Draft CI2050 Decarbonization Strategy
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I. INTRODUCTION

There is growing momentum in the United States toward a more robust response to climate change. Across the country, states, cities and companies 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. With a growing majority of Americans favoring stronger efforts, proposals in Washington for carbon pricing and for a Green New Deal are spurring a long overdue debate on comprehensive long-term solutions.

This report offers one vision for aligning the United States' world-leading 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 and are committed to working with policymakers, their customers and investors, and other stakeholders to develop and implement strategies to 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.

This strategy emerges from 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*, an earlier report based on a year-long collaboration with companies envisioning three alternative pathways to substantially decarbonizing the economy by 2050.

Our proposed strategy is grounded in the firm belief that unchecked climate change poses grave risks to America's well-being, and that an effective and durable response that reduces those risks can also help to grow and sustain our nation's prosperity. Toward those ends, this report:

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

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 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.

II. THE DECARBONIZATION CHALLENGE

Decarbonizing the U.S. and global economies represents perhaps the most ambitious and complex social 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 human-induced climate change. The result is a large and strong body of evidence and analysis documenting its causes and present-day effects and the very high probability of worsening physical, economic and social effects from unchecked 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 on 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 human-induced warming exceeds 1.5 degrees Celsius. The Fourth National Climate Assessment, published by the U.S. government in November 2018, exhaustively details the potential impacts of climate change on the United States, and projects hundreds of billions of dollars in potential economic losses (https://nca2018.globalchange.gov/).

Guided by this 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 include keeping the rise in global average temperature well below 2°C, and pursuing efforts to limit it to 1.5°C, above pre-industrial levels. In line with these temperature goals, the agreement calls for global greenhouse gas emissions to peak as soon as possible and for a balance between greenhouse gas emissions and removals (i.e., net zero emissions) in the second half of this century. The subsequent IPCC analysis underscores the imperative 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. Figure X [waterfall chart] illustrates how these shifts are reflected in the report's three scenarios. They include:

- Decarbonizing the power supply by transitioning to zero-carbon electric generation technologies;
- Increasing energy efficiency across the economy;
- Switching to electricity and other zero- and low-carbon fuels in transportation, buildings and industry;
- Increasing carbon sequestration by enhancing natural sinks, including forests and agricultural soils, and through the use of carbon capture and removal technologies; and
- Reducing emissions of non-CO_2 climate pollutants such as methane and HFCs.

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

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 and the role of new drilling technologies in enabling the substitution of natural gas for coal in electrical generation, the single largest source of the XX percent reduction in U.S. emissions achieved since XXXX. Fully decarbonizing the economy will similarly require innovation across all key sectors, at a pace and on a scale without precedent.

Driving this innovation is the responsibility of both the public and private sectors and requires a strong partnership between the two. Federal research and policies nurtured the drilling technologies that have led to the U.S. natural gas boom, better enabling private industry to bring them to scale. 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 technologies.

It is critical to understand, however, that while technological innovation can greatly facilitate decarbonization, it alone will not achieve it. Without adequate incentives, many carbon-saving technologies are not widely deployed – existing energy efficiency technologies are a prime example. It is also important to understand that rapidly emerging technologies such as artificial intelligence or autonomous vehicles may contribute to – or may deter – decarbonization depending on the market and policy environments in which they evolve. Ultimately, translating innovation into carbon neutrality is contingent on sufficient policy support and guidance.

All Must Do Their Part

The breadth and scale of the decarbonization challenge necessitate an all-in effort. We must look to government 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 innovation, 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. Because we failed to act early, we are now behind the curve, and we must act urgently to make up for lost time.

Urgent action is required not only because the risks of catastrophic climate change have grown greater but because the actions needed to reduce them will in many cases not produce instantaneous results. Even with massive infusions of R&D resources, new technologies can take decades to emerge and mature. Where the necessary technologies exist, building the infrastructure needed to deploy them at scale takes time. So, too, does finding the right mix of policy mandates and incentives.

However, achieving decarbonization without causing undue economic harm requires close attention to other temporal dimensions as well. Each sector presents its own challenges, whether it be the long-term investment cycles of the power and industrial sectors or the natural turnover rate 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 harm, among them the costly impacts of extreme weather 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.[1] As other countries undertake their own energy transitions, U.S. firms can leverage their innovative technologies and know-how into leading positions in the soaring global clean energy market.

III. 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 take into account and adequately address a combination of important climate and non-climate objectives. Its overarching objectives should be:

Carbon Neutrality – There is broad recognition within the scientific community, and among governments, that 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 Paris Agreement, which sets a goal of the latter half of the century, the United States should aim to achieve net zero emissions no later than 2050.

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 this issue, better enabling it to press other countries to contribute their fair share to the global effort.

Technology Inclusiveness – Analyses consistently demonstrate that achieving carbon neutrality will be most – and perhaps only – feasible if we succeed in mobilizing 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 available and emerging technologies, including renewable energy, nuclear power and carbon capture. It also should seek to ensure that emerging technologies such as artificial intelligence and autonomous vehicles develop in ways that contribute to 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, and it should rely wherever feasible on market-based approaches such as carbon pricing that provide incentives 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 benefit all Americans – and leave none worse off. It must 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 ensure they are treated equitably. And it must help workers and communities once or still dependent on high-carbon industries to ensure them a place in the zero-carbon economy.

Resilience – Fully addressing climate change requires both mitigation – actions to reduce greenhouse gas resilience – 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 maximize opportunities for actions – such as increasing energy efficiency and strengthening the nation's electric grid – both of which can deliver mitigation and adaptation benefits.

Adaptability – No strategy of such scale and duration can be fully formed from the outset. On multiple fronts – policy, technology, finance – success will hinge heavily on learning by doing. Unforeseen circumstances 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 goals and priorities.

Predictability – While remaining adaptable, a U.S. decarbonization strategy must also outline clear goals and pathways providing 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 to minimize regulatory confusion and overlap without compromising environmental integrity and benefits.

IV. CORE ELEMENTS

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 White House 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 Mandatory Goal

Congress should set in law the goal of making the United States carbon neutral no later than 2050 and should provide the executive branch the authorities necessary for its achievement. 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 low- and zero-carbon technologies and practices.

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

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pollution, so it is incorporated into economic decision-making. This price signal incentivizes carbon reduction

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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 should take into account:

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

Mobilizing Finance

Chapter Outline

By 2050

High-level vision of finance in 2050

- Investment in energy and other sectors has shifted to low-carbon pathways as climate-related risks and opportunities are fully incorporated into financial decision-making
- Low-carbon investments match or out-perform alternative investments and meet widespread investor demand for environmental performance
- Financial sector is resilient to systemic climate-related risk, contributing to macroeconomic and financial stability

By 2030

Estimates of the financial resources required to decarbonize the U.S. economy vary widely. Some say the total costs could be $10-12 trillion. Only some of these costs, especially in the early years, will be additional to what Americans would otherwise already be spending to procure energy, goods, and services. Over time, these incremental costs will be far outweighed by the savings of avoided climate impacts. While there may be additional investment needed, the far greater portion of the financial resources needed to decarbonize will reflect not additional costs but a *shift* in investment from higher- to lower-carbon technologies and strategies.

The policies recommended elsewhere in this report would create different types of incentives for this shift in long-term investment. This section recommends additional priorities over the coming decade to more broadly shift and mobilize investment toward decarbonization. These include policies to better internalize climate-related risks and opportunities in private-sector financial decision-making and to use public investment to leverage significantly higher levels of private capital for low-carbon projects in the United States and abroad.

Factoring Climate into Investment

- Mandatory disclosure
- Context
    - TCFD
    - Growing numbers of shareholder resolutions calling for climate-related disclosure
    - European companies soon facing mandatory climate risk disclosure
- Recommendation
        - Congress should enact legislation directing the Securities and Exchange Commission (SEC) to require public companies to disclose, in their filings with the SEC, their climate-related risks (and opportunities), how they would be affected by material physical and transition risks, and their strategies for managing those risks

- Managing broader impacts on the U.S. financial system
    - Context
        - 2019 formation of CFTC Climate-Related Market Risk Subcommittee to identify and examine the risks that climate change poses to the stability of the U.S. financial

system, how market participants can improve integration of climate-related stress-testing into financial and market risk assessments and reporting, and more
    - 2019 economic letter from the Federal Reserve Bank of San Francisco noting that climate risks "are relevant considerations for the Federal Reserve in fulfilling its mandate for macroeconomic and financial stability"
    - 2019 call for action from the Network for Greening the Financial System (NGFS) – which includes 36 central banks including UK, France, and China – noting that climate-related risks are a source of financial risk and recommending that central banks and supervisors integrate climate-related risks into financial stability monitoring and supervision

  - Recommendation
    - Congress should direct the Federal Reserve to conduct – or direct financial institutions to conduct – climate stress tests to assess institutions' solvency under a range of climate risk scenarios
    - The Federal Reserve should map climate risks (physical and transition) within the financial system, adopt risk indicators to monitor them, incorporate them into analyses and financial stability monitoring, and integrate them into its supervisory engagement with financial firms
    - Like the CFTC, the Financial Stability Oversight Council should form a subcommittee to identify risks and develop responses to threats to U.S. financial stability as a result of climate change

Leveraging Private Finance

- Context
    - Given the scale of investment needed for deep decarbonization, it is neither feasible nor politically desirable for all the finance to come from public dollars. Public dollars must be used to leverage much greater amounts of private capital.
    - Examples of state (and local) green banks already in place (e.g., Connecticut, New York, Montgomery County) and some leverage stats
    - Green bond / climate bond trends
    - Stats on private spending leveraged by some clean energy tax incentives
- Recommendation
    - Create a federal green bank and more state and local ones
    - The potential U.S. "green banks" on the international stage are the newly restored ExIm Bank and the new U.S. International Development Finance Corporation (DFC) – created largely from OPIC – which provide financial instruments that mitigate specific risks and thus increase the flow of private capital. DFC should follow OPIC's carefully developed environmental and social policy standards, and both DFC and ExIm should support a rapid, significant transition to low-carbon energy sources by focusing their energy-related efforts on spurring private financing for climate-relevant projects overseas.

- Tax incentives where needed to boost deployment (e.g., tech- or sector-specific ones mentioned elsewhere in the report), preferably with incentives being as tech-inclusive as possible for all low/zero-carbon solutions
- Preferential tax treatment for privately issued climate bonds

Driving Innovation

By 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.

By 2030

Top priorities over the coming decade are establishing and implementing a long-range low-carbon research and development agenda, significantly scaling up federal resources for low-carbon innovation, and optimizing 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 Quadrennial Technology Review**, in order to regularly assess gaps and opportunities and better target federal RDD&D support; and direct the White House to lead an interagency effort to **develop carbon-neutrality research and development strategies 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 the low-carbon innovation agenda** across the federal government. This office should lead the interagency effort to produce the Quadrennial Technology Review and to develop and implement sector-specific innovation strategies. It also should direct **targeted efforts across the government to accelerate technology transfer**, working through programs such as the Department of Energy's (DOE) Office of Technology Transitions to improve private-sector licensing and develop other commercialization partnerships.

Funding Low-Carbon Innovation

The rationale for federally funded research in socially critical areas is well established. Privately funded technology development often produces public benefits beyond those that a firm is able to monetize;[2] this "spillover" phenomenon 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.

Congress has significantly increased funding for low-carbon research and development in recent years. Funding for energy-related research at DOE has increased more than $1.3 billion from fiscal year 2016 (FY16) to FY19. However, these increases still do not put the U.S. on a path toward meeting its Mission Innovation commitment of doubling funding for low-carbon research from $6.4 billion in FY16 to $12.8 billion by FY21.[3] Even greater resources will be needed in the years beyond. By 2030, to ensure a robust federal innovation ecosystem, **Congress should provide at least $20 billion a year in funding for climate-related technology research and development**.

Where possible, this increased funding should be directed toward scaling up existing efforts and prioritize engagement with private sector partners. The **Advanced Research Projects Agency for Energy (ARPA-E) should be funded at $2 billion a year by 2030**. Other priorities include elevating DOE's Advanced Manufacturing Office (AMO), scaling up programs such as the Department of Agriculture's Agriculture Advanced Research and Development Authority, and bolstering interagency, public-private partnerships such as the Manufacturing USA institutes.

R&D funding priorities should be guided by the White House-led low-carbon innovation agenda, and should target areas like industrial processes and aviation fuels that are especially difficult to decarbonize; platform technologies like smart grid that can enable greater, system-wide efficiencies across one or more sectors; and technologies like carbon sequestration and long-duration energy storage that are critical to a variety of decarbonization pathways.[4]

Translating this research into commercially competitive technologies often requires support at the critical intermediary step of technology demonstration. Federal support is especially important in the demonstration of technologies requiring large-scale projects that carry high technical, policy and market risks. In fact, many of these projects can run in the billions of dollars, making federal cost-sharing critical.[5] Coupled with the management improvements described below, **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 financing on their own. For example, DOE's Loan Program Office (LPO), 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 technologies. While the LPO currently has roughly $40 billion in existing loan authority, it has not issued new loans since 2015. **The LPO should immediately begin issuing new solicitations for its existing authority**, which could leverage up to $100 billion in new energy infrastructure investments.[6] It should **support a growing pipeline of shovel-ready projects and backstop state and local green banks.**

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

Optimizing the Innovation Ecosystem

Additional funding for low-carbon research is only part of the solution. Indeed, without building the administrative capacity of state and federal agencies tasked with carrying out a low-carbon research agenda, and strengthening interagency coordination, these investments could produce far less innovation than needed while diverting resources away from other priorities.

The current U.S. research network – including the national laboratories, universities and non-profit and private sector efforts – is among the world's best.[7] A critical first step in improving the efficiency of the innovation system is **streamlining DOE's management of the national labs to provide them with greater autonomy** and ensuring that they have the capacity and processes in place to work efficiently within and across offices and research programs. [8] Additionally, administrative issues have slowed the disbursement of R&D funds already appropriated.[9] At 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**.

White House-level leadership should ensure the **stronger interagency coordination** also needed to optimize the innovation ecosystem. Intra-agency coordination must also be a priority. 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.[10][11]

The government's success in fostering a robust innovation ecosystem will depend on its ability to strengthen and simplify public-private collaboration. The **private sector and other non-government stakeholders should be closely consulted** by the White House in developing the low-carbon innovation agenda. **The national laboratories must prioritize technology transfer efforts**.[12] And the government should scale up **new institutional models fostering collaboration among industry, academia and public researchers**, such as DOE's Energy Innovation Hubs. [13] Other steps include prize competitions, technology investment agreements and increased flexibility in setting cost-share requirements.

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. [14] 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 through low-carbon technology incubators** providing access to grants and tax incentives and fostering connectivity between the research and business communities.

Ensuring a Just Transition

Chapter Outline

Cushioning the Impact

- Avoid disproportionate impacts on low-income families and small businesses

Protecting Frontline Communities

- Address the needs of minority and other communities disproportionately affected by climate change and the response to it

Helping Communities and workers in Transition

- Support economic diversification in areas disadvantaged by the transition from fossil fuels

Building the Low-Carbon Workforce

- Ensure a workforce with the skills needed in a decarbonizing economy

V. SECTORAL ELEMENTS

- Power
- Transportation
- Industry
- Buildings
- Land Use
- Oil and Gas

Power

By 2050

By mid-century, the U.S. power sector will produce nearly twice as much electricity as today to support economic growth and substantial electrification in other sectors. This growing demand will be tempered by wide-scale deployment of energy-efficiency strategies and technologies. As the generation portfolio evolves, electricity will be far less carbon-intensive, and a national high-voltage transmission system will connect renewable resources more with demand centers across the United States. Advanced weather models and digital controls will help balance supply and demand, while decentralized power generation and new energy storage options will 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 mandatory on all fossil fuel-fired generation plants. Small advanced nuclear reactors provide industrial heat, desalinated water, 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, and cross-sectoral purposes (e.g., transportation and industry fuel).

By 2030

Over the coming decade, the power sector is expected to be the lynchpin in the effort to decarbonize the economy. It must dramatically lower its carbon intensity while meeting significantly higher levels of demand. Economy-wide carbon pricing, as recommended earlier, can provide stable price signals for utility forecasting and planning and drive significant emission reductions in the sector, but a range of complementary policies will also be needed. Priorities over the next decade include accelerating the deployment of zero-carbon technologies, building low-carbon infrastructure, and modernizing wholesale power markets.

Accelerating Zero-Carbon Generation

Since 2005, electric power sector emissions have fallen 27 percent as a result of a shift from coal to natural gas, increased use of renewable energy, and a leveling of electricity demand. A range of factors, both market- and policy-related, contributed to this decline. However, the latest business-as-usual projections from the U.S. Energy Information Administration suggest that the share of total U.S. electricity generation obtained from zero-emitting sources is unlikely to increase by more than a few percentage points over the next 30 years.[15] At the same time, existing nuclear plants are projected to close (both prematurely due to economic pressures and because they are beginning to reach the end of their economic lifespans), hampering the overall growth of zero-emission electricity sources.

Stronger efforts are needed at both the state and federal level to accelerate the deployment of zero-carbon generation technologies. **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. States that now have renewable portfolio standards should convert them to broader clean energy standards. All states have unique generation mixes. All states do not have equal renewable resource potential. Expanding the definition of clean electricity, provides states more flexibility to produce greater quantities of clean electricity. States can immediately increase their clean electricity targets and achieve them sooner.

The federal government should reinforce states' efforts though an overarching national framework, ideally an economy-wide pricing system. **In the absence of economy-wide carbon pricing, Congress should establish a national clean energy standard that allows for trading among power generators**. States with equivalent or stricter state-level standards should be able to opt out of the federal program. In addition, Congress should **require the use of carbon capture technology for all fossil fuel-based power generation starting in 2035.**

To help utilities and states meet these ambitious standards, Congress should **provide a range of tax incentives for zero-carbon generation.** It should extend existing tax credits for renewable generation and provide new tax credits for investments in existing nuclear power plants and enact a dedicated investment tax credit for offshore wind. To help extend the lives of existing nuclear power plants, Congress should **ensure timely review of nuclear license renewals** allowing qualifying plants to operate for up to 80 years.

To ensure a wider range of technology options, Congress should **increase funding for the research, development and demonstration of new zero-carbon generation sources**, as recommended by the White House-led low-carbon innovation agenda. Priorities include advanced nuclear technologies; CCUS retrofits for a range of plant types (e.g. steam coal, natural gas combined cycle, and natural gas peakers); advanced renewables (e.g., solar, on-shore and offshore wind, geothermal, hydro, and tidal power), batteries, and other storage); and advanced fuels like hydrogen, ammonia and biofuels.

Creating the Infrastructure

At greater penetration levels of variable renewable energy, more transmission lines, distribution lines, substations, and energy storage will likely be necessary. In addition to better integrating renewable resources, an expanded and strengthened grid can help optimize the use of 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 FERC could override state authorities when necessary on siting decisions. Court challenges, however, have stymied FERC's use of these authorities.

Congress should direct FERC to develop a comprehensive, long-range national infrastructure strategy and should more clearly establish FERC's 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. While individual utilities are required to periodically produce long-range plans (i.e., integrated resource plans) that include transmission and other infrastructure upgrades, regional and national coordination is lacking. Currently, there is no systematic way to track progress, measure or ensure that a collection of plans will coalesce into the necessary power system backbone of the future. A strategy should include guidance, timetables, demand forecasts, recommended resources (i.e., what needs to be built and where it needs to be built), at the necessary level of granularity to manage progress and ensure the desired system is deployed before mid-century. It should assess the value of national or regional interconnection of existing networks, and prioritize development of complementary networks for distributing hydrogen, carbon dioxide, renewable natural gas, ammonia and other fuels for seasonal energy storage and cross-sectoral purposes (e.g. fuels for transport and industry). **Informed by FERC's national infrastructure strategy, Congress should prioritize the siting of "climate-critical" infrastructure**, including grid upgrades and other key resources such as storage batteries and energy pipelines.

Modernizing Wholesale Power Markets

The nation's wholesale power market will also need to be modernized to facilitate decarbonization while maintaining diverse, reliable and affordable power supplies. Under current market rules, prices are set largely on the basis of a generator's fuel costs. As growing quantities of renewable energy are deployed, wholesale power prices will continually decline, providing an insufficient revenue stream to sustain other sources needed for a well-balanced power supply. This dynamic is contributing already to the early retirement of nuclear power plants, which presently account for more than half of the nation's zero-carbon power, without the intermittency issues of solar and wind power.

FERC should undertake rulemaking to reform wholesale power markets to more explicitly value the carbon and reliability values of competing power sources. This should include new ways of compensating a fleet of mostly zero-emission generators in energy, capacity and ancillary markets, including new methods of market bidding (e.g., total costs versus production costs) as well as paying generators for essential system attributes (i.e., system reliability, low cost, non-polluting sources, flexible generation, and expanded ancillary services).

Transportation

By 2050

Rapid changes in technology and business models, coupled with the decarbonization imperative, will 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 other personal mobility and public transit 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, which also supplement electricity in other subsectors, including passenger vehicles.

By 2030

While the economy-wide carbon pricing recommended earlier 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.[16] Strong complementary policies are thus especially critical in the transportation sector. Key strategies for decarbonizing the sector include accelerating the deployment of net-zero-emission vehicles, building out the charging and fueling infrastructure these vehicles require, supporting a wider range personal mobility options, and decarbonizing other modes of transportation, including aviation, rail and shipping.

Deploying net-zero-emission vehicles (NZEVs)

The top priority in decarbonizing transportation is the conversion of the nation's automotive, truck and bus fleets, which produce the vast majority of the sector's carbon emissions, to zero-emission vehicles. Given the average lifetime of a vehicle, this turnover will take time, so strong, early signals are vital.

The U.S Mid-Century Strategy estimates that half of new passenger car sales need to be zero-emission vehicles by 2035.[17] **Congress should establish either a mandatory net-zero-emission vehicle (NZEV) program or a greenhouse gas vehicle standard** in line this goal. Under either approach, the policy should accommodate any *net-zero*-emission vehicle, including battery electric vehicles, fuel cell electric vehicles and any biofuel vehicle that can be demonstrated to be net-zero. It should establish increasingly stringent sales/production targets for light-, medium- and heavy-duty vehicles, and allow trading of credits within and among classes. Any **state-level NZEV or greenhouse gas vehicle programs should be harmonized with the federal standards**.

Although their lower fuel and maintenance costs make electric cars cheaper than conventional models over the life of a vehicle, their higher upfront costs have slowed consumer adoption. Existing federal tax credits of $7,500 help to offset that premium but phase out at 200,000 vehicles per manufacturer. **Congress should extend the current EV tax credit, make it available as a point-of-sale rebate, and expand it to include all new and used NZEVs** (including fuel cell EVs and eligible biofuel vehicles). **A substantially higher tax credit should be offered for medium- and heavy-duty NZEVs** to offset their higher initial costs. **States should similarly offer point-of-sale rebates and tax credits** for new and used light-, medium-, and heavy-duty NZEVs.

Public-sector transit and fleet operators don't benefit from tax credits because they are exempt from federal taxes, and are currently forbidden to use federal support to lease vehicles, an option that in the case of NZEVs would lower their costs by transferring risks such as battery degradation.[18] **Congress should**

increase funding to help states and cities expand NZEV transit and fleet procurement, including through leasing and programs like the Federal Transit Authority's Low or No Emission Vehicle Program and the Environmental Protection Agency'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 private investment, **states should set clear targets for the electrification of mass transit**. For example, California has established a requirement that by 2029, all new public transit buses will be electric. New York City has likewise established the goal of 100 percent-electric 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.[19]

The conversion of the fleet to low- and zero-emission vehicles must take place against the backdrop of other fundamental shifts such as the emergence of shared mobility services and autonomous vehicles. Analyses to date suggest that these changes could either increase or decrease vehicle miles traveled and, by extension, emissions.[20] 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.**

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 NZEV deployment.

States should develop comprehensive long-range plans to accelerate the deployment of NZEV charging and refueling infrastructure. These plans should identify priority needs, provide for coordinated state and local efforts, and ensure infrastructure access for multi-family housing and low-income communities. 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.[21] To support state and local efforts, **Congress should fund the development of state infrastructure plans and should provide funding to states with plans to establish NZEV charging and refueling infrastructure**.

State public utility commissions (PUCs) play a vital role in facilitating and maximizing the potential benefits of linkages between the transportation and power sectors. **PUCs should allow utilities to own and operate charging infrastructure**, as well as invest and partner with other companies building NZEV infrastructure. Given the potential of battery, fuel cell and plug-in hybrid electric vehicles to act as additional storage capacity for the power grid, PUCs also should **work with electric utilities, auto manufacturers and other stakeholders to develop safety and market access standards for vehicle-to-grid charging**. Vehicle-to-grid integration can improve the economics of all EVs, particularly medium- and heavy-duty vehicles with larger batteries that, in some cases, sit idle for long durations in centralized locations. PUCs also should **support vehicle-to-grid integration pilots for electrified mass transit**.

To promote compatibility across systems– rather than each vehicle manufacturer having its own proprietary infrastructure – **DOT should work with stakeholders to develop interoperability standards** for charging and refueling infrastructure.

Beyond facilitating the infrastructure needed for broad NZEV deployment, government should act at all levels to reduce the emissions impact of other transportation-related infrastructure. **The federal government should assess the carbon footprint of all major transportation infrastructure-related grants programs**, where possible. For example, a recent study found that the use of stiffer, better maintained pavements could save 1 billion gallons of fuel in California over a 5-year period.[22] Further, attention should be paid to the impact of transportation materials such as cool pavements, on the urban heat island effect.[23] While it can be difficult to assess embedded carbon in construction materials, efforts to incorporate this type of life-cycle analysis into these assessments will be critical to long-term decarbonization efforts.

Driving Alternative Mobility Solutions

Local conditions factor heavily in both mobility needs and the viability of particular technologies or policy solutions to assist in meeting those needs. **Local governments should develop integrated transportation and land use plans to expand non-automotive transportation options that strengthen mobility while reducing congestion, air pollution and carbon emissions.** More than 1300 cities across the country have adopted Complete Streets policies incorporating walkable, bike-able, transit-friendly principles.[24] 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 or 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 (DOT) smart cities program to Columbus, Ohio, has helped leverage $700 million in investment for EV infrastructure and procurement, and a variety of ridesharing, carpooling, and commuter services. The program has allowed for experimentation, built local capacity and expertise, and enabled the program to become self-sustaining. Seventy-eight cities applied for this competitive grant, suggesting a significant opportunity to scale the program. Congress should fund the smart cities program to meet demand, while requiring continued private sector and local cost share. Wherever possible, these funds should focus on outcomes, rather than prescriptive measures.

To provide additional support in growing demand for public transit, **Congress should pass legislation to allow individuals to create their own tax-advantaged public transit accounts.** These accounts should provide access to a variety of multi-modal public transportation options – such as individual, last-mile service – that reflect the evolving set of available offerings and consumer needs that vary widely by location.

Other Modal Recommendations

Measures are needed to decarbonize the other major modes of transportation (e.g., air, water, rail) and to facilitate inter-modal connections allowing greater efficiencies in the movement of freight.

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.

In the aviation and maritime sectors, electrification appears to offer limited potential, at least as of now, underscoring the importance of continuing to advance energy efficiency and developing new low- or zero-carbon fuels. To address aviation emissions, **Congress should establish an emissions-offsetting system for domestic air travel modeled on the International Civil Aviation Organization's Carbon Offsetting and Reduction Scheme for International Aviation.** DOT's Maritime Administration provided only $3 million in FY19 for a range of environmental and energy technology research, development and demonstration, through the Maritime Environmental and Technical Assistance (META) program. **META should be scaled significantly and expand its focus** to include electrification, efficiency and other technologies that could reduce maritime emissions.

Key Technologies

Technology	Status
Battery Electric Vehicles	-The number of electric light-duty models with greater driving ranges is increasing, and the availability of crossovers, Sport Utility Vehicles, and pickup trucks also appears poised to increase, which will be key to meeting a wider scope of consumer demand. -There are a limited number of medium-duty models of commercial vans and delivery trucks. -The first all-electric heavy-duty Class 8 tractors are expected to be available in late 2020 or in 2021. -Across all classes of on-road transport, there is a need for greater compatibility of charging standards. In addition, smart charging, time-of-use rates, and co-location of storage with chargers could help address demand peaks caused by EV charging. -All-electric short-haul aircraft are being developed, as are electric short-haul container ships, but wider electrification of aviation and maritime will require significant technological improvements (e.g., regarding energy density in batteries).
Biofuels	-Some fuels, like ethanol, are widely available, but more work needs to be done to develop second-generation biofuels for aviation, maritime, and other forms of transportation. -In a low oil price environment, research on biofuels has slowed.
Hydrogen Vehicles	-Only a few light-duty hydrogen fuel cell vehicle models are available. -Sales are limited due to inadequate refueling infrastructure and restrictions on the use of fuel cell electric vehicles in underground road tunnels in the East Coast. -The first commercial fuel cell electric Class 8 tractors are now in service at the Los Angeles and Long Beach ports.

Industry

By 2050

A modernized U.S. industrial sector continues to create jobs, growth and exports while substantially reducing its carbon footprint. The sector is much more energy-efficient, relies more heavily on electricity and other low-carbon sources for energy and process heat, and has taken advantage of digital advances to achieve system-level efficiencies and data analytics. Companies have adopted new manufacturing processes, discovered and advanced lower-carbon substitutes, and deployed carbon capture technologies for energy and process emissions. Captured carbon is converted into a wide range of new products. Industrial hubs have bolstered regional economic development, making greater use of waste heat and other byproducts 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 sequestration and direct air capture.

By 2030

Given its tremendous diversity, its heavy reliance on large quantities of thermal heat, and the fundamental nature of many core manufacturing process, the industrial sector is especially challenging to decarbonize. Economy-wide carbon pricing, as recommended earlier, can drive significant emission 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 and 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 rapidly advancing 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 (bulk chemicals, refining, iron and steel, food products, paper products, transportation equipment, fabricated metal products, plastics, cement and lime, and aluminum) account for two-thirds of the sector's energy-related carbon dioxide emissions. The largest source of this energy demand is heat for industrial processes. Metal, glass, and cement making, 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 the higher temperature range. Advanced nuclear designs, particularly molten salt reactors, offer a clean alternative for some high-temperature heating needs. Renewable heat sources including renewable natural gas (e.g., from agriculture, wastewater treatment and landfills), solar thermal, and geothermal also hold significant promise. Congress should **significantly increase funding to develop and commercialize alternative thermal heat technologies including renewables and advanced nuclear** producing combined heat and power**.**

In addition to emissions from energy use, industrial processes themselves produce significant levels of emissions in subsectors such as cement, steel and bulk chemicals. Congress should **increase funding to research and develop innovative industrial processes with smaller carbon footprints**. 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 Cross-Sectoral Element: Carbon Capture).

Setting Performance Standards

To orient companies toward decarbonization, the federal government should **undertake a benchmarking process to establish greenhouse gas performance standards for the major sub-industries**. The benchmarking process will highlight best practices and promote industry-wide learning; the intensity-based standards will provide ongoing incentive and flexibility for companies to pursue their most affordable decarbonization options. These intensity-based standards should be used to establish a company's or facility's obligations within the economy-wide carbon pricing system; in the absence of economy-wide pricing, performance standards should be enforced and be tradable within and across sub-industries.

Providing Incentives

To drive the deployment of emerging technologies and help companies meet performance standards, government should **provide targeted incentives for efficiency, fuel switching and carbon capture,** including:

- Federal, state, and local governments should support the deployment of **conventional combined heat and power** systems.
- Congress should extend and increase the existing 45Q tax credit for **CCUS technologies** to support the capture of process and on-site energy-related emissions, and should provide tax credits for **energy efficiency** improvements.
- To promote electrification and reduce dependence on fossil fuels, federal and state incentives 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 the private sector better understand the opportunities for clean energy and systems efficiency. In addition to elevating the Advanced Manufacturing Office within DOE, Congress should **expand funding for manufacturing initiatives,** which should champion a circular economy approach (i.e., recycling) and seek decarbonization opportunities in advanced manufacturing, digitization and automation.

Federal, state, and local agencies procure significant quantities of materials for infrastructure projects, operations and other purposes. 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, as well as various stages of production.

Safeguarding Industrial Competitiveness

For subsectors that are energy-intensive and trade-exposed – i.e., 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 "carbon leakage." To date, all existing carbon pricing programs globally include specific provisions aimed at minimizing competitiveness and carbon leakage risks. An economy-wide carbon pricing program should include such provisions (e.g., free allocation of allowances in a cap-and-trade system, offering tax credits, rebates, border adjustments or other exemptions), which should be reexamined every four years during the periodic review.

Buildings

By 2050

Residential and commercial buildings will have sophisticated, automated control systems that dynamically adapt to meet occupants' needs while maximizing energy efficiency.[25] Buildings are more closely integrated with the electrical grid, relying on decarbonized electricity in place of fossil fuels, and in many cases serving themselves as sources of self-generation with rooftop solar and storage.[26] Natural gas use in residential buildings is minimal and in commercial buildings serves primarily in combined heat and power (CHP) systems.[27] Better real-time and lifetime data on building performance, energy use and energy costs enable improved decision making for long-term financial investment, construction, renovation, and operation of buildings.[28]

By 2030

Over the coming decade, the federal, state and local governments should work in concert to set overarching goals for decarbonizing the building sector, implement targeted measures to electrify buildings and improve the energy efficiency of buildings and appliances, and help building owners and occupants finance building upgrades.

Setting Building Decarbonization Goals

State and city governments should set decarbonization goals for all new and existing residential and commercial buildings. These goals could take a variety of forms depending on a jurisdiction's particular needs and priorities. California provides a number of examples: Former Governor Jerry Brown set a goal of doubling the efficiency of existing buildings; as part of the Pacific Coast Collaborative, the state has a goal of lowering the carbon intensity of heating fuels in buildings; and in adopting the World Green Building Council's Net Zero Carbon Buildings Commitment, the state committed to making all new buildings net zero carbon by 2030 and all buildings by 2050.[29]

To ensure progress toward their goals, **state and local governments should continually update their building codes to require the use of all available and affordable carbon-reducing practices and technologies** in new construction and major renovations. As governments are setting these goals, they can inform their constituents about the benefits of carbon reduction.

All levels of government should also set goals and institute practices to decarbonize their own building stock. The federal government owns and leases 361,000 buildings, which presents a significant opportunity to achieve carbon reductions across the country.[30]

Moving to Electricity

Much of the decarbonization of the buildings sector must be achieved by switching from fossil fuels to electricity, for instance by installing electric heat pumps. **States and local governments should adopt standards and provide incentives to switch to electric appliances.** For example, Maine has a target to install 100,000 heat pumps by 2025 and is issuing rebates for residential and commercial customers. Some jurisdictions are weighing the option of ending new natural gas hookups.

Along with increased electrification, buildings will become more closely integrated both the power and transportation sectors. **DOE should allocate funding to its Buildings-to-Grid Integration and Grid-Interactive Efficient Buildings research programs to research and develop how buildings will**

integrate and interact with a suite of technologies for electricity grid needs.[31] Scaling up research to evaluate how interactive appliances will work with the grid can alleviate future grid stress to avert blackouts and to increase connectivity without disrupting comfort or productivity.

Electrifying buildings is cost-effective for new and existing buildings using oil and propane (which represent more than 20 percent of residential fossil fuel carbon emissions), but is more costly for existing natural gas customers.[32] **An electrification tax credit should be given for natural gas users to switch to electric appliances, including electric heat pumps, electric water heaters, and renewable thermal systems.**

As buildings electrify and rooftop solar expands as a means of electricity generation, **all states should have a net metering program that enables residential and commercial customers to sell power to the grid and requires them to contribute appropriately to meeting the fixed costs of the electricity grid.**

Increasing Energy Efficiency

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

To maximize efficiency in buildings, **all state and local governments should adopt and enforce building codes requiring the latest proven and affordable energy-saving practices and technologies**. They should draw on model building codes developed by the federal government, which should continue to require that underlying model codes developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the International Codes Council (ICC) provide for steady advances in energy efficiency. In developing model codes, DOE should seek to maximize the potential 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.**[33]

To ensure equitable access to efficiency opportunities, Congress should **increase funding to improve building efficiency in low-income communities.** DOE's Weatherization Assistance Program (WAP) 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.[34,35] Congress should increase funding for WAP and, for homes that are not in adequate condition to be weatherized, create a new program to help restore them to be weatherization-ready.

To reduce energy use in buildings by improving the efficiency of heating, cooling and other appliances, **DOE should continue to strengthen energy efficiency standards for residential and commercial appliances** under the Energy Policy and Conservation Act (EPCA). EPCA is a federal law governing procedures, labeling, and energy targets for appliances and equipment representing 90 percent of home energy use and 60 percent of commercial building use.[36] Standards implemented under EPCA since 1987 have avoided 2.3 billion tons of carbon dioxide emissions.[37,38]

Financing Building Upgrades

In some states, Property Assessed Clean Energy (PACE) programs help residential and commercial property owners cover the upfront costs of energy or other property improvements by enabling them to repay those costs over time through an assessment tied to the property instead of the owner.[39] More than $500 million in commercial PACE programs have been deployed, while more than $4 billion in energy efficiency improvements have been made through residential PACE programs. **PACE programs should be deployed at the residential and commercial level in every state.** Commercial PACE should also be expanded to property owners of new construction projects and major redevelopments, as some states such as Connecticut have already done.[40]

Energy service performance contracts are used by federal and state agencies to partner with an energy service company to make improvements to a facility that increase operational efficiency. [41] They are a budget-neutral approach since energy savings from the project are guaranteed to pay for the improvements.[42] **States and localities should remove regulatory barriers that limit energy saving performance contract terms.** Removing these barriers would allow a significant number of public facilities such as municipal buildings, universities, colleges, schools, hospitals, and governments to be eligible for efficiency upgrades.

State and local governments should offer tax abatements to owners of existing buildings who invest in qualifying improvements. A qualifying building would be charged lower property taxes for a certain number of years, based on the level of the improvements. The state's role would be to authorize and facilitate the program, determine the metrics for minimum performance (such as energy or greenhouse gas intensity), and share costs with the local government.[43] local governments would implement the program and receive tax reimbursement from the state fund. This approach addresses the challenge of split incentives, where energy efficiency improvements often benefit building tenants instead of building owners. While typically a tenant reaps the advantages by paying lower energy bills, in this case the building owner also benefits from tax relief. [44]

Land Use

By 2050

Farms, forests and wetlands have become even larger carbon sinks, absorbing about half of the United States' residual emissions. Standardized, low-cost technology allows accurate measurement of carbon storage, and farmers and forest 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 needs of a growing U.S. and global population, while simultaneously reducing agriculture's reliance on fossil fuel-intensive pesticides, fertilizers, and energy. Well-informed consumers choose from a wide array of alternative low-carbon foods, and food waste has been minimized throughout the food system.

By 2030

Quick emissions profile: % of overall; breakdown; projections

Priorities over the coming decade to decarbonize the land use sector include steps to strengthen incentives and capacity for carbon sequestration on farms and forests; reduce on-farm emissions from fertilizers and livestock; bring lower-carbon food products to market; and reduce 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 like industry that are especially challenging to decarbonize. Economy-wide carbon pricing can steer significant resources toward enhanced farm and forest sequestration if the pricing program allows for the trading of these emission offsets. Whether in advance of or in parallel with carbon pricing, other measures are needed to conserve and expand lands with sequestration potential and to actively promote sequestration on both farms and forests.

Growth in population and agricultural demand 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 were developed in the United States, 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 acres of development and a 50 percent to 70 percent increase in demand for agricultural products.[45]

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 continue to provide cost-share and tax incentives to private forest owners to avoid conversion. Local, county and state governments should partner with non-profits to conserve forested lands through public ownership or conservation easements. Urban and suburban communities should expand forests through urban tree planting programs. Afforestation (addition of forests) could yield up to 225 Tg of forest carbon uptake per year if widely implemented.[46]

Additional sinks like wetlands should also be valued and enhanced. Congress should increase support for NOAA's research[47] 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.[48]

Stronger efforts are needed to improve the health of existing forests, both to enhance their sequestration potential and to avoid carbon emissions resulting from wildfires. Forests are increasingly threatened by extreme climate conditions like heat and drought that make sequestration less predictable and expose them to greater risk of wildfire, wind damage and infestation.[49] In 2018, Congress adopted legislation to strengthen funding for wildfire suppression through 2027. **Congress should further strengthen funding for the U.S. Forest Service's forest restoration and wildfire resilience efforts, and to provide technical and financial support for private forest owners in areas at risk.**

On agricultural lands, practices that enhance carbon storage, like the use of cover or perennial plants, can also reduce erosion, retain water and enhance nutrient cycling, improving yield and crop resilience. Despite long-term benefits, upfront costs and other challenges often deter farmers from adopting these practices. 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 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** like lower federal farm loan interest rates and lower federal crop insurance premiums. Additionally, Congress should **increase funding for agricultural extension services and the National Resources Conservation Service** (NRCS) to educate farmers about carbon sequestration practices, their co-benefits, available incentive programs, and about ways to cope with climate impacts. **States can coordinate and support soil carbon storage and health improvements as Nebraska has modeled with its Healthy Soils Task Force.** These state and federal programs should include support for renters and small family farms.

More reliable and affordable means of measuring, monitoring and verifying carbon storage are essential to scaling up of carbon sequestration across working lands. **The USDA should expand research and development in 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 GPS, soil sampling and remote sensing that can contribute to soil carbon monitoring. Federal cost-sharing, support for agricultural equipment cooperatives and subsidies of precision agriculture equipment that contributes to improved soil carbon storage should be provided to increase application of that technology.

Reducing Farm Emissions

Much of the agricultural sector's greenhouse gas emissions result from soil management, especially the use of synthetic fertilizers emitting nitrous oxide.[50] 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 how to apply the right kind of fertilizers at the right time and in the right amount to avoid emissions**. Precision agriculture can further reduce these emissions by allowing farmers to finetune nitrogen fertilizer application. **USDA 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 NRCS'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 (enteric fermentation and manure management represented nearly half of the sector's emissions in 2017).[51] Congress should support **stronger research, incentives and public-private partnerships to improve manure management, develop feed additives that can reduce enteric emissions from animals, and increase animal productivity through genetic selection**, yielding higher output per feed input. This should include incentives through the Environmental Quality Incentives Program (EQIP) and Rural Energy for America Program (REAP) 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 (food lost in the supply chain) and waste (throwing out edible food products). The USDA Economic Research Service estimated that 31 percent of the food supply was lost in 2010.[52] 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 use food residues to create other products**, helping the United States reach its goal of reducing food waste and loss by 50 percent by 2030.[53] To reduce methane emissions from landfills, **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, many of these products use less water, inputs and land. 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 alternative food companies and a better understanding of impacts on the farm industry, landscapes and health**.

In addition, Congress should increase funding for **USDA to continue research, development, and field testing of food, fiber and biomass crops that require fewer inputs and can better sequester carbon.** Research of perennial grains especially provides opportunity to meet these multiple objectives while storing carbon in deeper soil and roots.

Oil and Gas

By 2050

The oil and gas industry will have undergone a fundamental transformation as the economy decarbonizes. While the conversion of transportation fleets to net zero emission vehicles has dramatically reduced demand for oil, the oil and gas sector has capitalized on advances in bioenergy with carbon capture to offer a new generation of bio-based liquid fuels. Meantime, natural gas coupled with carbon capture helps meet the rising demand for zero-carbon power from the transportation, buildings and industry sectors, which have largely turned to electricity to reduce their own emissions. Advanced control technologies have nearly eliminated operational emissions from flaring and from methane leakage throughout the natural gas value chain. Beyond the extensive use of carbon capture technologies to sequester emissions from bio-refining and natural gas combustion, the sector relies heavily on direct air capture and land-based sequestration for "negative emissions" offsetting its remaining carbon emissions.

By 2030

Emissions associated with the end-use or combustion of oil and natural gas currently account for more than half of U.S. greenhouse emissions. Many of the policies recommended elsewhere throughout this strategy will dramatically reduce these emissions by transitioning other sectors away from fossil fuels and by facilitating or mandating the capture of emissions from remaining fossil fuel use. Economy-wide carbon pricing will provide an incentive to all sectors to improve energy efficiency and switch to lower-carbon fuels. Federal standards driving the conversion of the automotive fleet to net zero emissions vehicles will dramatically reduce oil demand. Policies aimed at decarbonizing the buildings sector will reduce demand there for natural gas. 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 wide range of other incentives will drive the development and deployment of technologies and practices such as carbon capture and utilization, land-based sequestration, direct air capture and zero-carbon biofuels.

As a longtime technological innovator with deep expertise in related fields and technologies, the oil and gas industry is well positioned to partner with government and other sectors to develop and shift investment toward low-carbon energy production, distribution and storage solutions.

This chapter recommends additional policies to reduce the oil and gas sector's operational emissions and to reduce incentives for high-carbon investment. Top priorities over the coming decade include federal and state measures to reduce emissions from flaring and methane leakage, phasing down inefficient fossil fuel subsidies as part of a comprehensive review of energy subsidies, and closely analyzing the long-term greenhouse gas impact of any new oil and gas infrastructure.

Limiting Operational Emissions

The United States is the world's largest producer of oil and gas, and rising global demand is expected to continue to drive investments in the U.S. oil and gas sector. As such, resources that continue to be developed and produced in the United States must have a minimal emissions footprint.

The industry can significantly reduce its operational footprint by addressing fugitive methane emissions, which accounts for 80 percent of the sector's direct emissions. "Fugitive emissions" typically occur from equipment leaks, process venting, evaporation losses, disposal of waste gas streams, and accidents and equipment failures.[54] Methane is a greenhouse gas that is 28-36 times more potent than CO2 (over a 100 year time frame) and has a much shorter atmospheric lifetime. Therefore, reducing methane emissions provides significant near-term climate benefits.[55]

EPA has existing authority to regulate methane through the Clean Air Act (CAA). EPA previously enacted New Source Performance Standards (NSPS) regulating methane emissions from new oil and gas wells; however, those standards have been weakened and need to be updated.[56] **EPA should enact stringent standards on new sources of oil and natural gas sector methane emissions that align with best practice.** For example, the Oil and Gas Climate Initiative, a group of 13 of the world's largest oil and gas companies, has set a voluntary goal to reduce the average methane intensity of aggregated upstream oil and gas operations to below 0.25 percent by 2025.[57] EPA's standard should be designed to achieve this level of performance industry-wide. The CAA requires that NSPS regulations eventually be extended to preexisting sources of emissions. When the standards for new sources are finalized, **EPA should enact comparable existing source regulations for oil and gas facilities that have already been built** so that all oil and gas facilities are covered by methane emissions regulations.

State policymakers also have significant authority to regulate emissions from the oil and gas industry. **In the absence of stronger federal regulation, state regulators should enact their own stringent standards on methane emissions from the oil and gas sector.**

One way that operators limit the direct release of methane emissions while drilling and completing a well is through flaring, which converts methane into CO2, a less potent greenhouse gas, rather than directly venting the methane into the atmosphere. Flares are typically used for a short period, typically 10 to 15 days, 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 massive growth in oil and gas production. In turn, flaring of natural gas has increased enormously across the country, resulting in wasted natural resources and increased emissions.

The Bureau of Land Management, which regulates oil and gas production on federal lands, adopted the Methane and Waste Prevention Rule in 2016 requiring producers to capture 98 percent of all associated gas by 2026.[58] However, those provisions have been rescinded.[59] **BLM should reinstate the Methane and Waste Prevention Rule.** On private lands, state regulators have significant responsibility for regulating air quality as it relates to oil and gas production, including flaring.[60] **States should implement stringent rules on long-term flaring practices, such as setting capture targets or flaring limits or requiring gas capture plans prior to drilling.** State regulators should take care to define "unavoidable" venting and flaring to reduce uncertainty on how rules are enforced. **State regulators should also subject flared gas that exceeds flaring limits to royalty payments.**

Reforming Federal Practices

Apart from the regulation of emissions, a wide range of federal policies shape investment and information flows that bear on the carbon intensity of the nation's energy supply. Many of these policies need to be updated to better align with a midcentury carbon neutrality goal.

A wide range of federal tax provisions directly or indirectly subsidize oil and gas production. As recommended above, the long-term decarbonization framework enacted by Congress should mandate a comprehensive review of federal energy subsidies to ensure 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 toward lower-carbon energy sources, including fossil fuels with carbon capture.**

Under the National Environmental Policy Act, federal agencies must analyze the potential environmental impacts of all major federal actions to ensure they are considered by decisionmakers. In line with the recommendation above for updated NEPA guidance, **federal agencies should assess the lifetime 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 to expand federal oil and natural gas leasing requiring federal approval**.

VI. CROSS-SECTORAL-ELEMENTS

- Carbon Capture, Utilization and Storage
- Digitalization
- Bioenergy
- Hydrogen

Carbon Capture

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

Carbon capture, utilization, and storage (CCUS) represents a well-proven set of technologies and applications that remove CO_2 from power generation and industrial processes and either store it underground or incorporate it into new products. Nineteen full-scale carbon capture projects are in operation around the world (11 in the United States), capturing nearly 40 million metric tons of CO_2 each year. Meanwhile, beneficial utilization of CO_2 in the production of building materials, fuels, and algae-based products is an area of growing opportunity. Direct air capture of CO_2 is potentially a critical pathway for "negative emissions," helping to offset remaining emissions to achieve carbon neutrality.

The UN Intergovernmental Panel on Climate Change (IPCC) has found achieving the Paris Agreement's target of keeping warming below 2 degrees C will be twice as costly *without* CCUS. In the realm of power generation, it is expected that some level of fossil-fuel generation—likely from natural gas—will remain online through at least 2050, necessitating a strategy for capturing the associated emissions. Moreover, CCUS may be particularly important in the manufacture of steel, cement, glass, and chemicals as these processes often require extremely high temperatures and "renewable" alternatives may not be readily available.

CCUS will provide the greatest greenhouse gas benefit if deployed sooner, therefore emphasis should be placed on the adoption of policies aimed at achieving the widest deployment of CCUS by the 2030 timeframe. In the absence of specifically mandated emissions levels or an economy-wide carbon price, near-term deployment of CCUS in the United States will be dependent upon creating market conditions through supportive policies. Top priorities over the coming decade include expanding R&D, strengthening incentives for CCUS deployment, and establishing a robust CO_2 transportation infrastructure.

Capture R&D

The principal aim of the Department of Energy's Fossil R&D carbon capture program is to reduce the cost of capture per metric ton of CO_2. Current program goals would cut the average conventional capture cost to $40/ton by 2020-2025 and to $30/ton by 2030. An associated goal is scaling up novel technologies to the level where they can be commercially deployed in a variety of applications, including industrial processes and power generation as discussed above.

Congress should reauthorize and increase funding for this program, and establish performance-based objectives that direct research toward technologies with the greatest greenhouse gas reduction potential. It also should authorize more and bigger pilot and demonstration projects, and consider greater cost sharing with the private sector to encourage early deployment. International collaboration efforts, such as the current joint testing program with Norway, are valuable and should continue to be pursued.

Finally, a "moonshot"-style R&D program should aim to cut the cost of direct air capture from the current estimated $400 per metric ton to less than $100 per ton. According to one study, this would require a 10- to 20-fold increase in federal DAC R&D from the current $10-12 million annual funding level.

Enabling Financial Incentives

The February 2018 passage of an improved tax credit for carbon oxide 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 U.S. Internal Revenue Service (IRS) is expected to publish taxpayer guidance by early 2020, at which time developers under the law will have less than four years remaining to begin construction, and less than 10 years to claim the credit.

Congress should extend the begin construction deadline and the time period during which the 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. Moreover, it should make other financial tools available to developers, including the use of private activity bonds (PABs) and Master Limited Partnerships (MLPs). These have very little cost to the Treasury but would give developers access to useful financing tools already available to other types of publicly beneficial projects. Finally, to support the "development" phases of R&D, programs such as the federal loan guarantee program should be targeted at enabling deployment of commercial scale capture projects.

CO_2 Transportation Infrastructure

Moving captured CO_2 from its source to where it can be used or permanently stored is another major cost component, and a critical step to creating a market for CO_2. The United States currently has more than 4,000 miles of dedicated pipelines that safely transport CO_2. By contrast, the nation has more than 300,000 miles of interstate and intrastate natural gas transmission pipelines, along with millions of miles of distribution pipelines.

It is estimated that a pipeline network of 25,000 miles is needed to connect the largest sources of CO_2 with both enhance oil recovery (EOR) storage 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 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 networked devices, sensors, data, and analytics—has enabled a system-based approach to efficiency that can significantly reduce energy use and carbon emissions across the economy.[61] 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 consumer energy use.
- **Transportation:** The digitalization of transportation through sensors and connected vehicles can improve efficiency and reduce maintenance costs through improved fleet management and route optimization. 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 plants while reducing emissions.
- **Buildings:** The digitalization of buildings through management systems, smart heating and cooling systems, smart lighting, and connected appliances and equipment, can reduce energy use through greater efficiency and shifting energy use to reduce emissions.
- **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 inputs.

Digital energy can 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 system-based efficiency through digital technologies. A systems-based approach that interconnects the built environment, with electrified transportation and 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 digital energy is quantifying its system-based performance so companies, state utility commissions, and other stakeholders can better understand the financial benefits and associated emission reductions. Congress should direct DOE to provide financial and technical assistance to develop real-time measurement and verification protocols for system-level efficiencies in buildings, industry and transportation. As connected devices and management systems proliferate, DOE and NIST should work with relevant stakeholders to develop interoperability standards and communication protocols between devices and systems.

Government procurement

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

Expand and Upgrade 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 nationwide, 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 intelligent efficiency technology.[62]

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. Theoretically, the CO_2 released by the burning of biofuels can be balanced out by the CO_2 absorbed from the atmosphere by the biomass used to produce them, resulting in net zero emissions. Pairing bioenergy with carbon capture and storage (BECCS) – for instance, running a power plant on biofuels and capturing the resulting emissions – can contribute further to decarbonization by producing "negative emissions" offsetting emissions from other activities.

Current and potential forms of bioenergy include:

- **Transportation –** Biomass can be converted into liquid fuels for transportation, including possibly aviation fuels. Today biofuels are primarily corn ethanol and biodiesel with select application and research of cellulosic ethanol and other fuel applications.
- **Power** – Biomass fuels can be converted into heat and electricity through burning, bacterial decay and conversion to gas or a liquid fuel. Bioenergy can offset fossil fuels burned in power plants more flexibly and reliably than some other renewable energies.
- **Industry –** Bioenergy is 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 be used in the manufacturing of plastics, chemicals and other products traditionally derived from petroleum or natural gas.

Biofuels currently supply about 5 percent of U.S. energy use, 47 percent from biofuels (mainly ethanol), 44 percent from wood and wood-derived biomass, and about 10 percent from biomass in municipal waste.[63] Biomass production can be resource-intensive, with potential tradeoffs including the conversion of open space to croplands, higher N_2O emissions from increased fertilizer use, increased water pollution, and higher 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 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 the emissions reductions or negative emissions opportunities of BECCS technology and encourage commercial development. DOE should lead continued research on additional biomass materials and growing methods, like 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 conversion of thinned vegetation from wildfire resilience efforts to biomass to demonstrate economic benefits for private and public forest owners.

Improving Measurement and Analysis

Additional research is also needed to better assess the emissions benefits and other potential impacts of bioenergy. Current life-cycle estimates of emissions benefits vary widely; recent studies on currently available ethanol technology estimate greenhouse reductions of 27 to 43 percent compared to gasoline.[64]

Federal agencies should work collaboratively to develop consistent methodologies to calculate supply chain and land use change emissions and fossil fuel displacement benefits, in order to more accurately assess the net emissions benefits of biofuels. This could include improving existing tools like DOE's GREET model to inform decisions about agricultural production and the design of products that might use bioenergy. Efforts are needed to better understand the land use change implications of different biomass options and to identify lands that are the best suited to growing biomass instead of food crops, thereby limiting food crop displacement.

Establishing Standards and Incentives

Improved analysis should be used to determine which biofuels qualify under the program recommended in the Transportation chapter to accelerate the deployment of net zero emission vehicles. Farmers and foresters will change growing methods and crops to meet the growing demand for net-zero biofuels.

As additional bioenergy options are developed and their emissions and other impacts are better understood, incentive programs administered by states and by the USDA are needed to scale up use of the most efficient or net zero emission biofuels to replace carbon-intensive fuels and products. Targeted incentives are needed to promote the use of bioenergy/BECCS systems in the power and industrial sectors.

The USDA should support farmers that grow experimental biofuel crops. This support should include by federal crop insurance for additional biomass crops and payments to farmers hosting biomass growth pilots. States and the USDA should develop conservation incentives that accompany federal biomass grower support through specialized programs to support agricultural conservation and soil health growing methods in biomass production.

VII. BUSINESS LEADERSHIP

By 2050

By mid-century, U.S. companies will have reduced their net greenhouse gas emissions to near zero — across sectors and across value chains. Backed by a supportive policy environment, companies will routinely integrate low-carbon frameworks into their strategic, financial and operational decision making. This will reflect 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 will shift investment toward low-carbon technologies and business models, and will work with suppliers and consumers to facilitate decarbonization throughout the value chain. American companies will be leaders in the global clean energy market, contributing strongly to U.S. growth and competitiveness.

By 2030

Over the coming decade, companies 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. Key elements of this strategy should include managing emissions, investing for long-term decarbonization, disclosing climate-related risks, strengthening resilience to climate impacts, and partnering with policymakers, the public, and private-sector peers.

Managing Emissions

All major companies should institute comprehensive strategies to achieve carbon neutrality.

As a cornerstone of these strategies, companies should **adopt carbon-neutrality goals and report regularly on progress toward them**. These goals should provide for achieving a net balance of greenhouse gas emissions and withdrawals, phasing down all but sequestration-based emission offsets by 2050. 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.[65] Some companies have adopted science-based targets in line with keeping warming below 2 degrees C, committed to 100 percent renewable energy, or set goals encompassing emissions from their products as well.

Companies also should **employ internal practices such as carbon pricing** to systematically incorporate climate-related costs into 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 an actual internal fee charged to business units (the revenues from which can fund corporate emission reduction efforts).[66] 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.[67]

To **reduce the carbon footprints of their internal operations**, companies should take steps to improve energy efficiency wherever possible, and to transition to renewables and other zero-carbon power 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.[68] Others are 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.

Companies also 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, or factor the embedded emissions of materials into their procurement processes.[69] In addition to working back up the supply chain, companies should factor emissions into their product distribution choices (e.g., mode-switching from road to rail, improving freight fleet efficiency).[70]

Investing for the Long Term

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 lower internal investment hurdle rates or create special pools of capital or corporate divisions to advance low-carbon solutions.[71] 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 workers with the skillsets needed for a decarbonizing economy and to assist workers and communities disadvantaged by the transition from high-carbon resources. The nature and geographic distribution of work in energy will change both as the energy system decarbonizes and due 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.[72]

Boosting Resilience

Companies should undertake comprehensive strategies to assess their exposure and strengthen their resilience to extreme weather and other climate impacts.

In addition to reducing emissions, companies should **plan for the 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

To help investors better integrate climate-related considerations into their investment decisions, companies should **thoroughly assess and voluntarily disclose their climate-related risks and opportunities**.

Companies should disclose to stakeholders and investors their strategies to manage emissions, invest in long-term needs, and boost resilience. 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. Indeed, companies are facing growing pressure from shareholders, activists, consumers, and others to disclose information on climate-related risks, opportunities, and strategies. In 2018 alone, dozens of climate-related shareholder resolutions were filed with companies in a range of sectors.[73] Companies operating in the European Union will soon face mandatory climate risk disclosure under new sustainable finance regulations put forth in 2018.[74]

In advance of any mandatory U.S. disclosure requirements (see Chapter X), all major companies should follow the recommendations of the Financial Stability Board's Task Force on Climate-related Financial Disclosures (TCFD). The TCFD recommendations address both physical and transition risks, focusing on corporate governance, strategy, risk management, and metrics and targets. As of July 2019, more than 800 companies and other organizations had expressed support for the TCFD recommendations[75].

Partnering with Others

Beyond their own business operations, companies should actively engage policymakers, the public, and their 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 policymakers at all levels to voice support for the policies needed to progressively 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 playing field among companies 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 also 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.

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