CLIMATE INNOVATION

GETTING TO ZERO: A U.S. CLIMATE AGENDA

C2ES CLIMATE INNOVATION 2050

by

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EXECUTIVE SUMMARY

This report outlines a comprehensive agenda for decarbonizing the U.S. economy by 2050, with an emphasis on priority actions needed over the coming decade. This agenda was developed in close consultation with leading companies in key sectors through the Center for Climate and Energy Solutions' (C2ES's) Climate Innovation 2050 initiative. It builds on an earlier report, *Pathways to 2050: Alternative Scenarios for Decarbonizing the U.S. Economy.*

A strong body of scientific evidence underscores the imperative of decarbonizing the global economy in order to avoid the worst potential impacts of climate change. Key strategies for achieving that goal include increasing energy efficiency, decarbonizing the power sector, switching to electricity and other low- and zero-carbon fuels, reducing non-CO_2 climate pollutants, and using both nature and technology to remove carbon from the atmosphere.

In the United States, achieving net-zero emissions by 2050 will require action across society—by governments, the private sector, and the public at large. It will require both innovative technologies and strong policies to ensure they are deployed. And apart from reducing the grave risks of climate change, it will provide a strong foundation for continued U.S. growth and competitiveness.

Getting to Zero: A U.S. Climate Agenda recommends that a U.S. decarbonization strategy be guided by these key objectives: achieving net-zero emissions no later than 2050, reestablishing U.S. global leadership on climate change, developing and mobilizing a broad array of technological solutions, promoting cost-effective solutions, protecting and enhancing U.S. competitiveness and energy security, ensuring an equitable transition, strengthening climate resilience, responding to new information and circumstances, and providing predictability to drive long-term investment.

With these objectives in mind, *Getting to Zero* outlines a comprehensive set of policies needed over the coming decade to put the United States on the path to carbon neutrality.

At the core of this policy agenda is a long-term federal framework, including an economy-wide carbon pricing program. The agenda also includes many complementary federal, state, and local measures addressing key sectors: power, transportation, industry, buildings, land use, and oil and gas. In addition, the agenda offers recommendations to drive innovation, mobilize finance and ensure a just transition, and advance especially critical technologies. Finally, the agenda recommends steps that companies should take, recognizing the critical role of the private sector in leading the climate effort.

The diverse array of policy approaches recommended here are intended to work in concert to address the many facets of the overall decarbonization challenge. While a robust carbon price will send a broad signal across the economy to reduce emissions, companion policies, from the federal to the local, will help mobilize private investment, ensure that the necessary technologies and infrastructure are in place, and provide targeted incentives to both companies and consumers to accelerate the transition. The nature of these companion policies varies across sectors, and their precise mix and timing will depend in part on how quickly a meaningful carbon price is put in place. But for any given sector, it is the totality of these approaches working together, rather than any single policy, that will produce the necessary results.

The agenda's core, sectoral, cross-sectoral, and business-focused recommendations are briefly summarized below.

CORE ELEMENTS

Establishing a Long-Term Framework

- Congress should set a national goal of making the United States carbon neutral no later than 2050 and establish an overarching statutory framework for achieving carbon neutrality, including a comprehensive review of progress every four years.
- Congress should vest the President with the statutory responsibility to direct a phased effort across the federal government toward meeting the goal of carbon neutrality.
- Congress should enact an economy-wide market-based policy that effectively puts an escalating price on carbon and other major greenhouse gas emissions.

Driving Innovation

- Congress should establish decarbonization as a principal objective of the research mission of all relevant federal agencies and should direct the White House to lead an interagency innovation effort, including research, development, demonstration, and deployment strategies aiming for carbon neutrality in the transportation, power, buildings, industry, land use, and oil and gas sectors.
- Congress should ramp up funding for climate-related research and development to at least $20 billion per year by 2030, including $2 billion per year for the Advanced Research Projects Agency–Energy, and should provide $50 billion to $100 billion over the next decade for high-impact demonstration projects.
- The federal government should strengthen administrative capacity and management practices to ensure the efficient and timely use of research funding and should consult closely with the private sector and other non-government stakeholders in developing and executing the low-carbon innovation agenda.

Mobilizing Finance

- Congress should direct the Securities and Exchange Commission to require public companies to disclose material climate-related financial risks under a range of climate scenarios and their strategies for managing those risks.
- Congress should require the Federal Reserve to integrate consideration of climate-related risks into the periodic stress testing required of major financial institutions.
- Congress should create a national green bank to leverage private investment in clean energy, energy efficiency, and other activities contributing to decarbonization. More states and localities should also create green banks for use in their own markets.

Ensuring a Just Transition

- Policies that could increase the cost of energy should include mechanisms to minimize any cost burden on low-income populations and small businesses.

- A share of climate investment should be dedicated to deploying solutions and infrastructure in historically marginalized communities, including urban tree planting, energy efficiency retrofits, community solar, electric vehicle charging, and low- and zero-carbon public transit.
- Congress should increase support to communities in transition to train workers and foster new industries that can contribute to a stable economy and tax base.

SECTORAL ELEMENTS

Power

- Congress should provide a range of tax credits for zero-carbon generation and should mandate the use of carbon capture or corresponding sequestration-based offsets for all fossil fuel-fired power generation by a date certain.
- In the absence of meaningful economy-wide carbon pricing or a national clean energy standard, all states should adopt ambitious clean energy standards that can be met by the full range of zero-carbon technologies, including renewables, nuclear, large hydro, and fossil fuel generation with carbon capture.
- Congress should direct the Federal Energy Regulatory Commission to develop a comprehensive, long-range infrastructure strategy and should prioritize the siting of "climate-critical" infrastructure. The commission also should reform wholesale power markets to more explicitly value the low-carbon, capacity, and reliability attributes of competing power sources.
- State public utility commissions should work with the power sector to help facilitate the electrification of other sectors.

Transportation

- Congress should direct the Environmental Protection Agency to establish a greenhouse gas performance standard ensuring that half of new light-duty vehicle sales are zero-emission vehicles by 2035, and a similarly ambitious standard for medium- and heavy-duty trucks.
- Congress should extend the current electric vehicle tax credit, make it available as a point-of-sale rebate, and expand it to include all new zero-emission vehicles, including fuel cell electric vehicles and medium- and heavy-duty trucks.
- States should develop comprehensive long-range plans to accelerate the deployment of zero-emission-vehicle charging and refueling infrastructure. Congress should fund the development of these state plans and should provide funding to states that have plans to construct charging and refueling infrastructure.
- Local governments should—with dedicated federal planning support—develop integrated transportation and land use plans that expand non-automotive transportation options in order to strengthen mobility while reducing congestion, air pollution, and carbon emissions.
- Congress should establish a performance standard that freezes aviation emissions at 2020 levels, allowing for the use of biofuels and offsets, modeled on the Carbon Offsetting and Reduction Scheme for International Aviation.

Industry

- Congress should increase funding to develop and commercialize alternative thermal heat technologies and to develop innovative industrial processes with much smaller greenhouse gas footprints.
- The federal government should undertake a benchmarking process to establish intensity-based greenhouse gas objectives for major sub-industries.
- Congress should extend and increase the existing 45Q tax credit for carbon capture to support the capture of process and on-site energy-related emissions, and should provide tax credits for energy efficiency improvements.
- Federal, state, and local governments should support the deployment of combined heat and power systems.
- An economy-wide carbon pricing program should include provisions aimed at safeguarding competitiveness and minimizing carbon leakage risks.
- The United States should ratify the Kigali Amendment phasing down the use of hydrofluorocarbons and Congress should provide the Environmental Protection Agency with clear authority to take the steps necessary to implement it.

Buildings

- State and local governments should set overarching goals for the decarbonization of commercial and residential buildings, and should regularly update their building codes to require the use of available and affordable energy efficiency measures and other carbon-reducing practices.
- Federal, state, and local governments should provide incentives for building owners and homeowners to switch from fossil fuel-powered to electric appliances such as electric space and water heating systems.
- All states should authorize Property Assessed Clean Energy (PACE) programs to help finance energy-related improvements in both residential and commercial buildings.
- States and localities should encourage the use of energy savings performance contracts in public buildings to improve energy efficiency, reduce emissions, and save taxpayer money.

Land Use

- Congress should provide the U.S. Forest Service stronger funding to restore forests, increase forests' resilience to wildfires, and provide support for private forest owners in areas at risk.
- Congress should strengthen incentives for farmers to adopt carbon-sequestering growing practices by authorizing them as emission offsets in an economy-wide carbon pricing program, and through lower interest rates for farm loans, lower crop insurance premiums, and other changes to the federal crop insurance program.
- Congress should fund the U.S. Department of Agriculture to develop improved soil carbon measurement methods and equipment and to develop food, fiber, and biomass crops that require fewer inputs and can better sequester carbon.
- Local governments should implement and support composting programs that use post-consumer food waste to produce fertilizer or use biodigesters to generate biogas.

Oil and Gas

- The Environmental Protection Agency should establish standards under the Clean Air Act regulating methane emissions across the oil and gas value chain, including emissions from natural gas flaring, venting, and unintentional leaks during production, processing, transmission, and distribution.
- State policy-makers should implement renewable natural gas programs including tax and other financial incentives, such as capital investment or project rebate programs. Drawing on the success of Renewable Portfolio Standards in electricity markets, states should expand or create renewable portfolio standards for renewable thermal energy, including renewable natural gas.
- Congress should amend the tax code and other provisions to phase federal subsidies away from higher-carbon energy sources and toward lower-carbon energy sources, including fossil fuels with carbon capture.
- Federal agencies should assess the climate-related impacts of new oil and natural gas infrastructure projects and conduct similar assessments on proposals at the programmatic level that expand oil and natural gas leasing on federal lands.

CROSS-SECTORAL ELEMENTS

Carbon Capture, Utilization, and Storage

- Congress should reauthorize and increase funding for the Department of Energy's carbon capture program and should extend both the "begin construction" and claiming deadlines for the 45Q tax credit for carbon capture, utilization, and storage.
- Congress should strongly ramp up research and development to cut the cost of direct air capture, and should establish a direct air capture tax credit, possibly by amending 45Q.
- Creating a "CO_2 superhighway"—a network of pipelines connecting sources of CO_2 to locations where it will be utilized or stored—should be a national priority in any major infrastructure legislation, with the aim of substantially completing such a network by 2030.

Digitalization

- Congress and the Department of Energy should prioritize RDD&D efforts that enable systems-based efficiency through digital technologies, and should support the development of real-time measurement and verification protocols for systems-level efficiencies in buildings, industry, and transportation.
- All levels of government—federal, state, and local—should lead by example by requiring agencies to procure digital solutions, documenting the related energy efficiencies and cost-savings and publicizing the lessons learned.
- Congress should fund and oversee the scaling and accelerated deployment of broadband infrastructure nationwide, especially in rural areas.

Bioenergy

- The Department of Energy should partner with businesses on pilot demonstrations of bioenergy with carbon capture and storage to study its emissions-reducing or negative-emissions potential and to encourage commercial development.
- Federal agencies should work collaboratively to develop consistent methodologies to more accurately assess the net emissions benefits of biofuels.
- States should provide incentives to the power and industrial sectors to use low-carbon bioenergy and bioenergy with carbon capture and storage in place of carbon-intensive fuels.

Hydrogen

- The Department of Energy should partner with industry to accelerate the development of low-carbon pathways to produce hydrogen and to develop alternative industrial processes that rely on hydrogen instead of fossil fuels.
- Congress should fund the development of state and regional plans to kickstart the buildout of storage, pipeline networks, and other infrastructure to support higher levels of hydrogen use across sectors.
- Congress and states should provide incentives for the adoption of technologies employing hydrogen, such as hydrogen fuel cells.

Business Leadership

- Companies should adopt carbon-neutrality goals and use only sequestration-based emission offsets after 2050. They should employ internal practices such as carbon pricing to systematically incorporate climate-related costs into investment and operational decisions.
- Companies should invest now in the technologies and workforce needed to decarbonize the economy.
- Companies should thoroughly assess and voluntarily disclose to stakeholders and investors their climate-related risks and opportunities, as well as their strategies to lower emissions, invest in long-term needs, and boost resilience.
- Companies should actively engage policy-makers at all levels to voice support for the policies needed to decarbonize the economy, partner with their private-sector peers and collaborate across and between sectors to spread action throughout their industries, and help consumers understand their options for reducing their carbon footprints.

Getting to Zero: A U.S. Climate Agenda offers one vision for aligning the U.S. economy with the historic imperative of ensuring future generations a safe and stable climate. It draws both on a very extensive body of research and analysis and on the insights of leading companies committed to climate action. The prospects for, and the ultimate shape of, a comprehensive U.S. climate strategy depend on whether, when, and how we mobilize the necessary political will.

Through the Climate Innovation 2050 initiative, C2ES will continue working with companies and other stakeholders to refine, elaborate, and advance this agenda. It is our sincere hope that these initial recommendations serve to inform and stimulate this vital debate, and we look forward to working with partners in all spheres to mobilize a U.S. climate effort commensurate with this historic challenge.

I. INTRODUCTION

There is growing momentum in the United States toward a more robust response to climate change. States, cities, and companies across the country are stepping up their efforts, driven both by the rising toll of extreme weather and other climate impacts and by the economic dividends of a clean energy transition. A growing majority of Americans favor stronger climate efforts, and debate is again underway in Washington on comprehensive long-term solutions.[1]

This report offers policy-makers and stakeholders one vision for aligning the U.S. economy with the historic imperative of ensuring future generations a safe and stable climate. It is based on extensive consultations with leading companies across key economic sectors—companies that recognize the irrefutable risks and realities of climate change and are committed to working with policy-makers, customers and investors, and other stakeholders to develop and implement strategies that will progressively decarbonize the U.S. economy.

No single volume can hope to enumerate all the facets of a comprehensive U.S. climate strategy. Rather, the objective here is to outline the broad contours of an effective long-term strategy and to identify a set of key actions that should be taken over the coming decade to put the United States firmly on the path to decarbonization.

Getting to Zero: A U.S. Climate Agenda emerges from the Center for Climate and Energy Solutions' (C2ES's) Climate Innovation 2050 initiative, which provides an ongoing forum for companies to examine decarbonization challenges and solutions. It builds on *Pathways to 2050: Alternative Scenarios for Decarbonizing the U.S. Economy*, our earlier report based on a year-long collaboration with companies and experts envisioning three alternative pathways to substantially decarbonize the economy by 2050.[2]

Our agenda is grounded in the firm belief that unchecked climate change poses grave risks to America's wellbeing—and that an effective and durable response can not only reduce those risks but also help to grow and sustain our nation's prosperity.

Toward those ends, this report:

- Examines the fundamental nature of our decarbonization challenge and recommends overarching objectives for a U.S. decarbonization strategy
- Outlines the core elements of a long-term climate policy framework, including policies to price carbon, accelerate innovation, mobilize finance, and ensure a just transition
- Outlines priority federal, state and local policies to help decarbonize the power, transportation, industry, buildings, oil and gas, and land-use sectors
- Highlights technology pathways with significant potential across multiple sectors
- Recommends ways that companies can demonstrate stronger leadership in meeting the decarbonization challenge

Throughout the report, we offer snapshot visions of the future this agenda could help to produce.

The diverse array of policy approaches recommended here are intended to work in concert to address the many facets of the overall decarbonization challenge. While a robust carbon price will send a broad signal across the economy to reduce emissions, companion policies from the federal to the local level will help mobilize private investment, ensure that the necessary technologies and infrastructure are in place, and provide targeted incentives to both companies and consumers to accelerate the transition. The nature of these companion policies varies across sectors, and their precise mix and timing will depend in part on how quickly a meaningful carbon price is put in place. But for any given sector, it is the totality of these approaches working together, rather than any single policy, that will produce the necessary results.

Through Climate Innovation 2050, C2ES will continue working with companies on a sector-by-sector basis to elaborate and refine these strategies. It is our sincere hope that these initial recommendations benefit policy-makers and stakeholders alike and serve to inform and stimulate this vital national debate. We look forward

to working with partners in all spheres to mobilize a U.S. climate effort commensurate with this historic challenge.

THE DECARBONIZATION CHALLENGE

Decarbonizing the U.S. and global economies represents perhaps the most ambitious and complex societal transformation ever undertaken. A successful strategy must be grounded in a firm understanding of the strong scientific rationale for this mission; the scale, scope, and urgency of this transformation; and the fundamental features of the decarbonization challenge.

What Science Tells Us

For more than three decades, the United States has worked in partnership with other countries to advance scientific understanding of climate change. The result is a large and strong body of evidence and analysis documenting the worsening physical, economic, and social effects of human-induced climate change. This broad consensus is reflected in the series of assessments undertaken since 1990 by the Intergovernmental Panel on Climate Change (IPCC) and in separate analyses by the U.S. National Academy of Sciences and other independent scientific bodies.

Two recent reports outline the potential impacts of climate change on a global scale and in the United States. The IPCC's special report *Global Warming of 1.5°C*, adopted by the United States and other governments in October 2018, warns of wide-scale and, in some cases, catastrophic or irreversible impacts on ecosystems, economies, and human populations if average warming exceeds 1.5 degrees C.[3] The *Fourth National Climate Assessment*, published by the U.S. government in November 2018, exhaustively details the expected impacts of climate change on the United States and projects hundreds of billions of dollars in further economic losses.[4]

Guided by the overwhelming scientific consensus, the United States and other governments set out in the Paris Agreement a set of collective goals to limit the impacts of climate change. These goals include keeping the rise in global average temperature well below 2 degrees C above pre-industrial levels (and pursuing efforts to limit it to 1.5 degrees C), achieving peak global emissions and reducing them as quickly as possible, and achieving a balance between greenhouse gas emissions and removals (i.e., net-zero emissions) in the second half of this century. The IPCC's subsequent 1.5°C analysis underscores the importance of achieving carbon neutrality no later than 2050.

Key Elements of Decarbonization

Consistent with a broad range of previous analyses, the scenario exercise described in our *Pathways to 2050* report demonstrated that any pathway to decarbonization entails fundamental shifts in the way we power our homes and economies, produce goods, deliver services, transport people and goods, and manage our lands.[5] Figure 1 illustrates how these shifts are reflected in the *Pathways* report's three scenarios. They include:

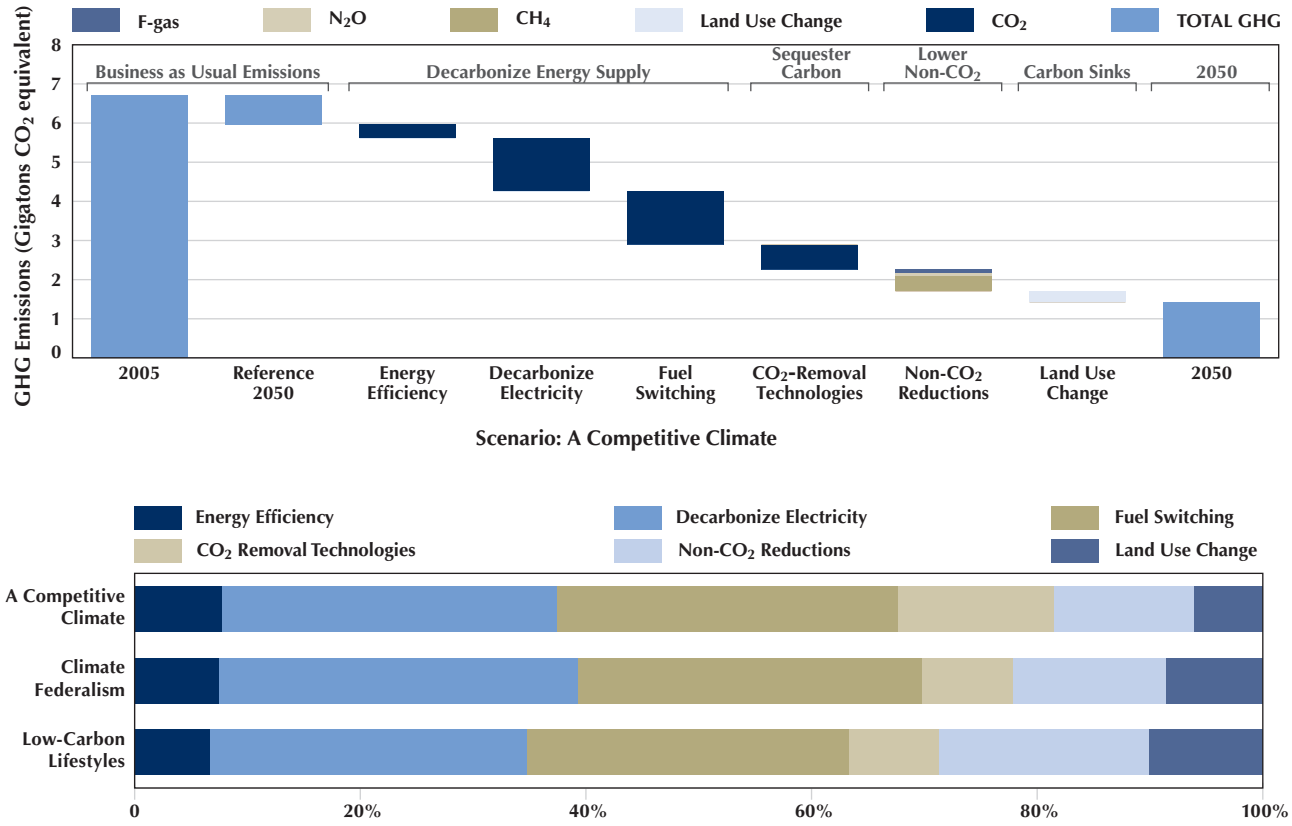
- Increasing energy efficiency across the economy
- Decarbonizing the power supply
- Switching to electricity and other zero- and low-carbon fuels in transportation, buildings, and industry
- Increasing sequestration of carbon dioxide (CO_2) through the use of carbon capture technologies
- Reducing emissions of non-CO_2 climate pollutants including methane, nitrous oxide, fluorinated gases and hydrofluorocarbons (HFCs)
- Increasing sequestration of CO_2 by enhancing natural carbon sinks, including forests and agricultural soils.

Major decarbonization analyses consistently indicate that each of these elements must play an important role, although as Figure 1 suggests, the relative contributions of each can vary depending on a host of factors. For instance, how heavily society must rely on different forms of carbon sequestration to achieve carbon neutrality will depend on our success in reducing emissions.

An Innovation Challenge

Our successes thus far in decarbonizing the U.S. economy are largely the result of technological innovation. Prime examples include the rapid growth of renewable energy, as well as the role of new drilling technologies in enabling the substitution of natural gas for coal in electricity generation, the largest source of the 13 percent reduction in U.S. emissions achieved since 2005. Fully decarbonizing the economy will similarly require innovation across all key sectors, at a pace and on a scale without precedent.

FIGURE 1: Key elements of decarbonization



These figures illustrate the principal strategies for decarbonizing the U.S. economy as reflected in the three scenarios presented in *Pathways to 2050: Alternative Scenarios for Decarbonizing the U.S. Economy*.[6] The three scenarios are named A Competitive Climate (a strong federal response, including an economy-wide carbon price), Climate Federalism (growing state responses, transitioning to an economy-wide carbon price) and Low-Carbon Lifestyles (rapid adoption of low-carbon technologies, consumption patterns, and business models). All three scenarios achieve an 80 percent reduction in greenhouse gas emissions by 2050. The top figure illustrates the relative contributions of the key emissions-reducing strategies in A Competitive Climate. The lower figure shows that the relative contributions of these strategies are roughly similar across all three scenarios.

Driving this innovation is the responsibility of both the public and private sectors and requires strong partnership between the two. The drilling technologies that led to the U.S. natural gas boom were nurtured by federal research and policies, better enabling private industry to bring them to scale. The same is true for many renewable energy technologies. A U.S. climate strategy must dedicate the public resources and foster the public-private collaboration needed to accelerate innovation across a wide of range of decarbonization technologies.

However, while technological innovation can greatly facilitate decarbonization, innovation alone is not enough. Without adequate incentives and policies, many carbon-saving technologies are not being widely deployed; some existing energy efficiency technologies are a prime example. In addition, rapidly emerging technologies such as artificial intelligence or autonomous vehicles could, depending on how they evolve, either contribute to or deter decarbonization. Ultimately, translating innovation into carbon neutrality is contingent on sufficient policy drivers.

All Must Do Their Part

The breadth and scale of the decarbonization challenge necessitate an all-in effort. We must look to governments at all levels to set goals and standards, provide market signals and incentives, invest public resources, and

maintain a level playing field. We must look to the private sector to mobilize capital, apply its expertise and entrepreneurial energies, accelerate both technology and business model innovation, collaborate across and between sectors, and support enabling policies. We must look to investors to steer finance toward low- and zero-carbon technologies and business models. And we must look to the public at large to express, as citizens and consumers, a preference for the policies and products that can deliver a decarbonized future.

Timing Is Critical

For many years, experts and advocates encouraged "early action" to address climate change, believing it would produce valuable lessons and reduce long-term costs. That time is now past. While some important progress has been made, we are now far behind the curve, and we must act urgently to make up for lost time. The IPCC's 1.5 degrees C report makes clear that decisive action is critical by 2030 to avoid the worst potential impacts of warming.

Urgent action is required not only because the risks of catastrophic climate change are growing, but also because the actions needed to reduce them will in many cases not produce instantaneous results. Even with substantial new investment in research and development, new technologies can take decades to emerge and mature. Where the necessary technologies already exist, it takes time to build the infrastructure to deploy them at scale. So, too, does determining the right mix of policy mandates and incentives.

Achieving decarbonization without causing undue economic harm requires close attention to other temporal dimensions as well. Each sector presents its own challenges, whether the long-term investment cycles of the power and industrial sectors or the natural turnover rates for buildings, vehicles, and major appliances. A climate strategy will be most successful and least costly to the degree that it can align with, capitalize on, and judiciously accelerate these economic rhythms.

The Benefits Are Many

The strongest rationale for a decarbonization strategy may be the avoidance of escalating harms, including the costly impacts of extreme weather, floods, and wildfires on life, property, and commerce; the dire health consequences of heat waves and more rampant infectious disease; and the national security implications of instability and conflict driven by worsening drought, food shortages, and refugee flows.

Beyond avoiding such harms, decarbonization can yield enormous co-benefits, especially in driving economic growth and enhancing U.S. competitiveness. Natural gas, renewables, and energy efficiency—all helping to decarbonize the U.S. power supply—accounted in 2017 for more than half of the 6.5 million jobs in the U.S. energy industry.[7] As other countries undertake their own energy transitions, U.S. firms can leverage their own innovative technologies and know-how into leading positions in the soaring global clean energy market.

STRATEGIC OBJECTIVES

An effective decarbonization strategy must be not only appropriately scaled but also durable, which requires that it rest on a broad political consensus. For such a consensus to emerge and be sustained, the strategy must consider and address a combination of important climate and non-climate objectives. Its overarching objectives should be the following:

Carbon Neutrality. There is broad recognition within the scientific community, and among governments, that

BOX 1: CARBON NEUTRALITY vs. NET-ZERO EMISSIONS

This agenda aims for the decarbonization of the U.S. economy. The goal is "carbon neutrality" or "net-zero emissions"—terms we use interchangeably here. Both describe a state in which greenhouse gas emissions to the atmosphere are balanced by greenhouse gas withdrawals from the atmosphere. Some activities or sectors may continue emitting greenhouse gases, provided these emissions are fully offset by withdrawals. These withdrawals (or "negative emissions") can be achieved either by increasing carbon sequestration by plants and soils (sometimes referred to as nature-based solutions) or through direct air capture, technologies that absorb carbon from the atmosphere.

averting the worst potential consequences of climate change requires achieving a net balance between greenhouse gas emissions and withdrawals within the coming decades. In line with the latest findings of the IPCC, the United States should aim to achieve net-zero emissions no later than 2050 (**see Box 1**, **Carbon Neutrality vs. Net-Zero Emissions**).

Global Leadership. Climate change is an inherently global challenge that cannot be met by the United States alone. The Paris Agreement marks a fundamental shift in the global climate effort, committing all countries to undertake progressively stronger efforts and providing mechanisms to verify whether they are fulfilling their promises. A strong U.S. climate strategy will reestablish the United States as a global leader on climate, better enabling it to press other countries to contribute their fair share to the global effort.

Technology Inclusiveness. Achieving carbon neutrality will require the mobilization of a broad array of low- and zero-carbon technologies. Given the scale and urgency of the challenge, we cannot afford to exclude potentially viable solutions. A U.S. strategy should take full advantage of the range of available and emerging technologies, including renewable energy, nuclear power, and carbon capture. It also should seek to ensure that emerging technologies not obviously climate-related, such as artificial intelligence and autonomous vehicles, develop in ways that contribute to, rather than detract from, decarbonization.

Cost-Effectiveness. Decarbonizing the economy requires a significant shift in the allocation of public and private capital—investments that will reap significant long-term dividends in the form of economic growth and avoided climate damages. These economic benefits, as well as public support for climate action, can be maximized by making sure our decarbonization strategy is as cost-effective as possible. It should to the degree practical align with natural capital cycles and stock turnover. Wherever feasible, it should rely on market-based approaches to reduce emissions at the lowest possible cost.

U.S. Competitiveness. The United States should seek to fully capture the competitive benefits of its decarbonization efforts. The public and private sectors should work closely to maximize opportunities for the export of U.S. technologies, products, and expertise. A U.S. strategy must also preserve competitiveness by providing appropriate safeguards for energy-intensive trade-exposed industries.

Equity. A U.S. climate strategy must strive to benefit all Americans and leave none worse off. It should ensure that the costs of decarbonizing do not fall disproportionately on those least able to absorb them. It should take account of the relative circumstances of different states and regions and treat them equitably. It should also help workers and communities once or still dependent on high-carbon industries to ensure them a place in a decarbonizing economy.

Resilience. Fully addressing climate change requires both mitigation (actions to reduce greenhouse gas emissions) and adaptation (actions to strengthen our resilience to the impacts of climate change that cannot be avoided). A decarbonization strategy, by definition, focuses primarily on mitigation, but it should also maximize opportunities for actions that can deliver both mitigation and adaptation benefits, such as deploying microgrids and upgrading the built environment.

Adaptability. No strategy of the scale and duration that we are urging can be fully formed from the outset. On multiple fronts—policy, technology, finance—success will hinge heavily on learning by doing. Unforeseen circumstances and unintended consequences may arise at any stage. A U.S. climate strategy should set clear milestones but be designed to adapt based on experience and evolving circumstances. It should include mechanisms to periodically assess progress, evaluate new information, and, when warranted, adjust policies and priorities.

Predictability. While remaining adaptable, a U.S. decarbonization strategy must outline clear goals and pathways that provide sufficient predictability and stability to guide long-term investment decisions. It also should be designed to facilitate a smooth transition from existing to new policy structures in order to minimize regulatory confusion and overlap without compromising environmental integrity and benefits.

ECONOMY-WIDE EMISSIONS AT A GLANCE

Current and cumulative emissions. The United States currently produces about 14 percent of the world's greenhouse gas emissions, second only to China. The climate change occurring today is the result of cumulative emissions over time, however, and the United States remains by far the world's largest cumulative emitter.

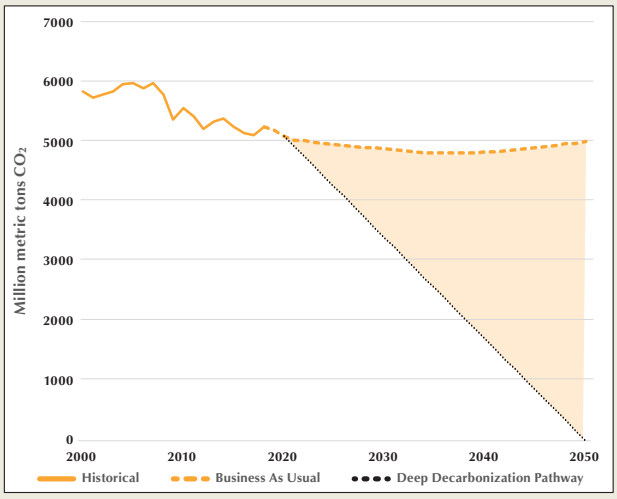
Trends. U.S. emissions have declined by 13 percent since 2005. Under business as usual (no new policies), energy-related CO_2 emissions are projected to remain relatively level through 2050.

Principal greenhouse gases. CO_2 represents 82 percent of total U.S. emissions, with fossil fuel combustion the largest source. Other gases including methane, nitrous oxide, and fluorinated gases (i.e., HFCs, perfluorocarbons , sulfur hexafluoride, and nitrogen trifluoride) also contribute to atmospheric warming. While these "short-lived" gases do not remain in the atmosphere as long as CO_2, they are more potent. For example, one ton of methane creates as much warming as 25 tons of CO_2 over a 100-year time period.

Emissions by sector. About 30 percent of U.S. emissions result from the generation of electricity. A sector's total emissions include both its direct emissions and the "indirect" emissions associated with the electricity it consumes. Looking at both direct and indirect emissions, the largest-emitting sectors are buildings (31 percent), industry (30 percent), transportation (29 percent), and agriculture (10 percent).

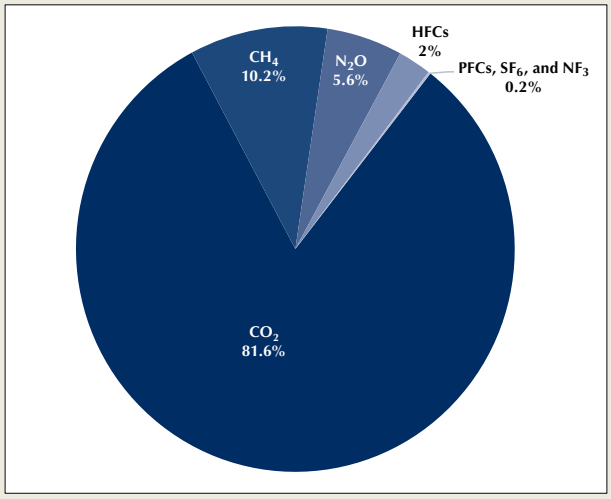
Negative emissions through land use. U.S. emissions are offset somewhat by the natural sequestration of carbon in soils and vegetation. These "negative emissions" currently offset about 11 percent of U.S. emissions.

Energy-related CO_2 emissions, 1990–2050



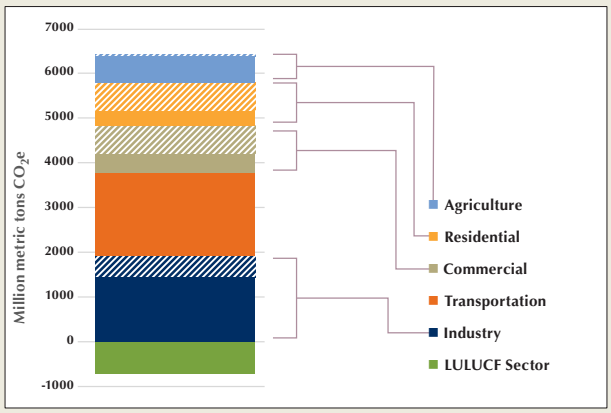
Sources: U.S. Energy Information Administration (2019a) and U.S. Energy Information Administration (2019c).

U.S. emissions by greenhouse gas, 2017



Source: U.S. Environmental Protection Agency (2019c).

U.S. emissions by sector, 2017



Source: U.S. Environmental Protection Agency (2019c).

Solid color denotes a sector's direct emissions; hatched color denotes indirect emissions from the generation of electricity used in that sector.

Sources: CAIT Climate Data Explorer (2017) and U.S. Environmental Protection Agency (2019c).

II. CORE ELEMENTS

ESTABLISHING A LONG-TERM FRAMEWORK

As the foundation for a successful decarbonization strategy, Congress should enact an overarching statutory framework that (1) sets a long-term goal and interim milestones, (2) charges the President with driving and coordinating cost-effective action across the federal government, (3) establishes a market-based system that incentivizes carbon reduction across the economy, and (4) provides for periodic review of progress and policies. Many of the additional policies recommended throughout this report should be incorporated into this framework either from the start or over time.

A 2050 Goal

Congress should set a national goal of making the United States carbon neutral no later than 2050 and establish an overarching statutory framework for achieving it. Carbon neutrality should be defined as a net balance of greenhouse gas emissions and withdrawals across the U.S. economy. To make carbon neutrality feasible, and to achieve it as cost-effectively as possible, this goal should allow for a full range of emissions reduction and sequestration solutions.

To further orient the government, the private sector, and the public at large, Congress should also establish, or direct the President to establish, interim milestones defining a trajectory toward carbon neutrality by 2050.

White House Leadership

Decarbonizing the economy requires strong, steady leadership from the top. Congress should vest the President with the statutory responsibility to direct—and should maintain continuous oversight of—a phased effort across the federal government toward meeting the goal of carbon neutrality. Lead responsibility should be assigned to a designated White House office headed by a Senate-confirmed appointee. This office should coordinate across executive branch offices and agencies to:

- Direct the effective, timely, and cost-effective implementation of climate-related policies
- Ensure the inclusion of climate-related needs and priorities in the President's annual budgets
- Develop a low-carbon innovation agenda and carbon-neutrality strategies for key sectors of the economy
- Support the climate-related efforts of state, local, and tribal governments
- Regularly assess progress toward milestones and the 2050 goal, as well as opportunities to accelerate progress
- Recommend to Congress further actions to ensure the achievement of the 2050 goal

KEY RECOMMENDATIONS

- *Congress should set a national goal of making the United States carbon neutral no later than 2050 and establish an overarching statutory framework for achieving carbon neutrality, including a comprehensive review of progress every four years.*
- *Congress should vest the President with the statutory responsibility to direct a phased effort across the federal government toward meeting the goal of carbon neutrality.*
- *Congress should enact an economy-wide market-based policy that effectively puts an escalating price on carbon and other major greenhouse gas emissions.*

This White House office should also engage closely and regularly with the private sector, labor groups, public interest groups, and other stakeholders to gather broad input into policy development and implementation. In addition, it should direct public education efforts across the government to encourage and equip citizens to contribute to the decarbonization effort.

Economy-wide Carbon Pricing

A central element of the overarching framework enacted by Congress should be a market-based policy that effectively creates an escalating, economy-wide price on carbon emissions.

In economic terms, climate change is a "negative externality," a symptom of the market's failure to internalize the social and environmental costs of carbon pollution. Market-based policies aim to correct this failure by assigning a price to this pollution, so that it is incorporated into economic decision-making. This price signal incentivizes carbon reduction across the economy, though it will spur action in some sectors more than in others. Market-based policies generally are more cost-effective than command-and-control policies because, rather than mandate specific technologies or approaches, they allow emitters the flexibility to choose their least-cost options. Market-based approaches also provide an ongoing incentive for low-carbon innovation and, depending on their design, can generate revenue for climate-related or other purposes. Globally, 54 carbon pricing programs had been adopted as of September 2019.[8]

While pricing is a cornerstone of a long-term decarbonization strategy, the market "pull" of an economy-wide price signal must be complemented by other policies that either create a market "push" (e.g., by supporting the development of critical technologies) or address other types of market failures (e.g., the split incentives between a building owner and occupant). Such complementary policies are recommended throughout this report. The need for such policies depends on the given sector and on the timing and strength of a carbon pricing program.

An economy-wide market-based policy could take many forms. The three major options are a carbon tax, cap and trade, and tradable performance standards.

Carbon Tax. The most basic form of a market-based policy is a tax that sets a price on each unit of pollution. The additional expense gives an emitter an ongoing incentive to use available means, and develop innovative means, of reducing emissions. The more that emissions are reduced, the less tax a company pays. The revenue raised by such a policy can be rebated to Americans, channeled to climate-related projects, and/or utilized for other purposes. A tax-based approach offers greater predictability for companies on compliance costs but, without an ancillary mechanism, less certainty on environmental outcomes.

Cap and Trade. Another option is a cap-and-trade program that sets a cap on total U.S. emissions, auctions or allocates a corresponding quantity of emission allowances to emitters, and allows emitters to trade them. An emitting company can choose to reduce its emissions or buy additional allowances, whichever is more economical. A company able to reduce emissions more than required can bank its excess allowances for future use or sell them to a firm facing higher emissions-reduction costs. If some or all allowances are auctioned, the resulting revenue can be channeled to climate-related and/or other purposes. A cap-and-trade approach can offer greater certainty about environmental outcomes but less certainty for companies about the cost per unit of pollution. A cap-and-trade approach can also be linked to other comparable cap-and-trade programs to allow trading across jurisdictions, giving companies more flexibility and reducing price volatility.

Tradable Performance Standards. A third option is a set of sector-based performance standards that allow for trading. One example, in the case of the power sector, is a clean energy standard that requires utilities to obtain a certain portion of their electricity from a defined set of clean or renewable sources. Allowing utilities to trade between different types of qualified clean energy effectively establishes a market-based carbon price. Other types of performance standards could be established for all of the major sectors of the economy; allowing trading across sectors would yield an economy-wide carbon price. Offering covered entities the option of an alternative compliance payment or applying a transfer tax on source-to-source transactions could also raise revenue, though not at the level of cap-and-trade or carbon tax policies.

Depending on the type of market-based policy Congress chooses to enact, some or all of the following design principles should be applied:

- **Environmental integrity.** A market-based policy should be robust enough to deliver timely emissions reductions and include mechanisms that provide environmental certainty that the emissions goals will be met.
- **Predictability and transparency.** The policy should be stable and predictable to ensure that investment and innovation are incentivized. This could include a predictable escalation rate in a tax-based approach or a price floor in a cap-and-trade program. Any program changes should be phased in or introduced with sufficient advance notice.
- **Competitiveness.** The policy should include safeguards to protect the competitiveness of energy-intensive, trade-exposed industries and prevent emissions "leakage" to other countries. These safeguards could include preferential emissions allocations for energy-intensive, trade-exposed industries under a cap-and-trade program or a border tax adjustment under a carbon tax.
- **Cost containment.** The policy should include measures to reduce price volatility and moderate unexpectedly high compliance costs. Depending on the type of market-based policy established, these could include the banking and borrowing of allowances, emissions offsets, a ceiling and floor on allowance prices, or a credit, dividend, or refund to cover program costs for certain types of participants.
- **Alignment with state policies.** The policy should provide for an economy-wide framework while allowing states the option of continuing existing market-based programs, provided they are deemed equivalent (or more stringent) and do not impose an undue burden on participants.
- **Inclusion of complementary federal measures.** The policy should provide for complementary federal measures needed to accelerate key technologies and to address other market failures. It also should retain or establish back-stop regulatory authorities that can be employed if emissions reduction targets are not being met.

Periodic Review

The overarching statutory framework established by Congress should include a mechanism for a comprehensive review every four years. This review should be directed by the White House and result in a report to Congress assessing progress toward interim milestones and the 2050 carbon-neutrality goal, and recommending any necessary policy adjustments. It also should inform periodic updates of the United States' nationally determined contribution under the Paris Agreement.

The review should consider:

- The findings of the latest National Climate Assessment
- The effectiveness, cost-effectiveness, and economic impact of federal climate policies
- The contributions of state, local, tribal, and private-sector efforts
- Technological and market advances or setbacks affecting the scale or speed of decarbonization efforts
- The status of decarbonization efforts of other major economies
- Opportunities to strengthen economic growth and U.S. competitiveness

DRIVING INNOVATION

Rapidly accelerating low-carbon innovation will be essential to reaching carbon neutrality by mid-century. Top priorities over the coming decade are to establish and implement a long-range low-carbon research and development agenda, significantly scale up federal resources for low-carbon innovation, and optimize the low-carbon innovation system.

Setting the Low-Carbon Innovation Agenda

Congress and the President should work together to orient all relevant federal agencies and capabilities toward the objective of generating and advancing the innovative technologies needed to decarbonize every sector of the economy.

Congress should establish decarbonization as a principal objective of the research mission of all relevant federal agencies as part of future agency reauthorizations; codify the Department of Energy's (DOE's) Quadrennial Technology Review—an assessment of energy technologies and their pathways to commercialization—in order to regularly assess gaps and opportunities and target federal resources; and direct the White House to lead an interagency effort to develop strategies for carbon-neutrality research, development, demonstration, and deployment (RDD&D) for each major sector.

As part of the White House-led decarbonization effort recommended above, the President should designate an office within the Executive Office of the President to oversee the alignment and execution of this low-carbon innovation agenda across the federal government. The office will lead interagency efforts to produce the Quadrennial Technology Review and to develop and implement sector-specific innovation strategies. This office will also direct targeted efforts across the government to accelerate technology transfer, working through programs such as the Office of Technology Transitions within DOE to improve private-sector licensing and develop other commercialization partnerships.

KEY RECOMMENDATIONS

- *Congress should establish decarbonization as a principal objective of the research mission of all relevant federal agencies and should direct the White House to lead an interagency innovation effort, including research, development, demonstration, and deployment strategies aimed at carbon neutrality in the transportation, power, buildings, and industry, land use, and oil and gas sectors.*
- *Congress should ramp up funding for climate-related research and development to at least $20 billion per year by 2030, including $2 billion per year for the Advanced Research Projects Agency–Energy, and should provide $50 billion to $100 billion over the next decade for high-impact demonstration projects.*
- *The federal government should strengthen administrative capacity and management practices to ensure the efficient and timely use of research funding and should consult closely with the private sector and other non-government stakeholders in developing and executing the low-carbon innovation agenda.*

Funding Low-Carbon Innovation

The rationale for federally funded research in societally critical areas is well established. Privately funded technology development often produces public benefits beyond those that a firm is able to monetize,[9] a "spillover" phenomenon that leads firms to consistently underinvest in research relative to societally optimal levels. This challenge is exacerbated in the climate arena, as many firms are neither required nor easily able to pass along to consumers the costs of reducing their emissions or avoiding climate impacts.

Funding priorities should be guided by the White House-led, low-carbon innovation agenda and should target clean electricity; carbon capture, utilization, and storage; energy storage; advanced clean fuels; advanced manufacturing; renewable thermal energy; advanced computing; and advanced agriculture. (**See Box 2, Innovation Priorities.**)

Congress has significantly increased funding for innovation, particularly early-stage research and development. Funding for energy-related research at DOE increased by more than $1.3 billion from fiscal year (FY) 2016 to FY19. However, the United States is still not on a path toward doubling funding for low-carbon research by FY21, a pledge it made with 19 other countries as part of the Mission Innovation initiative

launched at the 2015 Paris summit. What's more, even greater resources will be needed in the years beyond, both to continue scaling up energy-related research and for non-energy, climate-related RDD&D. To provide the foundation for a robust national innovation ecosystem, Congress should ramp up funding for climate-related research and development to at least $20 billion a year by 2030.

Where possible, this increased funding should be directed toward scaling up existing programs and should prioritize engagement with private-sector partners. The Advanced Research Projects Agency–Energy should be funded at $2 billion a year by 2030, up from $366 million in FY19. DOE's Advanced Manufacturing Office should also be elevated and tasked with coordinating manufacturing RDD&D efforts across the DOE complex. Additional priorities include scaling up programs such as the U.S. Department of Agriculture's Agriculture Advanced Research and Development Authority and bolstering interagency and public-private partnerships such as the Manufacturing USA institutes.

Translating successful, early-stage applied research into commercially competitive technologies often requires support at the critical intermediary step of technology demonstration. Federal support at this stage is especially important in the case of technologies requiring large-scale demonstration projects that carry technical, policy, and market risks—such as carbon capture, utilization, and sequestration or advanced nuclear.[10] Given the cost of such projects, and the urgency of building confidence that the necessary technologies will be available, Congress should provide $50 billion to $100 billion over the next decade to support a robust portfolio of high-impact, low- and zero-carbon technology demonstration efforts.

Federal support for innovation must also extend to de-risking first-of-a-kind deployment projects that are unable to secure project financing on their own. For example, DOE's Loan Program Office, which provides project finance for large-scale energy infrastructure projects, can play an important supporting role, in partnership with the private sector, to accelerate the deployment of new, high-impact technologies. While the Loan Program Office currently has roughly $40 billion in existing loan authority, it has not issued new loans since 2015. It should immediately begin issuing new solicitations for its existing authority, which could leverage up to $100 billion in new energy infrastructure investments.[11] Further, the Loan Program Office should increase its risk appetite, to increase the number of potentially transformative projects it supports.

The Small Business Innovation Research and Small Business Technology Transfer programs, each of which receives a percentage of research budgets at qualifying federal agencies, play an important role in ensuring that small businesses have a chance to compete and contribute meaningfully to the innovation ecosystem. As federal research funding increases, these programs should maintain at least their current funding percentage as part of federal agencies' total research budgets.

Optimizing the Innovation Ecosystem

Additional funding for low-carbon RDD&D is only part of the solution. Indeed, these investments could produce far less innovation than is needed while diverting resources away from other priorities unless the administrative capacity of state and federal agencies tasked with carrying out a low-carbon RDD&D agenda is enhanced, interagency coordination is strengthened, and technology transfer is made more effective.

A VISION: INNOVATION IN 2050

The United States has leveraged its world-class innovative prowess to produce breakthrough technologies that help to sustain a growing, decarbonized global economy. A strong infusion of federal resources and close public-private collaboration have nurtured a sophisticated and integrated U.S. innovation ecosystem. The resulting breakthroughs have played a crucial role in meeting U.S. and global climate goals and in strengthening U.S. competitive and geopolitical positioning as the country helps lead the global transition to carbon neutrality. U.S. companies play a dominant role in driving innovation, partnering with universities, states, and federal agencies and laboratories to generate a range of advanced technologies that provide stable and affordable energy supplies, boost industrial and agricultural productivity, and create jobs and economic growth, all while enabling decarbonization. Other companies invest in the United States to tap into the opportunities produced by its unrivaled innovation ecosystem.

BOX 2: INNOVATION PRIORITIES

A technology-inclusive approach to decarbonization requires continuous innovation across the full technology development cycle, including: basic, applied, and translational research; demonstration projects; first-of-a-kind deployments; and incremental post-deployment advances. Countless technologies will be needed across every facet of the economy. The following are among the technologies that hold particular promise and should be high priorities in a decarbonization-focused RDD&D agenda.

Clean electricity. Given the central role of electrification in a decarbonized future, continued research into low- and zero-carbon sources of electricity is essential. It will be important to pursue advanced renewables such as solar perovskites, offshore wind and marine energy, and low- and zero-carbon fuels like hydrogen. Other emissions-free technologies, such as small and advanced nuclear, are also key research priorities.

Carbon capture, utilization, and storage. Technologies to capture, utilize, and store carbon can assist in managing emissions from power generation and, more critically, from industrial processes. Further, technologies such as direct air capture that remove CO_2 directly from the atmosphere could prove transformative. The development of commercial products from captured carbon will play an important role in generating demand for carbon capture technologies. Further research is also needed into sequestration techniques.

Energy storage. Energy storage can significantly boost the efficiency of the overall electricity system and the value of a variety of low- and zero-carbon generation technologies. Improvements in non-lithium-ion battery technology will be important to overcome performance and materials supply constraints. Other priorities include advanced battery chemistries and materials; fuel cell technologies, which have numerous applications including vehicles and stationary power; and approaches such as electrolysis that can be used to produce zero-carbon hydrogen, meeting the need for long-duration, seasonal energy storage.

Advanced clean fuels. Not all energy end uses are well suited to electrification and some—such as aviation—are especially emissions-intensive. In these cases, low-carbon liquid fuels will be needed. Hydrogen, biofuels, and ammonia are the most promising options in a variety of applications, and additional research is needed into these and other synthetic fuels.

Advanced manufacturing. New technologies are needed to reduce emissions from industrial processes themselves and from the large quantities of energy they consume. Priorities include research into renewable thermal energy, combined heat and power systems, waste heat recovery, and alternative manufacturing processes, including additive manufacturing and circular manufacturing.

Renewable thermal energy. Thermal energy is a significant source of emissions, particularly in the buildings and industrial sectors. Approaches such as bioenergy (including biogas, renewable natural gas, and biomass), solar fuels, solar thermal, geothermal, and renewable electrification will play an important role in reducing emissions by providing renewable thermal energy.

Advanced computing. Supercomputing, machine learning, and deep learning can enable significant decarbonization across the entire economy, including efficiency gains from logistics, supply chain, and power grid management. Advanced computing can also greatly accelerate the development of advanced materials and will play an important role in the advancement of autonomous vehicles.

Advanced agriculture. Precision agriculture can help reduce farm inputs, optimize yields, and improve soil health and increase carbon sequestration. Improved soil-carbon monitoring equipment can provide better information about the efficacy of new agricultural methods. Other priorities include research to develop low-carbon agricultural inputs and shrink the emissions footprint associated with protein production (e.g., plant-based protein, feed additives).

The current U.S. research network—including the national laboratories, universities, nonprofits, and the private sector—is among the world's best.[12] But it must be made even better, and a critical first step in improving the efficiency of the innovation system is streamlining DOE's management of the national laboratories to provide them with greater autonomy. DOE should focus on setting program objectives, fostering coordination among the labs, and ensuring they have the capacity and processes in place to work efficiently within and across offices and research programs.[13]

At federal agencies implementing the low-carbon innovation agenda, the government must increase administrative capacity and standardize best management practices to ensure efficient and timely use of research funding. For instance, administrative issues at DOE have slowed the disbursement of RDD&D funds already appropriated.[14] Further, agencies need to adopt a more risk-tolerant approach to better target federal support to research that is too risky for the private sector but provides public benefit. White House-level leadership should ensure the stronger interagency coordination needed to optimize the innovation ecosystem, as well as strong intra-agency coordination. For example, to avoid the challenges faced by recent demonstration projects, DOE should consolidate oversight of demonstration projects into a single office staffed with project management experts—a process successfully implemented within the DOE National Nuclear Security Administration.[15]

The government's success in fostering a robust innovation ecosystem will depend on its ability to strengthen and simplify public-private collaboration. The White House should engage the private sector and other non-government stakeholders in the development of the low-carbon innovation agenda. The national laboratories must prioritize technology transfer efforts,[16] and the government should scale up new institutional models fostering collaboration among industry, academia, and public researchers, such as DOE's Energy Innovation Hubs.[17]

States can also foster a robust innovation ecosystem—and seize opportunities in the emerging low-carbon economy—by aligning networks and institutions toward strategic, regionally focused decarbonization priorities. States should work with the private sector to assess state innovation assets and capacities to better target their efforts. State and local governments also should support local entrepreneurs by funding low-carbon technology incubators, providing access to grants and tax incentives, and fostering connectivity between the research and business communities.

MOBILIZING FINANCE

Estimates of the financial resources that must be marshalled to decarbonize the U.S. economy vary widely, potentially running into the trillions of dollars.[18] Only some of these costs, however, will be additional to what would otherwise already be spent to procure energy, goods, and services. Most of the financial resources needed for decarbonization will, rather, reflect a *shift* in investment flows.

Many of the policies recommended in this report—from economy-wide carbon pricing to measures to decarbonize particular sectors—will create incentives for this shift in long-term investment. Here we outline additional policy priorities over the coming decade to broadly mobilize private capital toward decarbonization. Top priorities include better informing private investment through the disclosure of companies' climate-related risks and opportunities, assessing and managing the broader risks that climate change poses to the U.S. financial system, and using public investment to leverage significantly higher levels of private capital for decarbonization in the United States and abroad.

Providing Climate-Risk Information to Investors

It will be easier for private capital to shift into low- and zero-carbon investments—and into companies that are resilient to changing physical and policy environments—if investors better understand the climate risks and opportunities that companies face.

Investors are increasingly realizing that climate change, both physical risks (from climate change itself) and transition risks (from societal responses to climate change), could affect the value of their investments. Many are asking companies to disclose more information so that they can better assess climate-related investment risks. In 2019 alone, dozens of shareholder resolutions were filed with companies in a range of sectors seeking climate risk analyses and strategies, targets for reducing emissions or increasing the use of renewable energy, and more. Groups of investors, such as the Climate Action 100+ initiative, which has more than 360 investors in dozens of countries, have called on companies to strengthen climate-related disclosures, improve governance on climate change, and take actions to reduce emissions and improve their resilience to climate risks. Nearly 7,000 companies disclosed climate-related information in 2018 through CDP (formerly the Carbon Disclosure Project). A growing number of companies are implementing the recommendations of the Financial Stability Board's Task Force on Climate-related Financial Disclosures, which focus on corporate governance, strategy, risk management, and metrics and targets. As of July 2019, more than 800 companies and other organizations had expressed their support for the task force recommendations.

While this activity has increased the availability of climate-related financial information from a range of companies, investors still often lack relevant information on material climate-related risks across their portfolios. The U.S. Securities and Exchange Commission issued high-level guidance nearly a decade ago describing how its existing rules may require climate-related disclosures depending on the facts, circumstances, and materiality for any particular company. To provide more relevant and consistent disclosure across the private sector, Congress should direct the Securities and Exchange Commission to require public companies to disclose material climate-related financial risks under a range of climate scenarios and their strategies for managing those risks. These requirements should be informed by a working group of investors, issuers, rating agencies, standard-setting organizations, and nongovernmental organizations. The requirements should encompass both physical and transition risks, build on systems and frameworks that already exist, provide for different

KEY RECOMMENDATIONS

- *Congress should direct the Securities and Exchange Commission to require public companies to disclose material climate-related financial risks under a range of climate scenarios and their strategies for managing those risks.*
- *Congress should require the Federal Reserve to integrate consideration of climate-related risks into the periodic stress testing required of major financial institutions.*
- *Congress should create a national green bank to leverage private investment in clean energy, energy efficiency, and other activities contributing to decarbonization. More states and localities should also create green banks for use in their own markets.*

metrics relevant to different sectors, and avoid undue burden on companies. Absent action by Congress, the Securities and Exchange Commission should act under its existing authority to enhance climate-risk disclosure requirements.

Managing Broader Impacts on the Financial System

Climate change poses risks not only to individual companies but also to the financial system as a whole. To properly guide private capital, it will be important for policymakers and investors to understand potential systemic risks, such as business interruptions, bankruptcies, and macroeconomic shocks caused by extreme weather events; reductions in the value of assets and companies dependent on fossil fuels; increased credit risk exposure for firms with loans tied to coastal real estate; and other types of systemic volatility.

In March 2019, the Federal Reserve Bank of San Francisco issued an economic letter noting that these climate-related risks "are relevant considerations for the Federal Reserve in fulfilling its mandate for macroeconomic and financial stability."[19] Less than a month later, the Network for Greening the Financial System—which includes 36 central banks including those of the United Kingdom, France, and China—recommended that central banks and supervisors integrate climate-related risks into financial stability monitoring and supervision.[20] In July, the U.S. Commodity Futures Trading Commission, which oversees markets for derivatives and other products, voted to establish a Climate-Related Market Risk Subcommittee. The subcommittee is examining the risks posed by climate change to the stability of the U.S. financial system, how market participants can integrate climate-related stress-testing into financial and market risk assessments and reporting, and more.[21]

Further steps are needed. In April 2019, the Bank of England directed financial institutions to conduct climate-related scenario analyses and stress testing to identify near- and long-term risks to their business models.[22] Congress should similarly require the Federal Reserve to integrate consideration of climate-related risks into the periodic stress testing required of major financial institutions. As a first step, the Financial Stability Oversight Council, which is charged with identifying and responding to risks to the stability of the U.S. financial system, should form a subcommittee to define climate-related risks and to develop guidance to financial institutions on how to identify such risks. The Federal Reserve should also map climate risks within the financial system by adopting risk indicators, incorporating them into analyses and financial stability monitoring, and integrating them into its supervision of financial firms.

Leveraging Private Finance

Given the scale of investment needed to decarbonize the economy, public dollars must be strategically deployed to leverage much greater amounts of private capital.

Green banks are one way to leverage private investment. Several states around the country—including Connecticut, Hawaii, Michigan, Nevada, New York, and Rhode Island—operate programs like green banks to attract private capital by offering products and services such as credit enhancements, loans, and aggregation to lower risks or reduce transactional costs. Serving largely as revolving loan funds, green banks have leveraged private investment in projects such as solar installations, microgrid construction, micro-hydro generation, electric vehicle-charging infrastructure, and energy efficiency upgrades. The Connecticut Green Bank, for example, invested $237 million in state funds between FY12 and FY18 to leverage $1.2 billion in private investment, roughly a 6:1 leverage ratio.[23] Congress should create a national green bank, as a corporation owned by the federal government, to provide capital to state and local green banks (which are often under-capitalized) and/or to offer its own investments and products that leverage private investment in clean energy, energy efficiency,

A VISION: FINANCE IN 2050

Private investment in energy and other sectors has shifted to low-carbon pathways, and climate-related risks and opportunities are fully incorporated into financial decision-making. A major shift in public resources has leveraged far greater amounts of private investment in low-carbon solutions, which now match or out-perform alternative investments and meet widespread investor demand for environmental performance. In addition, the financial sector and the financial system as a whole have become resilient to systemic climate-related risks, contributing to macroeconomic and financial stability.

and other activities contributing to decarbonization and climate resilience. In addition, more states and localities should create green banks designed to leverage private capital for emissions-reducing projects in their markets.

Certain U.S. entities could similarly serve the role of a green bank on the international stage, helping to leverage U.S. innovation toward decarbonization globally and to strengthen U.S. companies' competitiveness in the global clean energy market. The newly restored U.S. Export-Import Bank and the new U.S. International Development Finance Corporation (which was created largely from the Overseas Private Investment Corporation) can help increase the flow of private capital by mitigating specified investment risks. The Export-Import Bank, the official U.S. export credit agency, facilitates the export of U.S. goods and services, while the Development Finance Corporation offers financial products to support private investments in the developing world. Both should support a rapid transition to low-carbon finance.

Climate bonds are another mechanism for directing capital into climate solutions both in the United States and abroad. As a subset of the broader green bond market, climate bonds are like regular bonds but are designed to raise capital for climate mitigation and adaption, including in the energy, transport, buildings, and land use sectors. Globally, in 2018, more than $23 billion of bonds were certified by the Climate Bonds Initiative as meeting the Climate Bonds Standard, which provides sector-specific eligibility criteria.[24] Climate bonds can be issued by governments, banks, other financial institutions, and non-financial corporate actors. To encourage more climate bond activity, Congress should explore adopting preferential tax treatment (e.g., incentives for issuers or investors) for the issuance of climate bonds that are verified as advancing climate mitigation and adaptation solutions.

ENSURING A JUST TRANSITION

Policies to decarbonize the U.S. economy must be bold, but they must also be equitable. They must bring everyone into a zero-carbon future, including frontline communities, such as low-income communities and communities of color, and those whose economic fortunes have been closely tied to high-emitting energy sources and industries.

Some policies recommended in other parts of this report will have multiple benefits for vulnerable communities. Measures to accelerate the adoption of low- and zero-carbon power and transport technologies, for instance, will help reduce local air pollution in some communities. This section recommends additional policy priorities over the coming decade to ensure a just, equitable transition to a zero-carbon economy. While an essential element of an equitable transition is strengthening the resilience of frontline communities to the impacts of climate change, the focus here is on steps more closely related to the decarbonization challenge.

A top priority is ensuring that pollution-burdened and low-income communities—as well as small businesses—are not harmed by and can benefit from climate policies. Another priority is to help build a sound economic future for communities and workers disadvantaged by the transition away from high-carbon fuels.

Cushioning the Impact and Spreading the Benefits of Climate Policy

Policies to address climate change should be designed in ways that avoid disproportionate impacts on vulnerable families and communities and on small businesses.

Policies that could increase the cost of energy should include mechanisms to minimize any cost burden on low-income populations. For instance, a portion of any revenue raised through an economy-wide carbon pricing program should be directed toward rebates or dividends to alleviate the regressive impacts of the carbon price. Different measures may be needed to avoid the regressive impacts of other types of climate policies.

Likewise, many frontline communities are concerned that while market-based policies such as carbon trading will reduce overall greenhouse gas emissions, they may at the same time contribute to pollution hotspots in communities already experiencing higher levels of local air pollution. To address environmental injustice, a decarbonization strategy must include measures to promote the reduction of conventional air pollutants in burdened communities, thereby improving public health and quality of life, and monitor pollution levels more closely to ensure standards are enforced.

Beyond avoiding harms, climate policies should also ensure that low- and zero-carbon solutions and technologies are accessible to all. A share of climate investment must be dedicated to deploying solutions and infrastructure in historically marginalized communities, including urban tree planting, energy efficiency retrofits, community solar, electric vehicle charging, and low- and zero-carbon public transit. Similarly, clean energy deployment programs, energy efficiency upgrade programs, and zero-carbon innovation programs should be designed in ways to make it easier and more cost-effective for small businesses to participate.

Helping Economies in Transition

An equitable decarbonization strategy must also address the needs of workers and communities disadvantaged in the transition to a zero-carbon economy. Communities long dependent on high-carbon industries have played an integral role in building America's economy and, as these industries contract, need help revitalizing and diversifying their economies. Elsewhere around the country, even as decarbonization creates new economic opportunities, some industries and workers may be disadvantaged.

KEY RECOMMENDATIONS

- *Policies that could increase the cost of energy should include mechanisms to minimize any cost burden on low-income populations and small businesses.*
- *A share of climate investment should be dedicated to deploying solutions and infrastructure in historically marginalized communities, including urban tree planting, energy efficiency retrofits, community solar, electric vehicle charging, and low- and zero-carbon public transit.*
- *Congress should increase support to communities in transition to train workers and foster new industries that can contribute to a stable economy and tax base.*

A VISION: JUST TRANSITION IN 2050

The decarbonization of the U.S. economy has brought benefits to all Americans, including frontline communities and communities once heavily reliant on greenhouse gas-emitting energy sources and industries. Affordable low- and zero-carbon energy and transport are accessible by all, and historically marginalized communities have cleaner air and healthier neighborhoods. Workers in high-emitting industries have transitioned to good jobs in other fields, and communities that had been reliant on those industries have thriving, diversified economies.

Using revenue from carbon pricing or other resources, Congress should increase support to communities in transition to train workers and foster new industries that can contribute to a stable economy and tax base. Affected communities should lead in charting their economic futures and have a direct voice in shaping place-based strategies addressing structural needs, such as broadband access, that are critical to their economic development.

III. SECTORAL ELEMENTS

POWER

Over the coming decades, the power sector is expected to be the lynchpin in efforts to decarbonize the economy. The electrification of transportation, industry, and buildings could reduce their collective emissions by nearly 70 percent by 2050, assuming a substantially decarbonized power sector.[25] The sections below outline policies to drive these sectors' electrification and to improve their energy efficiency. Their increased reliance on electricity means the power sector must meet much higher levels of demand even as it dramatically reduces its own carbon intensity. Meaningful economy-wide carbon pricing, as recommended above, can drive significant emissions reductions, but a range of complementary policies will also be needed to decarbonize the power sector and to ensure coordinated efforts across all sectors. Priorities over the coming decade include accelerating the development and deployment of low- and zero-carbon generation technologies, building low-carbon infrastructure, and modernizing wholesale power markets.

Accelerating Zero-Carbon Generation

Since 2005, U.S. electric power sector emissions have fallen by 27 percent due to a shift from coal to natural gas, the increased use of renewable energy, and a leveling of electricity demand.[26] Both market- and policy-related factors contributed to this emissions decline. Voluntary targets recently adopted by some of the country's largest utilities will help drive further emission reductions. However, several existing nuclear plants, currently the largest source of zero-carbon electricity, are projected to close—either prematurely, due to economic pressures, or as they reach the end of their permitted lifespans in the 2030s. Without new policies, the share of electricity obtained from all zero-emitting sources is not projected to rise quickly enough over the next 30 years.[27]

An economy-wide carbon price enacted in the near term and escalating over time, as recommended above, will provide the power sector the incentive and flexibility to more rapidly reduce emissions by accelerating deployment of the full range of low- and zero-carbon options.

Alongside a carbon pricing program, Congress should extend existing tax credits for renewable generation, provide new investment tax credits to help keep existing nuclear plants in operation, and provide dedicated investment tax credits for offshore wind and energy storage. To help extend the lives of existing nuclear plants, Congress should ensure timely review of nuclear license renewals. To ensure the expeditious transition of

KEY RECOMMENDATIONS

- *Congress should provide a range of tax credits for zero-carbon generation and should mandate the use of carbon capture or corresponding sequestration-based offsets for all fossil fuel-fired power generation by a date certain.*
- *In the absence of meaningful economy-wide carbon pricing or a national clean energy standard, all states should adopt ambitious clean energy standards that can be met by the full range of zero-carbon technologies, including renewables, nuclear, large hydro, and fossil fuel generation with carbon capture.*
- *Congress should direct the Federal Energy Regulatory Commission to develop a comprehensive, long-range infrastructure strategy and should prioritize the siting of "climate-critical" infrastructure. The commission also should reform wholesale power markets to more explicitly value the low-carbon, capacity, and reliability attributes of competing power sources.*
- *State public utility commissions should work with the power sector to help facilitate the electrification of other sectors.*

the nation's expanding fleet of natural gas-fired power plants to zero-carbon power, Congress also should mandate the use of carbon capture or corresponding sequestration-based offsets for all fossil fuel-fired power generation by a date certain, so that any necessary retrofits can then be integrated into plants' planned upgrades. As an economy-wide carbon price escalates, technology-specific incentives should be phased out.

To ensure the availability of a wide range of technology options, Congress also should increase funding for the research, development, and demonstration of new low- and zero-carbon generation sources, as recommended by the White House-led low-carbon innovation agenda. Priorities should include advanced nuclear technologies; carbon capture, utilization, and sequestration retrofits for a range of plant types (e.g., steam coal, natural gas combined cycle, natural gas peakers); advanced renewables (e.g., solar, onshore and offshore wind, geothermal, hydro, tidal power); and batteries and other storage, including long-term options such as hydrogen and ammonia.

Many states are already employing renewable energy or clean energy standards to require utilities to supply a growing portion of their electricity from zero-carbon sources. A growing number of states have adopted or are considering the goal of fully decarbonizing their power sectors. In the absence of meaningful economy-wide carbon pricing or a national clean energy standard, all states should adopt ambitious clean energy standards that can be met by the full range of zero-carbon technologies, including renewables, nuclear, large hydro, and fossil fuel generation with carbon capture. In the interim, states with existing renewable portfolio standards should convert them to a more inclusive clean energy standard.

A VISION: POWER IN 2050

The U.S. power sector is producing nearly twice as much electricity as in 2019 to support economic growth and the electrification of other sectors. This growing demand has been tempered by wide-scale deployment of energy efficiency strategies and technologies. As the generation portfolio has evolved, electricity has become far less carbon-intensive, and a national high-voltage transmission system connects renewable resources with demand centers across the United States. Advanced digital controls help balance supply and demand, while decentralized power generation and new energy storage options help reduce peak load and improve system stability. Onshore and offshore renewable generation supply a much larger portion of the nation's power, and carbon capture is deployed on all fossil fuel-fired electricity generation plants. Small advanced nuclear reactors provide industrial heat, hydrogen, district heating, and water heating, in addition to clean electricity. New and repurposed pipeline networks for hydrogen, carbon dioxide, and ammonia are used for seasonal energy storage; power plant fuel; carbon capture, utilization, and sequestration; and cross-sectoral purposes (e.g., transportation and industry fuel).

Creating the Infrastructure

Greater contributions of variable renewable energy to the grid, and higher electricity demand as other sectors electrify, will require additional transmission and distribution lines, substations, and energy storage. An expanded and strengthened grid can also help optimize electricity generation, make the power system more resilient to climate impacts and other risks, and take advantage of digital advances to more efficiently manage supply and more quickly recover from outages.

Creating a 21st-century grid to facilitate the decarbonization of the economy requires strong leadership from the federal government. In 2005, Congress granted the Federal Energy Regulatory Commission (FERC) new authorities under the Federal Power Act to expand, modernize, and improve the reliability of the nation's transmission grid. This included the designation of national interest energy transmission corridors, where the commission could override state authorities when necessary on siting decisions. Court challenges, however, have stymied its use of these authorities.

Congress should direct FERC to develop a comprehensive, long-range infrastructure strategy and should more clearly establish its authority on siting decisions. This infrastructure strategy should be informed by a multi-stakeholder process and establish clear priorities for staged expansion and enhancement of the grid, including the designation of high-priority high-voltage transmission routes (co-located, where feasible, with existing rights of way).

While most utilities produce periodic long-range plans that include transmission and other infrastructure upgrades, greater national, regional, and cross-utility coordination (typically, electricity and natural gas) is needed. FERC's strategy should identify what needs to be built and where, at a level of granularity necessary to manage progress and ensure that the desired system is deployed before mid-century. It should assess the value of national or regional interconnection of existing networks and should prioritize the development of complementary networks for distributing hydrogen, CO_2, renewable natural gas, ammonia, and other fuels for seasonal energy storage and cross-sectoral purposes (e.g., fuels for transport and industry). Informed by the commission's national infrastructure strategy, Congress should prioritize the siting of "climate-critical" infrastructure, including grid upgrades (and grid hardening, to better protect customers from weather-related outages) and other key resources such as storage batteries and energy pipelines.

Modernizing Power Markets

The nation's power markets will also need to be modernized in order to facilitate decarbonization while maintaining diverse, reliable, and affordable power supplies.

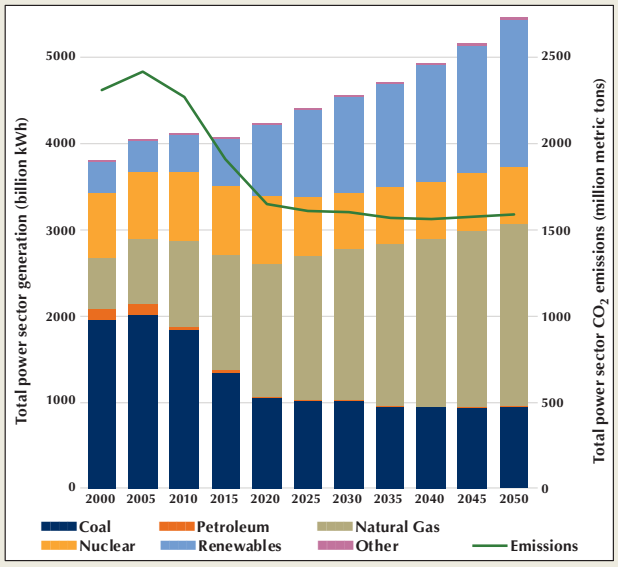
Under current market rules, wholesale power prices are set largely on the basis of a generator's fuel costs. With rising deployment of wind and solar energy, whose fuel costs are effectively zero, wholesale prices will continually decline, providing utilities with insufficient revenue to deploy other generation sources needed for a well-balanced power supply. This dynamic is contributing already to the early retirement of nuclear power plants, which currently account for more than half of the nation's zero-carbon power.

The Federal Energy Regulatory Commission should undertake rulemaking to reform wholesale power markets to more explicitly value the low-carbon, capacity, and reliability attributes of competing power sources. This should include new ways of compensating zero-

POWER: EMISSIONS AT A GLANCE

- Electricity generation accounts for 28 percent of total U.S. greenhouse gas emissions. The sector's emissions rose steadily through the early 2000s, as growing power demand led to increased coal use, then started to decline as natural gas began to replace coal.
- Improved energy efficiency has held total power consumption steady in recent years. The continued substitution of natural gas for coal and the rapid growth of wind and solar energy have reduced the sector's emissions by 28 percent since 2005.
- Under business as usual, emissions will continue to fall in the near term. But as power demand steadily rises, emissions are projected to return almost to today's levels by 2030 and remain there through 2050. Under these projections, natural gas rises to 39 percent of total electricity generation and renewables to 31 percent, while coal falls to 17 percent and nuclear to 12 percent.

U.S. electricity generation by source and total sector emissions



Sources: U.S. Energy Information Administration (2019a), and U.S. Energy Information Administration (2019c).

Sources: U.S. Environmental. Protection Agency (2019c) and U.S. Energy Information Administration (2019a), and U.S. Energy Information Administration (2019c).

emission generators in energy, capacity, and ancillary markets, including new methods of market bidding (e.g., total costs versus variable costs) and of paying generators for essential system functions (such as system reliability or flexible generation).

Power regulators must also play a role in managing the electrification of the transportation, industry, and buildings sectors. The increased demand for electricity from these other sectors must be coupled with energy efficiency and the decarbonization of the power sector to avoid unintentionally increasing demand for fossil fuels. At the state level, public utility commissions (PUCs) should work with the power sector to help facilitate the electrification of other sectors, including through appropriate rate structures and incentives to maximize the environmental benefits of electrification at the lowest possible cost.

TRANSPORTATION

While the economy-wide carbon pricing recommended above will encourage lower-carbon transportation, its impact on the sector will be limited, as fuel represents only a small portion of the cost of owning and operating a vehicle.[28] Strong complementary policies are thus especially critical in the transportation sector. Key strategies for decarbonizing the sector include accelerating the deployment of zero-emission vehicles (ZEVs), building out the charging and fueling infrastructure these vehicles require, supporting a wider range of personal mobility options, and decarbonizing other modes of transportation, including aviation, rail, and shipping. The White House-led decarbonization effort should include a working group to coordinate these efforts.

Deploying Zero-Emission Vehicles

On-road transportation constitutes roughly 82 percent of the sector's overall emissions, making the conversion of the nation's automotive, truck, and bus fleets to ZEVs the top priority in decarbonizing transportation.[29] Given the average lifetime of a vehicle, this transition will take time; therefore, strong, early signals are vital. A suite of complementary policies are needed to establish a pathway for rapidly converting to ZEVs, including vehicle standards, support for new infrastructure, and targeted incentives.

Light-duty passenger vehicles are responsible for approximately 41 percent of total U.S. transportation emissions.[30] According to the U.S. Mid-Century Strategy, decarbonizing transportation requires that ZEVs represent half of new passenger car and truck sales by 2035.[31] Congress should direct the Environmental Protection Agency (EPA) to establish a greenhouse gas performance standard ensuring that half of new vehicle sales are ZEVs by 2035. Standards should also be set for medium- and heavy-duty trucks, which account for about 40 percent of transportation emissions.[32] Unified national standards that allow trading of credits among vehicle classes will enable manufacturers to expand the market as efficiently as possible. Any state-level standards should be at least as stringent as the corresponding federal standard.

As an incentive to rapidly expand manufacturers' ZEV offerings, rather than prioritizing incremental improvements to internal combustion engines such as hybrids, manufacturers should receive additional credits for every ZEV sold during the early years of the program. In addition to the vehicle standards, the federal regulatory framework should accommodate any biofuels demonstrated through lifecycle analysis to be low- or zero-carbon fuels.

Although electric cars' lower fuel and maintenance costs can make them cheaper than conventional models over the life of a vehicle, their higher upfront costs have hindered consumer adoption. An existing $7,500 federal tax credit helps to offset that premium, but phases out after 200,000 vehicles per manufacturer. Congress should extend the existing tax credit, make it available as a point-of-sale rebate, and expand it to include all

KEY RECOMMENDATIONS

- *Congress should direct the Environmental Protection Agency to establish a greenhouse gas performance standard ensuring that half of new light-duty vehicle sales are zero-emission vehicles by 2035, and a similarly ambitious standard for medium- and heavy-duty trucks.*
- *Congress should extend the current electric vehicle tax credit, make it available as a point-of-sale rebate, and expand it to include all new ZEVs, including fuel cell electric vehicles and medium- and heavy-duty trucks.*
- *States should develop comprehensive long-range plans to accelerate the deployment of zero-emission vehicle charging and refueling infrastructure. Congress should fund the development of these state plans and should provide funding to states that have plans to construct charging and refueling infrastructure.*
- *Local governments should—with dedicated federal planning support—develop integrated transportation and land use plans that expand non-automotive transportation options in order to strengthen mobility while reducing congestion, air pollution, and carbon emissions.*
- *Congress should establish a performance standard that freezes aviation emissions at 2020 levels, allowing for the use of biofuels and offsets, modeled on the Carbon Offsetting and Reduction Scheme for International Aviation.*

new ZEVs (including fuel cell electric vehicles). A substantially higher tax credit should be offered for medium- and heavy-duty ZEVs, offsetting their higher initial costs. States should similarly offer point-of-sale rebates and tax credits for new light-, medium-, and heavy-duty ZEVs.

Specific strategies for incentivizing ZEVs for public-sector transit and fleets are needed since operators do not benefit from tax credits because they are exempt from federal taxes. Congress should increase funding to help states and cities expand ZEV transit and fleet procurement, including through leasing and programs such as the Federal Transit Authority's Low or No Emission Vehicle Program and EPA's School Bus Rebate Program. Where feasible, cities and states should utilize cost-sharing agreements to attract private-sector support for such projects.

To orient state and local efforts and drive investment in manufacturing capacity, states, counties, and cities should set clear targets for the electrification of mass transit. For example, California has established a requirement that all new public transit buses be electric by 2029, and New York City has likewise set a goal of a fully electrified bus fleet by 2040. Further, to leverage their buying power, cities and states should undertake collective procurement of fleet vehicles through initiatives such as the Climate Mayors EV Purchasing Collaborative.

The conversion of fleets to low- and zero-emission vehicles will likely take place against the backdrop of other fundamental shifts, such as the growth of shared mobility services and the emergence of autonomous vehicles. Research suggests that the electrification of ride-hailing services could have significant emissions benefits, provided they do not draw commuters away from public transit or lead to a dramatic increase in the overall volume of traffic.[33] States and cities should set targets and provide incentives for the electrification of ride-hailing services and provide support to help low-income ride-share drivers with upfront costs. Meanwhile, analyses to date suggest that the introduction of autonomous vehicles could either increase or decrease vehicle miles traveled and, by extension, emissions.[34] The White House-led decarbonization effort should include an interagency working group to recommend steps to ensure that the wide deployment of autonomous vehicles contributes to decarbonization.

A VISION: TRANSPORTATION IN 2050

Rapid changes in technology and business models, coupled with the decarbonization imperative, have led to a radically transformed transportation sector with a much smaller carbon footprint. Autonomous passenger cars running primarily on electricity—from either grid-fed batteries or onboard fuel cells—are available on demand through competing mobility-service companies. In densely populated areas, improved planning has produced a wider array of public transit and other personal mobility options that avoid congestion, local air pollution, and carbon emissions. All forms of passenger and freight transportation—from light- to heavy-duty road vehicles, along with trains, aircraft, and watercraft—are as fuel-efficient as technology allows. Modes that are difficult to electrify, such as aviation, rely on other low-carbon fuels, such as biofuels. These low-carbon fuels are also used to supplement electricity in other subsectors, including passenger vehicles.

Creating the Infrastructure

All levels of government must play a role in mobilizing investment and new business models to quickly build the charging and alternative fueling infrastructure needed to enable broad ZEV deployment.

States should develop comprehensive long-range plans to accelerate the deployment of ZEV charging and refueling infrastructure. These plans should be developed in consultation with local governments and the private sector and should provide for coordinated state and local efforts, provide for any necessary changes in land use policy, and ensure infrastructure access for multi-family housing and low-income communities. To facilitate private-sector investment, local governments should establish clear, standardized permit review and inspection processes for the installation of new infrastructure. To address interstate needs, states should work together to develop regional charging and refueling networks such as the REV-West Initiative, in which eight mountain west states are collaborating to develop EV charging corridors. To support state and local efforts, Congress should fund the development of state infrastructure plans and provide funding to states that have such plans to establish ZEV charging and refueling infrastructure.

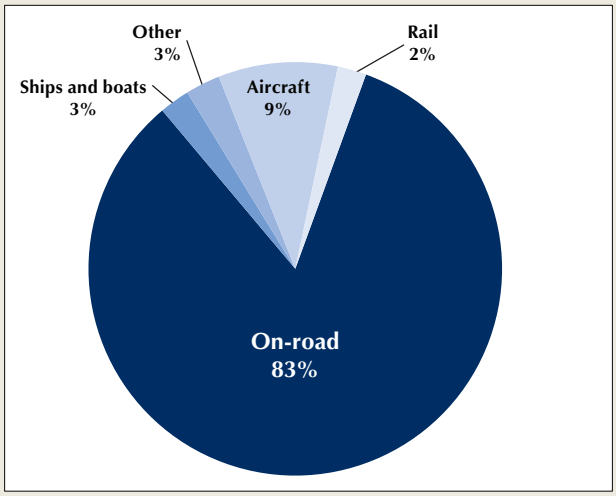
Another priority is to ensure the interoperability of vehicles, chargers, and payment systems is another priority, and efforts are underway within the private sector to develop a common set of interoperability standards. To promote compatibility across systems, Congress should require that any charging and refueling infrastructure built with federal funding meet prevailing industry standards for interoperability.

State public utility commissions play a vital role in facilitating linkages between the transportation and power sectors. Many have authorized programs to incentivize workplace, home, or multi-family unit charger procurement by offering rebates and incentives through the local utility. Where feasible, public utility commissions should allow utilities to own and operate—or to partner with other companies that are building—charging infrastructure, provided that a competitive market is maintained. Given the potential of battery and plug-in hybrid electric vehicles to act as additional storage capacity for the power grid, public utility commissions should also work with electric utilities, vehicle manufacturers, and other stakeholders to develop safety and market access standards and pilot programs for vehicle-to-grid integration. Vehicle-to-grid integration has the potential to improve the economics of all EVs, particularly medium- and heavy-duty vehicles with larger batteries that, in some cases, sit unused for long durations in centralized locations. Such integration,

TRANSPORTATION: EMISSIONS AT A GLANCE

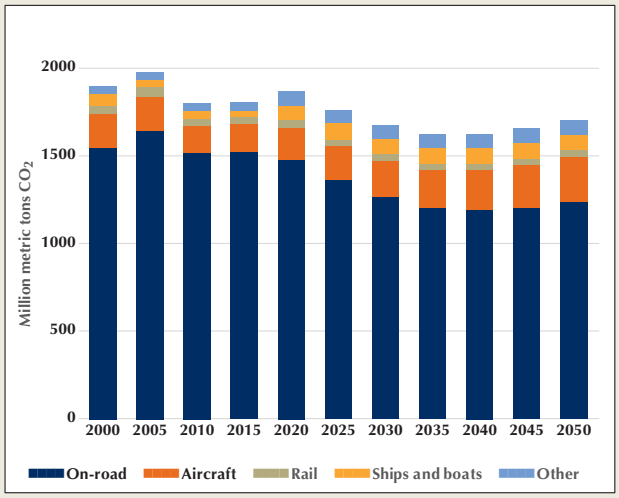
- Since 2016, transportation has been the largest direct source of U.S. greenhouse gas emissions, accounting for 29 percent of the total. Roughly three-quarters of the emissions come from road transport, with passenger vehicles the largest source.
- Although emissions fell by 5.6 percent from 2005 to 2017 as vehicle efficiency improved, they have been rising in recent years, largely as a result of increased use of passenger vehicles. Federal standards now being rolled back were expected to reduce auto emissions significantly through 2035, although even with the standards in place, increased driving was projected to outweigh vehicle efficiency gains in later years, pushing emissions back up.
- Emissions from other subsectors are projected to rise through 2050 under business as usual, with freight truck travel increasing by almost 50 percent, freight rail travel increasing by 27 percent, and domestically originating air travel projected to double.

Transportation emissions by mode, 2017



Source: U.S. Environmental Protection Agency (2019c).

Recent and projected transportation emissions



Sources: U.S. Environmental Protection Agency (2019c) and U.S. Energy Information Administration (2019a).

Sources: U.S. Environmental Protection Agency (2019c) and U.S. Energy Information Administration (2019a).

when applied to electrified mass transit, could generate valuable revenue for local transit agencies.

Beyond facilitating the infrastructure needed for broad ZEV deployment, governments should act at all levels to reduce the emissions impact of transportation-related infrastructure. The federal government should assess the carbon footprint of all major transportation-related infrastructure grant programs, where possible. Governments also should use their procurement dollars to support infrastructure-related materials that can reduce emissions, such as carbon-absorbing cement and stiffer pavements. (A recent study found that the use of stiffer, better maintained pavements could save 1 billion gallons of fuel in California over a five-year period.)[35] Further, attention should be paid to the impact of transportation materials, such as cool pavements, on the urban heat island effect.[36]

Importantly, as the automotive fleet electrifies, Congress will need to identify alternative resources for the highway trust fund, which is now supported by a federal tax on gasoline sales.

Driving Alternative Mobility Solutions

Local conditions factor heavily into both mobility needs and the relevance of particular technologies or policy solutions in meeting those needs. Local governments should develop integrated transportation and land use plans to expand non-automotive transportation options that make it easier to get around while reducing congestion, air pollution, and carbon emissions. These efforts should engage community-based organizations to ensure that historically marginalized communities benefit. Already, more than 1,300 cities across the country have adopted Complete Streets policies incorporating walkable, bikeable, transit-friendly principles.[37] Seattle, for instance, has significantly increased bus ridership, designated arterial streets to serve freight transportation, dedicated spaces for alternative modes of transportation, and undertaken safety measures that have increased public willingness to walk and bike.

The federal government should support local governments in implementing their low-carbon mobility plans. As one example, a $40 million grant from the U.S. Department of Transportation's smart cities program to Columbus, Ohio, has helped leverage $700 million in investment for EV infrastructure and procurement, as well as a variety of ride-sharing, carpooling, and commuter services. Congress should increase funding to expand the smart cities program to other cities, while requiring continued private-sector and local cost share. Wherever possible, this support should focus on outcomes rather than prescribed approaches.

To increase the use of public transit, Congress should allow tax-advantaged public transit accounts for individuals. These accounts should provide access to a variety of multi-modal public transportation options—including individual, last-mile service—that reflect the evolving set of available offerings and consumer needs that vary widely by location.

Addressing Freight, Aviation, and Maritime Emissions

Measures are needed to decarbonize the other major modes of transportation (air, water, and rail) and to facilitate intermodal connections that can allow for greater efficiencies in the movement of freight, which accounts for nearly a quarter of transportation emissions.[38]

The electrification of freight and passenger rail should be a priority for local and state development agencies, and public-private partnerships such as the Norfolk Southern Heartland Corridor can serve as a template for such efforts. To help decarbonize the movement of freight, state and local governments should support the development of high-density, multi-modal freight projects that can leverage electrified rail for longer hauls. The Federal Highway Administration should also study and provide recommendations to Congress on federal actions that can support the electrification of freight infrastructure and its integration into connected, multi-modal transportation systems.

Electrification appears to offer limited potential, at least as of now, for aviation, which accounts for 9 percent of transportation emissions. To address rising aviation emissions, Congress should establish a performance standard that freezes emissions at 2020 levels, allowing for the use of biofuels and offsets, modeled on the Carbon Offsetting and Reduction Scheme for International Aviation, established by the International Civil Aviation Organization. To reduce emissions over the long term, research on low-carbon aviation fuels should be a priority for the White House-led low-carbon innovation agenda.

Roughly 5 percent of U.S. freight is transported via inland waterways, generally by diesel-powered barge.[39] Electric barges offer a promising zero-emission alternative. Congress should increase funding to the Maritime Administration's Marine Highway Program to support the electrification of barges, tug-boats, and ferries, as well as to the U.S. Department of Transportation's Port Infrastructure Development Program to support low-carbon maritime infrastructure, including steps to reduce emissions from ships, trucks, trains, cargo-handling equipment, and harbor craft.

INDUSTRY

Given its tremendous diversity, its heavy reliance on large quantities of heat, and the fundamental nature of many core manufacturing processes, the industrial sector is especially challenging to decarbonize. Economy-wide carbon pricing, as recommended above, can drive some emissions reductions across the sector, but a wide range of complementary policies are also needed. Priorities over the next decade include developing innovative lower-carbon manufacturing processes, setting standards to drive energy efficiency, electrification and other forms of fuel switching, and safeguarding the competitiveness of energy-intensive, trade-exposed sectors.

Advancing Low-Carbon Technologies

A critical aim of the White House-led low-carbon innovation strategy recommended above must be to rapidly advance a wide range of technologies to reduce or capture emissions from industrial processes and energy use. The federal government should support the research, development, and demonstration of critical technologies, stronger public-private partnerships, and fast-track commercialization efforts.

Just 10 of the 100-plus industrial sub-sectors account for two-thirds of the industrial sector's energy-related CO_2 emissions: bulk chemicals, refining, iron and steel, food products, paper products, transportation equipment, fabricated metal products, plastics, cement and lime, and aluminum.[40] The largest source is energy used to generate heat for industrial processes. Manufacturing processes for metal, glass, and cement, for instance, demand temperatures in excess of 2,000 degrees F. Generating this heat with sources other than conventional fossil fuel combustion is challenging, particularly at higher temperature ranges, although advanced nuclear designs, particularly molten salt reactors, offer a zero-carbon alternative for some high-temperature heating needs. Other promising renewable heat sources include renewable natural gas (such as from agriculture, wastewater treatment, and landfills), solar thermal, and geothermal. Congress should significantly increase funding to develop and commercialize alternative thermal heat technologies, including renewables and advanced nuclear, that can produce both heat and power.

In addition to emissions from energy use, significant levels of emissions result from industrial processes that chemically or physically transform materials, as is done in subsectors such as cement, steel, and bulk chemicals. Congress should increase funding to develop innovative industrial processes with smaller greenhouse gas footprints. For example, new breakthroughs in cement production could reduce the footprint of cement and concrete by up to 70 percent.[41]

Even with such advances, and with reductions in energy-related emissions, significant levels of emissions will likely remain. Capturing those emissions for storage or utilization will be an essential strategy for decarbonizing the industrial sector. It is critical that Congress increase support for the development and deployment of carbon capture technologies (see the Carbon Capture chapter).

KEY RECOMMENDATIONS

- *Congress should increase funding to develop and commercialize alternative thermal heat technologies and to develop innovative industrial processes with much smaller greenhouse gas footprints.*
- *The federal government should undertake a benchmarking process to establish intensity-based greenhouse gas objectives for major sub-industries.*
- *Congress should extend and increase the existing 45Q tax credit for carbon capture to support the capture of process and on-site energy-related emissions, and should provide tax credits for energy efficiency improvements.*
- *Federal, state, and local governments should support the deployment of combined heat and power systems.*
- *An economy-wide carbon pricing program should include provisions aimed at safeguarding competitiveness and minimizing carbon leakage risks.*
- *The United States should ratify the Kigali Amendment phasing down the use of hydrofluorocarbons and Congress should provide EPA with clear authority to take the steps necessary to implement it.*

Setting Industrial Benchmarks

To orient companies toward decarbonization, the federal government should undertake a benchmarking process

to establish intensity-based greenhouse gas objectives for the major sub-industries. The benchmarking process, informed by programs already implemented in Canada and Europe, will highlight best practices and promote industry-wide learning. The resulting objectives will provide ongoing incentive and flexibility for companies to pursue their most affordable decarbonization options. These intensity-based objectives could be used to determine how a company or facility is treated within the economy-wide carbon pricing system; in the absence of economy-wide pricing, the objectives could serve as the basis of mandatory performance standards that can be traded within and across sub-industries.

Providing Support for the Transition

To drive the deployment of emerging technologies and help companies meet performance standards, government should provide additional, targeted support for efficiency, fuel switching, and carbon capture. In particular:

- Federal, state, and local governments should support the deployment of conventional combined heat and power systems. Such systems can reduce by half the energy-related emissions produced by separate heat and power systems.[42]
- Congress should extend and increase the existing 45Q tax credit for carbon capture to support the capture of process emissions and on-site energy-related emissions, and it should provide tax credits for energy efficiency improvements.
- To promote electrification and reduce dependence on fossil fuels, federal and state support should be offered for the adoption of electric boilers for industrial heat and other electrification measures (e.g., industrial heat pumps).

DOE has an important role in helping industry better understand the opportunities for clean energy and systems efficiency. Congress should, in addition to elevating the Advanced Manufacturing Office within DOE, expand funding for manufacturing initiatives. These should champion a circular economy approach (eliminating waste and reusing resources) and seek decarbonization opportunities in advanced manufacturing, digitization, and automation.

Federal, state, and local agencies procure large quantities of materials for infrastructure projects, their own operations, and other purposes, and this procurement can also be a lever for the decarbonization of industry. As a further incentive to industry to produce lower-emission goods, all levels of government should institute "clean procurement" criteria that favor products with the lowest carbon intensity on a full lifecycle basis wherever possible. This requires establishing methodologies and criteria to evaluate a product's embedded carbon from cradle to disposal, including supply chains, transportation, and various stages of production.

Phasing Out Hydrofluorocarbons

Hydrofluorocarbons (HFCs), unlike other greenhouse gases, are intentionally manufactured and used in a variety of applications such as refrigeration, air conditioning, aerosols, fire protection, and solvents. When released to the atmosphere, HFCs create hundreds to thousands of times more warming than an equivalent amount of CO_2. The Kigali Amendment to the Montreal Protocol calls for a global phasedown of HFCs, and American companies are leaders in the development of alternatives. To promote the rapid adoption of these safer alternatives in the United States, and to ensure U.S. firms a strong role in the global phasedown, the United States should ratify the Kigali Amendment and Congress should provide EPA with clear authority to take the steps necessary to implement it.

A VISION: INDUSTRY IN 2050

A modernized U.S. industrial sector continues to create jobs, growth, and exports with a substantially smaller carbon footprint. The sector is much more energy efficient, relies more heavily on electricity and other low-carbon energy sources, and has taken advantage of digital advances and data analytics to achieve system-level efficiencies. Companies employ new lower-carbon manufacturing processes, as well as technologies that capture carbon emissions and convert them into a wide range of commercial products. Industrial hubs have bolstered regional economic development, making greater use of waste heat and other by-products to consume less energy and add value across sectors. Industry has not fully decarbonized, so its remaining emissions are offset by "negative emissions" achieved through land-based sequestration and direct air capture.

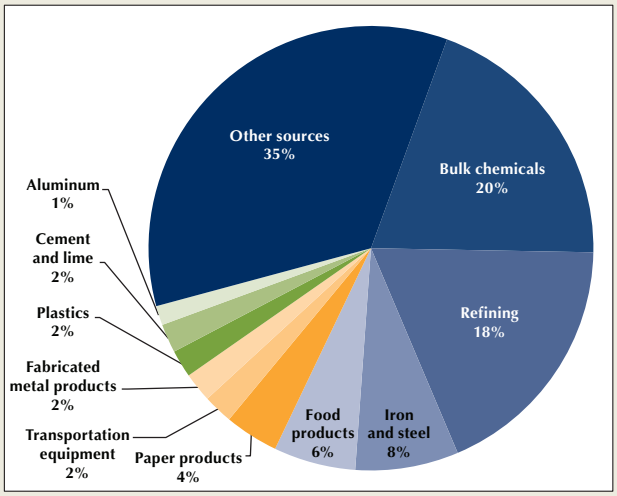
Safeguarding Industrial Competitiveness

For subsectors that are energy-intensive and trade-exposed—meaning that their products are traded globally—the costs of decarbonizing may pose a potential competitive disadvantage. There may also be a risk that production will move to countries where greenhouse gas standards are not yet as stringent, resulting in the "leakage" of emissions. All existing carbon pricing programs globally include specific provisions aimed at minimizing competitiveness and carbon leakage risks.[43] An economy-wide carbon pricing program should include such provisions (e.g., preferential allocation of allowances in a cap-and-trade system, tax credits, rebates, border adjustments), and these should be reexamined every four years during the periodic review recommended above as part of the long-term policy framework.

INDUSTRY: EMISSIONS AT A GLANCE

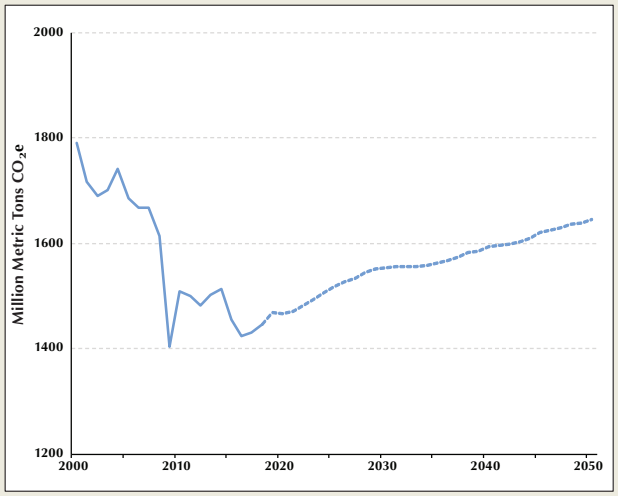
- Counting both direct emissions and indirect emissions (from electricity generated off-site), industry accounts for nearly 30 percent of total U.S. greenhouse gas emissions. Its six largest sources are bulk chemicals, refining, iron and steel, food products, paper products, and cement and lime production.
- Energy-related CO_2 emissions (from both on-site fossil fuel use and off-site electricity) account for around two-thirds of the sector's total greenhouse gas emissions. Fossil fuel combustion for heat and power is the largest source. Industry also accounts for 30 percent of U.S. non-CO_2 greenhouse gas emissions, including 42 percent of methane, 9 percent of nitrous oxide, and 26 percent of other greenhouse gases such as fluorinated gases (e.g., hydrofluorocarbons (HFCs) and perfluorocarbons).
- The sector's energy-related CO_2 emissions have declined by about 21 percent since 1997, but are projected to increase by 12 percent by 2050 under business as usual, as energy prices decline and industrial production rises.

Energy-related CO_2 emissions from industry, 2017



Source: U.S. Energy Information Administration (2019a)

Industry energy-related CO_2 emissions, 1990–2050



Sources: U.S. Energy Information Administration (2019a) and U.S. Energy Information Administration (2019c).

Sources: U.S. Energy Information Administration (2019a), U.S. Energy Information Administration (2019c, and U.S. Environmental Protection Agency (2019c).

BUILDINGS

Decarbonizing the buildings sector (both residential and commercial) requires improving energy efficiency and switching to lower-carbon energy sources—in particular, to electricity. Over the long term, reducing the carbon embedded in building materials will also be critical. Key challenges include the tremendous diversity of buildings, the slow turnover of the building stock, and the competing financial interests of owners, occupants, and lenders. Priorities over the coming decade include establishing overarching goals for decarbonizing the building sector, implementing targeted measures to electrify buildings and to improve the energy efficiency of buildings and appliances, and helping building owners and occupants finance building upgrades.

Setting Decarbonization Goals

As a means of driving action across the sector, state and local governments should set overarching goals for the decarbonization of commercial and residential buildings. Goals should be tailored to regional or local circumstances and can take multiple forms. For instance, several major U.S. cities have signed onto the World Green Building Council's Net Zero Carbon Building Commitment, which includes a goal of achieving net-zero operating emissions in both residential and commercial buildings by 2030.[44] The goal encompasses both emissions generated on site and those from off-site power production. As another example, California has set a goal for all new residential buildings to be zero net energy (consuming no more energy than they produce on site from sources such as rooftop solar) by 2020, and all new commercial buildings by 2030.[45]

To ensure progress toward these goals, state and local governments should regularly update their building codes to require the use of available and affordable carbon-reducing practices in new construction and major renovations, as elaborated below. Local jurisdictions should further incentivize decarbonization through practices such as benchmarking the carbon performance of commercial buildings.

In addition, all levels of government should set goals and institute standards and practices to decarbonize their own building stock, including leveraging procurement to stimulate market demand for low-carbon building materials. The federal government alone owns or leases 361,000 buildings, which presents a significant opportunity to achieve carbon reductions across the country.[46]

Switching to Electricity

A key strategy for decarbonizing the buildings sector is switching space and water heating systems, along with appliances, to electric units. Coupled with a decarbonized power sector, the electrification of buildings could reduce economy-wide emissions from fossil fuel combustion emissions by more than 22 percent.[47] Electrification is already cost-effective for buildings using oil and propane (which represent more than 20 percent of residential fossil fuel use) and, with additional support, would become more economical for existing natural gas customers.[48] State and local governments should provide incentives to switch to electric space and water heating systems as well as appliances. Maine, for example, is issuing rebates for electric heat pumps for residential and commercial customers in order to help reach its target of installing

KEY RECOMMENDATIONS

- *State and local governments should set overarching goals for the decarbonization of commercial and residential buildings, and should regularly update their building codes to require the use of available and affordable energy efficiency measures and other carbon-reducing practices.*
- *Federal, state, and local governments should provide incentives for building owners and homeowners to switch from fossil fuel-powered to electric appliances such as electric space and water heating systems.*
- *All states should authorize Property Assessed Clean Energy (PACE) programs to help finance energy-related improvements in both residential and commercial buildings.*
- *States and localities should encourage the use of energy savings performance contracts in public buildings to improve energy efficiency, reduce emissions, and save taxpayer money.*

100,000 of the units by 2025. To support state and local electrification efforts, Congress should provide a tax credit for switching from fossil fuel-powered to electric appliances, such as electric heat pumps and electric water heaters.

State and local governments should also establish electrification "reach codes"—enhanced codes that provide developers with a clear template for constructing fully electrified buildings. These codes can also provide guidance on facilitating electric vehicle charging and solar panel installation.

Public utility commissions should support the electrification of buildings by encouraging utilities to educate consumers, help developers meet reach codes, and provide incentives and rate structures that maximize cost and emissions benefits while ensuring that electrification programs and energy efficiency programs do not work at cross-purposes.

Increasing Energy Efficiency

Stronger standards will be essential in achieving greater energy efficiency in both buildings and appliances.

To maximize efficiency, all state and local governments should enact building codes ensuring state-of-the-art energy efficiency performance, and they should periodically update the codes to incorporate advances in materials and best practices. Building codes should take into account the building envelope, efficient end-use appliances, and increasingly digitization and smart sensors. Governments should draw on model building codes developed by the federal government, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and the International Codes Council (ICC). As these model codes are updated, they should incorporate practices to promote the integration of advanced digital technologies to achieve systems-level efficiencies. Congress should increase funding to DOE to assist state and local governments in adopting up-to-date codes.[49]

To ensure equitable access to efficiency opportunities, Congress should increase funding to improve building efficiency in low-income communities. DOE's Weatherization Assistance Program supports weatherization improvements and upgrades, helping low-income families reduce their energy costs by an average of $283 every year and reducing emissions by 7.38 million metric tons.[50] Congress should increase funding for the Weatherization Assistance Program and, for homes that require significant renovation before they can be weatherized, should establish a new program to help make them weatherization-ready.

To reduce energy use by improving the efficiency of lighting, heating, cooling, and other end uses, DOE should continue to strengthen energy efficiency standards for residential and commercial appliances and lighting under the Energy Policy and Conservation Act. This federal law governs procedures, labeling, and energy targets for appliances and equipment representing 90 percent of home energy use and 60 percent of commercial buildings' energy use.[51] Standards implemented under the Energy Policy and Conservation Act since 1987 have avoided 2.3 billion tons of CO_2 emissions.[52]

A VISION: BUILDINGS IN 2050

Residential and commercial buildings have sophisticated, automated control systems that dynamically adapt to meet occupants' needs while maximizing energy efficiency. Buildings are more closely integrated with the electricity grid, relying on decarbonized electricity in place of the direct combustion of fossil fuels, and in many cases serving themselves as sources of self-generation and energy storage. The increased availability of renewable natural gas has also helped to reduce the use of fossil natural gas in buildings. Better real-time and lifetime data on building performance, energy use, and energy costs enable improved decision-making for long-term financial investment in—and construction, renovation, and operation of—buildings of all types.

Financing Building Upgrades

In some states, Property Assessed Clean Energy (PACE) programs help property owners cover the upfront costs of energy-related improvements by adding them to property tax assessments; these are tied to the property rather than the owner, enabling a longer payback period. PACE programs have mobilized more than $5 billion in energy efficiency improvements in the residential sector.[53] In California alone, these programs have reduced greenhouse gas emissions by 1.15 million metric tons. [54] All states should authorize PACE programs for both residential and commercial buildings, including new construction and major redevelopments.[55] One

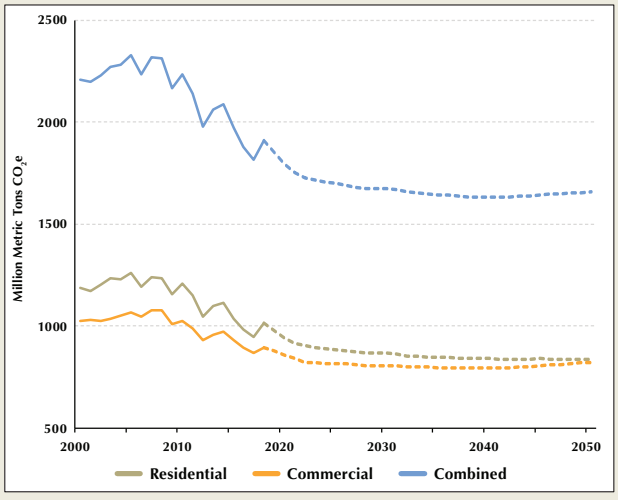
impediment to the use of PACE financing is a 2017 decision by the Federal Housing Administration to no longer insure mortgages with PACE liens attached. To ensure broader access to this innovative form of finance, the Federal Housing Administration should resume insuring such mortgages while safeguarding both consumer and taxpayer interests.

Energy savings performance contracts are another tool to unlock significant private investment in efficiency upgrades. In such a contract, a government agency (or other entity) partners with an energy service company, which finances and undertakes efficiency improvements that pay for themselves over time through energy and operational savings. A typical project reduces a building's energy consumption by 13 to 31 percent per year.[56] States and localities should authorize the use of these contracts in publicly owned buildings, including municipal offices, universities, schools, and hospitals.

BUILDINGS: EMISSIONS AT A GLANCE

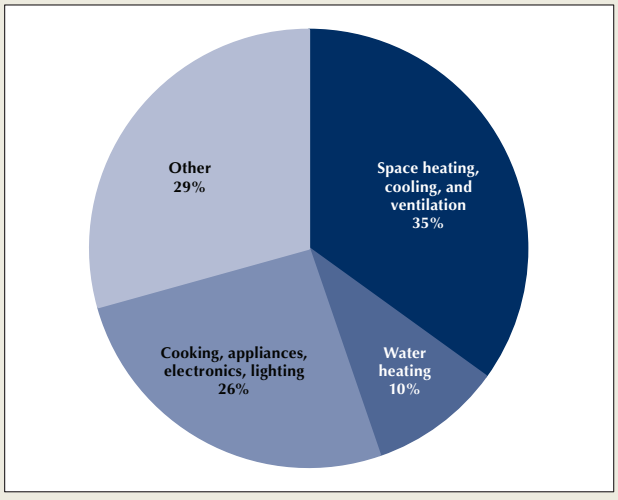
- Counting both direct emissions and indirect emissions (from electricity generated off-site), the buildings sector accounts for 31 percent of total U.S. greenhouse gas emissions. Commercial buildings generate 8 percent more emissions than residential buildings. The primary sources are heating and cooling, water heating, lighting, and appliances.
- Energy efficiency improvements have reduced CO_2 emissions from residential and commercial buildings by 19 percent and 17 percent, respectively, since a 2005 peak.
- Even with projected increases in population, electronics use, and air-conditioner use, further efficiency gains are expected to reduce growth in energy use by around 0.3 percent a year through 2050. Under business as usual, energy-related CO_2 emissions are expected to decline by 15 percent in the residential sector and 6 percent in the commercial sector.

Energy-related CO_2 emissions from buildings, 1990–2050



Sources: U.S. Energy Information Administration (2019a) and U.S. Energy Information Administration (2019c).

CO_2 emissions from buildings by end use, 2017



Source: U.S. Energy Information Administration (2019a).

"Other" includes items such as data servers, medical imaging equipment, ceiling fans, and pool pumps.

Sources: U.S. Environmental Protection Agency (2019c), U.S. Energy Information Administration (2019a), U.S. Energy Information Administration (2019c).

In the case of rental properties, energy efficiency investments face the challenge of split incentives—the owner bears the cost of the improvements, while the tenant reaps the benefits through lower energy bills. To overcome this barrier to investment, state and local governments should offer property tax abatements to building owners who invest in qualifying efficiency improvements. States would set performance standards and share costs with local governments, which would implement the program and receive tax reimbursement from states.[57] State and local governments should also look for opportunities to work with utilities on these programs. Public utility commissions have the ability to authorize innovative funding mechanisms for decarbonization, efficiency, and electrification upgrades, for example, through utility on-bill financing.

With the expansion of rooftop solar, both property owners and the power system as a whole can benefit by enabling the sale of any surplus power generated to the grid. This practice can help decarbonize the power system and bolster its reliability, while generating revenue that can help building owners and homeowners finance their solar investments. To maximize these benefits, all states should enact policies setting equitable terms for the sale of self-generated renewable power to electric utilities. These policies should fairly compensate property owners for the benefits they provide the power system and utilities for the cost of maintaining a reliable grid, while striving to maintain low-cost electricity for all consumers.

LAND USE

U.S. agricultural activities produce a variety of greenhouse gas emissions, but the land sector as a whole is a net greenhouse gas sink, with soils and vegetation absorbing significant quantities of CO_2 from the atmosphere. Increasing this land-based sequestration to help offset remaining emissions from other sectors will be essential to achieving carbon neutrality. Priorities over the coming decade include strengthening incentives and capacity for carbon sequestration on farms and in forests, reducing on-farm emissions from fertilizers and livestock, bringing lower-carbon food products to market, and reducing food waste throughout the system, from farmer to consumer.

Enhancing Natural Carbon Storage

The land use sector will play a vital role in achieving carbon neutrality across the economy by producing "negative emissions" to offset the remaining emissions of sectors, such as industry, that are especially challenging to decarbonize.

An economy-wide carbon pricing program could steer significant resources toward enhanced farm and forest sequestration if it allows for the trading of—or invests some of the revenues in—these emission offsets. Whether in advance of or in parallel with carbon pricing, other measures are also needed to conserve and expand lands with sequestration potential and to actively promote sequestration on farms as well as in forests.

Growth in population can drive the conversion of forest and agricultural lands to other uses that diminish their potential for carbon storage. From 1992 to 2012, almost 31 million acres of agricultural land in the United States was converted to other uses, the equivalent of New York State. The U.S. population is projected to reach 400 million by 2050, triggering an estimated 15 million to 45 million more acres of development, at the same time that global demand for agricultural products is expected to increase by 50 to 70 percent.[58]

All levels of government should take steps to conserve and expand lands with strong sequestration potential.

Local and state governments should employ smart growth policies to steer development to areas already developed or to marginal lands, avoiding the conversion of agricultural and forest lands. States should also expand cost-share and tax incentives for private forest owners to avoid conversion. Local, county, and state governments should partner with nonprofits to conserve forested lands through public ownership or conservation easements. Urban and suburban communities should expand tree populations through urban tree planting programs. The U.S. Forest Service should meet its goal of reforesting 5,000 acres of post-disturbance land by 2025 and continue to increase that goal and extend those efforts through 2050.[59] Afforestation (the addition of forests) could yield up to 225 teragrams of forest carbon uptake per year if widely implemented.[60]

Additional carbon sinks like wetlands should also be valued and enhanced. Congress should increase support for research by the National Oceanic and Atmospheric Administration[61] quantifying the value of restoring and establishing wetlands, including carbon sequestration, so that wetland restoration can qualify as an offset in an economy-wide carbon pricing system, as it now can in California.[62] In addition, EPA should maintain its protection of wetlands through the Clean Water Act,

KEY RECOMMENDATIONS

- *Congress should provide the U.S. Forest Service stronger funding to restore forests, increase forests' resilience to wildfires, and provide support for private forest owners in areas at risk.*
- *Congress should strengthen incentives for farmers to adopt carbon-sequestering growing practices by authorizing them as emission offsets in an economy-wide carbon pricing program, and through lower interest rates for farm loans, lower crop insurance premiums, and other changes to the federal crop insurance program.*
- *Congress should fund the U.S. Department of Agriculture to develop improved soil carbon measurement methods and equipment, and to develop food, fiber, and biomass crops that require fewer inputs and can better sequester carbon.*
- *Local governments should implement and support composting programs that use post-consumer food waste to produce fertilizer or use biodigesters to generate biogas.*

and states should pass their own wetland safeguards to reduce the conversion to other uses.

Stronger efforts are needed to improve the health of existing forests, too, both to enhance their sequestration potential and to avoid carbon emissions resulting from wildfires. Forests are increasingly threatened by extreme climate conditions such as heat and drought that make sequestration less predictable and expose forests to greater risk of wildfire, wind damage, and infestation.[63] In 2018, Congress adopted legislation to strengthen funding for wildfire suppression through 2027. Congress should further boost funding for the U.S. Forest Service's efforts to restore forests, increase resilience to wildfires, and provide technical and financial support for private forest owners in areas at risk.

On agricultural lands, practices that enhance carbon storage in soil, such as rotational grazing or the use of cover or perennial crops, can also reduce erosion, retain water, and enhance nutrient cycling, thus improving yield and crop resilience. Despite these practices' long-term benefits, upfront costs and other challenges often deter farmers from adopting these practices, also known as regenerative agriculture. To ease these barriers, the federal government should strengthen federal incentives and support for soil conservation practices that increase carbon sequestration. Congress should direct the U.S. Department of Agriculture to designate carbon sequestration as an objective in select voluntary conservation programs and should significantly increase funding for them. The Farm Service Agency, which administers the programs, should be expanded to support the enrollment of additional farmers and acreage.

Congress also should provide additional incentives for farmers to adopt carbon-sequestering growing practices by authorizing them as emission offsets in an economy-wide carbon pricing program, and through lower federal farm loan interest rates, lower federal crop insurance premiums, and changes in the structure of the federal crop insurance program. Additionally, Congress should increase funding for agricultural extension services and the Natural Resources Conservation Service in order to educate farmers about carbon sequestration practices, their benefits, available incentive programs, and ways farmers can cope with climate impacts. States should coordinate and support improvements in soil carbon storage and health, as Nebraska has modeled with its Healthy Soils Task Force. These state and federal programs should include support for producers who farm rented land and small family farms.

More reliable and affordable means of measuring, monitoring, and verifying carbon storage are essential to scaling up carbon sequestration across working lands. The U.S. Department of Agriculture should expand research and development in the soil carbon measurement methods and equipment needed to simplify and lower the cost of monitoring and verification. Precision agriculture relies on technology to inform farm management, including global positioning systems, soil sampling, and remote sensing that can contribute to soil carbon monitoring. Federal cost-sharing, support for agricultural equipment cooperatives, and equipment subsidies should be provided to expand the use of these technologies.

A VISION: LAND USE IN 2050

Farms, forests, and wetlands have become even larger carbon sinks, absorbing half of the residual emissions in the United States. Standardized, low-cost technology allows the accurate measurement of carbon storage, and farmers and forest owners and managers are encouraged by both policy and markets to optimally manage their lands to sequester carbon. Precision agriculture, soil conservation, and other innovations have significantly boosted farm productivity, meeting the food and fiber needs of growing U.S. and global populations while simultaneously reducing agriculture's reliance on fossil fuel-intensive pesticides, fertilizers, and energy. Well-informed consumers choose from a wide array of low-carbon foods, and food waste has been minimized throughout the food system.

Reducing Farm Emissions

Much of the agricultural sector's greenhouse gas emissions result from soil management practices, especially the use of synthetic fertilizers that emit nitrous oxide.[64] Many of the soil conservation practices recommended above can lower emissions by enhancing soil health and reducing the need for fertilizer applications. Strengthened agricultural extension services should advise farmers on optimal timing and quantities of fertilizer application for achieving emissions reductions. Precision agriculture can further reduce

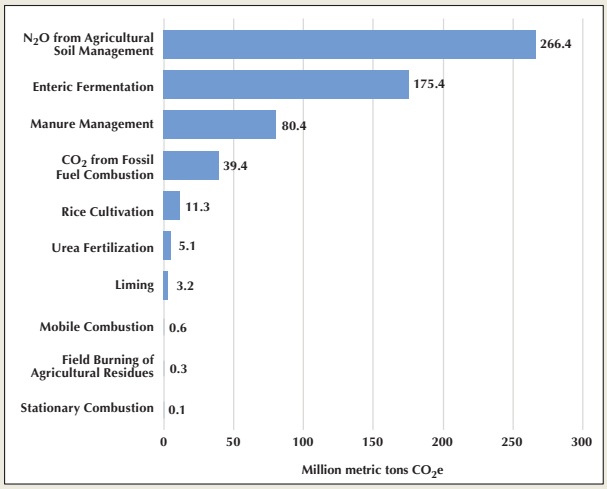
these emissions by allowing farmers to fine-tune nitrogen fertilizer application. U.S. Department of Agriculture research programs, in partnership with universities, extension services, and private-sector partners, should research and refine precision agriculture equipment and technology that can monitor moisture, weeds, and pests to better inform application of water, pesticides, and fertilizer. The Natural Resources Conservation Service's Precision Farming Incentive should be expanded and better funded to make precision agriculture technology more affordable for producers.

Livestock production is also a significant source of agricultural emissions. Indeed, enteric fermentation and manure management represented nearly half of the sector's emissions in 2017.[65] Congress should support stronger research, incentives, and public-private partnerships to improve manure management, develop feed additives that can reduce enteric emissions from

LAND USE: EMISSIONS AT A GLANCE

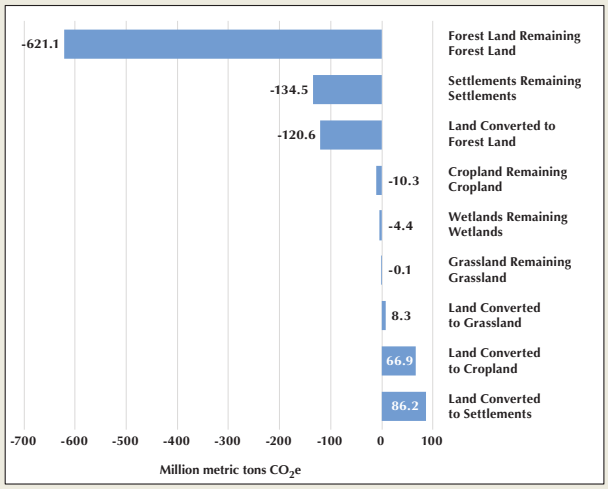
- U.S. lands—primarily forests—serve at present as a net greenhouse gas sink, absorbing the equivalent of about 11 percent of U.S. emissions each year. Under business as usual, forest sequestration is projected to fall by between 50 percent and 92 percent by 2050 (from 2005 levels) due to the conversion of forests to other uses, natural forest aging, and disturbances like wildfires, insects, and disease, which are likely to be exacerbated by climate change.
- Agriculture is responsible for 9 percent of U.S. greenhouse gas emissions. The largest component is nitrous oxide emissions from soil management practices, primarily the use of fertilizers. The next largest components are methane emissions from livestock-related sources, including enteric fermentation and manure management.
- Agricultural emissions have risen about 9 percent since 1990 and, under business as usual, are projected to increase by 3 percent to 9 percent above 2005 levels by 2050, depending on population and economic growth.

Sources of agricultural emissions, 2017



Source: U.S. Environmental Protection Agency (2019c).

Carbon emissions and sequestration from land use, land use change, and forestry, 2017



Source: U.S. Environmental Protection Agency (2019c).

Sources: U.S Department of Agriculture, "USDA Integrated Projections for Agriculture and Forest Sector Land Use" and U.S. Environmental Protection Agency (2019c).

animals, and increase animal productivity through genetic selection, yielding higher output per feed input. This should include incentives through the Environmental Quality Incentives Program and Rural Energy for America Program to help farmers manage manure by, for instance, installing anaerobic digesters or capturing methane and using it for energy generation.

Reducing Food Waste

A key strategy to limit food-related emissions and to alleviate the need for new agricultural lands to satisfy rising demand is to minimize food loss (i.e., food lost in the supply chain) and waste (i.e., the disposal of edible food products). In 2010, according to the U.S. Department of Agriculture's Economic Research Service, 31 percent of the food supply was lost.[66] Efforts to reduce food waste should include consumer education programs, but there is far greater waste-reduction potential along the food production chain. Congress should provide funding for research and public-private partnerships to develop new technologies to reduce food spoilage, extend shelf life, and utilize food residues to create other products, helping the United States reach its goal of reducing food waste and loss 50 percent by 2030.[67]

To reduce methane emissions from the food waste that remains, local governments should implement and support composting programs that use post-consumer food waste to produce fertilizer, which can displace fossil fuel-based fertilizers, or use biodigesters to generate biogas.

Offering Lower-Carbon Foods

Food producers have begun to offer consumers vegetable-based proteins and other alternative foods with smaller carbon footprints. In addition to their climate benefits, the production of many of these products uses less water, less land, and fewer agricultural inputs. Stronger federal and private R&D efforts can provide consumers with a wider range of sustainable options. Federal research should support assessments of the carbon footprint claims made by food companies and establish a better understanding of impacts on the farm industry, landscapes, and health.

In addition, Congress should increase funding for the U.S. Department of Agriculture to continue research, development, and field testing of food, fiber, and biomass crops that require fewer inputs and can better sequester carbon. Research on perennial grains provides particular opportunities to meet these multiple objectives while storing carbon in deeper soils and roots.

OIL AND GAS

Emissions associated with the combustion of oil and natural gas currently account for more than half of U.S. greenhouse emissions.[68] Many of the policies recommended elsewhere in this report will dramatically reduce these emissions by transitioning other sectors away from fossil fuels. Economy-wide carbon pricing, for instance, will provide an incentive to all sectors to improve energy efficiency and switch to lower-carbon fuels. Federal standards driving the deployment of net-zero emission vehicles will dramatically reduce oil demand in transportation. Policies to decarbonize buildings through efficiency and electrification will reduce demand for natural gas. Emissions-free hydrogen produced with surplus zero-carbon electricity could substitute for fossil fuels in the transportation, power, industrial, and buildings sectors.

Other recommended policies would enable the oil and gas sector to continue serving U.S. energy needs as the economy decarbonizes. Performance standards in the power and industry sectors will allow continued, and possibly growing, use of natural gas, provided the associated emissions are captured. The White House-led innovation agenda and a range of fiscal incentives will drive technologies and practices such as direct air capture, land-based sequestration, and carbon capture, utilization, and storage, which can be used to further reduce, or offset, fossil fuel emissions.

The oil and gas industry, as a longtime technological innovator with deep expertise in related fields and technologies as well as robust experience with executing large and complex engineering projects, is well positioned to partner with government and other sectors to develop new technologies and shift investment toward low-carbon energy production, distribution, and storage solutions.

Below we discuss policies that reduce the overall greenhouse gas intensity of U.S. oil and gas supply. Top priorities over the coming decade include implementing measures to greatly reduce methane emissions, establishing incentives for renewable natural gas, conducting a comprehensive review of energy subsidies, and closely analyzing the long-term greenhouse gas impact of any new oil and gas infrastructure.

Reducing Operational and Pipeline Emissions

Intentional and unintentional releases of methane account for a majority of the oil and gas industry's direct greenhouse gas emissions.[69] Methane is over 80 times more potent than CO_2 over a 20-year time frame (and 28 to 36 times more potent over a 100-year time frame) and has a much shorter atmospheric lifespan, so rapidly reducing methane emissions provides significant near-term climate benefits.[70]

EPA should establish standards under the Clean Air Act regulating methane emissions across the oil and gas value chain, including emissions from natural gas flaring, venting, and unintentional leaks during production, processing, transmission, and distribution. Revisions to existing EPA standards now underway would remove their applicability to transmission and storage and eliminate direct regulation of methane from oil and gas sources.[71] EPA should instead adopt new standards to address methane leakage from both new and existing oil and gas infrastructure as well as emissions from flaring.[72]

KEY RECOMMENDATIONS

- *EPA should establish standards under the Clean Air Act regulating methane emissions across the oil and gas value chain, including emissions from natural gas flaring, venting, and unintentional leaks during production, processing, transmission, and distribution.*
- *State policy-makers should implement renewable natural gas programs including tax and other financial incentives, such as capital investment or project rebate programs. Drawing on the success of renewable portfolio standards in electricity markets, states should expand or create renewable portfolio standards programs for renewable thermal energy, including renewable natural gas.*
- *Congress should amend the tax code and other provisions to phase federal subsidies away from higher-carbon energy sources and toward lower-carbon energy sources, including fossil fuels with carbon capture.*
- *Federal agencies should assess the climate-related impacts of new oil and natural gas infrastructure projects, and conduct similar assessments on proposals at the programmatic level that expand oil and natural gas leasing on federal lands.*

Flaring is a practice used by oil and gas operators to limit the direct release of methane emissions while drilling and completing a well. Flares burn methane and convert it to CO_2, but some methane leakage occurs. Most flares are assumed to be about 98 percent efficient, but some studies suggest rates that are lower.[73] Flares are typically used for a short period, until an operator is able to connect the gas stream to appropriate gathering and processing systems. However, U.S. pipeline infrastructure has not kept pace with the growth in oil and gas production. According to one study of the Permian Basin in Texas, 4.4 percent of gas produced was combusted, equal to about 104 billion cubic feet of natural gas.[74]

New EPA standards should build on best practices adopted by existing industry initiatives and seek to achieve similar performance industry-wide. For example, the Our Nation's Energy Future (ONE Future) Coalition, a voluntary collaborative of natural gas companies, has set a collective goal of reducing methane emissions associated with the production, processing, transmission, and distribution of U.S. onshore natural gas to 1 percent or less by 2025.[75] In addition, the World Bank's Zero Routine Flaring initiative seeks to eliminate routine flaring by 2030 and has received voluntary commitments from over 30 oil and gas companies and other stakeholders. EPA's new standards should implement best practices and allow for an expedited on-ramp for approving new technologies and methods proven to be environmentally effective. EPA should review and revise the methane standards at least every four years so that they align with industry best practice.

On private lands, state regulators have significant responsibility for regulating oil and gas production's impacts on emissions and air quality, including flaring.[76] States should implement stringent rules on long-term flaring practices, such as by setting capture targets or flaring limits or by requiring gas capture plans prior to drilling. State regulators should take care to define "unavoidable" venting and flaring in order to reduce uncertainty about how rules are enforced. State regulators should also subject flared gas that exceeds flaring limits to royalty payments.

Although more than 70 percent of methane emissions from the oil and gas supply chain are generated by upstream operations, opportunities exist to monitor and reduce emissions from the extensive U.S. pipeline system.[77] DOE, the Federal Energy Regulatory Commission, and state public utility commissions should all explore cost recovery mechanisms, grants, and technical assistance to modernize, repair, and replace pipelines at the interstate, state, and local levels. For example, cities can implement accelerated pipeline replacement and modernization programs to help repair and replace aging cast iron and steel pipelines with plastic pipelines and add digital monitoring and leak detection systems.

A VISION: OIL AND GAS IN 2050

The oil and gas industry has undergone a fundamental transformation as the economy has decarbonized. While the conversion of automotive fleets to zero-emission vehicles has dramatically reduced demand for oil, the oil and gas sector has employed a range of new technologies to provide alternative lower-carbon energy sources such as biofuels, renewable natural gas, and hydrogen. Natural gas coupled with carbon capture, utilization, and storage helps meet the rising demand for zero-carbon power from the transportation, buildings, and industrial sectors. Advanced control technologies have nearly eliminated operational emissions from flaring and methane leakage throughout the natural gas value chain. Beyond the extensive use of carbon capture, utilization, and storage technologies, the use of direct air capture and land-based sequestration for "negative emissions" helps offset the sector's remaining greenhouse gas emissions.

Supporting Renewable Natural Gas

One potential avenue for reducing the carbon intensity of oil and gas supply is the substitution of renewable natural gas and hydrogen for fossil resources across the economy. (See the Hydrogen chapter later in this report for related policy recommendations.) Renewable natural gas refers to both methane collected from anerobic digesters—often sited at dairies, farms, and landfills—and biogas produced through thermochemical means that is converted into pipeline-ready gas. The primary policies driving the deployment of renewable natural gas today are the federal renewable fuels standard, California's Low Carbon Fuel Standard, and some state renewable portfolio standards. However, these mechanisms currently support only the transportation and power sectors and are not sufficient to enable wide-scale deployment, particularly in the residential,

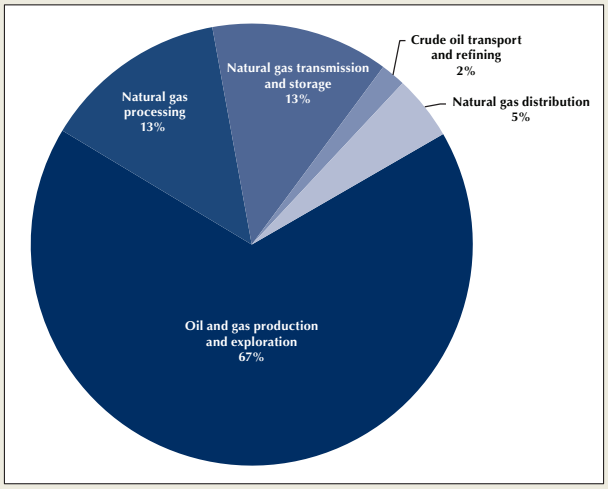
commercial, and industrial sectors. Since renewable natural gas is currently a higher-cost resource than fossil natural gas, a suite of policies and incentives is needed to enable greater investment in this energy source.

Policy-makers should develop programs that reduce the costs of bringing renewable natural gas to market, including high upfront infrastructure costs. State policy-makers should implement programs that include establishing clear injection standards and providing tax and other financial incentives, such as capital investment or project rebate programs. Public utility commissions should explore cost recovery programs that incentivize local distribution investments in renewable natural gas. Some states with renewable portfolio standards requiring electric utilities to deliver a certain amount of electricity from renewable or other clean energy sources allow renewable resources that produce thermal energy, such as renewable natural gas, to generate tradeable renewable energy credits. Renewable energy credits provide a monetary value to delivered renewable natural gas in those markets, making projects more economically viable. However, only 14 state renewable portfolio standard programs currently allow for thermal energy that is generated by renewable sources to be counted as an eligible resource. State regulators should allow for renewable thermal energy to contribute to existing

OIL AND GAS: EMISSIONS AT A GLANCE

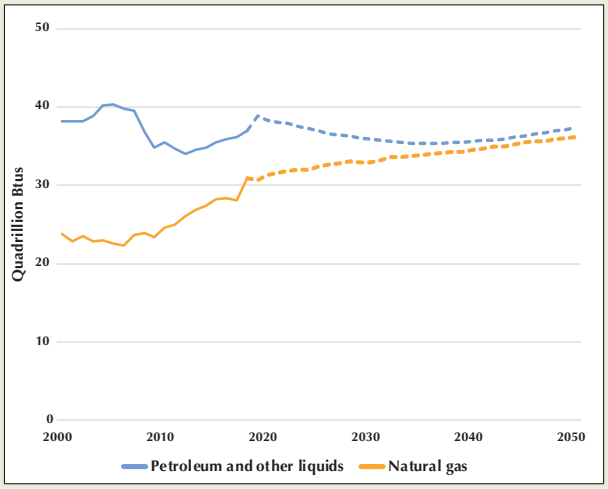
- The use of oil and natural gas across the economy accounts for more than half of total U.S. greenhouse gas emissions. Direct emissions from the production, processing, and distribution of these resources represent about 4 percent of the U.S. total.
- U.S. oil and gas production are projected to rise by 8 percent and 43 percent, respectively, by 2050. U.S. oil consumption is projected to decline slightly as fuel efficiency gains counterbalance rising demand, but natural gas consumption is expected to rise significantly, driven by demand in the industrial and power sectors. U.S. consumption of petrochemical feedstocks is expected to double.
- More than 80 percent of the sector's direct emissions are associated with the leaking and venting of methane, a greenhouse gas much more potent than CO_2. The sector accounts for nearly one-third of U.S. methane emissions.

Emissions from oil and natural gas sector, 2017



Source: U.U.S. Environmental Protection Agency (2019c).

Energy consumption by fuel, 1990–2050



Sources: U.S. Energy Information Administration (2019a) and U.S. Energy Information Administration (2019c).

Sources: U.S. Environmental Protection Agency (2019c), U.S. Energy Information Administration (2019a), and U.S. Energy Information Administration (2019c).

renewable portfolio standard carve-outs or create separate alternative energy portfolio standards that provide additional monetary value to resources such as renewable natural gas.[78]

Reforming Federal Practices

Apart from the regulation of emissions, a wide range of federal policies shape investment and information flows that influence the carbon intensity of the nation's energy supply. Many of these policies, including those relating to oil and gas, need to be updated to better align with a mid-century carbon-neutrality goal.

Several federal tax provisions directly or indirectly subsidize oil and gas production. Congress should mandate a comprehensive review of federal energy subsidies to ensure that they favor lower-carbon energy sources and contribute to carbon neutrality. This should include a review of tax provisions, such as deferred tax payments for capital expenses related to fossil fuel development and drilling. Based on the results of this review, Congress should amend the tax code and other provisions to phase federal subsidies away from higher-carbon energy sources and toward lower-carbon energy sources, including fossil fuels with carbon capture.

Under the National Environmental Policy Act (NEPA), federal agencies must analyze the potential environmental impacts of all major federal actions to ensure they are considered by decision-makers. Accordingly, federal agencies should assess the lifecycle emissions and other climate-related impacts of new oil and natural gas infrastructure projects. Similar assessments should be conducted at the programmatic level on proposals that expand oil and natural gas leasing on federal lands.

IV. CROSS-SECTORAL ELEMENTS

CARBON CAPTURE, UTILIZATION, AND STORAGE

The use of various technologies to capture carbon from industrial facilities, power plants, and, ultimately, the atmosphere must be a critical element of a U.S. decarbonization strategy.

Carbon capture, utilization, and storage (CCUS) represents a set of technologies and applications that capture CO_2 from industrial processes and power generation and either store it underground or incorporate it into new products. There are 19 full-scale carbon capture projects currently operating around the world (including 11 in the United States), capturing nearly 40 million metric tons of CO_2 per year.[79] The beneficial utilization of CO_2 in the production of building materials, fuels, and algae-based products is an area of growing interest.

IPCC scenarios for reaching the Paris Agreement's 2 degrees C goal show that doing so without CCUS could more than double the overall cost. As some level of U.S. fossil fuel-powered electricity generation is likely to continue for decades, a strategy is needed for capturing the associated emissions. CCUS will be even more critical in addressing industrial emissions, as the manufacture of steel, cement, glass, and chemicals often requires extremely high temperatures, and a zero-carbon alternative fuel may not be readily available (as discussed in the Industry chapter).

In the long run, technologies to directly capture of CO_2 from the atmosphere can produce the "negative emissions" likely needed to achieve carbon neutrality (alongside natural sequestration approaches such as afforestation and reforestation). The continued refinement of traditional post-combustion capture technologies is essential to reducing the cost of direct air capture.

In the long term, a meaningful carbon price is essential to driving the deployment of carbon capture. Other supportive policies can continue to advance CCUS and build a market for captured carbon in the interim. Top priorities over the coming decade include expanding R&D, strengthening incentives for CCUS deployment, and establishing a robust CO_2 transportation infrastructure.

Expanding Research and Development

The aim of DOE's Office of Fossil Energy's Carbon Capture Program is to reduce the cost of capture to $30 per metric ton of CO_2 by 2030. An associated goal is scaling up novel technologies to a level where they can be commercially deployed in a variety of applications, including industrial processes and power generation.

Congress should reauthorize and increase funding for DOE's Carbon Capture Program and establish performance-based objectives that direct research toward technologies with the greatest greenhouse gas reduction potential. Congress should also authorize

KEY RECOMMENDATIONS

- *Congress should reauthorize and increase funding for the Department of Energy's carbon capture program and should extend both the "begin construction" and claiming deadlines for the 45Q tax credit for carbon capture, utilization, and storage.*
- *Congress should strongly ramp up research and development to cut the cost of direct air capture, and should establish a direct air capture tax credit, possibly by amending 45Q.*
- *Creating a "CO_2 superhighway"—a network of pipelines connecting sources of CO_2 to locations where it will be utilized or stored—should be a national priority in any major infrastructure legislation, with the aim of substantially completing such a network by 2030.*

more and bigger pilot and demonstration projects and should consider larger cost-sharing with the private sector. International collaboration efforts, such as the current joint testing program with Norway, should be encouraged.

In addition, Congress should strongly ramp up research and development to cut the cost of direct air capture, now an estimated $400 to $700 per ton CO_2, to less than $100 per ton. The National Academy of Sciences has recommended that federal funding, a total of $11 million to date, be ramped up to $1.5 billion over 15 years and cover all phases of direct air capture RDD&D.[80]

Strengthening Financial Incentives

The 2018 enactment of an improved tax credit for CO_2 utilization and storage, known as 45Q, has created great interest in new CCUS projects of all sizes. However, the lack of official taxpayer guidance has hampered the ability of developers to utilize the 45Q tax credit to secure project financing. The Internal Revenue Service is expected to publish taxpayer guidance by early 2020, at which time developers will have less than four years remaining to begin construction and less than 10 years to claim the credit, which may not be long enough to realize a return on investment.

Congress should extend both the "begin construction" deadline and the period during which the 45Q credit can be claimed. In addition, it should lower the volume thresholds for credit eligibility to ensure that smaller (but still significant) projects can qualify. It should also make other financial tools available to developers, including private activity bonds and master limited partnerships. These have very little cost to the U.S. Treasury but would give developers access to useful financing tools already available to other types of publicly beneficial projects. Furthermore, programs such as DOE's loan guarantee program should be targeted at enabling deployment of commercial-scale CCUS projects.

As direct air capture technologies advance, Congress should amend 45Q or establish a new tax credit for CO_2 from air capture of $100 per ton or more. (The current credit for stored or utilized CO_2, regardless of how captured, ranges from $35 to $50 per ton.)

Building CO_2 Transportation Infrastructure

Moving captured CO_2 from its sources to where it can be used or permanently stored is another major cost component—and a critical step in creating a market for CO_2. The United States currently has more than 300,000 miles of large interstate and intrastate natural gas transmission pipelines, along with millions of miles of smaller distribution pipelines. In contrast, it has less than 5,000 miles of dedicated pipelines for transporting CO_2.

It is estimated that a pipeline network of 25,000 miles is needed to connect the largest sources of CO_2 with both enhanced oil recovery and saline storage sites. Much research into routing and building such a network has been completed, but it remains for states and the federal government to implement a transportation construction plan in a timely manner. Creating a "CO_2 superhighway" should be a national priority in any major infrastructure legislation, with the aim of substantially completing such a network by 2030.

DIGITALIZATION

As digital technologies become more ubiquitous, they are fundamentally changing how we use and consume energy. The digitalization of energy—through the use of sensors, networked devices, data, and analytics—has enabled a systems-based approach that can significantly reduce energy use and carbon emissions across the economy.[81] Examples include:

- **Power:** The digitalization of the grid can transform how power is generated and distributed. A combination of digital technologies can increase the efficiency of power plants and improve the power grid's ability to handle more intermittent generation from renewables and distributed resources while improving reliability. An interconnected power system can also expand the use of demand-response strategies to reduce or shift consumers' energy use and avoid capital costs associated with additional generation.
- **Transportation:** The digitalization of transportation through sensors and connected vehicles can help manage fleets and optimize routes, resulting in increased efficiency and reduced maintenance costs. Digital technologies also have the potential to reshape personal transportation through automated driving technologies and new shared mobility services.
- **Industry:** Smart manufacturing enabled through networked industrial equipment, advanced controls for industrial processes, and additive manufacturing (i.e., 3D printing) can increase the operating efficiency of manufacturing plants while reducing their emissions.
- **Buildings:** The digitalization of buildings through management systems, smart heating and cooling systems, smart lighting, and connected appliances and equipment can both reduce energy use through greater efficiency and shift when energy is used in order to reduce emissions.
- **Oil and Gas:** Utilizing digital tools such as advanced modeling, machine learning, and remote sensing, the oil and gas industry can increase efficiency, as well as better predict and identify equipment failure and methane leaks, thus enabling significant emissions reductions.
- **Agriculture:** Precision agriculture—which makes use of satellite and weather data, connected devices and sensors, and automated equipment—can increase productivity while reducing emissions-producing agricultural inputs.

Digitalization can thus play a significant role in moving the economy toward carbon neutrality. Priorities over the coming decade to realize the full potential of digital solutions include prioritizing systems-based research and development, addressing information gaps, leveraging government procurement of digital solutions, and expanding access to broadband networks.

Prioritizing Systems-Based RDD&D

Congress and DOE should prioritize RDD&D efforts that enable systems-based efficiency through digital technologies. A systems-based approach that interconnects the built environment, electrified transportation, distributed generation, and a smart grid can lead to real opportunities to reshape how power is generated and consumed so as to minimize carbon emissions.

Addressing the Information Gap

A key to unlocking the potential of digitalization is quantifying its systems-based performance so that companies, state public utility commissions, and other

KEY RECOMMENDATIONS

- *Congress and the Department of Energy should prioritize RDD&D efforts that enable systems-based efficiency through digital technologies, and should support the development of real-time measurement and verification protocols for systems-level efficiencies in buildings, industry, and transportation.*
- *All levels of government—federal, state, and local—should lead by example by requiring agencies to procure digital solutions, documenting the related energy efficiencies and cost-savings, and publicizing the lessons learned.*
- *Congress should fund and oversee the scaling and accelerated deployment of broadband infrastructure nationwide, especially in rural areas.*

stakeholders can better understand the financial benefits and associated emissions reductions. Congress should direct DOE to provide financial and technical assistance to develop real-time measurement and verification protocols for systems-level efficiencies in buildings, industry, and transportation.

As connected devices and management systems proliferate, DOE and the National Institute of Standards and Technology should work with relevant stakeholders to develop interoperability standards and communication protocols between devices and systems.

Increasing Government Procurement

All levels of government—federal, state, and local—should lead by example by requiring agencies to procure digital solutions, documenting the related energy efficiencies and cost-savings, and publicizing the lessons learned.

Expanding and Upgrading Broadband Access

Deployment of new connected devices requires the broad availability of reliable, high-speed internet. Congress should fund and oversee the scaling and accelerated deployment of broadband infrastructure nation-wide, especially in rural areas. Programs at the Federal Communications Commission, Rural Utilities Service, and U.S. Department of Agriculture that provide funding for expanded and upgraded broadband service should be scaled to help enable the deployment of digital solutions nation-wide.[82]

BIOENERGY

Bioenergy has significant potential to contribute to decarbonization across multiple sectors of the economy.

Different forms of bioenergy can be produced from a wide range of organic materials including crops, agricultural and food wastes, and forest products. The potential benefits of biomass energy are well established and have been recognized by the Intergovernmental Panel on Climate Change.[83] The CO_2 released by the burning of biofuels can be balanced out by the CO_2 absorbed from the atmosphere in the growth process, including through the long-term management of forests to increase carbon stocks. Pairing bioenergy with carbon capture and storage (BECCS), such as by running a power plant on biofuels and capturing and sequestering the resulting emissions, can contribute further to decarbonization by producing "negative emissions" that could offset emissions from other activities.

Current and potential applications of bioenergy include:

- **Transportation:** Biomass can be converted into liquid fuels for transportation, including possibly aviation fuels. The biofuels used most commonly today are corn ethanol and biodiesel, with select application and research of cellulosic ethanol and other fuels.
- **Power:** Biomass can be converted into heat and electricity through burning, bacterial decay, and conversion to gas or a liquid fuel. Bioenergy can more readily substitute for fossil fuels burned in power plants than some other types of renewable energy.
- **Industry:** Bioenergy can be used in industrial processes, primarily for heating applications in agricultural and chemical production, as well as in facilities like pulp and paper mills that have access to sources of biomass. (Biomass can also be used as a feedstock in the manufacturing of plastics, chemicals, and other products traditionally derived from petroleum or natural gas.)

Biomass fuels currently account for about 5 percent of U.S. energy use, most of which comes from biofuels (mainly ethanol) and from wood and wood-derived biomass, as well as a relatively small amount from biomass in municipal waste.[84] Biomass production can be resource-intensive, with potential tradeoffs that need to be managed, including higher nitrous oxide emissions from increased fertilizer use, increased water pollution, loss of carbon storage as natural lands are converted to croplands, and increased food prices as crops are diverted to energy use.

To realize the decarbonization potential of bioenergy while minimizing negative tradeoffs, efforts over the coming decade should focus on expanding research and development of potential applications, improving methodologies for measuring emissions and other impacts, and strengthening incentives for the use of net-zero bioenergy.

Researching Potential Applications

Federal research on bioenergy should be a key element of a White House-led low-carbon innovation agenda. DOE should partner with businesses on pilot demonstrations of BECCS to study its emissions-reduction and negative-emissions potential and encourage its commercial development. DOE should lead continued research on new biomass materials and growing methods, such as more efficient and higher-yield bioenergy crops, perennial grasses, and algae production on low-productivity land or offshore. The U.S. Forest Service should lead research on the conversion of vegetation thinned in wildfire resilience efforts to biomass in order to demonstrate economic benefits for private and public forest owners.

KEY RECOMMENDATIONS

- *The Department of Energy should partner with businesses on pilot demonstrations of bioenergy with carbon capture and storage to study its emissions-reducing or negative-emissions potential and to encourage commercial development.*
- *Federal agencies should work collaboratively to develop consistent methodologies to more accurately assess the net emissions benefits of biofuels.*
- *States should provide incentives to the power and industrial sectors to use low-carbon bioenergy and bioenergy with carbon capture and storage in place of carbon-intensive fuels.*

Improving Measurement and Analysis

Additional research is also needed to better assess the emissions benefits and other potential impacts of bioenergy. Current lifecycle estimates of emissions benefits vary widely; recent studies on currently available ethanol technology estimate greenhouse gas reductions of 27 to 43 percent compared to gasoline.[85]

To more accurately assess the net emissions benefits of biofuels, federal agencies should work collaboratively to develop consistent methodologies to calculate supply chain emissions, land-use change emissions, and fossil fuel displacement benefits. This could include improving existing tools—such as DOE's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model—to better inform decisions about agricultural production and the design of products that might use bioenergy. In particular, efforts are needed to limit the displacement of food crops through better understanding the land-use change implications of different biomass options and identifying lands that are best suited to growing biomass instead of food crops.

Establishing Standards and Incentives

Improved analysis can inform the development of standards ensuring the carbon benefits of biofuels. Some biofuels currently qualify for California's low carbon fuel standard by meeting requirements for reduced carbon intensity. The federal regulatory framework outlined in the Transportation chapter should similarly include biofuels that have qualified as low- and zero-carbon fuels.

As additional bioenergy options are developed and their emissions and other impacts are better understood, states should provide incentives to the power and industrial sectors to use low-carbon bioenergy and BECCS in place of carbon-intensive fuels and products, for instance through renewable portfolio standard carveouts.

The U.S. Department of Agriculture should support farmers growing biomass crops including experimental biofuel crops. This support should include federal crop insurance for additional biomass crops and payments to farmers hosting field tests. States and the Department of Agriculture should also develop conservation incentives that accompany federal biomass grower support, such as through specialized programs to support the use of agricultural conservation and soil health practices in biomass production.

HYDROGEN

Hydrogen has significant potential to contribute to decarbonization as a valuable zero-emission energy carrier across multiple sectors of the economy.

Currently, hydrogen is used primarily as a feedstock for crude oil refining, fertilizer production, and food processing.[86] However, it can also be used to generate electricity and heat across all sectors. Importantly, hydrogen can be stored for long periods and used on demand. Converting hydrogen into heat and electricity produces no emissions—only heat and water.

The production of hydrogen itself can generate significant greenhouse gas emissions, depending on the method used. The primary pathway today is steam methane reforming, which creates hydrogen from natural gas, producing significant CO_2 emissions.[87] Lower-emission pathways under development include methane pyrolysis, which splits natural gas directly to create hydrogen and solid carbon, and electrolysis, which uses electricity to create very pure streams of hydrogen and oxygen from water.[88]

Surplus electricity from zero-emitting renewables and nuclear can be used during periods of overgeneration to produce large quantities of "green" zero-carbon hydrogen.[89] Overgeneration, which typically occurs at times of day when electricity demand is low and renewables production is high, is projected to grow in the future, and hydrogen is an excellent and easy way to store that energy for later use, ideally as a substitute for carbon-emitting energy sources. In addition to "green hydrogen," carbon capture can be applied to the steam methane reformation process to produce "blue" hydrogen, currently the lowest-cost form of low-carbon hydrogen.

Current and potential hydrogen applications include:

- **Transportation:** Hydrogen can be used either in a fuel cell or an internal combustion engine to power a vehicle. Several auto manufacturers produce fuel cell electric vehicles. Fuel cells may be particularly useful in larger vehicles like buses and trucks, as well as in maritime shipping.
- **Power:** Hydrogen can be blended with natural gas to produce lower-emission electricity from natural gas combined-cycle power plants.[90]
- **Industry:** Hydrogen can be combusted to generate high-temperature heat for industry and used as a cleaner alternative for processing iron ore.[91]
- **Buildings:** Hydrogen can be used in appliances such as cookstoves and water heaters. Fuel cells also can provide residential and commercial heat and electricity.

To realize the decarbonization potential of hydrogen, priorities over the coming decade include expanding research and development of production pathways and potential industrial applications, developing the necessary infrastructure, and creating incentives and standards for the use of hydrogen.

Expanding Research and Development

Federal research on hydrogen should be a key element of a White House-led low-carbon innovation agenda. DOE should partner with industry to accelerate the development of hydrogen pathways by: bringing down the cost of low-carbon hydrogen production methods; developing alternative industrial processes that rely on hydrogen instead of fossil fuels; reducing the weight and volume, and increasing the durability, of hydrogen storage systems for vehicles and other applications; and developing alternative materials and standards for pipelines to transport hydrogen, which can embrittle steel and welds.

Building Hydrogen Infrastructure

To enable the increased use of hydrogen, a distribution network connecting production facilities and end users across multiple sectors must be established. As federal

KEY RECOMMENDATIONS

- *The Department of Energy should partner with industry to accelerate the development of low-carbon pathways to produce hydrogen and to develop alternative industrial processes that rely on hydrogen instead of fossil fuels.*
- *Congress should fund the development of state and regional plans to kickstart the buildout of storage, pipeline networks, and other infrastructure to support higher levels of hydrogen use across sectors.*
- *Congress and states should provide incentives for the adoption of technologies employing hydrogen, such as hydrogen fuel cells.*

and state infrastructure plans are developed, they should consider potential hydrogen demand from industrial, transportation, power, residential, and commercial consumers. Congress should fund the development of state and regional infrastructure plans to help kick-start the buildout of storage, pipeline networks, and other infrastructure to support higher levels of hydrogen use across sectors.

Creating Incentives for Using Hydrogen

To help increase demand, Congress and states should provide incentives for the adoption of products using hydrogen. For example, Congress should expand the electric vehicle tax credit to include fuel cell electric vehicles (as recommended in the Transportation chapter). Congress also should offer tax credits for companies that invest in hydrogen-based processes to reduce their emissions, as well as for commercial and residential installations of hydrogen fuel cells.

Establishing a Regulatory Framework

Akin to the Natural Gas Act, Congress should grant the Federal Energy Regulatory Commission authority to assist with interstate hydrogen pipeline, storage, and compressor station siting. The commission should also consider rules that would enable hydrogen technologies to be part of wholesale electricity and natural gas markets.

V. BUSINESS LEADERSHIP

One of the key findings of the scenario analysis presented in our *Pathways to 2050* report is that decarbonization requires action by all segments of society. The private sector, in particular, must play a leading role in positioning the United States for carbon neutrality by 2050. Every major company should develop and pursue an overarching strategy for contributing to and succeeding in this transition. These strategies can complement, supplement, and play an important role in informing government policies aimed at decarbonization. Key elements of these strategies should include managing emissions, investing for long-term decarbonization, disclosing climate-related risks, strengthening resilience to climate impacts, and partnering with policy-makers, the public, and private-sector peers.

Managing Emissions

As a cornerstone of their decarbonization strategies, companies should adopt carbon-neutrality goals and report regularly on progress toward them. Already, almost half of 2016 Fortune 500 companies—and more than 60 percent of the Fortune 100—have set targets to reduce greenhouse gas emissions, improve energy efficiency, and/or increase the use of renewables.[92] Many companies have adopted science-based targets in line with keeping warming below 2 degrees C, committed to 100 percent renewable energy, or set goals that encompass emissions from their products as well as their operations. Recently, some companies have started making net-zero-emission commitments—an encouraging trend that needs to accelerate. Companies' carbon-neutrality goals should aim for a net balance of greenhouse gas emissions and withdrawals. While some industries may need to use emission offsets to achieve carbon neutrality, only sequestration-based offsets should be employed after 2050.

Companies should also employ internal practices such as carbon pricing to systematically incorporate climate-related costs into their investment and operational decisions and to incentivize least-cost reductions. Companies in the oil and gas, minerals and mining, electric power, and other sectors have used internal carbon pricing as part of their risk mitigation strategies since the 1990s. Internal pricing can take the form of a shadow price that guides long-term planning and investment strategies, or it can be an actual internal fee charged to business units (the revenues from which can fund corporate emissions-reduction efforts).[93] As of 2017, almost 1,400 companies worldwide were factoring an internal carbon price into their business plans—an eight-fold increase from four years earlier.[94]

To reduce the carbon footprints of their internal

KEY RECOMMENDATIONS

- *Companies should adopt carbon-neutrality goals and use only sequestration-based emission offsets after 2050. They should employ internal practices such as carbon pricing to systematically incorporate climate-related costs into investment and operational decisions.*
- *Companies should invest now in the technologies and workforce needed to decarbonize the economy.*
- *Companies should thoroughly assess and voluntarily disclose to stakeholders and investors their climate-related risks and opportunities, as well as their strategies to lower emissions, invest in long-term needs, and boost resilience.*
- *Companies should actively engage policy-makers at all levels to voice support for the policies needed to decarbonize the economy, partner with their private-sector peers and collaborate across and between sectors to spread action throughout their industries, and help consumers understand their options for reducing their carbon footprints.*

operations, companies should take steps to improve energy efficiency wherever possible and to transition to renewables and other zero-carbon energy sources at their facilities and in their fleets. In 2018, companies signed deals to procure more than 6.5 gigawatts of renewable energy, shattering the previous annual record.[95] Companies are also making significant investments in on-site renewable generation. Beyond energy use, companies should employ "circularity" strategies to reduce emissions associated with resource extraction, industrial processing, waste handling, and more.

In addition, companies should work with their employees, suppliers, and major customers to promote carbon reduction throughout the value chain. For instance, companies can incorporate sustainability metrics into supplier scorecards and factor the embedded emissions of materials into their procurement processes.[96] Further, cross-sectoral and regional collaborations are essential to decarbonizing the value chain and can create opportunities for circularity. In addition to working back up the supply chain, companies should factor emissions into their product distribution choices as well (e.g., mode-switching from road to rail, improving freight fleet efficiency).[97]

Investing for the Long Term

A VISION: BUSINESS LEADERSHIP IN 2050

U.S. companies have reduced their net greenhouse gas emissions to near zero—across sectors and across value chains. Backed by a supportive policy environment, companies routinely integrate low-carbon frameworks into their strategic, financial, and operational decision-making. This reflects a broader shift within the business community toward generating stronger long-term value for shareholders, employees, consumers, and other stakeholders through sustainability and other efforts. In addition to reducing their own carbon footprints and strengthening their climate resilience, companies have shifted investment toward low-carbon technologies and business models and have worked with suppliers and consumers to facilitate decarbonization throughout the value chain. American companies are leaders in the global clean energy market, contributing strongly to U.S. growth and competitiveness.

With the greater certainty provided by robust climate policies, companies in climate-critical sectors should significantly ramp up investment in the technologies and workforce needed to decarbonize the economy.

Companies should work with investors to shift long-term investment from higher-carbon to lower-carbon resources, products, and business models. It is especially important that companies invest now in technologies that will make it easier to decarbonize over the long term. Companies, for instance, can advance low-carbon solutions by lowering internal investment hurdle rates or creating special pools of capital or corporate divisions.[98] Partnering with other companies in the value chain can strategically pool capital, resources, and expertise. In addition to the value chain, companies can partner with governments to commercialize low-carbon technologies.

Companies also should invest in efforts to transition the workforce—both to ensure that workers have the skillsets needed for a decarbonizing economy and to assist workers and communities disadvantaged by the transition away from high-carbon resources. The nature and geographic distribution of work in energy will change due to decarbonization of the energy system and to trends such as automation and digitization. The skills needed for some jobs will change, while new occupations will be created requiring new skillsets. Companies should assess their future needs and be leaders in moving the workforce to a low-carbon future. They can, for instance, institute training and retraining programs in collaboration with local and regional planning commissions, environmental justice groups, labor unions, secondary schools, universities, technical schools, and others.[99]

Boosting Resilience

Companies should undertake comprehensive strategies to assess their exposure and strengthen their resilience to extreme weather and other climate impacts that are already locked in. Small businesses can increase their insurance coverage, adopt disaster recovery plans, and add on-site energy resources. Large companies should assess the vulnerability of their assets in light of future climate conditions, adjust existing business planning and risk management processes, implement strategies to reduce risks, engage with stakeholders, form partnerships, and upgrade infrastructure and equipment.

Disclosing Climate-Related Risks and Opportunities

Companies should thoroughly assess and voluntarily disclose to stakeholders and investors their climate-related risks and opportunities, as well as their strategies to lower emissions, invest in long-term needs, and boost resilience. Indeed, as noted in the Mobilizing Finance chapter, companies are facing growing pressure from investors and others to disclose such information. Producing the information needed for disclosure can both increase the salience of climate action within companies and provide data to investors to help them make low-carbon investment decisions.

In advance of—or in the continued absence of—any mandatory U.S. climate risk disclosure requirements (again, see Mobilizing Finance above), all major companies should follow the recommendations of the Financial Stability Board's Task Force on Climate-related Financial Disclosures. These recommendations address both physical and transition risks, focusing on corporate governance, strategy, risk management, metrics, and targets. As of July 2019, more than 800 companies and other organizations had expressed support for the Task Force on Climate-related Financial Disclosures recommendations.[100]

Partnering with Others

Beyond their own business operations, companies should actively engage policy-makers, the public, their industry, and broader private-sector peers to facilitate decarbonization across the economy.

Individual corporate action, while important, is not sufficient to address the scale of the climate challenge. To drive action at the scale needed, companies must actively engage policy-makers at all levels to voice support for the policies needed to decarbonize the economy. Many business leaders recognize that well-designed climate policies are consistent with sound business planning and good corporate governance, provide more certainty for short- and long-term investments, and help them better anticipate regulatory risks and economic opportunities. Many favor comprehensive policies that level the competitive playing field by ensuring comparable levels of effort within and across sectors. Companies should work on their own and through their trade associations to constructively contribute to the assessment and enactment of effective climate policies.

Companies also should partner with their private-sector peers to spread action throughout their industries. Major companies in any given sector are often recognized for their leadership, but efforts are needed to raise the floor for action industry-wide. Decarbonization will move faster and more efficiently if more oars are rowing in the same direction. Trade associations can play a vital role in building broader action.

Companies should explore opportunities to reduce emissions across sectors as well. Companies should launch or actively seek out multi-sectoral decarbonization efforts that engage a broad and diverse group of stakeholders, such as regional efforts focused on the electrification of transportation, industry, and buildings.

In addition, companies should help consumers understand their options for reducing their carbon footprints. This includes, for instance, promoting lower-carbon products and advising consumers on practices that help save energy. Companies can use their powerful marketing and education tools to increase consumer awareness, promote behavior change, and prime the market for the shift to a low-carbon future.

VI. CONCLUSIONS

Climate change is perhaps the most profound challenge of our time. An effective global response is to some degree contingent on an effective U.S. response. While the United States has made important strides in reducing its global greenhouse gas emissions, far greater efforts are needed across society to decarbonize the U.S. economy and avoid the worst potential impacts of climate change.

Getting to Zero offers one vision for aligning the U.S. economy with the urgent need to address climate change. It builds on a very extensive body of research and analysis on decarbonization challenges and solutions, and is informed by close consultations with leading companies in key economic sectors. This is by no means a definitive blueprint, however. Rather, it is our best approximation at this stage of the efforts needed to achieve carbon neutrality. The most effective strategies for achieving that goal can only be fully ascertained over time, as we learn by doing and take account of new information and advances.

Ultimately, the prospects for, the shape of, and the success of a comprehensive U.S. decarbonization strategy rest heavily on political considerations. Analysis and dialogue can help point the way, but our destination can be reached only if we are able to summon the necessary political will. Through the Climate Innovation 2050 initiative, C2ES will continue working with companies and other stakeholders to refine, elaborate, and advance the agenda outlined here. We hope that the recommendations in *Getting to Zero* inform and stimulate this vital debate, and we look forward to working with partners in all spheres to mobilize a U.S. climate effort commensurate with this historic challenge.

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The Center for Climate and Energy Solutions (C2ES) is an independent, nonpartisan, nonprofit organization working to forge practical solutions to climate change. We advance strong policy and action to reduce greenhouse gas emissions, promote clean energy, and strengthen resilience to climate impacts.

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