent of investment costs.

Cost: $0.5 billion.

Investment tax incentives (at 10 percent of investment) for private companies to make broadband investments in low-income and rural communications.

Cost: $1.5 billion.

CO2 Pipeline Infrastructure

Consistent with the recommendations in Chapter 2 regarding the potential need for on the order of 50–75 MMT CO2 capture and storage per year by 2030 (predominately at industrial facilities) and as much as 250 MMT CO2 by 2035, the nation needs to plan and construct a new interstate CO2 transportation system to move quantities of CO2 from sources to long-term storage locations. Although there are currently 50 CO2 pipelines (totaling 4,500 miles) already in existence, they are used primarily to move CO2 for injection in oil-producing fields to enhance recovery of oil and are insufficient for carbon capture, utilization, and sequestration (CCUS) at this scale (Wallace et al., 2015). The Princeton Net Zero America study (Larson et al., 2020) has modeled CO2 pipelines required for lowest-cost net-zero energy systems in the United States in a variety of scenarios, the least-constrained and lowest-cost of which would require an additional 16,000 km (or around 10,000 miles) of pipelines before 2030 to facilitate installation of CCUS (Larson et al., 2020).

A recent study by researchers at the Great Plains Institute and the University of Wyoming concluded that it will be more economical to build out that CO2 delivery infrastructure if it is done in a coordinated fashion:

A regional network will require coordination between states, possibly coordination between multiple pipeline owners and operators, and long-term planning of likely capture and storage locations to determine routes and expected capacity requirements. A transport network built only with near-term projects in mind will require greater land use and induce higher costs on a

Page 216

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

per ton basis than a regional network planned with a longer time horizon. . . . Long-term, coordinated planning on regional CO2 transport corridors will result in optimized, regional scale infrastructure that minimizes costs, land use, and construction requirements while maximizing decarbonization across industrial and power sectors throughout the United States. . . . To avoid the business-as-usual and expensive outcomes in which CO2 transport infrastructure is built out in a piecemeal fashion, . . . planning and coordination must occur in the near term to begin building regional-scale transport networks for economy-wide deployment of carbon capture and storage. (Abramson et al., 2020)

Planning for such a CO2 transportation network should take place in the next 5 to 10 years, and include public participation and expert input. Such planning should take into account the current and likely future location of large point sources of CO2 (e.g., above 0.5 Mt CO2/year) and CO2 sequestration basins, and seek to enable 95 percent of all current and future likely large point sources of CO2 to fall within a reasonable distance (e.g., 100 miles) of the trunk-line system. The plan should focus on using, to the extent possible, existing rights-of-way to site CO2 trunk lines. One recent study matched potential sources and subsurface storage sites for carbon capture and sequestration (CCS) in California (EFI, 2020).

Other elements of planning for CO2 storage infrastructure involve characterization of reservoirs for safe and permanent storage of CO2. DOE, in conjunction with the U.S. Geological Survey (USGS) and the Department of the Interior (DOI), should begin to characterize all major basins for CO2 sequestration in order to identify with high-confidence sites suitable for at least 1 Gt CO2/year of injection with permanent containment. This effort should be conducted via a highly coordinated public-private partnership that supports exploration and appraisal, field development, extensive stakeholder engagement, plugging and abandonment of legacy wells, and environmental permitting.

Additionally, the regulatory infrastructure to review and approve facilities in this interstate system will need to be established during the next 5 to 10 years. Enhanced technical and legal regulatory capabilities will also be needed (e.g., at EPA, or FERC, or DOT) to review and permit CO2 injection sites. Congress should establish a National Commission to identify and present recommendations for legislation with regard to legal, policy, and financial considerations related to insurance, public and/or private ownership structure, financing risks, liability issues, regulation, enforcement, and other responsibilities in a CO2 transportation and sequestration industry.

The committee recommends that Congress:

Establish a temporary National Commission to identify and present recommendations for legislation related to roles and responsibilities of federal and state agencies and the private sector in a CO2 transportation and storage industry.

Cost: $20 million.

Page 217

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Assign responsibility to DOT, in consultation with DOE, DOI, and EPA, to conduct a planning process for the layout, location, siting principles, and timing of a national CO2 transportation infrastructure (or “trunk-line” system) to connect sources of CO2 with locations for permanent sequestration and/or use of CO2.

This planning process must include public participation of communities located near any of the potential routes of CO2 trunk-line systems, including locations where CCUS projects are likely to be located and locations where CO2 sequestration would likely occur. By mid-decade (2025–2026), DOT and DOE, in consultation with the other federal agencies, will conduct and publish the results of an assessment to determine the timing of when such a CO2 trunk-line system would be needed to achieve a net-zero economy by 2050. This report should contain a set of candidate trunk lines, routes, and a timeline for commencement and completion of pipeline segments consistent with the goal of a net-zero economy by 2050. The report should also consider and issue recommendations on what federal financing support, if any, is needed for such a system to be financed, built, and operated, including consideration of what role, if any, the Green Bank should play in supporting such financing.

Cost: $50 million for planning.

Appropriate block grants to support community and stakeholder engagement in the planning of the national CO2 transportation infrastructure above, including staff time for nongovernmental and community organizations to participate.

Cost: $50 million.

Direct and fund DOE, USGS, and DOI to characterize with high confidence all major basins for CO2 sequestration and, by 2030, identify sites suitable for injection of approximately 250 million metric tons of CO2 per year.

Cost: $5 billion.

Establish and fund federal research, development, and demonstration (RD&D) programs to expand technological options for carbon storage and use including the ability of building materials, products, and infrastructure to sequester carbon through bio-materials, carbon fuels, and encapsulation.

Extend 45Q tax credit for CCUS for projects that begin substantial construction prior to 2030 and make tax credit fully refundable for projects that commence construction prior to December 31, 2022. Set the 45Q subsidy rate for use equal to $35/tCO2 less whatever explicit carbon price is established and the

Page 218

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

subsidy rate for permanent sequestration to be equal to $70/tCO2 less whatever explicit carbon price is established.

Cost: $2 billion.

Invest in Educational Programs for a Clean Energy Workforce

To navigate the transition to a carbon-neutral economy, the United States needs substantial new investments in education and workforce development. The educational gap across a wide range of clean energy fields (engineering, sciences, architecture and design, construction and facility management, social sciences, public policy and administration, and business and entrepreneurship) is as stark as that which inspired the National Defense Education Act of 1958 after the Soviet Union launched Sputnik, inspiring the International Space Race.

Training the next generation of business, policy, and civil society leaders not only to successfully navigate the complexities of the transition but also to ensure that the United States regains the global lead in energy innovation will require significant new investments. To meet this need, Congress should establish a 10-year GI Bill-type of program to fund vocational, undergraduate, or master’s degrees related to clean energy, energy efficiency, building electrification, sustainable design, or low-carbon technology. The Post-9/11 GI Bill has supported approximately 228,000 beneficiaries per year at a cost of approximately $9 billion per year (CBO, 2019). Given the grave threat to the nation posed by climate change and the opportunities presented by a clean energy transition, a program at approximately half the size would position the nation to produce the workforce it needs to confront the threat and take advantage of the opportunity. Such a program would ensure that the U.S. workforce transitions along the physical infrastructure of energy, transportation, and economic systems. It would not only increase the skilled workforce for clean energy, which will require new skills and expertise, and prepare the energy workforce to effectively accommodate transformative technological change in machine learning, big data, automation, and artificial intelligence, but also ensure that the United States remains competitive in rapidly changing global energy markets and trade regimes. To collect the necessary data to understand clean energy workforce needs and gaps, and also to identify and implement ways to address them, the Energy Jobs Strategy Council should be reestablished.

The new GI program for worker training should provide effective and equitable access to good jobs, training (including job placement and/or a pipeline to those jobs) and advancement, particularly for those historically underrepresented or adversely impacted or dislocated by technological change such as energy, transportation, and trade-impacted communities. New educational programs can train an inclusive workforce

Page 219

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

for high tech, advanced manufacturing, as well as clean energy infrastructure build-out. This investment should also integrate with community services to maximize retention and advancement of workers, particularly disadvantaged or previously underrepresented workers, in clean economy careers. These investments will contribute to more equitable educational attainment in science, technology, engineering, and medicine (STEM) fields (Bound and Turner, 2002), which remains a critical shortcoming of U.S. higher education and an important reason why the benefits of science and technology disproportionately do not flow to low-income communities and communities of color.

Specific attention should be paid to training and providing access to manufacturing occupations to build the skilled workforce to produce the equipment needed for achieving a carbon neutral economy. Manufacturing jobs can provide a pathway to the middle class for workers and families, furthering support for the social contract for decarbonization. Pipelines can be started in high school and on to vocational schools that could have nationally accredited qualifications, making higher paid careers more accessible to lower-income Americans. Ongoing technical and on-the-job training can help workers gain skills, experience, and recognized credentials to advance in their careers. Mobile training labs can be used to bring training to Indigenous peoples and others located in isolated areas.

To meet the needs of these trainees and workers, Congress should support the creation of innovative new degree programs in community colleges and colleges and universities focused uniquely on the knowledge and skills necessary for a low-carbon economic and energy transformation. Too few degree programs, even in energy and environmental studies, provide rigorous training in transition management, and this gap is doubly significant in more traditional programs in engineering, business, policy and administration, which need to be upgraded to ensure graduates are positioned to add new knowledge and skills to their employers. Congress should fund grants to universities at a cost of $100 million per year to create or strengthen undergraduate and master’s degree programs in climate- and energy-transition-related studies, whether in engineering, design and architecture, social sciences, natural sciences, or public policy.

Last, Congress should also make significant new investments at the master’s, doctoral, and postdoctoral levels to support clean energy innovation. Expanding the number of academic institutions awarding doctorates related to clean energy (engineering, sciences, architecture and design, social sciences, public policy and administration) should be a priority. Congress should also provide grants of $50 million per year to create interdisciplinary doctoral and postdoctoral training programs, similar to those funded by the National Institutes of Health (NIH), which place an emphasis on training students to pursue interdisciplinary, use-inspired research in collaboration with external stakeholders that can guide research and put it to use in improving practical actions to support decarbonization and energy justice.

Page 220

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Overall (not exclusive to clean energy), university-based research, skill formation, and knowledge generation is highly concentrated. Just 115 U.S. universities perform three-quarters of all academic R&D and also award three-quarters of U.S. science and engineering doctoral degrees (NSF, 2020). Congress should provide $375 million per year to support government-funded doctoral and postdoctoral fellowships in science and engineering, policy, and social sciences, for students researching and innovating in low-carbon technologies, sustainable design, and energy transitions, with at least 75 fellowships per state to ensure regional equity and build skills and knowledge throughout the country. Allocation of scholarships must ensure that students of all backgrounds can pursue their passions. These scholarships should include appropriate training in skills in interdisciplinary research and communication, as well as collaboration with industry, government, and civil society stakeholders, in order to ensure that researchers are prepared to work effectively in teams on use-inspired research that contributes meaningfully to the needs of society and the economy.

In the past, the United States has had a comparative advantage through its ability to recruit and retain talent in its high-tech industries from around the world. Studies have shown that the recruitment of foreign graduate students to the United States has had a significant and positive impact on innovation as measured by both future patent applications and future patents awarded to university and non-university institutions (Chellaraj et al., 2008; Hunt and Gautheir-Loiselle, 2010). The United States must redouble efforts to attract talent in low-carbon energy. Visa restrictions for international students who want to study climate change and clean energy at the undergraduate and graduate levels should be eased or eliminated, where appropriate.

The committee recommends that:

Congress should establish a 10-year GI Bill-type program for anyone who wants a vocational, undergraduate, or master’s degree related to clean energy, energy efficiency, building electrification, sustainable design, or low-carbon technology. These programs should include a cost-of-living stipend. Such a program would ensure that the U.S. workforce transitions along the physical infrastructure of our energy, transportation, and economic systems.

Cost: $5 billion/year for 10 years.

Congress should support the creation of innovative new degree programs in community colleges and colleges and universities focused uniquely on the knowledge and skills necessary for a low-carbon economic and energy transformation.

Cost: $100 million/year.

Page 221

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Congress should also provide funds to create interdisciplinary doctoral and postdoctoral training programs, similar to those funded by NIH, which place an emphasis on training students to pursue interdisciplinary, use-inspired research in collaboration with external stakeholders that can guide research and put it to use in improving practical actions to support decarbonization and energy justice.

Cost: $50 million/year.

Congress should provide support for doctoral and postdoctoral fellowships in science and engineering, policy, and social sciences, for students researching and innovating in low-carbon technologies, sustainable design, and energy transitions, with at least 25 fellowships per state to ensure regional equity and build skills and knowledge throughout the United States.

Cost: $375 million/year.

The Department of Homeland Security should eliminate or ease visa restrictions for international students who want to study climate change and clean energy at the undergraduate and graduate levels, where appropriate.

Congress should pass the Promoting American Energy Jobs Act of 2019 to reestablish the Energy Jobs Strategy Council under DOE, require energy and employment data collection and analysis, and provide a public report on energy and employment in the United States.

Cost: $7 million over the 2020–2025 period (CBO, 2020).

Invest in a Revitalized Manufacturing Sector

The United States cannot gain global market share in clean energy industries if it does not produce clean energy technologies. Yet, the global market for clean energy is already immense and growing, and U.S. firms and workers are being left behind. The International Energy Agency (IEA) estimates that the global market for clean energy technologies will be $2 trillion during the 5-year period between 2020 and 2025 (IEA, 2019).

The United States can revitalize domestic manufacturing through smart and targeted industrial policies, including establishment of predictable and broad-based market formation policies (such as carbon taxes, performance standards, and tax credits that create demand for low-carbon goods and services), improving access to finance, creation of performance-based manufacturing incentives (including efficiency standards), and export promotion. Inconsistent and volatile policies will fail to revitalize the manufacturing sector because manufacturing firms cannot count on them. Firms must literally be able to capitalize on policies that create markets for low-carbon goods and services, and they cannot

Page 222

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

do that if policies are unstable and volatile. Firms must be able to demonstrate to financiers that a clear return on investments in production and workers is possible because a market for low-carbon products and services will certainly exist in the United States.

The U.S. government should provide manufacturing incentives to firms that are matched with corresponding performance requirements. Subsidies provided directly to manufacturers must be tied to the meeting of performance metrics, such as the achievement of production and export targets or meeting labor, efficiency, and environmental standards. Manufacturers should also be required to develop strategies for assuring the availability and resilience of their supply chain.

The main policy tools available include loans, loan guarantees, tax credits, export-promotion, and grants to manufacturers, some of which could be administered through the Green Bank, if established. The least costly to the taxpayer is the loan guarantee, which was used successfully during the American Reinvestment and Recovery Act. This program should be reformed to support new and additional advanced technologies, to finance more small and medium-size enterprises, and to encourage more risk-taking on the part of DOE. In export promotion, the U.S. Export-Import Bank needs to phase out support for fossil fuels and make support for clean energy technologies a top priority. U.S. export credit authorizations for renewables have fallen from $200 million in 2014 to just $19 million in 2019 (Ex-Im Bank, 2019). The committee recognizes that each of these policy approaches has limitations. Large corporations can already secure advantaged loan rates, thus loans may be best for small and medium-size manufacturers. Tax credits face limitations, because many companies have already taken the maximum amount of tax credits they can afford to take. Thus, the committee believes that all of these policy tools are necessary.

The committee recommends that Congress:

Establish predictable and broad-based market-formation policies that create demand for low-carbon goods and services, improve access to finance, create performance-based manufacturing incentives, and promote exports.

Provide manufacturing incentives through loans, loan guarantees, tax credits, grants, and other policy tools to firms that are matched with corresponding performance and wage requirements. Subsidies provided directly to manufacturers must be tied to the meeting of performance metrics, such as production of products with lower embodied carbon or adoption of low-carbon technologies and approaches. Specific items could include the following:

Expand the scope of the energy audits in the DOE Better Plants program and expanded technical assistance to focus on energy use and GHG emissions reductions at the 1,500 largest carbon-emitting manufacturing plants.

Page 223

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Support the hiring of industrial plant energy managers by having DOE provide manufacturers with matching funds for 3 years to hire new plant energy managers.

Enable the development of agile and resilient domestic supply chains through DOE research, technical assistance, and grants to assist manufacturing facilities address supply chain disruptions resulting from COVID-19 and future crises.

Cost: Initial appropriation of $1 billion/year phasing down over 10 years as performance targets are reached.

Provide loans and loan guarantees to manufacturers to produce low-carbon products, ideally through a Green Bank.

Require the U.S. Export-Import Bank to phase out support for fossil fuels and make support for clean energy technologies a top priority with a minimum of $500 million/year.

Create a new Assistant Secretary for Carbon Smart Manufacturing and Industry within DOE.

Invest in Research, Development, and Demonstration for Technology Innovation and Deployment and Research on Social and Economic Impacts

The United States needs to dramatically strengthen its knowledge base on cleanenergy technologies as well as on the social dimensions of transitions to a net-zero carbon economy. Such investments require increased federal support.

American public investments in clean energy technology RD&D have gradually risen since 2011 but U.S. leadership in clean energy RD&D is now being challenged by China and Europe. The United States led the world in public investments in clean energy RD&D from the 1970s until the late 2010s when China’s public investments began to rival or even exceed U.S. investments. China will likely double government RD&D spending on clean energy between 2015 and 2020 from $4 billion to $8 billion (Myslikova and Gallagher, 2020). This achievement will put China’s officially reported RD&D spending on clean energy ahead of that of the United States. U.S. investments in clean energy RD&D increased by 42 percent between 2015–2020 from $4.8 billion to $6.8 billion (including basic energy sciences) owing to sustained support from congressional appropriations, despite the Trump administration’s proposed drastic cuts of more than 60 percent to clean energy RD&D every year in its budget request to Congress (Myslikova and Gallagher, 2020). European clean energy RD&D investments as of 2018 were approximately $6.3 billion.

Page 224

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

To restore U.S. leadership in clean energy technology RD&D, the committee recommends that Congress triple the DOE’s funding of low- or zero-carbon RD&D over the next 10 years, in part by eliminating investments in fossil-fuel RD&D. A tripling of energy innovation investments was recommended by the American Energy Innovation Council in 2020 (AEIC, 2020), Sivaram et al. (2020), and by the President’s Council of Advisors on Science and Technology in 2010 (PCAST, 2010). Other recommendation to greatly increase DOE’s funding of clean energy technologies include the call by Nobel Prize winners to the Obama administration (Burton, 2009) and the testimony of eventual DOE Secretary Ernest Moniz during his confirmation hearing (S. Hrg. 113-17, 113th Cong., 2013). These investments should focus on the five critical actions discussed in Chapter 2 as well as the technologies that need to be better understood for possible deployment in the 2030s, including clean firm electricity resources, buildings and industrial efficiency, electricity storage, CCS, hydrogen and other low or net-zero carbon energy carriers, high-yield bioenergy crops, low-emissions industrial process technologies, and negative emission technologies (NETs). By eliminating investments in non-CCS fossil-fuel RD&D, the net increase to the energy RD&D budget will be partially offset. DOE should also fund energy innovation policy evaluation studies to better understand the extent to which policies implemented (both RD&D investment and market-formation policies) are working. Relatedly, DOE and/or the National Science Foundation (NSF) should support studies on the socioeconomic impacts of low-carbon transitions.

As funding ramps up, Congress should target under-resourced sectors and gaps in the U.S. innovation system for the largest increases. The end-use sectors are particularly under-represented in the current RD&D portfolio (Sivaram et al., 2020; IEA, 2020; Shah and Krishnaswami, 2019; Breakthrough Energy, 2019). Sivaram et al. (2020) find that less than a quarter of DOE’s portfolio targets innovations in the transportation, buildings, and industrial sectors. The IEA (2020) recommends that the world’s major economies provide more funding for end-use innovations in sectors such as heavy industry and long-distance transportation that have no or few commercially available low-carbon options.

It is important to note that there is critical gap in government funding between basic research and commercialization. For example, while the Advanced Research Projects Agency-Energy (ARPA-E) has been successful in the development of innovative technologies, the National Academies review of the agency noted that none of these innovations has resulted in new commercial technologies (NASEM, 2017a). Other reviews of ARPA-E have noted this same gap (Goldstein et al., 2020), and national laboratories face similar difficulties in moving innovations to commercial products (Stepp et al., 2013; Anadon et al., 2016; Chan et al., 2017). One method being explored is to scale up funding for entrepreneurial research fellows, which is showing promise in the current lab-embedded entrepreneurship program (LEEP) configuration, such as Cyclotron

Page 225

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Road at the Lawrence Berkeley National Laboratory or Chain Reaction at Argonne National Lab. Similarly, the Small Business Voucher Pilot Program, launched in 2015 to increase small business access to lab capabilities, was successful at helping small businesses advance their technologies and achieve commercial sales (Jordan and Link, 2018). Programs such as these that increase private-sector access to federal research facilities, as well as incentives that encourage research staff to collaborate with industry, should be expanded.

Successfully shepherding new technologies from concept to commercialization requires support at all stages, but the demonstration stage is particularly underfunded (C2ES, 2019; Nemet et al., 2018; Hart, 2018). The IEA defines technology demonstration as the “operation of a prototype . . . at or near commercial scale with the purpose of providing technical, economic and environmental information” (IEA, 2011). The fundamental role of demonstration is to instill confidence in technology developers, users, investors, and the public that a technology will perform as intended. However, the first several large demonstrations of an emerging technology generally entail a level of technical and financial risk beyond what private industry can support, leading to a “commercialization valley of death” (Nemet et al., 2018).

The federal government virtually stopped funding demonstrations after the American Recovery and Reinvestment Act of 2009 expired. Today, the only federal funding for demonstration projects is under a new program for advanced nuclear reactors, which was approved by Congress in FY 2020 (U.S. Congress, Senate, 2019). The Title XVII Loan Guarantee Program provides some support for first-of-a-kind commercial projects that could include demonstrations. But loan guarantees on their own may not be sufficient to induce the private sector to invest in novel technology demonstrations. Green banks—which are generally expected to retain their initial capital and therefore require a return on their investments—are similarly ill-suited for large demonstrations (Rozansky and Hart, 2020).

Congress has repeatedly affirmed its support for later-stage R&D and demonstration activities (H. Rep. 116-83, 116th Cong., 2019; U.S. Congress, Senate, 2019), but demonstrations remain a critically underfunded portion of the federal energy innovation portfolio (Rozansky and Hart, 2020; Krishnaswami and Higdon, 2020; Sivaram et al., 2020). The American Energy Innovation Act introduced in the Senate in February 2020 would require DOE to conduct 17 demonstration projects across four technology areas: energy storage, carbon capture, enhanced geothermal systems, and advanced nuclear (U.S. Congress, Senate, 2020). But demonstrations across a broader range of technologies will be necessary to address the full range of innovation needs. Within the RD&D portfolio, Congress should increase funding for demonstration projects.

Page 226

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Meanwhile, the softer costs (e.g., permitting, interconnection) of clean energy remain higher in the United States than in other countries, indicating that there is still room for final cost reductions for clean energy technologies. Therefore, DOE should fund studies aimed at reducing the soft costs of zero-carbon technology, including through policy.

The private sector is a major contributor to U.S. energy RD&D, but owing to the lack of reporting, it is unclear how much firms are investing in clean energy RD&D and whether public investments duplicate private investments. Thus, the committee recommends that all firms receiving funds from the government be required to report on their aggregate investments in RD&D annually, by type of investment (basic energy sciences, applied RD&D) and category (e.g., solar, wind, smart grid, fission, fusion, negative emission, efficiency). Additionally, the committee recommends that such RD&D expenditures be disclosed in corporate filings to the Securities and Exchange Commission.

Certain public-private partnerships (PPPs) have been successful for DOE in the past, and those should be studied with a view to enhancing PPPs in clean energy. Relatedly, low-carbon advanced manufacturing capabilities should be bolstered through PPPs for RD&D on advanced manufacturing in clean energy, the establishment of government-sponsored platforms for demonstration of improved manufacturing techniques, and establishment of regional innovation and manufacturing hubs for low-carbon energy around the country.

DOE should establish regional innovation hubs where they do not yet exist to focus involvement of the private sector and state, private, and rural colleges and universities and national laboratories. These regional innovation hubs should be focused on deep energy efficiency activities (e.g., ones that could reduce a building’s energy consumption by 50 percent or more) and the development and exploitation of clean energy resources where there is a comparative advantage for that region (e.g., solar in the Southwest, offshore wind in the Northeast, onshore wind in the upper Midwest).

The committee recommends that Congress should:

Triple DOE’s government investments in low- or zero-carbon RD&D over the next 10 years, in part by eliminating investments in fossil-fuel RD&D. These investments should include renewables, efficiency, storage, transmission and distribution, CCUS, advanced nuclear, and NETs and increase the agency’s funding of large-scale demonstration projects. By eliminating investments in non-CCS fossil-fuel RD&D, the net increase to the energy RD&D budget will be partially offset.

Cost: Increase from $6.8 billion per year in 2020 to $20 billion per year by 2030, but partially offset by eliminating the non-CCUS fossil budget, which for FY 2020 is $273 million for coal and $15 million for gas and unconventional, which would be $2.8 billion over 10 years.

Page 227

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Direct DOE to fund energy innovation policy evaluation studies so that the extent to which policies implemented (both RD&D investment and market-formation policies) are working.

Cost: $25 million/year.

Direct DOE and NSF to create a joint program to fund studies of the social, economic, ethical, and organizational drivers, dynamics, and outcomes of the transition to a carbon-neutral economy, as well as studies of effective public engagement strategies for strengthening the U.S. social contract for decarbonization. Such studies should improve the understanding of how large-scale energy transitions can be accomplished; the full complexity of the diverse scientific, industry, and societal innovation systems involved; the factors that contribute to accelerating or delaying processes of change; and the rich intersections between changes in energy technologies and social practices and other processes of social and economic change.

Cost: $25 million/year.

Direct DOE to establish regional innovation hubs where they do not exist or are critically needed using funds appropriated in tripling DOE’s government investments in low- or zero-carbon RD&D.

Cost: $20 million/year.

Direct DOE to enhance public-private partnerships for low-carbon energy.

Invest in Efficiency Improvements for Low-Income Households Through Program Redesign and Expanded Funding

High energy burdens and lack of capacity to invest in infrastructure improvements work to reinforce energy and economic insecurity for many low-income households, small businesses, and communities in the United States. In some cases, total energy costs can be as high as 25 percent or more of monthly income, especially when electricity, natural gas, and gasoline costs are included.

The two principal federal programs to assist in lowering low-income consumers’ energy bills are the Weatherization Assistance Program (WAP) and the Low-Income Home Energy Assistance Program (LIHEAP), both of which are administered by the states. DOE has responsibility for WAP, and the Department of Health and Human Services (HHS) manages LIHEAP, with HHS allowing each state to use up to 15 percent of LIHEAP dollars to add to WAP funding (and up to 25 percent with an approved

Page 228

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

“good cause” waiver). Although low-income customers benefit in the short term from the assistance they receive in paying their energy bills, the federal government should expand on the ability to use federal dollars to leverage long-term efficiency investments to lower bills for years to come. As part of the ARRA economic stimulus funding, Congress expanded WAP funding from $236 million in 2008 to $2 billion in 2010; this provided substantial energy savings in the nation’s residential buildings, d each participating household thousands of dollars in energy bills, provided them with health and safety benefits, and produced thousands of jobs in local communities (Tonn et al., 2015). In addition, the USDA’s Rural Energy Savings Program allows consumers to finance energy-saving home improvements with no upfront costs through rural electric co-ops. Loans are paid back over time with savings resulting from the consumers’ reduced energy consumption.

Congress should increase the combined dollars that go to LIHEAP and WAP, as various analyses have indicated the success of these programs (Murray and Mills, 2014; Fowlie et al., 2018; Tonn et al., 2018; Terman, 2018), allow the states to request approvals of using a higher percentages of LIHEAP dollars (up to 25 percent across the board, and up to 35 percent with a good cause waiver), and encourage states to coordinate WAP grants to households with other energy-efficiency programs funded by utilities and their customers. Specifically, expanded funding from the WAP program should also fund electrification of buildings’ heating and cooling systems, and include financial support for low-income communities (e.g., through local hiring requirements, local supply sourcing, or other approaches, to ensure that local communities benefit from the employment and spending associated with these programs).

The committee recommends that Congress:

Expand funding of the WAP program to $12 billion over the next the next 10 years (front-loading spending to get the benefits as soon as possible), without reducing funding for LIHEAP, and direct HHS to allow states to use a greater share of LIHEAP dollars for investments in energy efficiency measures and electric heating and cooling systems.

Cost: $1.2 billion/year for 10 years.

Invest in Electrification of Tribal Lands

Access to electricity is critical for improving standards of living, education, and health (U.N. Development Programme, 2019), but as many as 160,000 Native Americans still lack access to electricity (DOE, 2017). In the Navajo Nation alone, about 15,000 homes have no electricity (DOE, 2018). More than 175 remote Alaska Native villages are not

Page 229

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

connected to a larger electricity grid and rely on imported diesel fuel for electricity generation, resulting in electricity costs as high as $1.00/kWh—8 times the national average (Schwabe, 2016). A poll conducted by NPR, the Robert Wood Johnson Foundation, and the Harvard T.H. Chan School of Public Health (2019) found that more than a quarter of Native Americans have experienced problems with electricity, internet access, and safe drinking water. About one in four Native Americans lives in poverty, with unemployment rates twice as high as those among non-Native Americans nationally (DOE, 2020c).

DOE (2017) found that “it is a moral imperative that the federal government support tribal leadership and utility authorities to provide basic electricity service for the tens of thousands of Native Americans who currently lack access to electricity and to foster the associated economic development on tribal lands,” and recommended that federal agencies support full tribal land electrification. However, electrification of tribal lands faces significant challenges. For example, the low population density in the Navajo Nation means the connection cost is as high as $40,000 per home (NPR, 2019).

Current federal programs to support tribal electrification include the DOE Office of Indian Energy (DOE-IE), which provides financial and technical assistance, and the DOI Bureau of Indian Affairs (DOI-BIA), which provides support for strategic development and project planning. Additionally, USDA’s Rural Utilities Service offers low-cost loans to rural utilities and tribal authorities to expand grid access. The Energy Policy Act of 2005 authorized the DOE Tribal Energy Loan Guarantee Program (TELGP) to provide up to $2 billion in partial loan guarantees to support energy development projects. However, Congress did not appropriate funding for the credit subsidy until fiscal year 2017. As of February 2020, DOE had not issued a single tribal energy loan guarantee (DOE, 2020c).

Congress should increase funding for tribal electrification programs at DOE, DOI, and USDA to enable full electrification by 2030, while respecting the sovereignty of tribal and Alaska Native communities. DOE-IE and DOI-BIA should provide technical assistance in long-term planning, project development, legal and regulatory assistance, and siting and permitting assistance for projects. Additionally, Congress should increase direct financial assistance for the buildout of electricity infrastructure through DOE-IE grant programs.

The committee recommends that Congress:

Provide $20 million per year over the next 5 years for needs assessment, strategic development, and planning through DOE-IE grants and the USDA Rural Utilities Service (USDA-RUS) High Energy Cost Grant Program.

Cost: $20 million/year for next 5 years.

Page 230

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Expand funding of the DOE-IE financial assistance program to $200 million per year over the next 10 years, and amend the Rural Electrification Act to allow USDA-RUS to lend at 0 percent interest through the Substantially Underserved Trust Areas program.

Cost: $200 million/year for next 10 years.

STRENGTHENING THE U.S. CAPACITY TO EFFECTIVELY AND EQUITABLY TRANSITION TO A CLEAN ENERGY FUTURE

A just, equitable, effective, and rapid transition to a carbon neutral economy in the United States will require significantly improved coordination of planning and action within and across various levels of decision making, including local, state, and federal governments and countless other stakeholders in industry and civil society. This extensive coordination is essential to properly design and implement accelerated technological changes toward carbon neutrality and also to ensure that the resulting economic and societal transformation advances the broad goals identified in Chapter 3 and meets the benchmarks for equity and inclusion established and monitored by the White House Office of Equitable Energy Transition (recommended earlier in this chapter). This section describes the policies needed to enable institutions to manage and plan the transition.

The committee emphasizes that strengthened coordination is especially required to address several key features of the transition to decarbonization. The first is the extensive and complex interactions between the energy system and multiple sets of critical infrastructures, including but not limited to manufacturing, transportation, food, water, communication and information, supply chains, housing, and security. Many of these systems depend on public and private investments and governance structures affected by markets and multiple layers of government. The second is the tight coupling of energy systems operations, performance, supply chains, and regulation across local, state, regional, national, and global scales, much of which will need to be adjusted and reoptimized during the transition process. The third is the need for careful attention to ensuring that the broad goals identified in Chapter 3 are met throughout the transition, including rebuilding a strong U.S. economy, ensuring a broad distribution of economic success across the diverse U.S. regions, actively promoting equity and justice for diverse communities, and ensuring that harms created by the transition itself are appropriately anticipated, assessed, and mitigated.

To help facilitate an energy transition that anticipates and addresses these challenges, the committee recommends that the federal government support significantly enhanced planning and coordination efforts across the various levels of government.

Page 231

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

At least three impediments stand in the way of accelerated action to advance a just and equitable transition to net zero: a shortage of human and financial resources for planning and coordination; a lack of existing coordination mechanisms and processes at appropriate scales; and a mismatch between existing knowledge resources about low-carbon energy technologies and transitions and the needs of diverse decision makers and other stakeholders. In particular, many local actors, governments, and nongovernmental organizations (NGOs) do not have the capacity or ability to access federal funds, determine what to apply for, or know how to implement the funds for impact. Funding for technical assistance should be provided for local planners, public and private, who know and understand the community and are skilled at accessing and implementing funds for impactful uses.

Congress should act to address these gaps by establishing and funding a multiscale planning infrastructure at federal, state, regional, and local levels with both the capacity to plan and coordinate an accelerated transition and to secure the knowledge resources necessary for that work.

The committee recommends:

Federal: The bulk of the effort at the federal level is described earlier under the sections describing the National Transition Task Force and Office on Equitable Energy Transitions. Efforts from those entities should be focused on instituting better information, analysis, and coordination on issues related to equitable energy transitions. In addition:

Congress should direct a portion of federal energy research, development, demonstration, and deployment spending at DOE to provide usable and use-inspired social-science and techno-economic knowledge for decision makers at all levels to support their efforts to plan and implement accelerated actions toward a carbon-neutral U.S. economy. As part of this effort, Congress should provide additional annual funding to the national laboratories to establish a coordinated, multilaboratory capability to provide energy modeling, data, and analytic and technical support to cities, states, and regions to complete a just, equitable, effective, and rapid transition to net zero. This funding should commence at the level of $200 million per year, rising to $500 million/year by 2025, and $1 billion/year by 2030.

Cost: $4.5 billion over 10 years.

Regional: Congress should create a regional planning and coordination infrastructure to support regional efforts to accelerate the equitable energy transition.

Page 232

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Major U.S. energy, transportation, and economic systems vary significantly across regions and are often organized and governed in regional, multistate arrangements according to regional priorities. Considerable work involved in coordinating, planning for, and managing the transition to a carbon neutral U.S. economy will therefore be necessary at the regional scale. Historically, regional authorities have played important roles in rapid energy system transformation in the past, including during the Depression-era New Deal, and offer the right scale and coordinating function to address the needs of deep decarbonization (Wiseman, 2011). Regional planning offers a mechanism for strengthening the capacity of localities and communities to successfully navigate transitions, to build relationships and work collaboratively with state and federal actors to implement strategic planning, and to integrate energy system planning and economic development (Healey, 1998; Morrison, 2014).

Congress should therefore establish 10 regional transition coordination offices under the auspices of the U.S. Department of Commerce, with advisory assistance from the White House Office of Equitable Energy Transitions, with the mandate to

Coordinate federal agency actions at the regional scale through the deployment of federal agency staff to regional offices with specific attention and funding for local technical assistance.

Host a coordinating council of regional governors and mayors that meets annually to establish high-level policy goals for the transition.

Establish mechanisms for ensuring the effective participation of low-income communities, communities of color, and other disadvantaged communities in regional dialogue and decision making about the transition to a carbon-neutral economy.

Provide information annually to the White House Office of Equitable Energy Transitions detailing regional progress toward decarbonization goals and benchmarks for equity.

Cost: $5 million/year for each regional office to provide funding for coordinating and hosting meetings, reporting, and information dissemination.

Congress should also:

Provide $25 million per year for a multi-university collaborative research center in each region to provide the data, models, and social science needed by regional transition coordination offices and local and state organizations to successfully navigate the complexities of regional transitions to net zero.

Page 233

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

These centers should be funded and administered through a competitive grant-making process coordinated by the National Science Foundation, with clear guidance regarding required collaboration with local, state, and regional stakeholders to set research agendas, design research, and disseminate research findings.

Cost: $25 million/year.

State: Congress should encourage each state to accelerate and coordinate the decarbonization of its economy. To accomplish this, Congress should direct DOE to:

Provide up to $1 million per year in matching funds to establish in each state an office of equitable energy transition in the governor’s office or other cross-agency senior administrative position. This office will coordinate state efforts to accelerate the transition of the state’s economy to carbon neutrality, host statewide stakeholder and community councils to coordinate decarbonization efforts, and coordinate state participation in regional transition coordinating councils. The office will also provide information to the Office of Equitable Energy Transitions on state progress toward carbon neutrality, the societal and economic criteria identified in Chapter 3, and the benchmarks established by the Office of Equitable Energy Transitions. The office will also establish mechanisms for ensuring the effective participation of low-income communities, communities of color, and other disadvantaged communities in state dialogue and decision making about the transition to a carbon-neutral economy consistent with standards set by the Office of Equitable Energy Transitions.

Cost: Up to $50 million/year.

Local: The capacity of cities and counties to pursue planning has been severely undermined by the erosion of state and local budgets during and after the recession of 2008–2010. COVID-19 has compounded these challenges, further reducing city and county finances and staffing. These impacts pose severe challenges to the ability of municipalities and communities to pursue the scale and depth of planning necessary to ensure successful decarbonization by 2050.

Congress should therefore provide incentive-based financial support and local technical assistance to municipal and county governments to create and strengthen local processes for planning decarbonization. These planning processes should (1) ensure coordinated planning at the local level across sectors

Page 234

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

and communities; (2) remove local planning barriers to accelerating actions to promote decarbonization and meet societal and economic criteria; (3) provide annual progress reporting; and (4) enable proactive identification of vulnerable communities, assess the challenges they face, and ensure their effective participation in transition planning. To create these incentives, Congress should:

Fund $1 billion per year in community block grants to support local decarbonization planning through a federal grant-making program. The grant-making program would be funded through DOE, while the grants would be administered and synthesized through the regional transition coordination office with local technical assistance for the region where the community is located.

Cost: $1 billion/year.

Include provisions so that the block grants include appropriate processes and allocation of resources to ensure inclusive, effective engagement and participation of low-income communities, communities of color, and other disadvantaged communities in planning processes.

REFERENCES

Abramson, E., D. McFarlane, and J. Brown. 2020. Transport Infrastructure for Carbon Capture and Storage: Whitepaper on Regional Infrastructure for Midcentury Decarbonization. Minneapolis, MN: Great Plains Institute and University of Wyoming.

AEIC (American Energy Innovation Council). 2020. Energy Innovation: Supporting the Full Innovation Lifecycle. Washington, DC. February.

Aggarwal, S., S. Corneli, E. Gimon, R. Gramlich, M. Hogan, R. Orvis, and B. Pierpont. 2019. Wholesale Electricity Market Design for Rapid Decarbonization. San Francisco, CA: Energy Innovation.

Ahlquist, J.S. 2017. Labor unions, political representation, and economic inequality. Annual Review of Political Science 20: 409–432.

Aldy, J.E. 2011. “Promoting Clean Energy in the American Power Sector.”The Hamilton Project Discussion Paper 2011-04.

Aldy, J.E. 2017. Designing and updating a U.S. carbon tax in an uncertain world. Harvard Environmental Law Review Forum 41: 28–40.

Aldy, J.E. 2020. Carbon tax review and updating: Institutionalizing an act-learn-act approach to U.S. climate policy. Review of Environmental Economics and Policy 14(1): 76-94.

Aldy, J.E., and W.A. Pizer. 2015. The competitiveness impacts of climate change mitigation policies. Journal of the Association of Environmental and Resource Economists 2(4): 565–595.

Aldy, J.E., M. Hafstead, G.E. Metcalf, B.C. Murray, W.A. Pizer, C. Reichert, and C. Williams III. 2017. Resolving the inherent uncertainty of carbon taxes. Harvard Environmental Law Review Forum 41: 1–13.

Alliance Commission on National Energy Efficiency Policy. 2013. The History of Energy Efficiency. Washington DC: Alliance to Energy.

Anadon, L., C. Chan, A. Bin-Nun, and V. Narayanamurti. 2016. The pressing energy innovation challenge of the U.S. National Laboratories. Nature Energy 1.

Page 235

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Anderson, M., and M. Kumar. 2019. “Digital divide persists even as lower-income Americans make gains in tech adoption.” Pew Research Center. https://www.pewresearch.org/fact-tank/2019/05/07/digital-divide-persistseven-as-lower-income-americans-make-gains-in-tech-adoption.

Architecture 2030. 2014. Roadmap to Zero Emissions. Amended Version. Santa Fe, NM.

Baker III, J., M. Feldstein, T. Halstead, N.G. Mankiw, H.M. Paulson, G.P. Shultz, T. Stephens, and R. Walton. 2017. The Conservative Case for Carbon Dividends. Washington DC: The Climate Leadership Council.

BEA (U.S. Bureau of Economic Analysis). 2018. “Value Added by Industry as a Percentage of Gross Domestic Product, 2018 data.” https://www.bea.gov/news/2019/gross-domestic-product-industry-fourth-quarter-and-annual-2018.

Bergquist, P., M. Mildenberger, and L. Stokes, 2020. Combining climate, economic, and social policy builds public support for climate action in the US. Environmental Research Letters 15(5).

Bielen, D., D. Burtraw, and K. Palmer. 2017. The Future of Power Markets in a Low Marginal Cost World. Washington, DC: Resources for the Future.

Bivens, J. 2015. A Comprehensive Analysis of the Employment Impacts of the EPA’s Proposed Clean Power Plan. Washington, DC: Economic Policy Institute.

Bivens, J., L. Engdahl, E. Gould, T. Kroeger, C. McNicholas, L. Mishel, Z. Mohkiber, et al. 2017. How Today’s Unions Help Working People. Washington DC: Economic Policy Institute.

Blonz, J., B. Laird, and K. Palmer. 2018. The benefits of flexible policy design: US energy conservation standards for appliances. Resources Magazine. April 6.

Bound, J., and S. Turner. 2002. Going to war and going to college: Did World War II and the G.I. Bill increase educational attainment for returning veterans? Journal of Labor Economics 20(4): 784–815.

Breakthrough Energy. 2019. Advancing the Landscape of Clean Energy Innovation. https://www.breakthroughenergy.org.

Brooks, S., and N.O. Keohane. 2020. The Political economy of hybrid approaches to a U.S. carbon tax: A perspective from the policy world. Review of Environmental Economics and Policy 14(1).

Brückmann, G. and T. Bernauer, 2020. What drives public support for policies to enhance electric vehicle adoption? Environmental Research Letters 15.

Burton, T. 2009. “34 Nobel Prize Winners Write President Obama Urging Support for Clean Energy R&D.”The Breakthrough Institute. http://thebreakthrough.org.

Burtraw, D., K. Palmer, and D. Kahn. 2010. A symmetric safety valve. Energy Policy 38(9): 4921–4932.

Burtraw, D., A. Keyes, and L. Zetterberg. 2018. Companion Policies under Capped Systems and Implications for Efficiency—The North American Experience and Lessons in the EU Context. Washington DC: Resources for the Future.

California Climate Investments. 2020. Annual Report to the Legislature on California Climate Investments Using Cap-and-Trade Auction Proceeds. Sacramento CA: California Energy Commission.

CA DGS (California Department of General Services). 2018. “Buy Clean California Act.” https://www.dgs.ca.gov/PD/Resources/Page-Content/Procurement-Division-Resources-List-Folder/Buy-Clean-California-Act.

California. 2020a. “CALGreen.” https://www.dgs.ca.gov/BSC/Resources/Page-Content/Building-Standards-Commission-Resources-List-Folder/CALGreen#@ViewBag.JumpTo.

California. 2020b. “Zero-Emission Vehicle Program | California Air Resources Board.” https://ww2.arb.ca.gov/our-work/programs/zero-emission-vehicle-program/about.

CBO (Congressional Budget Office). 2013. Effects of a Carbon Tax on the Economy and the Environment. Washington, DC.

CBO. 2019. The Post-9/11 GI Bill: Beneficiaries, Choices, and Cost. Washington, DC.

CBO. 2020. “Cost Estimate.” https://www.cbo.gov/system/files/2020-02/s2508.pdf.

Chan, G., A.P. Goldstein, A. Bin-Nun, L. Diaz Anadon, V. Narayanamurti. 2017. Six principles for energy innovation. Nature 552 (7683).

Chellaraj, G., K.E. Maskus, and A. Mattoo. 2008. The contribution of international graduate students to US innovation. Review of International Economics 16(3): 444–462.

Clark, C.E. 2019. Department of Energy Appliance and Equipment Standards Program. Washington DC: Congressional Research Service.

Cleary, K., K. Palmer, and K. Rennert. 2019. Clean Energy Standards: Exploring the options available for policy makers to implement a CES at the state or federal level. Washington, DC: Resources for the Future.

Page 236

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Clements, A. 2017. “Market Reform to Facilitate Public Policies and a Changing Resource Mix By Allison Clements.” The Future of Centrally-Organized Wholesale Electricity Markets. Berkeley, CA: Lawrence Berkeley National Laboratory.

Climate Leadership Council. 2020. The Baker Shultz Carbon Dividends Plan: Bipartisan Climate Roadmap. Washington, DC.

Climate-Related Market Risk Subcommittee. 2020. Managing Climate Risk in the U.S. Financial System. Washington, DC: U.S. Commodity Futures Trading Commission.

Coalition for Green Capital. 2019. Mobilizing $1 Trillion Towards Climate Action: An Analysis of the National Climate Bank. Washington DC.

Cohen, J.E. 1995. How Many People Can the Earth Support? New York, NY: W.W. Norton and Co.

Collantes, G., and D. Sperling. 2008. The origin of California’s zero emission vehicle mandate. Transportation Research Part A: Policy and Practice 42: 1302–1313.

Conexon. 2018. “Rural Electric Cooperative Consortium Awarded $186M in FCC’s Connect America Fund Phase II Auction, Becoming Single Largest Gigabit Winning Bidder.” PR Newswire. https://www.prnewswire.com/news-releases/rural-electric-cooperative-consortium-awarded-186m-in-fccs-connect-america-fund-phase-ii-auction-becoming-single-largest-gigabit-winning-bidder-300703739.html.

Corneli, S. 2018. Efficient Markets for High Levels of Variable Renewable Energy. Oxford, UK: Oxford Institute for Energy Studies.

Cronin, J., D. Fullerton, and S. Sexton. 2017. “Vertical and Horizontal Redistributions from a Carbon Tax and Rebate.” Working paper. Cambridge, MA: National Bureau of Economic Research.

CRS (Congressional Research Service). 2010. The Federal Government’s Role in Electric Transmission Facility Siting. Washington, DC.

CRS. 2018. Water Resources Development Act of 2018 and America’s Water Infrastructure Act of 2018: An Overview. Washington, DC.

Cullenward, D., and D.G. Victor. 2020. Making Climate Policy Work. Cambridge, MA: Polity Press.

Cushing L, D. Blaustein-Rejto, M. Wander, M. Pastor, J. Sadd, A. Zhu, and R. Morello-Frosch. 2018. Carbon trading, co-pollutants, and environmental equity: Evidence from California’s cap-and-trade program (2011–2015). PLoS Medicine 15(7).

C2ES (Center for Climate and Energy Solutions). 2019. “Carbon Tax Basics.” https://www.c2es.org/content/carbon-tax-basics/.

C2ES. 2020a. Getting to Zero: A U.S. Climate Agenda. Arlington, VA.

C2ES. 2020b. “Federal Vehicle Standards.” https://www.c2es.org/content/regulating-transportation-sector-carbon-emissions/.

C2ES (Center for Climate and Energy Solutions) and RAP (Regulatory Assistance Project). 2011. Clean Energy Standards: State and Federal Policy Options and Implications. Arlington, VA.

DiChristopher, T. 2020. “Banning’ Natural Gas Is out; Electrifying Buildings Is In.” S&P Global. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/banning-natural-gas-is-out-electrifying-buildings-is-in-59285807.

DOE (U.S. Department of Energy). 2015. ARRA Grid Modernization Highlights: A Glimpse of the Future Grid through Recovery Act Funding. Washington DC: Office of Energy Efficiency and Renewable Energy.

DOE. 2016. Smart Grid Investment Grant Program Final Report. Washington, DC: Office of Electricity Delivery and Energy Reliability.

DOE. 2017. Quadrennial Energy Review. Transforming the Nation’s Electricity System: The Second Installment of the QER. Washington, DC.

DOE. 2018. Strengthening TribalCommunities, Sustaining Future Generations. Washington, DC: Department of Energy Office of Indian Energy.

DOE. 2019. “There are More Than 68,800 Electric Vehicle Charging Units in the United States.” https://www.energy.gov/eere/vehicles/articles/fotw-1089-july-8-2019-there-are-more-68800-electric-vehicle-charging-units.

DOE. 2020a. “Frequently Answered Questions.” https://www.eia.gov/tools/faqs/faq.php?id=86&t=1.

DOE. 2020b. “Resource Center | Building Energy Codes Program.” https://www.energycodes.gov/resource-center.

DOE. 2020c. FY 2021 Congressional Budget Request. Volume 3 Part 2. Washington, DC.

DOE. n.d. “Buy American.” https://www.energy.gov/gc/action-center-office-general-counsel/faqs-related-recovery-act/buy-american.

Page 237

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Doris E., J. Cochran, and M. Vorum. 2009. Energy Efficiency Policy in the United States: Overview of Trends at Different Levels of Government. Golden CO: National Renewable Energy Laboratory.

Driscoll, C.T., J.J. Buonocore, J.I. Levy, K.F. Lambert, D. Burtraw, S.B. Reid, et al. 2015. US power plant carbon standards and clean air and health co-benefits. Nature Climate Change 5: 535–540.

DSIRE. 2019. “Database of State Incentives for Renewables and Efficiency.” https://www.dsireusa.org/resources/detailed-summary-maps/.

Eccles, R., and S. Klimenko. 2019. The investor revolution. Harvard Business Review. https://hbr.org/2019/05/theinvestor-revolution.

EDF (Environmental Defense Fund). 2019. “Colorado Becomes First State in the Central U.S. to Adopt Zero Emission Vehicle Standards.” https://www.edf.org/media/colorado-becomes-first-state-central-us-adopt-zero-emission-vehicle-standards.

EIA (Energy Information Administration). 2019. “Energy Power Annual.” Table 10.10. October. https://www.eia.gov/electricity/annual/html/epa\_10\_10.html.

EIA. 2020. U.S. Energy-Related Carbon Dioxide Emissions, 2019. Paris, France.

EFI (Energy Futures Initiative). 2020. An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions. https://energyfuturesinitiative.org.

Ela, E., M. Milligan, A. Bloom, A. Botterud, A. Townsend, and T. Levin. 2014. Evolution of Wholesale Electricity Market Design with Increasing Levels of Renewable Generation. Golden, CO: National Renewable Energy Laboratory.

EPA (U.S. Environmental Protection Agency). 2009. Interagency Report on International Competitiveness and Emission Leakage. Washington, DC.

EPA. 2012. “Benchmarking and Energy Savings.” https://www.energystar.gov/buildings/tools-and-resources/datatrends-benchmarking-and-energy-savings.

Eto, J. 2016. Building Electric Transmission Lines: A Review of Recent Transmission Projects. Berkeley, CA: Lawrence Berkeley National Laboratory.

Ex-Im Bank. 2019 Annual Report. Washington, DC.

Farber, H., D. Herbst, I. Kuziemko, and S. Naidu. 2018. Unions and Inequality Over the Twentieth Century: New Evidence from Survey Data. Report no. w24587. Cambridge, MA: National Bureau of Economic Research.

FCC (Federal Communication Commission). 2019. 2019 Broadband Deployment Report. Washington DC.

Fell, H., D. Burtraw, R. Morgenstern, and K. Palmer. 2011. Climate policy design with correlated uncertainties in offset supply and abatement cost. Land Economics 88(3): 589-611.

FERC (Federal Energy Regulatory Commission). 2011. “Demand Response Compensation in Organized Wholesale Energy Markets.” Order No. 745. Washington, DC.

FERC. 2018. “Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators.” Order No. 841. https://ferc.gov/sites/default/files/2020-06/Order-841.pdf.

FERC. 2020. “Participation of Distributed Energy Resources.” Order No. 2222. https://www.ferc.gov/sites/default/files/2020-09/E-1\_0.pdf.

FHWA (Federal Highway Administration). 2020. “Alternative Fuel Corridors Program.” https://www.fhwa.dot.gov/environment/alternative\_fuel\_corridors.

Fink, L. 2020. “BlackRock Capital, Letter to CEOs.” https://www.blackrock.com/us/individual/larry-fink-ceo-letter.

Fischedick M., A. Roy, O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, et al. 2014. Industry. In Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Fischer, C. 2004. Who Pays for Energy Efficiency Standards? Washington, DC: Resources for the Future.

Fischer, C., and A.K. Fox. 2011. The role of trade and competitiveness measures in US climate policy. American Economic Review 101(3): 258–262.

Fischer, C., and R.G. Newell. 2008. Environmental and technology policies for climate mitigation. Journal of Environmental Economics and Management 55(2): 142–162.

Fischer, C., and W.A. Pizer. 2018. Horizontal equity effects in energy regulation. Journal of the Association of Environmental and Resource Economists 6(1): 209–237.

Page 238

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Fitzpatrick, R., J. McBride, J. Lovering, J. Freed, and T. Nordhaus. 2018. Clean Energy Standards: How More States Can Become Climate Leaders—Third Way. Washington, DC: Third Way and the Breakthrough Institute. http://thebreakthrough.org.

Fowlie, M., M. Greenstone, and C. Wolfram. 2018. Do energy efficiency investments deliver? Evidence from the Weatherization Assistance Program. The Quarterly Journal of Economics 133(3): 1597–1644.

Fox-Penner, P. 2020. Power after Carbon: Building a Clean, Resilient Grid. Cambridge, MA: Harvard University Press.

Frankel, J.A. 2008. “Addressing the Leakage/Competitiveness Issue in Climate Change Policy Proposals [with Comment].” Pp. 69–91 in Brookings Trade Forum 2008/2009. Washington, DC: Brookings Institution Press.

Friedmann, S.J. 2019. Congressional Testimony before the Committee on Energy and Commerce in the U.S. House of Representatives. September 18.

Fu, R., D. Feldman, and R. Margolis. 2018. U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018. Golden, CO: National Renewable Energy Laboratory.

Gillingham, K., R. Newell, and K. Palmer. 2004. Retrospective Examination of Demand-Side Energy Efficiency Policies. Washington, DC: Resources for the Future.

Gillingham, K., R. Newell, and K. Palmer. 2006. Energy efficiency policies: A retrospective examination. Annual Review of Environment and Resources 31: 161–192.

Goldstein A., C. Doblinger, E. Baker, and L. Diaz Anadon. 2020 Patenting and business outcomes for cleantech startups funded by the Advanced Research Projects Agency-Energy. Nature Energy 5: 803–810.

Grab, D., and A. Shah. 2020. “California Can’t Wait on All-Electric New Building Code.” Rocky Mountain Institute. July 28. https://rmi.org/california-cant-wait-on-all-electric-new-building-code/.

Gramlich, R., and M. Hogan. 2019. Wholesale Electricity Market Design for Rapid Decarbonization: A Decentralized Markets Approach. San Francisco, CA: Energy Innovation.

Green, T., and C. Knittel. 2020. Distributed Effects of Climate Policy: A Machine Learning Approach. Roosevelt Project. Cambridge, MA: MIT’s Center for Energy and Environmental Policy Research.

Greene, D.L., C.B. Sims, and M. Muratori. 2020. Two trillion gallons: Fuel savings from fuel economy improvements to US light-duty vehicles, 1975–2018. Energy Policy 142: 111–517.

Griffith-Jones, S., and J.A. Ocampo. 2018. The Future of National Development Banks. The Initiative for Policy Dialogue Series. United Kingdom: Oxford University Press.

Griffith-Jones, S., S. Attridge, and M. Gouett. 2020. “Securing Climate Finance Through National Development Banks.” Overseas Development Institution. http://www.stephanygj.net/papers/SecuringClimateFinanceThroughNationalDevelopmentBanksJan2020.pdf.

Haggerty, J.H., M.N. Haggerty, and R. Rasker. 2014. Uneven local benefits of renewable energy in the U.S. West: Property tax policy effects. Western Economics Forum 13(1): 1-16.

Hafstead, M., G.E. Metcalf, and R.C. Williams. 2016. Adding quantity certainty to a carbon tax through a tax adjustment mechanism for policy pre-commitment. Harvard Environmental Law Review Forum 41: 41–57.

Hafstead, M., and R.C. Williams III. 2020. Designing and evaluating a U.S. carbon tax adjustment mechanism to reduce emissions uncertainty. Review of Environmental Economics and Policy 14(1).

Hahn, R.W., and R.N. Stavins. 1992. Economic incentives for environmental protection: Integrating theory and practice. The American Economic Review 82(2): 464–468.

Hart, D.M. 2018. Beyond the technology pork barrel? An assessment of the Obama administration’s energy demonstration projects. Energy Policy 119: 367–376.

Hausman, J.A., and P.L. Joskow. 1982. Evaluating the costs and benefits of appliance efficiency standards. The American Economic Review 72(2): 220–225.

Healey, P. 1998. Building institutional capacity through collaborative approaches to urban planning. Environment Planning A: Economy and Space 30(9): 1531–1546.

Hernandez-Cortes, D., and K.C. Meng. 2020. Do Environmental Markets Cause Environmental Injustice? Evidence from California’s Carbon Market. Cambridge, MA: National Bureau of Economic Research.

Hibbard, P.J., and S.F Tierney. 2011. Carbon control and the economy: Economic impacts of RGGI’s first three years. The Electricity Journal 24(10): 30-40.

Page 239

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Hibbard, P.J., S.F. Tierney, P. Darling, and S. Cullinan. 2018. An expanding carbon cap-and-trade regime? A decade of experience with RGGI charts a path forward. The Electricity Journal 31: 1-8.

Ho, M., R.D. Morgenstern, and J. Shih. 2008. Impact of Carbon Price Policies on U.S. Industry. Washington DC: Resources for the Future.

Hogan, W. 2014. Electricity market design and efficient pricing: Applications for New England and beyond. The Electricity Journal 27(7): 23-49.

Hogan, W. 2017. “Electricity Market Design Interactions of Multiple Markets.” Presentation at RFF’s Workshop on the Future of Power Markets in a Low Marginal Cost, September 14, 2017. https://media.rff.org/documents/170914\_PowerMarkets\_WilliamHogan.pdf.

Horowitz, J., J. Cronin, H. Hawkins, L. Konda, and A. Yuskavage. 2017. “Methodology for Analyzing a Carbon Tax.”Working Paper 115. Washington, DC: Department of Treasury, Office of Tax Analysis.

Horowitz, J., R Igielnik, and R. Kochhar. 2020. Most Americans Say There Is Too Much Economic Inequality in the U.S., but Fewer Than Half Call It a Top Priority. Washington, DC: Pew Research Center.

Houde, S., and C.A. Spurlock. 2016. Minimum energy efficiency standards for appliances: Old and new economic rationales. Economics of Energy and Environmental Policy 5(2).

Hunt, J., and M. Gautheir-Loiselle. 2010. How much does immigration boost innovation? American Economic Journal: Macroeconomics 2(2): 31–56.

IEA. (International Energy Agency). 2011. IEA Guide to Reporting Energy RD&D Budget/Expenditure Statistics. Paris, France.

IEA. 2019. World Energy Investment 2019. Paris, France.

IEA. 2020. Clean Energy Innovation. Paris, France.

IMT (Institute for Market Transformation). 2020. “U.S. Building Benchmarking Policy, Landscape.” https://www.buildingrating.org/graphic/us-building-benchmarking-policy-landscape.

Jaffe, A., S.R. Peterson, P.R. Portney, and R.N. Stavins. 1995. Environmental regulation and the competitiveness of U.S. manufacturing: What does the evidence tell us? Journal of Economic Literature 33(1): 132–163.

Jaffe, A., R. Newell, and R. Stavins. 2004. Economics of Energy Efficiency. Encyclopedia of Energy 2:79–90. Amsterdam: Elsevier.

Jaffe, A., R. Newell, and R. Stavins. 2005. A tale of two market failures: Technology and environmental policy. Ecological Economics 54(2-3): 164–174.

Jones, B., P. Philips, and C. Zabin. “The Link Between Good Jobs and a Low Carbon Future.”University of California, Berkeley. https://laborcenter.berkeley.edu/pdf/2016/Link-Between-Good-Jobs-and-a-Low-Carbon-Future.pdf.

Jordan, G., and A. Link. 2018. Evaluation of U.S. DOE Small Business Vouchers Pilot. Washington, DC: Department of Energy Office of Energy Efficiency and Renewable Energy.

Joskow, P and R. Schmalensee. 2020. “MIT Energy Initiative’s Energy Markets.” Podcast Episode #14. http://energy.mit.edu/podcast/electricity-markets/.

Jungclaus, M., C. Carmichael, C. McClurg, M. Simmons, R. Smidt, K.P. Hydras, S. Conger, et al. 2017. Deep energy retrofits in federal buildings: The value, funding models, and best practices. ASHRAE Transactions 124(1).

Kaufman, N., A.R. Barron, W. Krawczyk, P. Marsters, and H. McJeon. 2020. A near-term to net zero alternative to the social cost of carbon for setting carbon prices. Nature Climate Change 10: 1010–1014.

Kortum, S., and D. Weisbach. 2017. The design of border adjustments for carbon pricing. National Tax Journal 70(2): 421–446.

Krishnaswami, A., and J. Higdon. 2020. A Progressive Climate Innovation Agenda. Data for Progress. https://www.dataforprogress.org.

Larsen, J., N. Kaufman, P. Marsters, W. Herndon, H. Kolus, and B. King. 2020. Expanding the Reach of a Carbon Tax: Emissions Impacts of Pricing Combined with Additional Climate Actions. New York, NY: Columbia SIPA Center on Global Energy Policy.

Larson, E., C. Greig, J. Jenkins, E. Mayfield, A. Pascale, C. Zhang, S. Pacala, et al. 2020. Net-Zero America by 2050: Potential Pathways, Deployments, and Impacts. Princeton, NJ: Princeton University.

Larson J., S. Mohan, P. Marsters, and W. Herdon. 2018. Energy and Environmental Implications of a Carbon Tax in the United States. New York, NY: Columbia SIPA Center on Global Energy Policy and Rhodium Group.

Page 240

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Levin, B. 2019. “A Broadband Agenda for the (Eventual) Infrastructure Bill.” Brookings Institution. https://www.brookings.edu/blog/the-avenue/2019/03/19/a-broadband-agenda-for-the-eventual-infrastructure-bill/.

Litterman, R. 2020a. “Financial Regulation and Climate Risk Management.” Interview with Robert Litterman. Harvard Business School’s “Climate Rising” podcast. https://www.hbs.edu/environment/podcast/Pages/podcast-details.aspx?episode=15116819.

Litterman, R. 2020b. “Pricing Climate Risk in the Markets, with Robert Litterman.” Resources Radio. https://www.resourcesmag.org/resources-radio/pricing-climate-risk-markets-robert-litterman/.

Luna-Martinez, J., and C.L. Vicente. 2012. Global Survey of Development Banks. Washington, DC: The World Bank.

Lyubich, E. 2020. The Race Gap in Residential Energy Expenditures. Berkeley, CA: Berkeley Haas.

MacDonald, A., C. Clack, A. Alexander, A. Dunbar, J. Wilczek, and Y. Xie. 2016. Future cost-competitive electricity systems and their impact on US CO2 emissions. Nature Climate Change 6: 526-531.

Margolies, J. 2020. “‘All-Electric’ Movement Picks Up Speed, Catching Some Off Guard.” The New York Times. February 4. https://www.nytimes.com/2020/02/04/business/all-electric-green-development.html.

Meng, T., D. Hsu, and A. Han. 2016. Measuring Energy Savings from Benchmarking Policies in New York City, ACEEE Summer Study on Energy Efficiency in Buildings. Washington, DC: American Council for an Energy-Efficient Economy.

Metcalf, G.E. 2008. Using tax expenditures to achieve energy policy goals. American Economic Review 98(2): 90–94.

Metcalf, G.E. 2009. Market-based policy options to control U.S. greenhouse gas emissions. Journal of Economic Perspectives 23(2): 5–27.

Metcalf, G.E. 2020. An emissions assurance mechanism: Adding environmental certainty to a U.S. carbon tax. Review of Environmental Economics and Policy 14(1).

Moran, D., A. Hasanbeigi, and C. Springer. 2018. The Carbon Loophole in Climate Policy. KGM & Associates, ClimateWorks Foundation and Global Efficiency Energy Intelligence.

Morgan, M. 2019. “Buy American vs. Buy America: A Simple Guide to Successfully Navigating the Differences.” https://www.mbpce.com/blog/buy-american-vs-buy-america-a-simple-guide-to-successfully-navigating-the-differences/.

Morrison, T.H. 2014. Developing a regional governance index: The institutional potential of rural regions. Journal of Rural Studies 35: 101–111.

Mufson, S. 2020. “The Fastest Way to Cut Carbon Emissions Is a “Fee”and a Dividend, Top Leaders Say.”The Washington Post. https://www.washingtonpost.com/climate-environment/the-fastest-way-to-cut-carbon-emissions-is-a-fee-and-a-rebate-top-leaders-say/2020/02/13/b63b766c-4cfc-11ea-bf44-f5043eb3918a\_story.html.

Muro, M., A. Tomer, R. Shivaram, and J. Kane. 2019. Advancing Inclusion through Clean Energy Jobs. Washington, DC: Brookings Institute.

Murray, A.G., and B.F. Mills. 2014. The impact of Low-Income Home Energy Assistance Program participation on household energy insecurity. Contemporary Economic Policy 32(4): 811–825.

Murray, B.C., W.A. Pizer, and C. Reichert. 2017. Increasing emissions certainty under a carbon tax. Harvard Law Review Forum 41: 13–27.

Myslikova, Z., and K.S. Gallagher. 2020. Mission innovation is mission critical. Nature Energy 5: 732–734.

Nadel, S., N. Elliot, and T. Langer. 2015. Energy Efficiency in the United States: 35 Years and Counting. Washington, DC: American Council for an Energy-Efficient Economy.

NASEM (National Academies of Sciences, Engineering, and Medicine). 2017a. An Assessment of ARPA-E. Washington, DC: The National Academies Press.

NASEM. 2017b. Enhancing the Resilience of the Nation’s Electricity System. Washington, DC: The National Academies Press.

NASEO (National Association of State Energy Officials) and EFI (Energy Futures Initiative). 2019. The 2019 U.S. Energy and Employment Report 2019. https://www.usenergyjobs.org.

NASEO and EFI. 2020. 2020 U.S. Energy and Employment Report. Washington, DC.

Nemet, G.F., V. Zipperer, and M. Kraus. 2018. The valley of death, the technology pork barrel, and public support for large demonstration projects. Energy Policy 119: 154–167.

Page 241

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

Newbery, D.M. 2008. Climate change policy and its effect on market power in the gas market. Journal of the European Economic Association 6(4): 727–751.

NGA (National Governors Association). 2019. “Clean Energy Toolkit: Growing Electrification.” https://www.nga.org/wp-content/uploads/2019/11/NGA\_CleanEnergy\_Toolkit\_Growing\_Electrification.pdf.

NPR. 2019. “For Many Navajos, Getting Hooked Up To the Power Grid Can Be Life-Changing.” https://www.npr.org/sections/health-shots/2019/05/29/726615238/for-many-navajos-getting-hooked-up-to-the-power-grid-can-be-life-changing.

NPR, Robert Wood Johnson Foundation, and Harvard T.H. Chan School of Public Health. 2019. Life in Rural America Part II. https://www.rwjf.org/en/library/research/2019/05/life-in-rural-america—part-ii.html.

NRC (National Research Council). 2006. State and Federal Standards for Mobile-Source Emissions. Washington, DC: The National Academies Press.

NREL (National Renewable Energy Laboratory). 2017. “Green Banks.” https://www.nrel.gov/state-local-tribal/basics-green-banks.html.

NSF (National Science Foundation). 2020. Science and Engineering Indicators. Washington, DC.

NYC (New York City). 2019. “Local Laws of the City of New York for the Year 2019, No. 97.” https://www1.nyc.gov/assets/buildings/local\_laws/ll97of2019.pdf.

Office of the Governor. 2020. “Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars and Drastically Reduce Demand for Fossil Fuel in California’s Fight Against Climate Change.” https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-drastically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/.

Olson, E. 2020. Federal Investment in EV Charging Infrastructure for Economic Recovery, Climate, and Public Health. The Breakthrough Institute. http://thebreakthrough.org.

Omarova, S. 2020. The Climate Case for a National Investment Authority. Data for Progress. https://www.dataforprogress.org.

Palmer, K., and M. Walls. 2015. Does Information Provision Shrink the Energy Efficiency Gap? Washington, DC: Resources for the Future.

Palmer, K., A. Paul, and A. Keyes. 2018. Hanging Baselines, Shifting Margins: How Predicted Impacts of Pricing Carbon in the Electricity Sector Have Evolved over Time. Washington, DC: Resources for the Future.

Partridge, A., and B. Steigauf. 2020. Minnesota’s Power Plant Communities: An Uncertain Future. Minneapolis-St. Paul, MN: Center for Energy and Environment.

PCAST (President’s Council of Advisors on Science and Technology). 2010. Report to the President on Accelerating the Pace of Change in Energy Technologies Through an Integrated Federal Energy Policy. Washington, DC.

Perrin, A. 2019. “Digital Gap Between Rural and Nonrural America Persists.”Pew Research Center. https://www.pewresearch.org/fact-tank/2019/05/31/digital-gap-between-rural-and-nonrural-america-persists/.

Pierpont, B., and D. Nelson. 2017. Markets for Low Carbon, Low Cost Electricity Systems. San Francisco, CA: Climate Policy Initiative.

Pizer, W.A, and S. Sexton. 2019. The distributional impacts of energy taxes. Review of Environmental Economics and Policy 13(1): 104–123.

Pomerleau, K., and E. Asen, E. 2019. Carbon Tax and Revenue Recycling: Revenue, Economic, and Distributional Implications. Washington, DC: Tax Foundation.

Ramani, V. 2020. Addressing Climate Risk as a Systemic Risk: A Call to Action for U.S. Financial Regulators. Arlington, VA: The CERES Accelerator for Sustainable Capital Markets.

Rausch, S., G.E. Metcalf, and J.M. Reilly. 2011. Distributional impacts of carbon pricing: A general equilibrium approach with micro-data for households. Energy Economics 33(1): 20-33.

Reed, L., M.G. Morgan, P. Vaishnay, and D.E. Armanios. 2019. Converting existing transmission corridors to HVDC is an overlooked option for increasing transmission capacity. Proceedings of the National Academy of Sciences U.S.A. 116(28): 13879-13884.

Reed, L., M. Dworkin, P. Vaishnav, and M.G. Morgan. 2020. Expanding transmission capacity: Examples of regulatory paths for five alternative strategies. The Electricity Journal 33(6).

Page 242

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

RGGI, Inc. 2020. “Investments of Proceeds.” https://www.rggi.org/investments/proceeds-investments.

Rosenbloom, D., J. Markard, F.W. Geels, and L. Fuenfschilling. 2020. Opinion: Why carbon pricing is not sufficient to mitigate climate change—and how “sustainability transition policy” can help. Proceedings of the National Academy of Sciences U.S.A. 117(16): 8664–8668.

Rozansky, R., and D.M. Hart. 2020. More and Better: Building and Managing a Federal Energy Demonstration Project Portfolio. Washington, DC: Information Technology and Innovation Foundation.

Ruckelshaus, C., and S. Leberstein. 2014. Manufacturing Low Pay: Declining Wages in the Jobs That Built America’s Middle Class. New York, NY: National Employment Law Project.

Schwabe, P. 2016. Solar Energy Prospecting in Remote Alaska. Washington DC: U.S. Department of Energy, Office of Indian Energy.

Scott, R.E. 2020. “We Can Reshore Manufacturing Jobs, but Trump Hasn’t Done It.” Economic Policy Institute. https://www.epi.org/publication/reshoring-manufacturing-jobs/.

Shah, T., and A. Krishnaswami. 2019. Transforming the U.S. Department of Energy in Response to the Climate Crisis. New York, NY: Natural Resources Defense Council.

Shierholz, H. 2019. Working People Have Been Thwarted in Their Efforts to Bargain for Better Wages by Attacks on Unions. Washington, DC: Economic Policy Institute.

Sivaram, V., C. Cunliff, D. Hart, J. Friedmann, and D. Sandalow. 2020. Energizing America: A Roadmap to Launch a National Energy Innovation Mission. New York, NY: Columbia Center on Global Environmental Policy.

Stavins, R. 2009. “The Wonderful Politics of Cap-and-Trade: A Closer Look at Waxman-Markey.” An Economic View of the Environment. May 27. http://www.robertstavinsblog.org/2009/05/27/the-wonderful-politics-of-cap-and-tradea-closer-look-at-waxman-markey/.

Stepp, M., S. Pool, J. Spencer, and N. Loris. 2013. Turning the Page: Reimagining the National Labs in the 21st Century Innovation Economy. Washington, DC: Information Technology and Innovation Foundation.

Stehly, T., and P. Beiter. 2019. 2018 Cost of Wind Energy Review. Golden, CO: National Renewable Energy Laboratory.

Swanstrom, D., and M.M. Jolivert. 2009. DOE transmission corridor designations and FERC backstop siting authority: Has the Energy Policy Act of 2005 succeeded in stimulating the development of new transmission facilities? Energy Law Journal 30: 415-466.

TCFD (Task Force on Climate-related Financial Disclosures). 2017. FinalTCFDRecommendations Report: Executive Summary. June. https://www.fsb-tcfd.org/publications/.

Terman, J.N. 2018. Helping third-party implementers meet performance obligations: A multi-level examination of the Weatherization Assistance Program. Public Administration Quarterly 42(3).

Tierney, S., and P.H. Hibbard. 2019. Clean Energy in New York State: The Role and Economic Impacts of a Carbon Price in NYISO’s Wholesale Electricity Markets. Boston, MA: Analysis Group.

Tonn B., D. Carroll, E. Rose, B. Hawkins, S. Pigg, D. Bausch, G. Dalhoff, M. Blasnik, J. Eisenberg, C. Cowan, and B. Conlon. 2015. Weatherization Works II—Summary of Findings from the ARRA Period Evaluation of the U.S. Department of Energy’s Weatherization Assistance Program. Oak Ridge, TN: Oak Ridge National Laboratory.

Tonn, B., E. Rose, and B. Hawkins. 2018. Evaluation of the U.S. Department of Energy’s Weatherization Assistance Program: Impact results. Energy Policy 118: 279–290.

Traut, E.J., T.C. Cherng, C. Hendrickson, and J.J. Michalek. 2013. US residential charging potential for electric vehicles. Transportation Research Part D: Transport and Environment 25: 139–145.

TRB (Transportation Research Board) and NRC (National Research Council). 2015. Overcoming Barriers to Deployment of Plug-in Electric Vehicles. Washington, DC: The National Academies Press.

U.N. Development Programme. 2019. Human Development Report 2019. New York, NY.

Urbanek, L. 2017. “Changes to the Standards Program: More Harm than Good?” https://www.nrdc.org/experts/lauren-urbanek/changes-standards-program-more-harm-good.

U.S. Congress. House. 2020a. “E&C Leaders Release Framework of the CLEAN Future Act, a Bold New Plan to Achieve a 100 Percent Clean Economy by 2050.” Press release. House Committee on Energy and Commerce. https://energycommerce.house.gov/newsroom/press-releases/ec-leaders-release-framework-of-the-clean-future-act-a-bold-new-plan-to.

Page 243

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

U.S. Congress. House. 2020b. Solving the Climate Crisis: The Congressional Action Plan for a Clean Energy Economy and a Healthy, Resilient and Just America. Majority Staff Report. Select Committee on the Climate Crisis. Washington, DC.

U.S. Congress. House. 2020c. “Summary of the Climate Leadership and Environmental Action for Our Nation’s (CLEAN) Future Act.” House Committee on Energy and Commerce. https://energycommerce.house.gov/sites/democrats.energycommerce.house.gov/files/documents/Section-by-Section%20of%20CLEAN%20Future%20Act%20.pdf.

U.S. Congress. Senate. 2019. “FY2020 Energy and Water Development Appropriations Bill Advanced by Full Committee.” News. Committee on Appropriations. https://www.appropriations.senate.gov/news/fy2020-energy-and-water-development-appropriations-bill-advanced-by-full-committee.

U.S. Congress. Senate. 2020. “Murkowski, Manchin Introduce American Energy Innovation Act.” Republican News. Committee on Energy and Natural Resources. February 27. https://www.energy.senate.gov/2020/2/murkowski-manchin-introduce-american-energy-innovation-act.

USG (U.S. Government). 2017. “View Rule.” https://www.reginfo.gov/public/do/eAgendaViewRule?pubId=201704&RIN=1904-AE11.

Vaughan, E., and J. Turner. 2013. The Value and Impact of Building Codes. Washington, DC: Environmental and Energy Study Institute.

Vizcarra, H. 2020. The Reasonable Investor and Climate-Related Information: Changing Expectations for Financial Disclosures. Washington, DC: Environmental Law Institute.

Voos, P. 2009. “How Unions Can Help Restore the Middle Class.”Economic Policy Institute. https://www.epi.org/publication/how\_unions\_can\_help\_restore\_the\_middle\_class/.

Wallace, M., L. Goudarzi, K. Callahan, and R. Wallace. 2015. AReviewoftheCO2 PipelineInfrastructureintheU.S. Washington, DC: National Energy Technology Laboratory.

Weitzman, M.L. 1974. Prices vs. quantities. Review of Economic Studies 41(4): 477–491.

Weitzman, M. 2009. On modeling and interpreting the economics of catastrophic climate change. The Review of Economics and Statistics 91(1): 1-19.

Wigley, T., R. Richels, and J. Edmonds. 1996. Economic and environmental choices in the stabilization of atmospheric CO2 concentrations. Nature 379: 240–243.

Williams, R.C., H. Gordon, D. Burtraw, J.C. Carbone, and R.D. Morgenstern. 2015. The initial incidence of a carbon tax across income groups. National Tax Journal 68(1): 195–213.

Wiseman, H. 2011. Expanding regional renewable governance. Harvard Environmental Law Review 35(2): 477-540.

World Bank. 2020. “Stock Market Capitalization to GDP for United States [DDDM01USA156NWDB].” https://data.worldbank.org/indicator/CM.MKT.TRAD.GD.ZS.

Zaidi, A. 2020. “Mandates for Action: Corporate Governance Meets Climate Change.” Stanford Law Review Online. https://www.stanfordlawreview.org/online/new-mandates-for-action/.

Page 244

Suggested Citation:"4 How to Achieve Deep Decarbonization." National Academies of Sciences, Engineering, and Medicine. 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. doi: 10.17226/25932.×

The world is transforming its energy system from one dominated by fossil fuel combustion to one with net-zero emissions of carbon dioxide (CO2), the primary anthropogenic greenhouse gas. This energy transition is critical to mitigating climate change, protecting human health, and revitalizing the U.S. economy. To help policymakers, businesses, communities, and the public better understand what a net-zero transition would mean for the United States, the National Academies of Sciences, Engineering and Medicine convened a committee of experts to investigate how the U.S. could best decarbonize its transportation, electricity, buildings, and industrial sectors.

This report, Accelerating Decarbonization of the United States Energy System, identifies key technological and socio-economic goals that must be achieved to put the United States on the path to reach net-zero carbon emissions by 2050. The report presents a policy blueprint outlining critical near-term actions for the first decade (2021-2030) of this 30-year effort, including ways to support communities that will be most impacted by the transition.