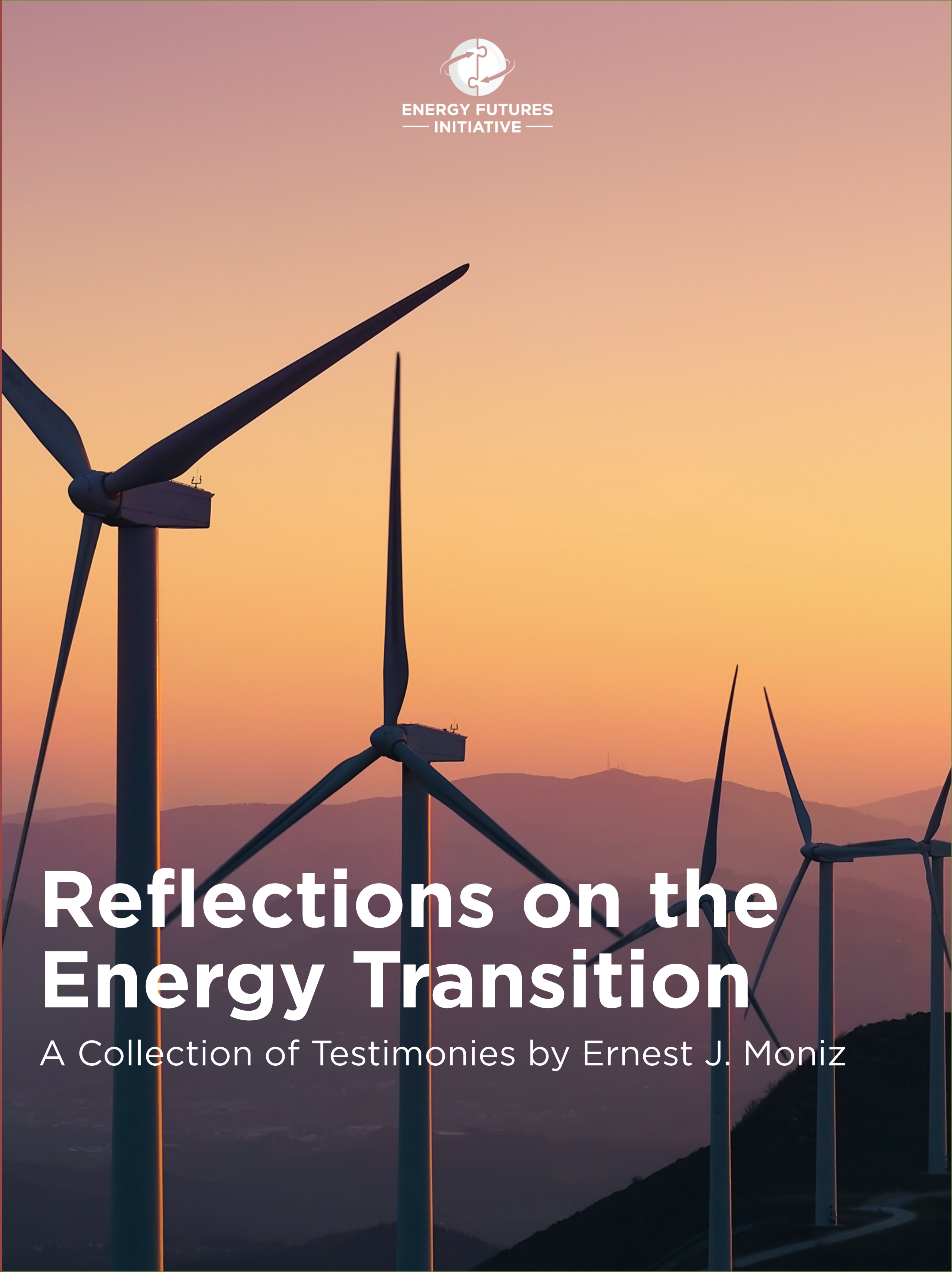

ENERGY FUTURES INITIATIVE

Reflections on the Energy Transition

A Collection of Testimonies by Ernest J. Moniz

About the Energy Futures Initiative

The Energy Futures Initiative advances technically-grounded solutions to climate change through evidence-based analysis, thought leadership, and coalition-building. Under the leadership of Ernest J. Moniz, the 13th U.S. Secretary of Energy, EFI conducts rigorous research to accelerate the transition to a low-carbon economy through innovation in technology, policy, and business models. EFI maintains editorial independence from its public and private sponsors.

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Written Testimony

21st Century Communities: Capitalizing on Opportunities in the Clean Energy Economy

On April 22, 2021, the Senate Committee on Banking, Housing, and Urban Affairs convened a hearing entitled, "21st Century Communities: Capitalizing on Opportunities in the Clean Energy Economy."

Witnesses included: The Honorable Ernest Moniz, President and CEO, Energy Futures Initiative; Mr. Khalil Shahyd, Senior Advisor, Natural Resources Defense Council; Ms. Zoe Lipman, Director, Manufacturing Advanced Transportation, BlueGreen Alliance; Dr. David Kreutzer, Senior Economist, Institute for Energy Research; and Mr. Neal Crabtree, Welder, Pipeliners Local Union 798.

Chairman Brown, Ranking Member Toomey, and Members of the Committee, I am pleased to have the opportunity to discuss with you today the risks associated with climate change and some possible options for addressing those risks.

Climate Change Poses Risks to U.S. Financial Systems

Late last year, the U.S. Commodity Futures Trading Commission (CFTC) released a groundbreaking report, *Managing Climate Risk in the U.S. Financial System*.

A central message of this report: "… U.S. financial regulators must recognize that climate change poses serious emerging risks to the U.S. Financial system, and they should move urgently and decisively to measure, understand, and address these risks.

Achieving this goal calls for strengthening regulators' capabilities, expertise, and data and tools to better monitor, analyze, and quantify climate risks. It calls for working closely with the private sector to ensure that financial institutions and market participants do the same. And it calls for policy and regulatory choices that are flexible, open-ended, and adaptable to new information about climate change and its risks, based on close and iterative dialogue with the private sector."

The CFTC report identified categories of assets that are most likely to be put at risk by climate change and examples of those categories of financial products, including real property; infrastructure;

TABLE 1
Categories of Assets Exposed to Climate Change Impacts

Categories	Examples
Financial assets tied to real property	→ Commercial mortgage-backed securities (CMBS) → Commercial real estate estate (CRE) bank loans → Government-sponsored enterprise (GSE) Credit Risk Transfer securities → Real Estate Investment Trusts (REITs) → Residential mortgage-backed securities (RMBS) → Residential mortgages
Financial assets tied to infrastructure	→ Debt and equities of power and water utilities and communication companies → Debt and equities of public and private transportation infrastructure
Financial assets tied to companies with business models or operations likely to be impacted by physical or transition risk	Equities and debt of firms in the following sectors: → Agriculture → Airlines and the broader transportation sector → Automobiles → Cement, steel, plastics → Energy, including coal, oil, and gas production → Hospitality → Metals and mining → Power generation → Service and infrastructure providers to oil and gas → Tourism
Financial assets tied to insurance providers	→ Insurance and reinsurance debt and equities → Insurance linked securities (ILS)
Financial assets tied to streams of government revenue	→ Municipal bonds → Sovereign bonds

companies whose assets are directly affected by climate risk; insurance companies; and government revenues (Table 1). A summary of some of the report's conclusions includes:

- The lack of standards and definitions for climate data and financial products is hindering the management of climate risk by market players and regulators. Methodologies, definitions, data on climate risks and financial products labeled "green" or "sustainable should be standardized and transparent.

- Corporate disclosures of climate-related financial risks are critical for understanding and assessing the impacts of climate change on the range of financial market participants, processes, and products.

- A carbon price, appropriately developed and supported, is essential for adequately assessing climate risks and informing financial and investment decision-making.

- Cascading and interacting risks could amplify climate impacts on financial systems. At the same time, the re-pricing of assets based on climate risk should be orderly, informed, and systematic.

Today we are dealing with two global challenges simultaneously—a pandemic and climate change—that can reinforce each other as they pose risks to financial institutions, commodities, credit, financial aid, exports, insurance, supply chains and more – all issues of concern to this committee. Reasons for the interdependence are that COVID has already stressed balance sheets, required large government expenditures and threatened the financial health of many families and businesses alike.

The Range of Climate Risks is Growing

I will start by offering some perspective on today's risks fromclimate change. These risks are growing and manifest in increasingly serious ways. More specifically, I will discuss:

- The global risks of and responses to climate change;

- U.S. climate risks and the changing risk profile;

- Risks to critical energy infrastructures;

- Risks to economic growth and jobs;

- Technology risks; and

- Supply chain risks, both for existing US energy supplies; as well as risks to the supply chains for our allies.

Quantifying these risks is difficult but efforts to elucidate these risks are essential for the stability of the nation's financial, security, social, and health systems going forward.

The Texas "Big Chill" of 2021

The Texas events of last February provide an example of how climate risks and finances intersect, an example of the kinds of risks and concerns outlined in the CFTC report. In Texas, the recent extreme cold snap left much of the state without power and heat. In Dallas, February temperatures were -2°F, while the average low for this time of year was around 40°. Because two-thirds of Texans rely on electric heating, this led to a surge in electricity demand throughout the state of about 20 GWs, or one-third of the winter peak; this far exceeded ERCOT's worst case planning scenario.

It is clear that Texas was unprepared for the polar vortex of February 2021 even though ten years earlier, the state experienced another major cold snap, albeit not as severe as the most recent one. The 2011 event led to a FERC/NERC report with a set of recommendations, such as winterization of assets; unfortunately, there was no systematic response to these recommendations by Texas regulators and policymakers.

Another key recommendation: understanding the interdependencies of the electricity and natural gas infrastructures. Actions were not taken on this issue either, with disastrous consequences. The natural gas producers had electrified important parts of their production system, while the electricity system had become extremely dependent on gas supply. The approach to shedding electricity load did not adequately incorporate the need for natural gas supply to run generation, and the need for electricity to produce natural gas. The separated regulatory responsibilities of the Texas PUC and the Railroad Commission created a structural impediment to this kind of coordination – the crisis underscored the need for new cross-cutting structures to reflect these interdependencies and an empowered decision-making process to ensure reliable and resilient electricity in the face of increasingly extreme weather events.

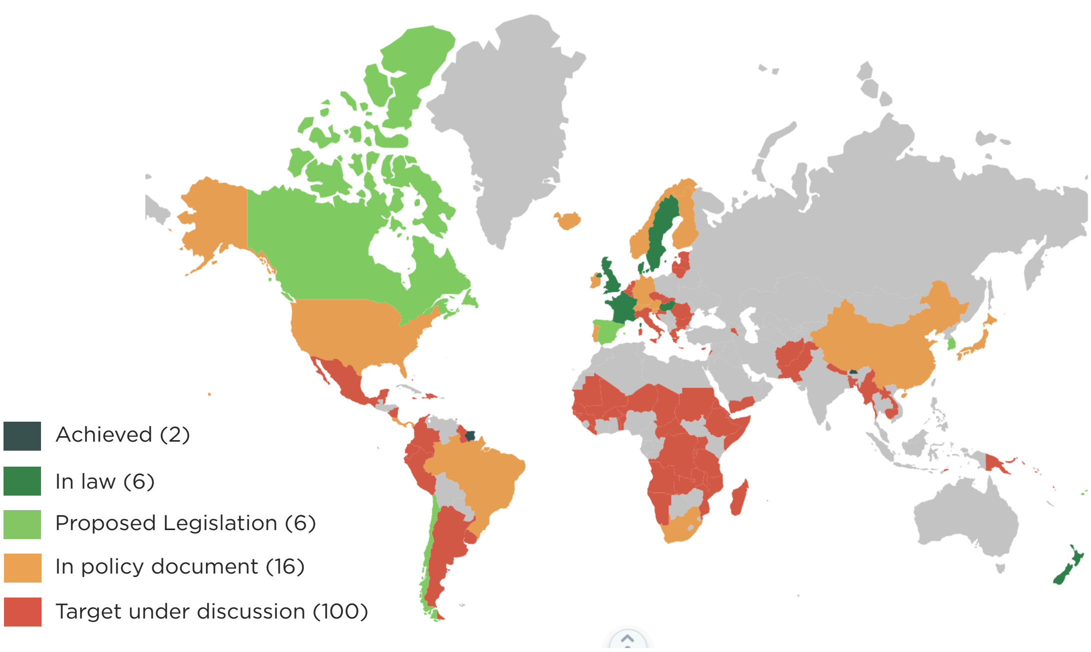
In this regard, it is clear that the PUC, state officials and ERCOT did not adjust to the changing risk profile generated by increased global warming and extreme weather – but they are not alone. *Institutions, policymakers, system operators, and investors across the country need to acknowledge that yesterday's weather is not a good predictor of future weather extremes.* It must also be emphasized that the extreme weather risks are not only about cold, and they are considerable: heat and cold, floods and droughts, sea level rise and tropical storm damage, wildfires, and more. All need appropriately updated regional risk profiles for damage to critical infrastructures.

The Texas electricity market structure

also needs reexamination. I stress that the choice of a deregulated system is not itself the issue, but rather the failure to erect sufficient guardrails in defining the energy-only market rules. I am reminded of the old joke about "How many Chicago economists does it take to change a light bulb?" Answer: "Zero – if the market wants it, the market will take care of it." Clearly, the "market" needs improved rules of the road to reduce physical and financial risk to the citizenry.

This brings us to the financial consequences. In addition to the enormous human suffering from the catastrophic weather event in Texas, there were huge financial consequences. Electricity rates were held at $9000/MWh for a sustained period, and natural gas prices exceeded $100/MMBtu, a price that had significant ripple effects on natural gas prices far from Texas. Within the state, there are now a significant number of stressed balance sheets for utilities, families, businesses, and even for military installations. The Navy reported, for example, that its electricity bill for Texas installations for

FIGURE 1
Countries That Have Either Achieved, Have Laws, Policies, Proposals Under Discussion for Net Zero Emissions Targets as of 2020



130 countries have either implemented or are considering implementing net-zero targets. Source: EFI, adapted from https://eciu.net/netzerotracker

February 2021 totaled $13.9 million, an order of magnitude greater than the February 2020 cost of $616,000.[i] The largest and oldest electric power cooperative in Texas filed for bankruptcy, and the last chapter has not yet been written on the financial fallout of the February events. Ultimately, some combination of rate payers, tax payers and shareholders will pay the price. This episode provides a stark example of the warnings in the CFTC's report. The open question is whether legislation in response to the big chill in Texas will materially improve resilience in the face of extreme weather events with highly uncertain risk profiles in the future.

Global Responses to the Increasing Risks From Climate Change

While the planet has seen major climate variation over its history, the pace of change today is well beyond that attributable to natural phenomena and is driven by human activity, especially from energy. The UN's 2019 Climate Action Summit brief noted that the last four years were the four hottest on record, and winter temperatures in the Arctic have risen by 3°C since 1990. The U.S. Fourth National Climate Assessment released in 2018 noted that, "Without significant reductions, annual average global temperatures could increase by 5°C or more by the end of this century compared to preindustrial temperatures."[ii] The growing intensity and frequency of floods, hurricanes, and droughts across the country and the world have underscored both the ferocity and costs of a changing climate.

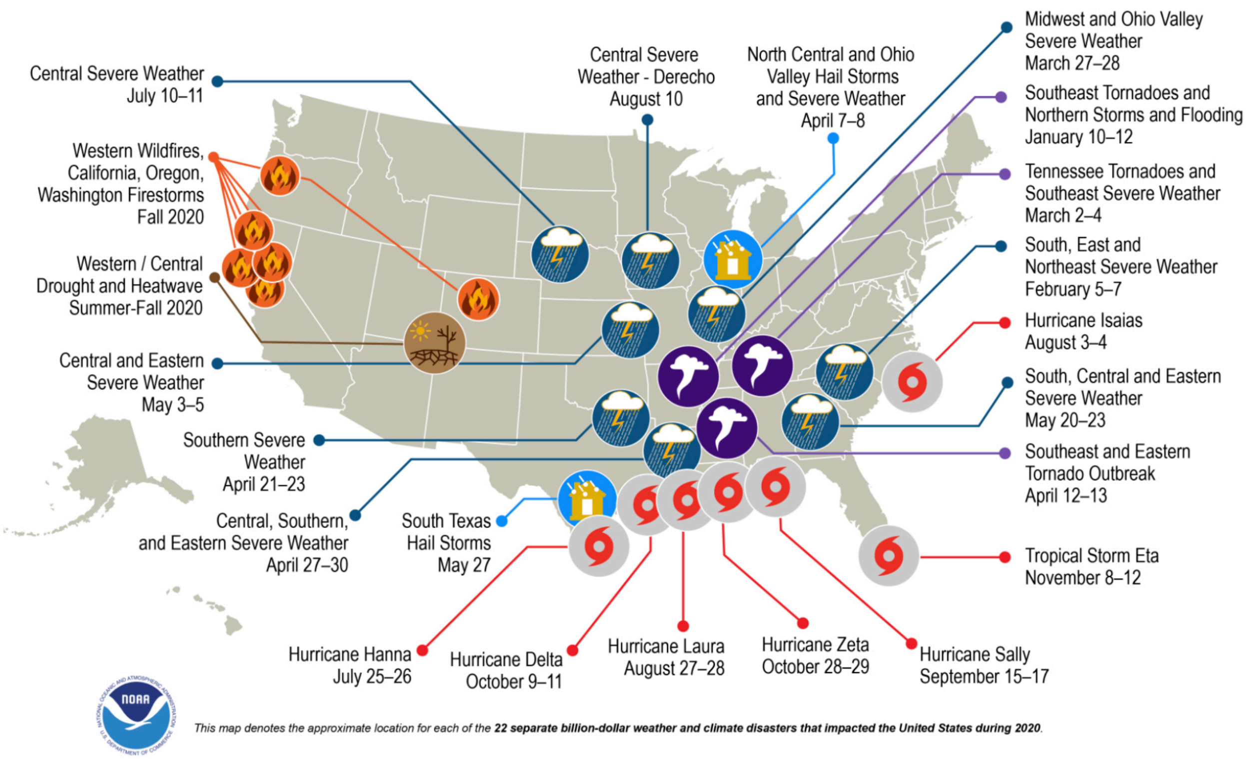
This has not gone unnoticed by the nations of the world. In 2015, 197 countries adopted the Paris Accord at COP21. According to the Special Report by the Intergovernmental Panel on Climate Change (IPCC) published only three years after Paris, "limiting global warming to 1.5°C is projected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans" while a 2°C rise would bring with it greater increases in frequency and intensity of heavy precipitation in several regions along with an increase in intensity or frequency of droughts in others.[iii]

According to the UNFCC, since COP21, 191 countries have submitted their first Nationally Determined Contribution (NDC) and eight have submitted their second.iv Importantly, since Paris, the number of countries that have implemented or are considering net zero emissions targets, now stands at 130, up from around 17 just two years ago (Figure 1).

U.S. Climate Risks

The Fourth U.S. Climate Assessment also found that "Climate change creates new risks and exacerbates existing vulnerabilities in communities across the United States, presenting growing challenges to human health and safety, quality of life, and the rate of economic

FIGURE 2
U.S. 2020 Billion-Dollar Weather and Climate Disasters



growth" and that "Without substantial and sustained global mitigation and regional adaptation efforts, climate change is expected to cause growing losses to American infrastructure and property and impede the rate of economic growth over this century." The events described earlier did not just impact Texas. The winter storm in mid-February 2021 affected large regions of the southern U.S., including Texas, with sustained subzero temperatures and snow. These events are not anomalies; they represent the new norm. According to the National Centers for Environmental Information at the National Oceanic and Atmospheric Administration, the U.S. has sustained 291 weather and climate disasters since 1980 where overall damages/costs reached or exceeded $1 billion (including CPI adjustment to 2021). The total cost of these 291 events exceeds $1.9 trillion. The 1980–2020 annual average is 7.1 events (CPI-adjusted); the annual average for the most recent 5 years (2016–2020) is 16.2 events (CPI-adjusted).

2020 sets the new annual record of 22 events - shattering the previous annual record of 16 events in both 2011 and 2017. 2020 is the sixth consecutive year (2015-2020), in which there have been ten or more, billion-dollar weather and climate disaster events that have impacted the United States.[1] The costs of such events are highlighted in Figure 2 which describes 2020 weather and climate- related events that caused $1 billion or more damage across regions in the U.S.

The Biden Administration is setting us on a new and accelerated course towards an economy with net zero greenhouse gas (GHG) emissions by mid-century. The U.S. has rejoined Paris and it is expected that at the Earth Day Summit, the Administration will release an updated ambitious Nationally Determined Contribution, setting a new interim target for GHG reductions by 2030. I look forward to working on ways the US can meet these increased ambitions and to highlight these and other U.S. actions at COP 26 in Glasgow later this year.

The Administration's actions are as warranted as they are critical. In the last two years, two of our largest states – Texas and California – have been devastated by the impacts of climate change. Wildfires in California forced the preemptive shutdown of large sections of the state's grid. Last August, a western US extreme heat wave forced rolling blackouts in California. These and other events suggest that weather and other risk profiles that have guided infrastructure protection, development, and investments are no longer adequate for risk assessment, associated policy actions, and infrastructure investments in the future. The number and magnitude of severe weather events increasingly fall outside historical ranges, e.g., the concept of a 100-year flood, may no longer be valid; the scope of adverse impacts has expanded due to the increasing interdependencies of infrastructures; and the geographic pattern of risks has changed due to changing climate. Simply stated, yesterday's weather is no longer a good guide for planning to meet tomorrow's weather extremes. We need new baselines for calculating climate risks.

Changes in the Work Environment

As we assess U.S. climate risk, we also need to consider the impacts COVID has had on work and the associated patterns of energy use. While no one knows for certain how the unprecedented experience of the pandemic will affect the work environment of the future, it appears likely that there will be dramatic increases in the numbers of people working from home. This could have significant implications for energy needs and the associated infrastructures to support the changed workplace.

First and foremost, it would likely increase demand for reliable and resilient electricity supplies across the entire grid as the productivity of highly decentralized working environments will be directly linked to power availability. It could also lower energy demand for

1. https://www.ncdc.noaa.gov/billions/

transportation at the same time it could increase residential electricity demand; the time of day for peak electricity demand, a critical consideration in grid management, could change. In addition, it would require universal access to broadband to ensure all Americans have equal workplace flexibility options. The COVID crisis drove this point home: children without access to broadband could not "go to school". Businesses without access to broadband couldn't meet customer needs. Finally, the increased use of broadband and the internet to conduct business could increase concerns about cyber-security. Innovation investments should consider this changing profile and address these needs. An overarching point: continued electrification of the economy ups the ante for reliability, resilience, security and power quality of the electric grid.

Climate Risks and Responses will Vary Greatly by Region of the Country

The resources, infrastructures, emissions profiles, innovation, and policy needs vary greatly by region of the country—a "one size fits all" approach to climate risks will likely impede, not accelerate progress towards deep decarbonization. EV charging infrastructures will, for example, look very different in both rural and urban areas, where the typical "suburban EV model mindset" and its associated infrastructure will have little relevance to densely populated cities and sparsely populated regions of the country. Industrial centers in the U.S. will have ongoing need for high quality process heat that cannot easily be provided by electricity. Many regions have sequestration options, some do not. Offshore wind resources are clearly available only to those regions with coastlines, and onshore wind resources vary greatly across the country as do solar resources. They also have large seasonal variations.

Risks to Critical Infrastructures

Another critical finding in the Fourth Climate Assessment: "Changes in energy technologies, markets, and policies are affecting the energy system's vulnerabilities to climate change and extreme weather. Some of these changes increase reliability and resilience, while others create additional vulnerabilities. Changes include the following: natural gas is increasingly used as fuel for power plants; renewable resources are becoming increasingly cost competitive with an expanding market share; and a resilient energy supply is increasingly important as telecommunications, transportation, and other critical systems are more interconnected than ever."

Existing U.S. infrastructure, aging and in need of repair, is especially vulnerable to climate impacts. The American Society of Civil Engineers *2021 Report Card* gives America's infrastructure a C- overall and a C- for the energy over the last four years, "however weather remains an increasing threat." Among the 638 transmission outage events between 2014 and 2018, severe weather was the predominant cause, and "in the coming years, additional transmission and distribution infrastructure, smart planning, and improved reliability are needed to accommodate the changing energy landscape as delivery becomes distributed and renewables grow."

The Complex Interdependencies of Critical Infrastructures.

Preliminary analysis of what went wrong in Texas, from a systems perspective, suggests that the natural gas, electricity, and water infrastructures were all affected by the extreme cold and that their interdependencies were major contributors to the electricity crisis.

We made energy infrastructure an early priority in my tenure as Secretary at DOE with the drafting and publication of the first installment of the Quadrennial Energy Review, or QER. The first installment of the QER focused on energy infrastructure. It was released in 2015 and included a section specifically focused on the growing interdependencies of the electricity and natural gas infrastructures highlighting the Big Chill in Texas and New Mexico in 2011 as an example. As noted earlier, this concern was borne out by the events in Texas 10 years later (see Box 1).

The second installment of the QER focused on the nation's electricity system. One of its many conclusions: the reliability of the electric system underpins virtually every sector of the modern U.S. economy. Reliability of the grid is a growing and essential component of national security. Standard definitions of reliability have focused on the frequency, duration, and extent of power outages. With the advent of more two-way flows of information and electricity—communication across the entire system from generation to end use, controllable loads, more variable generation, and new technologies such as storage and advanced meters—reliability needs are changing, and reliability definitions and metrics must evolve accordingly.[v]

This reliance on electricity is illustrated in Figure 3, which illustrates the interdependencies between several of the nation's critical infrastructures. It's important to note that in this figure, IT/Communications and Electricity are connected to all of the critical infrastructures depicted in the figure. Not shown but also critical, is the financial sector. It too is connected to all critical infrastructures in this figure. Electricity, however, not only supports all the other infrastructures, it supports Finance and IT/Communications as well.

This figure also clearly illustrates the centrality of electricity as the "uber" infrastructure, essential to the U.S. economy and the health and welfare of our citizens. Making all of these critical infrastructures more resilient is essential. Electricity infrastructure, however, which is especially exposed to the impacts of climate change, supports virtually all economic, health and safety

BOX 1

QER 1.1 Highlighted Growing Gas/Electric Interdependencies

The Big Chill: A Disruptive Event Made Worse by Infrastructure Interdependencies[1]

The "Big Chill" of 2011 illustrates the complicated relationship between natural gas and electric power, which had compounding effects during a period of extreme weather.

During the first week of February 2011, the U.S. Southwest was hit by an arctic cold front that was unusually severe in terms of its low temperatures, gusting winds, geographic extent, and duration. From January 31 to February 4, temperatures in Texas, New Mexico, and Arizona were the coldest experienced within the region since 1971. Dubbed the "Big Chill" in the media, it overwhelmed the routine preparations for cold weather that had been put in place by electric generators and natural gas utilities located in those states.

Within the Electric Reliability Council of Texas (ERCOT) Interconnection, starting in the early morning hours of February 2, the cold temperatures and wind chill caused a significant number of outages at generating plants, with approximately one-third of the total ERCOT generating fleet unavailable at the lowest point of the event. With electricity demand soaring because of the cold weather, ERCOT and some utilities in New Mexico instituted rolling blackouts to prevent collapse of their electric systems. For the Southwest as a whole, 67 percent of electric generator failures (by megawatt-hour) were due directly to weather-related causes, including frozen sensing lines, frozen equipment, frozen water lines, frozen valves, blade icing, and low-temperature cutoff limits on equipment.

Gas producers and pipelines were also affected in Texas, New Mexico, and Arizona. Natural gas production was diminished due to freeze-offs and the inability to reach gas wells (due to icy roads) to remove produced water and thereby keep them in operation. When rolling electricity blackouts hit gas producers and gas pipelines, it had the effect of causing further losses to natural gas supply. The ERCOT blackouts or customer curtailments caused or contributed to 29 percent of natural gas production outages in the Permian Basin and 27 percent of the production outages in the Fort Worth Basin, principally as a result of shutting down electric pumping units or compressors on gathering lines. As a result of all these factors, natural gas deliveries were affected throughout Texas and New Mexico. More than 30,000 customers experienced natural gas outages at some point during this period.

The majority of the problems experienced by the many generators that tripped, had their power output reduced, or failed to start during the event were attributable, either directly or indirectly, to the cold weather itself. However, at least another 12 percent of these problems were attributed afterward to the interdependencies between gas and electricity infrastructures (such as lost electricity generation due to natural gas curtailments to gas-fired generators and difficulties in fuel switching).

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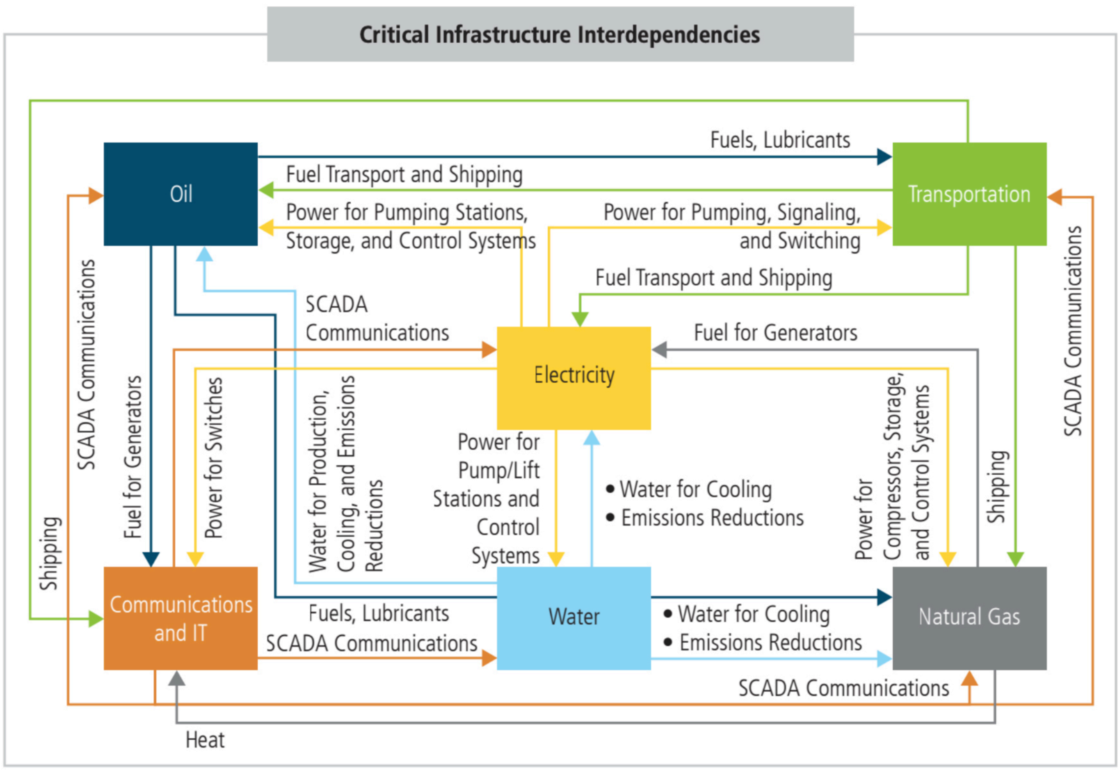
1. Federal Energy Regulatory Commission and North American Electric Reliability Corporation. "Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1-5, 2011: Causes and Recommendations." August 2011. http://www.ferc.gov/legal/staff-reports/08-16-11-report.pdf. Accessed February 2, 2015.

FIGURE 3

U.S. Critical Infrastructure Interdependencies: The Central Role of Electricity



Key critical infrastructure interdependencies represent the core underlying framework that supports the American economy and society. The financial services sector (not pictured) is also a critical infrastructure with interdependencies across other major sectors supporting the U.S. economy.

Acronyms: information technology (IT), supervisory control and data acquisition (SCADA).

Source: Transforming the Nation's Electricity System: the Second Installment of the Quadrennial Energy Review.

activities in the country; this raises the bar for both its reliability and its resilience. The centrality of electricity and the growing exposure of its infrastructures to the impacts of climate change, along with the associated risks, should be a major consideration as policies are being advanced to increase the electrification of the buildings and transportation sectors.

Risks to Conventional Energy Jobs Posed by the Clean Energy Transition

As the science of climate change has advanced and the impacts have become more obvious and severe, the Energy Futures Initiative's analysis has increasingly focused on policy and technology innovations that are central to any climate action plan that can both succeed in reaching the aggressive—but essential—net-zero goal and underpin a thriving economy in the U.S.

Achieving both climate and economic goals in the clean energy transition represents an enormous challenge. Technological revolutions have stimulated economic growth while leaving vulnerable workers behind. The First Industrial Revolution mechanized production, the Second introduced mass production, the Third brought automated production. The first two were enabled by new energy technologies, the third from electronics and information technology. The Fourth Industrial Revolution, already underway, is the digital revolution[2] which, like the others, can create opportunities as well as inequities and lost jobs. As noted, this past year, the economic divide associated with the digital revolution has become tragically and strikingly evident as work and education from home and tele-health have depended upon access to broadband and digital devices. It is imperative that we avoid such a divide as we transition to a clean energy economy.

It's a fact of the nation's changing energy profile: a number of energy jobs in key job classifications have been declining and will continue to decline. Coal jobs, for example, have been declining over the past two decades, along with the declines in the costs of wind, solar and natural gas technologies or supplies or both. Detailed data on these and other job classifications, numbers, and declines/increases can be found on the EFI website in several issues of the U.S. Energy Employment Report (USEER).

In this regard, EFI, in partnership with the National Association of State Energy Offices, has conducted an annual energy jobs survey that we started at DOE when I was Secretary. The previous Administration discontinued this survey. Understanding its importance, EFI and NASEO have sustained this critical work and released a five-year trend analysis of energy jobs last year. The data in this summary analysis (all pre-COVID) indicated that energy jobs were created at twice the rate of overall jobs in the economy, a critical consideration as we work on COVID recovery. I am pleased to tell the Committee that DOE has recently agreed to renew its support of this effort.

The USEER also documents the geographic concentration of many conventional energy jobs that are dependent on the location of key resources, generation technologies, refining and processing, etc. The largest percentage of energy jobs, however—efficiency jobs— are ubiquitous, present in 99.8 percent of all counties in the U.S. Energy efficiency employment grew 20 percent, more than any of the energy sectors between 2015-2019, and

2. https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/

TABLE 2

Cross-walking Conventional to Clean Energy Infrastructures

Opportunities for Using Existing Carbon Infrastructure for Decarbonization					
	Oil Refineries and Gas Processing	**Natural Gas Generation**	**Oil and Gas Pipelines**	**Waterborne Transportation & Ports**	**Storage**
Biofuels	→ Conversion of oil refineries to biorefineries → Upstream blending of oil with drop-in biofuels → Applying industry expertise	→ See renewable natural gas examples below	→ Transporting biofuels in petroleum product pipelines → Leveraging pipeline rights-of-way	→ Using fuel storage and transportation hubs	→ Using underground storage tanks for biofuels and petroleum-biofuel blends
Hydrogen Fuel or Feedstock	→ Leveraging industry expertise on hydrogen safely → Producing hydrogen → Redirecting hydrogen currently produced for refining petroleum to perform other energy services	→ Co-firing hydrogen (up to 50 percent with NG) → Gas turbine combined-cycle plants with expected efficiency ≥60 percent	→ Doping in NG pipelines (≤15 percent with minor pipeline upgrades needed) → Leveraging pipeline-rights of -ay	→ Using fuel storage and transportation hubs	→ Using salt caverns and other geologic formations → Capitalizing on industry expertise with NG storage
Negative Emissions Technologies/Carbon Capture, Utilization, and Storage (CCUS)	→ Applying industry expertise to CCUS technologies for direct air capture (DAC) and bioenergy with carbon capture and storage (BECCS)	→ Applying industry expertise: CCUS technologies DAC and BECCS	→ Using compression technologies similar to those in NG infrastructure CO_2 → Rail and roadway = existing infrastructure → Leveraging pipeline rights of way	→ Using industry expertise in liquefaction and transport of LPG/LNG for CO_2 → Marine vessels for CO_2 using the same technology as existing LPG or LNG tankers → Port infrastructure for loading → Offshore facilities for sub-sea injection	→ Using saline formations, O&G reservoirs, unmineable coal seams, basalt formations → Using industry expertise in large-scale CO_2 separation and sequestration → Applying technologies for drilling and injection, subsurface characterization and site monitoring, same as O&G sector → Leveraging similarities with NG storage, acid gas , CO_2-EOR
Renewable Natural Gas (RNG)	→ Processing technologies are similar to NG processing	→ Minimal processing for using RNG for power generation in gas turbines	→ Doping in NG pipelines → Leveraging pipeline rights of way	→ Utilizing existing fuel storage and transportation hubs	→ Leveraging industry expertise with NG storage
Smart Systems/ Platforms	→ Applying process automation for improved performance	→ Creating smart generation solutions: NG-battery and NG-solar	→ SCADA expertise → Improving the efficiency of transport, RNG, H_2, CO_2 → Enhanced leak detection	→ Using transport management systems and other IOT applications	→ Optimizing revenues from grid-scale storage systems

FIGURE 4
Upcoming LEP Regional Workshops Announced April 19, 2021

Resilient Infrastructure | Gulf of Mexico
The Gulf states process much of the United States' oil and gas and will be impacted by the clean energy transition. Pathways to deep decarbonization need to help transition conventional energy jobs

Metals & Minerals | Rocky Mountain West
Natural resources in the Rocky Mountain West can help develop the domestic supply chains for the metals and minerals needed for clean energy technologies

Hydrogen | The Carolinas
Given its current infrastructure and central location, the Carolina Region has a unique opportunity to build a market for clean hydrogen

Carbon Capture and Storage & Hydrogen | Ohio River Valley
The Ohio River Valley is a historic corridor of American manufacturing and deployment of carbon capture can reduce industrial emissions while preserving high paying jobs.

Nuclear | Upper Midwest
Nuclear capacity in the Upper Midwest has provided zero emissions electricity for decades. This region has an opportunity to preserve existing generation and explore next generation technologies.

Source: Labor Energy Partnership, 2021.

represented 2.38 million Americans in 2019; 56 percent of these jobs were in the construction industry. It is important that we continue to support these jobs or create new, comparable employment as we consider the risks to conventional energy jobs inherent in the clean energy transition, we catalogue skillsets, support the translation of the skills to focus on clean energy opportunities, and invest in programs and incentives to mitigate these risks. Table 2 shows an EFI work product that starts this cross-walking, looking first at conventional infrastructures/technologies and how these might be used for clean energy production and use.

Special attention also needs to be paid to providing the training needed as we transition from conventional to clean energy jobs. Again, offshore wind provides an example. The skills of oil and gas workers who have experience with building and maintaining offshore drilling platforms can be transferred to offshore wind platform construction and maintenance. CCUS, hydrogen, engineered geothermal and carbon dioxide removal offer other opportunities to apply the subsurface and pipeline construction and maintenance knowledge and skills of oil and gas workers to work on large scale decarbonization infrastructures. Many of the "new energy" opportunities will also be located in regions with oil and gas production, thereby minimizing dislocation of the workforce.

This underscores some of the key reasons why we formed the Labor Energy Partnership (LEP) with the AFL-CIO last year. The LEP is a joint effort of both organizations, designed to develop a framework for the 21st Century energy system that creates and preserves quality jobs while addressing the climate crisis. The LEP's four guiding principles demonstrate its approach to a range of issues, including grid modernization, offshore wind, CCUS, and hydrogen. These principles are: 1) Energy policy must be science-based; 2) We need an "all-of-the-above" energy strategy that is regionally focused, flexible, and preserves optionality; 3) preserving jobs, while creating new ones, is essential to climate policy; and 4) there are significant economic opportunities in the development and deployment of clean technologies and infrastructure.

The LEP is currently analyzing the policies needed to site and permit new electricity infrastructure projects in the near-term. It is also evaluating policy solutions to ensure rapid development of offshore wind resources along the east and west coasts, and in the Great Lakes region. In line with its wholistic approach to policy analysis, the LEP is considering local economic impacts, the opportunity to onshore the offshore wind manufacturing and supply chains, the social equity and environmental justice concerns, and the lessons learned from the existing global market. On Monday of this week, the LEP released a report detailing the highlights of a workshop it held on Offshore Wind and development of domestic supply chains, and also announced a set of five regional workshops, detailed in Figure 4.

Technology Risks Underscore the Need for an "All of the Above" Approach

The recent *Clean Energy Innovation Report* from the International Energy Agency provides a global context for immediate action on clean energy investment. The report emphasizes that while energy efficiency and renewable energy will be crucial, they are not sufficient to meet net-zero climate goals, especially in sectors like heavy industry and transportation.

The IEA Report also estimates that, on a global level, *at least 40 percent of emissions reductions to reach net zero will rely on technologies not yet at commercial scale*—including known technologies such as end-use electrification, CCUS, hydrogen, and bioenergy. In the study, IEA also stresses that action is necessary immediately because past innovations, such as LEDs and lithium-ion batteries, took decades to reach full commercialization, and some energy-consuming infrastructure operates on refurbishment cycles of 25-30 years.

FIGURE 5

California Wind and Solar Generation fo Each Day of 2017, CA Installed Capacity, 2019

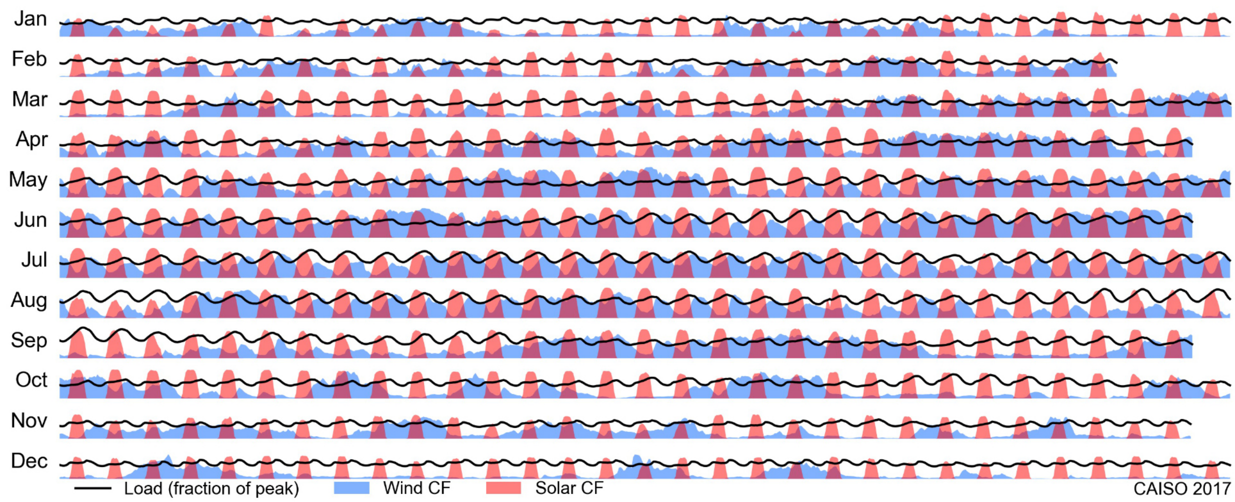


Figure 5 shows the hourly wind and solar generation for every day in 2017. Numbers in green count the days in the year where there was little to no wind generation in the state. The inset shows the installed battery storage capacity and duration in California which is currently insufficient to provide longer duration storage during multi-day periods with little to no wind generation. Source: CAISO data, EFI analysis.

Also, there will be no single nor simple solution to meet net zero emissions. While the key technological nearterm strategies to move towards net zero may be generally understood (policy support is a separate and less clear-cut issue), many that may be currently available could benefit from further improvements in performance and cost. In addition, *many of the technology solutions needed to meet mid-century targets are not yet available*, a conclusion specific to California but with broad application, that was made in the EFI study, *Optionality, Flexibility & Innovation: Pathways for Deep Decarbonization in California*, released in May 2019.

Electricity storage is a case in point. Deployment of electricity storage systems is only in its earliest stage. Current commercial battery storage technology typically provides from 4-6 hours of storage; other options may provide longer duration storage but are site-specific, limited by geography or geology. Large scale deployment of intermittent carbon free electricity generation will require significant levels of longer duration storage capable of meeting daily, weekly, and even seasonal variations. The 2019 California study illustrates the challenges associated with limited-duration storage, seen in Figure 5. Long duration storage is one of those technology solutions that is “not yet available” but, with increased penetration of variable renewables, is needed to ensure system reliability.

To illustrate the degree of uncertainty about technology options, it is worth noting that in 2003, then chair of the Federal Reserve, Alan Greenspan, testified before Congress that the U.S. was facing an impending natural gas crisis, noting that, “Today's tight natural gas markets have been a long time in coming, and futures prices suggest that we are not apt to return to earlier periods of relative abundance and low prices anytime soon… As the technology of LNG liquefaction and shipping has improved, and as safety considerations have lessened, a major expansion of U.S. import capability appears to be under way. These movements bode well for widespread natural gas availability in North America in the years ahead.”[3]

Eighteen years later, after a range of technology investments and supporting policies, the U.S. is now the number one producer of natural gas in the world because of hydraulic fracturing combined with horizontal drilling and is already the world’s third largest LNG exporter. Technologies enabled this dramatic turnaround in the U.S. natural gas supply profile and the associated security of supply issues. One of DOE’s earliest actions was characterizing shale basins. Research by the Gas Research Institute and a time-limited tax credit supported the development of shale gas (and oil) that has changed the U.S. energy profile in the last decade. This underscores the need for both a broad portfolio of technology innovation options that do not pick winners and losers, as well as policy support for demonstration and deployment.

The uncertainty and risks of the range of technology pathways and their successes suggests that there is ongoing need for an “all of the above approach” to federal innovation investments, both for risk management and to accommodate the significant regional differences in the U.S. Developing a portfolio based on any single variable, such as cost or a policy preference, may be inadequate. Some sectors, such as aviation and manufacturing, are more difficult to decarbonize than others but will require significant attention, innovation spending, and other types of policy, regulatory, and business model support.

There are also significant systems integration needs that cannot be met if innovation investments are too narrowly focused. We must also not lose sight of the importance of fundamental R&D in platform technologies – AI, data analytics, additive manufacturing, robotics, materials by design, and many more – that become enablers of technological progress in multiple domains.

3. https://www.federalreserve.gov/boarddocs/testimony/2003/20030610/default.htm

Supply Chain Risks for Clean Energy Technologies

Clean energy technologies introduce entirely new supply chain needs; there are corresponding and growing risks to those supply chains. Supply chain issues for new clean energy technologies must be evaluated and factored into policies. Clean energy technologies must accommodate potential material and process limitations, and the geopolitical risks that could, without policy support, delay or hinder U.S. and global decarbonization efforts.

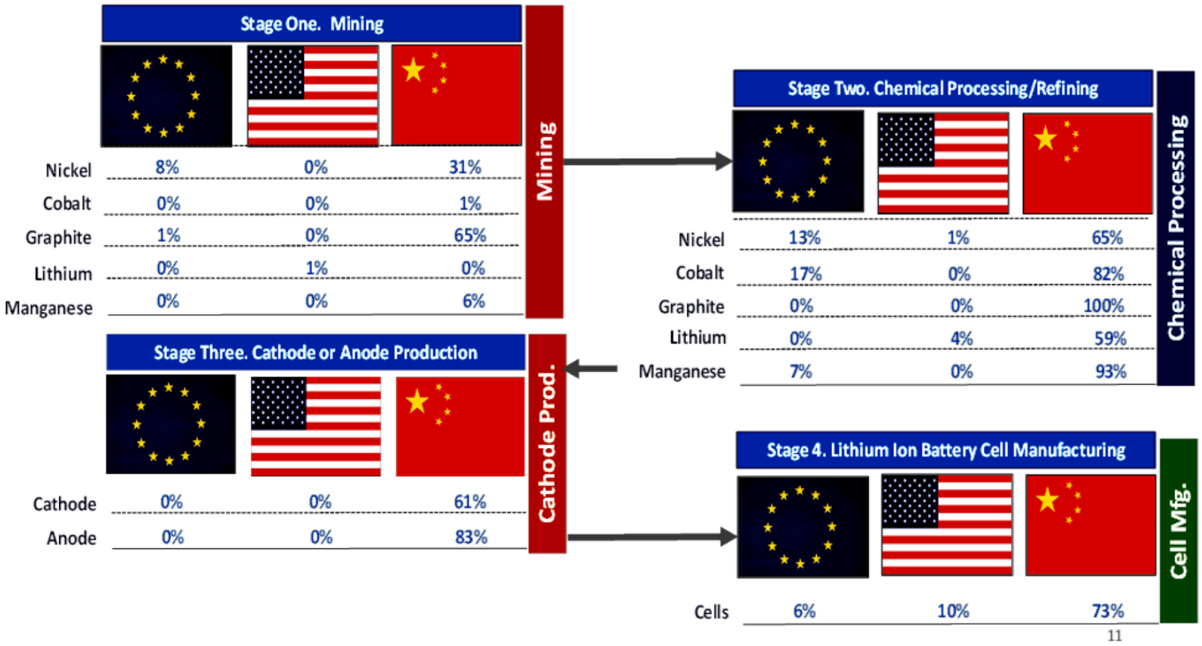
Meeting the increased demand for critical metals and minerals will likely require a corresponding- increase in domestic mining, albeit to support deep decarbonization, this will need to be mining that employs environmentally sustainable practices. Targeted RD&D activities can supplement these strategies. Opportunities for materials substitution and materials recycling, as well as alternative approaches for materials processing and equipment manufacturing, should become a more prominent part of DOE funded RD&D for clean energy technology. Strategies for commercial deployment should take into consideration security and reliability of supply chains and develop appropriate acquisition strategies to accelerate market development. As an example, Figure 6 underscores these risks and the need for innovation throughout the supply chain for the metals and minerals needed for EV battery manufacturing.

The need to address these issues was underscored by President Biden's Executive Order 14017, America's Supply Chains, which notes that "More resilient supply chains are secure and diverse—facilitating greater domestic production, a range of supply, built-in redundancies, adequate stockpiles, safe and secure digital networks, and a world-class American manufacturing base and workforce. Moreover, close cooperation on resilient supply chains with allies and partners who share our values will foster collective economic and national security and strengthen the capacity to respond to international disasters and emergencies."

It is also worth noting that Title VII of the Energy Act of 2020 promotes a robust effort to rebuild domestic supply chains, emphasizing responsible production and efficient use, recycling, and development of alternatives for critical metals and minerals. In particular, the establishment of a robust program for assessment of critical metals and minerals is an essential first step. The Act also authorizes DOE to conduct a comprehensive program of RD&D as well as commercial application for critical materials, including development of alternatives, recycling and efficient production and use. These efforts should expand to include all materials vital to the clean energy transition. Onshoring offshore wind supply chains, for example, including raw material extraction, manufacturing, and final assembly could generate thousands of good jobs that would

FIGURE 6

Select Process for Key Metals and Minerals Needed for EV Battery Production: EU, US, and China Shares, 2019



Source: Modified from Benchmark Mineral Intelligence.

generate significant regional economic activity.

Protecting global supply chains, growing domestic industries and options, and investing in innovation are all critical to providing the energy and associated infrastructures for a clean energy future. This should, in fact, inform and broaden the definition of both energy infrastructure and energy security to help ensure policymakers are providing adequate direction and incentives to support the supply chains and industries needed for a clean energy future. In sum, the heavy reliance on foreign supply at key points in the supply chain point to the need for RD&D and associated deployment policies to support net-zero domestic mining, chemical processing and refining, and manufacturing of electric vehicle lithium-ion batteries. Policies and programs that could enhance US capacity and reduce supply chain risk in these areas include:

- protection of global supply chains for minerals/metals needed for wind, solar and batteries;
- an increased focus on trade relationships with South America and Africa;
- support for innovation to support

new domestic, environmentally responsible, net-zero

- mining activities for key minerals/ metals, including associated infrastructures;
- an increase in the capacities, capabilities, and associated infrastructures needed for key
- mineral chemical processing/refining and battery manufacturing;
- significant recycling programs for key metals and minerals; and
- research into substitutions for key minerals by earth-abundant metals and minerals.

Corporate America is Investing in Clean Energy Technologies

Companies across America are also calling for strong climate targets and are committing to their own emission reductions. Responses to the climate crisis range from initial exploration to carbon net zero commitments. Many are incorporating climate risk to the business in their strategic planning and investing in clean energy technologies. Over 300 businesses and investors called on the Biden Administration to announce a 50% emissions reduction target by 2030.[4]

So far, over 200 US companies have made a public pledge to meet net-zero emissions by 2050.[5] The industrial sector is also starting to align on net zero climate plans. At the Davos World Economic Forum in January, for example, over 400 companies from aviation, aluminum, cement/concrete, chemicals, finance, shipping, steel and trucking, announced an agreement to work together to decarbonize by 2050.[6]

Oil and Gas Companies

According to S&P Global Market Intelligence, "Many of the largest oil and natural gas companies in the U.S. and Canada jumped on the train to combat climate change in the second half of 2020 as they began to more fully embrace the energy transition and started to adopt stricter goals to reduce emissions."[7] Eleven oil and gas companies with a market cap of over $450 billion, including seven large integrated companies, e.g., Shell and BP, have net zero targets. Two—Williams and Enbridge—are oil and gas storage and transportation companies, one is

4. https://www.wemeanbusinesscoalition.org/ambitious-u-s-2030-ndc/
5. https://www.wemeanbusinesscoalition.org/companies #country=USA&checkedOptions=Science%20Based%20Targets%20initiative
6. https://www.reuters.com/article/climate-change-industry-int/heavy-industry-transport-sectors-to-align-on-net-zeroclimate- plans-idUSKBN29W0EA; https://missionpossiblepartnership.org/join-us

exclusively an exploration and production company, and one is a refining and marketing company. Nineteen other oil and gas companies do not have net zero targets but have a range of emissions reduction targets such as “plans to reduce greenhouse gas emissions per boe processed to 30% below 2014 levels by 2030,” or “committed to reducing greenhouse gas emissions intensity by 25% and flaring intensity by 50% by 2020…”.

Automakers

U.S. and global automakers are also changing their products to address consumer demand for lower emissions personal vehicles. More specifically:

- Ford announced a $29 billion investment in EVs and autonomous vehicles through 2025 and the majority of Ford vehicles will be electric.[8]

- General Motors as set a goal to stop making gasoline-powered vehicles by 2035, investing $27 billion in electric and autonomous vehicles by 2025.

- Tesla, the electric vehicle only car manufacturer, represented 79% of all EVs registered in the U.S. in 2020[9] and reached a valuation well over half a trillion dollars.

- Volkswagen is seeking to become the global market leader in e-mobility, investing 35 billion euros by 2025 and is planning to launch 70 pure e-models, having started on 20 already.[10]

- An increase in the capacities, capabilities, and associated infrastructures needed for key mineral chemical processing/refining and battery manufacturing;

- Significant recycling programs for key metals and minerals; and research into substitutions for key minerals by earth-abundant metals and minerals.

- BMW has announced plans for half of its sedans, SUVs, and mini cars to be electrified in Europe by 2030, noting that currently 13.3% are either all electric or hybrid, compared to an average of 8% in Europe[11]

Electric and Gas Utilities

Seventy percent of the top 30 largest electricity and gas utilities in the U.S.

7. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/path-to-net-zero-climatechange-takes-center-stage-at-more-us-oil-companies-61440277
8. https://www.caranddriver.com/news/a35432253/ford-ev-commitment-announced/
9. https://www.cnet.com/roadshow/news/tesla-cars-ev-registrations-us/
10. 1https://www.cleanenergywire.org/factsheets/dieselgate-forces-vw-embrace-green-mobility

Have net zero commitments, including giants like Duke, Southern, Sempra and PG&E. While the remaining nine do not have net zero commitments, many of their emissions reduction targets are significant. NextEra for example, has a 67% reduction target by 2025 from 2005 levels. Exelon has a 15% reduction by 2022 from 2015 levels and AEO has a 70% reduction by 2030 from 2000 levels (it also has a loose aspirational net zero goal by 2050).

CFTC Recommendation

With this background, the CFTC made a clear overarching recommendation: "The United States should establish a price on carbon. It must be fair, economy-wide, and effective in reducing emissions consistent with the Paris Agreement. This is the single most important step to manage climate risk and drive the appropriate allocation of capital." This is obviously a challenging recommendation, but it surfaces a critical point: if we are to meet ambitious goals for decarbonization in the mid-century time frame, we must address greenhouse gas emissions across the entire economy, not just in the electricity sector. At the same time, any such policy should respect the core principles of the Jim Baker – George Shultz proposal: the resources generated by a carbon emissions fee should be returned to the citizenry in a socially progressive manner, and mechanism, such as a carbon border adjustment, should be put in place to counter moves to "leak" domestic manufacturing and jobs outside the United States.

The Investment Community: An Increased Focus on Climate Change Risks

Returning to the financial dimensions of climate risk, the U.S. Department of the Treasury's Financial Stability Oversight Council, at its meeting last month, discussed climate risk and the implications of this risk for the nation's financial systems. The Council is charged with identifying risks to the financial stability of the U.S. The U.S. Securities and Exchange Commission, Federal Reserve and the U.S. Commodity Futures Trading Commission are also analyzing options on disclosure of climate risks.

Specifically, the Federal Reserve is working to "...understand the potential implications of climate change for financial institutions, infrastructure and markets." These activities need to be supported by research to update climate risk assessments in order to better guide investment planning and disclosure requirements. These actions also reinforce the Environmental, Social,

11. https://www.forbes.com/sites/neilwinton/2020/08/14/bmw-50-electrification-target-for-2030-is-ambitious-but-isit-achievable/?sh=1d57ec5201fe

and Corporate Governance (ESG) focus of shareholders and institutional investors. Taken together, we anticipate profound shifts in corporate priorities in the direction of accelerating the response to climate change. The rationale for the Fed's role was succinctly summarized by Chairman Powell:

> The reason we're focused on climate change is that our job is to make sure that financial institutions, banks, particularly the largest ones, understand and are able to manage the significant risks that they take.
>
> Jerome Powell, Chair, Federal Reserve
>
> Economic Club of Washington, April 14, 2021

Chairman Powell's perspective is shared by major investors and corporations. In February, both the International Monetary Fund and World Bank committed to increase efforts to address climate change by examining climaterelated financial stability risk. World Bank President David Malpass noted that the World Bank is launching new reviews to integrate climate into all its country diagnostics and strategies.

Similarly, this past January, IMF chief Kristina Georgieva, underscored that climate change posed a fundamental risk to economic and financial stability. Founded simultaneously under the 1944 Bretton Woods Agreement, the World Bank and International Monetary Fund are organizations responsible for significant investment pools.

Governed by its 190 member countries, the IMF has the ability to lend $1 trillion. And by June 2021, the World Bank expects to have deployed up to $160 billion in the past 15 months.[12]

The private sector is also examining the role of climate risks and the associated impacts on investment strategies. At an important convening of oil and gas industry and other executives in 2019, the second meeting of this group, Pope Francis challenged the industry, saying that climate change is a threat to the future of humanity, and that "Time is running out...Deliberations must go beyond mere exploration of what can be done, and concentrate on what needs to be done. We do not have the luxury of waiting for others to step forward, or of prioritizing short-term economic benefits." The dialogue also focused on economic, environmental, and social justice and how solutions and responses to climate change could and should assist the world's poor.

At this summit, major oil producers pledged to support "economically meaningful" carbon pricing regimes. I

12. https://www.dailysabah.com/business/economy/imf-world-bank-to-step-up-efforts-against-global-climate-risks

was included as CEO of an NGO focusing on deep decarbonization as were leaders from the energy investment community. US oil and gas companies at the summit at the CEO level included ExxonMobil, Chevron, ConocoPhillips, and Occidental. US financial institutions were also represented, and included Vanguard, BlackRock, State Street and CALSTRS, among others. Obviously, these are major players in our economy. Participants signed a joint statement to reflect conclusions of the dialogue, noting that:

"As leaders in the energy sector, the global investment community, and other organizations, we recognize that a significant acceleration of the transition to a low-carbon future beyond current projections requires sustained, large-scale action and additional technological solutions to keep global warming below 2°C while advancing human and economic prosperity.

- Companies should provide clarity for investors about how they are planning and investing for the energy transition. This includes issuing disclosures that provide meaningful and material information consistent with the reporting obligations in their jurisdictions.

- Companies should be encouraged to work with investors on the evolving recommendations of the Task

- Force on Climate-Related Financial Disclosures (TCFD), aligned with its four pillars of (1) governance, (2) strategy, (3) risk management, and (4) metrics and targets.

- Further, we support scenario analysis as an important and useful tool for assessing how resilient company strategies are to climate-related risks and opportunities pertaining to the 2°C or lower scenarios. We encourage companies to conduct a range of scenario analyses in line with the principles of TCFD.

- It is important that boards of directors assess climate-related issues as part of their risk oversight function, as well as management's role in evaluating and addressing these issues. These include sector and company-specific transition risks incorporating financial, policy and legal, technology, market, reputation and physical risks both acute and chronic. Opportunities such as resource efficiencies, new energy sources, new products and services should also be considered.

- Investors play a critical role through dialogue and feedback in supporting companies regarding appropriate disclosures on governance, strategy, and performance on climate-related risks."

Following up on the Vatican Summit, BlackRock, Vanguard, and State Street enhanced their ESG practices and leadership. Known as the "Big Three" they manage over $15 trillion in global assets, equivalent to 75% of U.S. GDP, and accounting for about 82% of the S&P 500's market capitalization.[13]

In his 2021 letter to CEOs, Larry Fink of BlackRock identified four issues pivotal to creating durable value: capital management, long-term strategy, purpose, and climate change. Fink made another statement that is fundamental to the point I wish to make at this hearing. He stated: "We know that climate risk is investment risk. But we also believe the climate transition presents a historic investment opportunity."[14]

Vanguard and Blackrock have both expressed support for the Sustainability Accounting Standards Board (SASB) and Task Force on Climate-related Financial Disclosures (TCFD) disclosure frameworks. State Street announced that beginning in 2022, they will vote against independent directors at companies that underperform according to SASB disclosures. The Big Three and Corporate Carbon Emissions Around the World, a paper to be published in the Journal of Financial Economics, examined the role of the BlackRock, Vanguard, and State Street Global Advisors on the reduction of global corporate carbon emissions. The authors found a "strong and robust negative association between the Big Three Ownership and subsequent carbon emissions among MSCI[15] index constituents."[16]

Regarding climate risk, Vanguard is placing greater focus on boards' "climate competency" and joined the "Net Zero Asset Managers Initiative" to cut the net GHG emissions of its funds to zero by 2050. BlackRock changed its thinking on shareholder resolutions, which were historically seen as a tool of last resort. Now, BlackRock characterizes shareholder votes as a "primary tool" for companies that are ESG laggards. In late 2020, State Street joined Climate Action 100+, which is an investor initiative focused on companies' plans to align with the goals under the Paris Agreement. This is the single most important step to manage climate risk and drive the appropriate allocation of capital."

13. https://www.thinkadvisor.com/2020/11/30/group-aims-to-limit-power-of-blackrock-vanguard-state-street/
14. https://www.blackrock.com/corporate/investor-relations/larry-fink-ceo-letter; https://www.forbes.com/sites/iese/2021/01/27/how-does-blackrock-measure-up-on-climatechange/?sh=6cfbcbc243e1
15. The Morgan Stanley Capital International (MSCI) index measures equity market performance in global emerging markets, and represents 13% of global market capitalization.
16. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3553258

Conclusion: The Need for New Climate Risk Frameworks and Methodologies

Clearly, the private sector is moving rapidly towards climate risk disclosure as a fundamental pillar of investment decisions. The proliferation of expensive extreme weather events helps drive this. Governments and multilateral institutions, such as the G-20, are looking to incorporate such risk disclosure into their financial regulatory responsibilities to provide relevant information to investors. President Biden is expected to take executive action requiring financial institutions and companies to disclose climate risks, and a number of central banks are working on climate risk reporting and are preparing to stress-test the global financial system's response to such risks.

The IMF has a new "Climate Change Indicators Dashboard" that provides definition and information on a range of climate change issues, underscoring the increasing interest of financial institutions in climate risk. On a link on the dashboard entitled, Financial, Physical and Transition Risk Indicators," it notes that, "These indicators include green finance indicators to illustrate the financial support towards a low-carbon emission environment, such as carbon footprint adjusted loans for deposit takers and green bonds. Other indicators cover climate-related physical risk and transition risk."[17]

Another link on the IMF dashboard labeled, "cross border" climate indicators, notes that, "Indicators in this category examine how CO_2 emissions from production in one economy can be used to meet demand at home or abroad as well as how they are impacted by the decisions of multinational enterprises on where to locate their production. They include CO_2 emissions embodied in trade, measures of trade in environmental goods, and several indicators related to direct investment, including measures of emissions associated with tangible investments financed by direct investment and with value added of multinational enterprises.

It's clear that the global finance community is rapidly moving towards climate risk disclosures and the stakes are

high both for the climate and for the financial relationships of countries, allies and adversaries alike in the geopolitical domain. For example, the EU is working on a border adjustment tariff for products with embedded emissions that could affect exports from the U.S. to Europe.

Closer to home, as noted earlier, the Commodities Futures Trading Commission, in an extensive analysis of

17. https://climatedata.imf.org/pages/go-indicators

climate change risk, made many recommendations on how to address threats to the Nation's financial systems. Important to this discussion, it recommended, "Financial regulators, in coordination with the private sector,

should support the development of U.S.-appropriate standardized and consistent classification systems or taxonomies for physical and transition risks, exposure, sensitivity, vulnerability, adaptation, and resilience, spanning asset classes and sectors, in order to define core terms supporting the comparison of climate risk data and associated financial products and services. To develop this guidance, the United States should study the establishment of a Standards Developing Organization (SDO) composed of public and private sector members."[18]

It is critical that we develop a new, flexible climate risk profile for energy systems and the broader economy, including the associated analytical tools. This is an area that needs significant innovation investments in new models, techniques, and approaches for considering climate change-based risk into the system. We need to answer key questions about supply chain and Scope 2 and 3 emissions to ensure that the methodologies for any risk disclosures we develop are fair, focused on emissions and not favored products or technologies, accommodate regional differences, and that we maximize emissions reductions in all sectors. We also need to understand climate disclosure actions and activities of other regions and countries of the world to adequately assess their impacts on U.S. export markets.

It is also critical that multi-agency efforts, with support from universities, DOE's National Laboratories, and other research institutions continue to develop tools, programs, and partnerships that closely monitor climate conditions, feeding into decision making processes in both the public and private sectors. The risk profiles need to be developed with regional granularity not just for polar vortices but for the entire spectrum of weather and other climate change extremes. It is a major challenge and requires rapid action – but it is essential that we reset how we assess climate risks and develop technologies and policies for reaching net zero emissions by midcentury.

Mr. Chairman, ranking member Toomey and members of the Committee, thank you for the opportunity to testify today and I look forward to your questions.

17. https://www.cftc.gov/sites/default/files/2020-09/9-9 20%20Report%20of%20the%20Subcommittee%20on%20Climate-Related%20Market%20Risk%20%20Managing%20Climate%20Risk%20in%20the%20U.S.%20Financial%20System%20for%20posting.pdf

Endnotes

i. Energy Wire, April 19, 2021.

ii. https://nca2018.globalchange.gov/

iii. https://www.ipcc.ch/sr15/chapter/spm/

iv. https://www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx

v. Transforming the Nation's Electricity System: the Second Installment of the Quadrennial Energy Review, released by the Department of Energy, January, 2017

Written Testimony

Reimagining Our Innovation Future

On April 15, 2021, the House Committee on Science, Space and Technology convened a hearing entitled, "Reimagining Our Innovation Future."

Witnesses included: Mr. Norm Augustine, Former CEO of Lockheed Martin; Dr. Frances H. Arnold, Linus Pauling Professor of Chemical Engineering, Bioengineering and Biochemistry, California Institute of Technology; Research; The Honorable Ernest J. Moniz, President and Chief Executive Officer, Energy Futures Initiative and Former Secretary, U.S. Department of Energy; and Dr. Farnam Jahanian, President, Carnegie Mellon University.

Madam Chair, Ranking Member Lucas, members of the Committee, thank you for the opportunity to testify before you today.

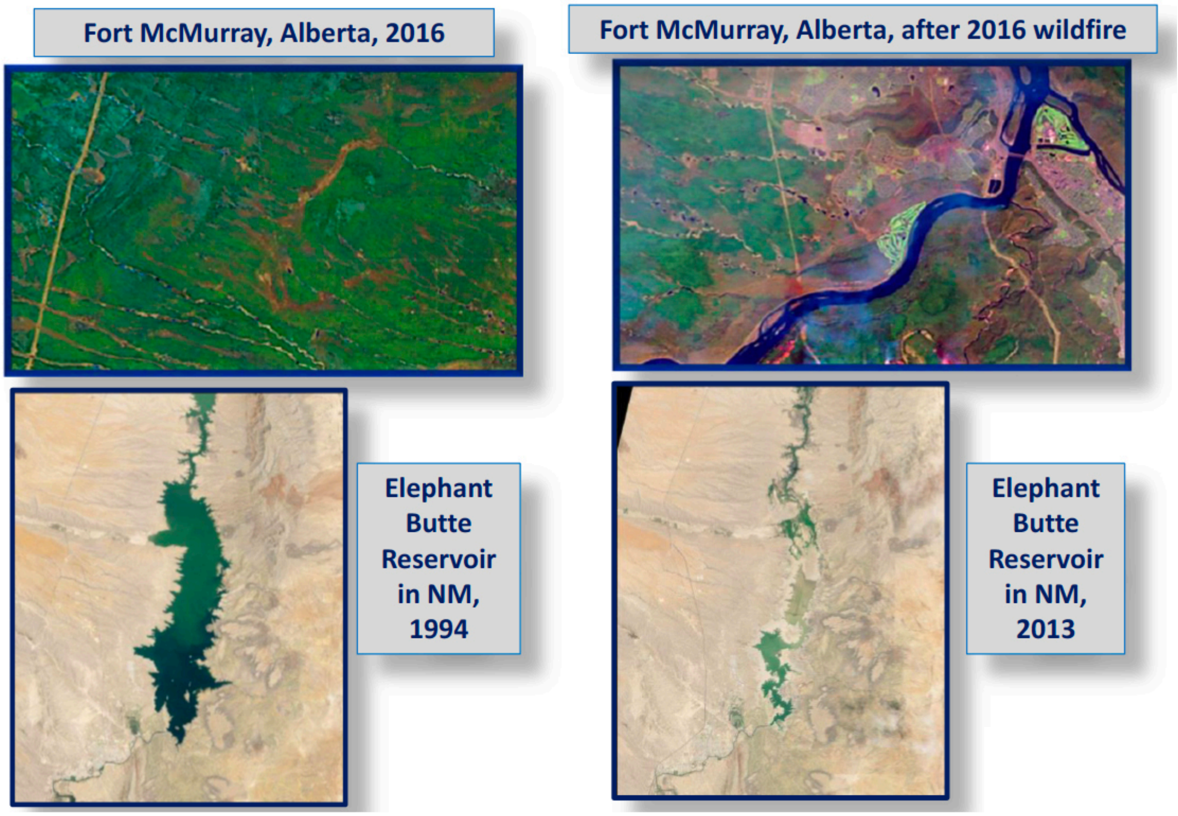
The US is approaching 600,000 deaths from the COVID pandemic. The loss of decades old businesses, millions of jobs, and the overall impacts of the pandemic on the US and global economy are without parallel in modern times.

At the same time, the world is facing another crisis of global and existential proportions: climate change. Its impacts and their growing severity are becoming increasingly clear. According to NOAA, 2011–2020 was the warmest decade on record for the globe, with a surface global temperature of 1.48°F above the 20th century average. Every month of 2020 except December was in the top four warmest on record for that month.

There are, as we have seen, a range of physical impacts of these temperature increases – rising sea levels, increased frequency and intensity of storms, increased drought, declining water supplies, melting glaciers, increased wildfires, greater extremes of both heat and cold. Figure 1 offers graphic pictures taken by NASA of the impacts of wildfires and droughts in North America. The science is clear, and the data are compelling—climate change is a major threat to our planet and to our way of life, and the clock is ticking.

The growing severity of these changes – and the urgent signals they are sending – has not gone unnoticed by the world's nations. In 2015, 197 countries adopted the Paris Agreement. According to the UNFCCC, 191 countries have submitted their first Nationally Determined Contribution (NDC) and eight have submitted their second.[i] Importantly,

FIGURE 6
Examples of the Impacts of Climate Change in North America: Increased Wildfires, Severe Drought



Source: NASA Images of Change.

since Paris, the number of countries that have implemented or are considering net zero emissions targets, now stands at 130, up from around 17 just two years ago.

This is true in the US as well, where the Biden Administration is setting us on a new and accelerated course towards an economy with net zero greenhouse gas (GHG) emissions by mid-century. The U.S. has rejoined Paris and within a matter of days, it is expected that the Administration will release an updated ambitious Nationally Determined Contribution setting a new interim target for GHG reductions by 2030. I applaud these actions and look forward to working on ways the US can meet these increased ambitions and to highlight these and other U.S. actions at COP 26 in Glasgow later this year.

Critical Context for Guiding Innovation Investments

There is a range of responses that are needed to address the climate crisis but today I would like to focus on one: the critical need for technology innovations to address both the growing impacts of climate change and the increased ambitions of most of the world's nations, including the United States. As the science of climate change has advanced and the changes in the impacts of climate become more manifest and severe, the Energy Futures Initiative's analysis has increasingly focused on those innovations that are central to any climate action plan that can succeed in reaching the aggressive—but essential—net-zero goal.

Before I discuss some of the innovations that will be key to deep decarbonization, I think it is important to place the associated investments in a larger context as we consider the portfolio of technologies needed to meet net zero targets by mid-century. These include: the changing risk profile; the growing interdependencies of critical infrastructures; the potential, indeed likely, changes in our work environment, post-COVID; the growing importance of supply chains; and regional differences and needs.

- **The changing risk profile.** In the last two years, two of our largest states – Texas and California – have been devastated by the impacts of climate change. Wildfires in California forced the preemptive shutdown of large sections of the state's grid. Last August, a western US extreme heat wave forced rolling blackouts in California. More recently in Texas, the extreme cold snap left much of the state without power and heat. These and other events suggest that weather and other risk profiles that have guided infrastructure protection, development, and investments are no longer adequate for risk assessment, associated policy actions, and infrastructure investments in the future. Yesterday's weather is no longer a good guide for planning to meet tomorrow's weather extremes

  Late last month, the Financial Stability Oversight Council met; its agenda included a discussion of climate risk and the implications of this risk for the nation's financial systems. The SEC, Federal Reserve and CFTC are all analyzing options on disclosure of climate risks. The Federal Reserve is working to "…understand the potential implications of climate change for financial institutions, infrastructure and markets." These activities need to be supported by research to update climate risk assessments in order to better guide investment planning and disclosure requirements. These actions also reinforce the ESG focus of shareholders and institutional investors. Taken together, we anticipate profound shifts in corporate priorities in the direction of accelerating the response to climate change.

- **The complex interdependencies of critical infrastructures.** Preliminary analysis of what went wrong in Texas, from a systems perspective, suggests that the natural gas, electricity, and water systems were all affected by the extreme cold and that their interdependencies were major contributors to the electricity crisis.

  This is not surprising. The first installment of the Quadrennial Energy Review, released in in 2015, included a section specifically focused on the 2011 cold snap in Texas and New Mexico, emphasizing the growing interdependencies of the electricity and natural gas infrastructures, borne out by the events in Texas 10 years later (see Text Box 1).

- **The growing importance of supply chains.** Increased electrification, new clean energy technologies, LNG exports to allies, and COVID have raised issues about the security of global supply chains and the need to focus on creating, building, and reinvigorating domestic options. Increased electrification and the buildout of transmission lines and variable renewable generation technologies will, for example, mean dramatic increases in demand for steel, EV battery manufacturing, the mining, processing, and refining of key metals and minerals including lithium, cobalt, manganese, and nickel, and cathode and anode production. Also, this demand growth is not occurring in a vacuum. Net zero targets are increasing demand—and competition—for steel, EVs, batteries, and other key materials and technologies around the world. cascading and inter-acting risks could amplify climate impacts on financial systems. At the same time, the re-pricing of assets based on climate risk should be orderly, informed, and systematic.

  The need to address these issues was underscored by President Biden's Executive Order 14017, America's Supply Chains, which notes that "More resilient supply chains are secure and diverse—facilitating greater domestic production, a range of supply, built-in redundancies, adequate stockpiles, safe and secure digital networks, and a world-class American manufacturing base and workforce. Moreover, close cooperation on resilient supply chains with allies and partners who share our values will foster collective economic and national security and strengthen the capacity to respond to international disasters and emergencies."

- **Changes in the work environment, post-COVID.** While no one knows for certain how the unprecedented experience of the pandemic will affect the work environment of the future, it appears likely that there will be dramatic increases in the numbers of people working from home. This could have significant implications for energy needs and the associated infrastructures to support the changed workplace.

First and foremost, it could require increased demand for reliable and resilient electricity supplies as productivity will be directly linked to power availability. It may also lower energy demand for transportation at the same time it could increase residential electricity demand; peak electricity demand profiles could change. In addition, it would require universal access to broadband to ensure all Americans have equal workplace flexibility options. The COVID crisis drove this point home: children without access to broadband could not "go to school". Businesses without access to broadband couldn't meet customer needs. Finally, the increased use of broadband and the internet to conduct business could increase concerns about cyber-security. Innovation investments should consider this changing profile and address these needs. An overarching point: continued electrification of the economy ups the ante for reliability, resilience, security and power quality of the electric grid.

- **Regional differences and needs.** Last, and perhaps most important for the members who represent varied constituencies across the country, the resources, infrastructures, emissions profiles, innovation, and policy needs vary greatly by region of the country—a "one size fits all" approach will likely impede, not accelerate progress towards deep decarbonization. EV charging infrastructures will, for example, look very different in both rural and urban areas, where the typical "suburban EV model mindset" and its associated infrastructure will have little relevance to densely populated cities and sparsely populated regions of the country. Industrial centers in the U.S. will have ongoing need for high quality process heat that cannot easily be provided by electricity. Many regions have sequestration options, some do not. Offshore wind resources are clearly available only to those regions with coastlines, and onshore wind resources vary greatly across the country as do solar resources. They also have large seasonal variations.

BOX 1

QER 1.1 Highlighted Growing Gas/Electric Interdependencies

The Big Chill: A Disruptive Event Made Worse by Infrastructure Interdependencies[1]

The "Big Chill" of 2011 illustrates the complicated relationship between natural gas and electric power, which had compounding effects during a period of extreme weather.

During the first week of February 2011, the U.S. Southwest was hit by an arctic cold front that was unusually severe in terms of its low temperatures, gusting winds, geographic extent, and duration. From January 31 to February 4, temperatures in Texas, New Mexico, and Arizona were the coldest experienced within the region since 1971. Dubbed the "Big Chill" in the media, it overwhelmed the routine preparations for cold weather that had been put in place by electric generators and natural gas utilities located in those states.

Within the Electric Reliability Council of Texas (ERCOT) Interconnection, starting in the early morning hours of February 2, the cold temperatures and wind chill caused a significant number of outages at generating plants, with approximately one-third of the total ERCOT generating fleet unavailable at the lowest point of the event. With electricity demand soaring because of the cold weather, ERCOT and some utilities in New Mexico instituted rolling blackouts to prevent collapse of their electric systems. For the Southwest as a whole, 67 percent of electric generator failures (by megawatt-hour) were due directly to weather-related causes, including frozen sensing lines, frozen equipment, frozen water lines, frozen valves, blade icing, and low-temperature cutoff limits on equipment.

Gas producers and pipelines were also affected in Texas, New Mexico, and Arizona. Natural gas production was diminished due to freeze-offs and the inability to reach gas wells (due to icy roads) to remove produced water and thereby keep them in operation. When rolling electricity blackouts hit gas producers and gas pipelines, it had the effect of causing further losses to natural gas supply. The ERCOT blackouts or customer curtailments caused or contributed to 29 percent of natural gas production outages in the Permian Basin and 27 percent of the production outages in the Fort Worth Basin, principally as a result of shutting down electric pumping units or compressors on gathering lines. As a result of all these factors, natural gas deliveries were affected throughout Texas and New Mexico. More than 30,000 customers experienced natural gas outages at some point during this period.

The majority of the problems experienced by the many generators that tripped, had their power output reduced, or failed to start during the event were attributable, either directly or indirectly, to the cold weather itself. However, at least another 12 percent of these problems were attributed afterward to the interdependencies between gas and electricity infrastructures (such as lost electricity generation due to natural gas curtailments to gas-fired generators and difficulties in fuel switching).

1. Federal Energy Regulatory Commission and North American Electric Reliability Corporation. "Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1-5, 2011: Causes and Recommendations." August 2011. http://www.ferc.gov/legal/staff-reports/08-16-11-report.pdf. Accessed February 2, 2015.

The Need for a Decade of Super-charged Innovation

Energy innovation is the essence of America's security and strength. Our ability to innovate is at the heart of American economic success and optimism. It is essential for national security, addresses complex societal challenges and improves our quality of life. It is critical for addressing the existential threat of climate change. Central to U.S. leadership in innovation is our unparalleled innovation ecosystem which includes the Federal, state, local and tribal governments; national laboratories; research universities; the private sector; nonprofits and philanthropies

Several groups, including the American Energy Innovation Council comprised of CEOs of large American companies, have argued for tripling federal clean energy investment. The Biden Administration has proposed an even more ambitious agenda—the President's request for FY 2022 discretionary funding includes more than $10 billion, a 35 percent increase over FY 2021, for clean energy innovation across all non-defense agencies. Further, as stated in the budget summary, "The 2022 discretionary request puts the Nation on a path to quadruple clean energy research Government-wide in four years."[1] The federal energy innovation portfolio—indeed the portfolio across the entire innovation chain—needs to be "all of the above" to match time scales and geographies and to emphasize optionality. History shows that we achieve better results when flexible innovation pathways are favored over planned, prescriptive outcomes.

This broad approach is critical as we accelerate clean energy innovation investments—both public and private—over the next decade or so. Maximum optionality and flexibility will be needed to address the needs of different regions and of all end use sectors—including the industrial, heavy transportation and agricultural sectors that are hard to decarbonize. Breakthrough technologies will be needed.

Innovation can also drive job creation, which is essential as we come out of the COVID crisis with a need to create millions of good jobs. These are bipartisan opportunities to create clean energy jobs and strengthen our country, where coalitions—labor and business, environmental groups and financial institutions, religious and military leaders, public and private sectors, Republicans and Democrats, and others—are needed to accelerate legislative solutions to the climate challenge.

Accelerating this transformation, however, will not be easy. U.S. energy systems are highly capitalized and provide essential services. making them risk averse and prone to considerable

1. U.S. Office of Management and Budget, Letter from Acting Director Shalanda D. Young to Senate and House Leadership, April 9, 2021.

FIGURE 2
California Wind and Solar Generation fo Each Day of 2017, CA Installed Capacity, 2019

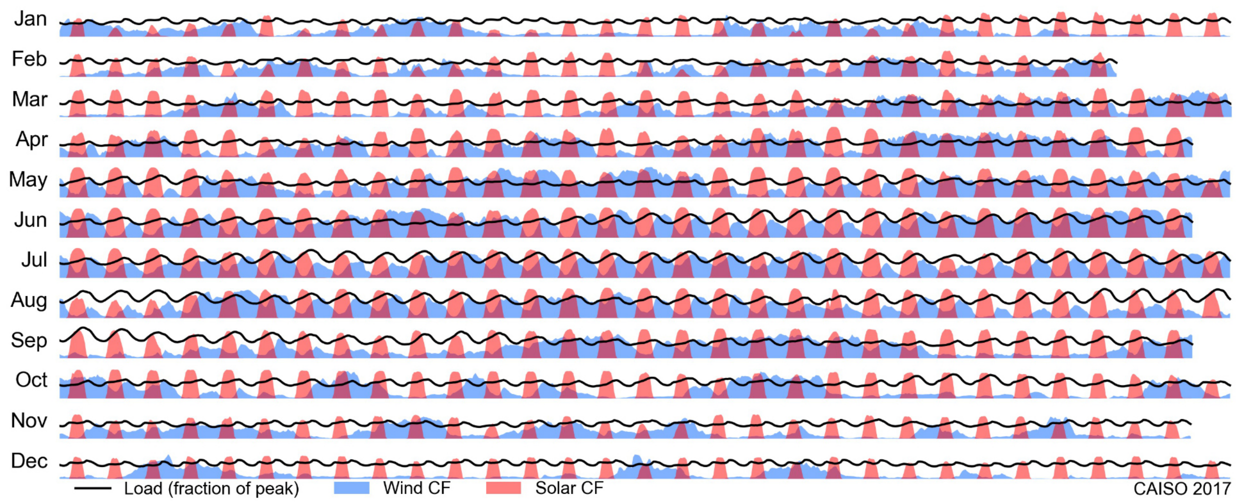


Figure 2 shows the hourly wind and solar generation for every day in 2017. Numbers in green count the days in the year where there was little to no wind generation in the state. The inset shows the installed battery storage capacity and duration in California which is currently insufficient to provide longer duration storage during multi-day periods with little to no wind generation. Source: CAISO data, EFI analysis.

inertia. This creates an inherent tension between the energy incumbents and the technology disruptors; mitigating this tension through innovation, thoughtful policies, and creating clean energy job options is essential for a more rapid transition to deeply decarbonized energy systems and end use sectors.

Innovation is at the Core of Climate Change and Infrastructure Modernization

As noted, there will be no single nor simple solution to meet net zero emissions. While the key technological near-term strategies to move towards net zero may be generally understood (policy support is a separate and less clear-cut issue), many that may be currently available could benefit from further improvements in performance and cost. Also, many of the technology solutions needed to meet mid-century targets are not yet available, a conclusion specific to California that was made in the EFI study, *Optionality, Flexibility & Innovation: Pathways for Deep Decarbonization in California,* released in May, 2019.

Electricity storage is a case in point. Deployment of electricity storage systems is only in its earliest stage. Current commercial battery storage technology typically provides from 4-6 hours of storage; other options may provide longer duration storage but are site-specific, limited by geography or geology. Large scale deployment of intermittent carbon free electricity generation will require significant levels of longer duration storage capable of meeting daily, weekly, and even seasonal variations. The 2019 California study illustrates the challenges associated with limited-duration storage, seen in Figure 2.

The recent Clean Energy Innovation Report from the International Energy Agency provides a global context for immediate action on clean energy investment. The report emphasizes that while energy efficiency and renewable energy will be crucial, they are not sufficient to meet net-zero climate goals, especially in sectors like heavy industry and transportation.

The IEA Report also estimates that, on a global level, at least 40 percent of emissions reductions to reach net zero will rely on technologies not yet at commercial scale—including known technologies such as end-use electrification, CCUS, hydrogen, and bioenergy. In the study, IEA also stresses that action is necessary immediately because past innovations, such as LEDs and lithium-ion batteries, took decades to reach full commercialization, and some energy-consuming infrastructure operates on refurbishment cycles of 25-30 years.

There is also a large body of analytical evidence about the need for increased national investment – both public and private - across the full spectrum of energy innovation, from use-inspired fundamental research through demonstration and initial deployment. Various metrics have been used to assess the adequacy of investment in energy innovation. The 2019 Report by EFI and IHS-Markit, Advancing the Landscape of Clean Energy Innovation, estimated that global private R&D spending in the energy industry is substantially lower, both in dollars and in share of revenue, than in other major industries.

Looking at trends in government investment, federal energy R&D spending has been decreasing as a share of GDP. Federal energy R&D spending also lags other areas of federal R&D. A recent study by Columbia University Center for Global Energy Policy, for example, noted that federal energy R&D spending is less than one quarter the level for health care R&D and less than 10 percent of national defense R&D spending.

These issues have been documented in other studies as well, and the resulting recommendations have been clear and consistent. Also, the American Energy Innovation Council (AEIC) noted that government investment fills an essential niche by funding innovation where "the private sector cannot or will not."[2]

2. American Energy Innovation Council, Energy Innovation: Fueling America's Economic Engine (Washington, D.C., 2018)

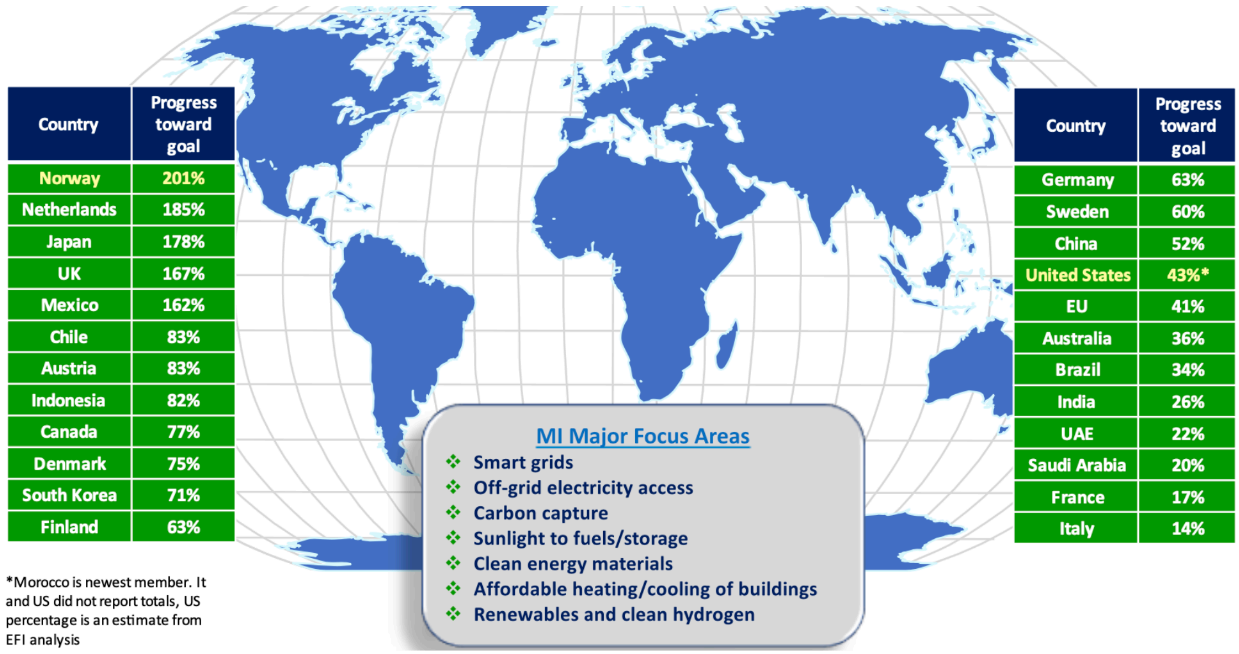
There is significant consensus from these and other reports on recommendations for federal energy innovation support that include:

- Expand the federal government's innovation role beyond early-stage R&D to fund demonstration, as well as establish complementary programs to promote deployment
- Fund new or vastly expanded innovation programs in key breakthrough technology areas
- Improve coordination across the federal government and expand the decarbonization innovation mission beyond DOE
- Harness the full range of tools for federal support, such as loan guarantees, financing support, tax credits, and procurement
- Create programs that can unlock funding from the private sector and collaborations that bring together public and private innovation resources
- Collaborate with state, Tribal, and local governments to support regional innovation, in many cases building on DOE national laboratory support
- Build on and supercharge successful innovation structures like ARPA-E, DOE Innovation Hubs, and Energy Frontier Research Centers

As Secretary, I led the effort to develop Mission Innovation, a collaborative commitment by 24 countries as well as the European Union to double the level of public investment of national governments in clean energy innovation over a five-year period. Mission Innovation was highlighted by national leaders at the first day of COP-21, a key companion effort to support the Paris Agreement. The Trump Administration did not follow-through on that commitment, and instead sought to cut DOE applied energy R&D programs dramatically in successive budget proposals over the past four years. Fortunately, Congress rejected those proposals and instead provided sustained growth in the DOE energy investment portfolio in the face of these headwinds, but at a slower pace than envisioned in the Mission Innovation commitment. As the most recent Mission Innovation scorecard shows (Figure 3), the U.S. public investment increased by over 43% over the first four years of Mission Innovation, but at a slower pace than 15 of the 24 Mission Innovation countries, including China.

Successful innovation requires sustained multi-year investment, and action by the Administration and Congress to revitalize and enhance the U.S. commitment to Mission Innovation. As part of this effort, the current seven focus areas of Mission Innovation noted in Figure 3 also should be expanded to include emerging promising technologies for carbon dioxide removal and advanced nuclear fission and fusion

FIGURE 3
Progress of Mission Innovation Countries/EU on 2015 Commitment to Double National Investment in Clean Energy Innovation Over Five Years



energy technologies.

A robust Mission Innovation program will not only be essential to any new agreement that will emerge at COP-26 in Glasgow, but also will serve to strengthen our global energy security posture. In 2014 after the Russian incursion in Ukraine, as Secretary I led an effort to develop the "G-7 Energy Security Principles" to move the U.S. and its allies off the decades-old oil-centric definition of energy security. The new, modernized view of energy security incorporates conventional energy as well as clean energy risks and, for the first time, formalizes the geopolitical security risks of climate change. These principles were adopted by G-7 energy ministers in Rome and by G-7 and EU leaders later that year in Brussels. The modernized principles, summarized in Figure 4, acknowledge the importance of clean energy as an enabler of energy security and underscore the high value of clean energy innovation as an enduring contributor to global security (highlighted in green).

FIGURE 4
Energy Security Principles Adopted By G7/EU Leaders, 2014

- Flexible, transparent, and competive markets, including gas markets, should be developed.
- Infrastructure modernization will improve energy system resilience. Promoting suppy and demand policies will help withstand systemic shocks.
- Energy fuels, sources, and routes should be diversified and development of indigenous sources of energy should be encouraged.
- Reducing our greenhouse gas emissions and accelerating the transition to a low carbon economy are key contributors to enduring energy secutiry.
- Energy efficiency in demand and supply, and demand response management should be enhanced.
- Deployment of clean and sustainable energy technologies and continued investment in research and innovation should be promoted.
- Energy response systems, including reserves and fuel substitution for importing countries, should be put in place to manage major energy disruptions.

Adapted from Joint Statement, Rome G7 Initiative or Energy Security, May 2014.

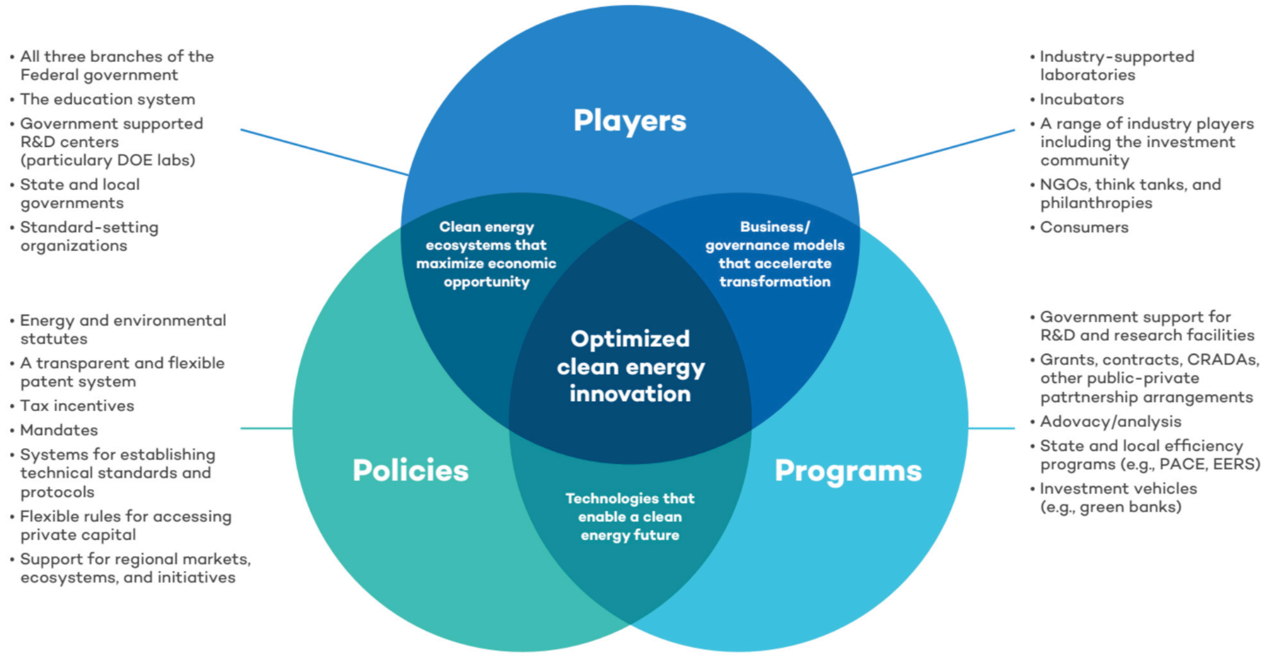
Portfolio Elements for a Supercharged Innovation Program

The U.S. clean energy innovation system is unparalleled. It includes extensive collaboration among all levels of government, national laboratories, research and academic institutions, and the private sector. To ensure the U.S. economy reaches net zero carbon by midcentury, there must be a supercharging of clean energy innovation. This means increased, and more targeted, public, and private sector investment and close alignment across all stages of innovation—from basic research through demonstrations and deployment.

Federally supported and led energy innovation research depends on close alignment of activities across agencies, regardless of appropriated amounts. A key focus is the Department of Energy, which has historically administered the lion's share of Federal investment in clean energy innovation. Other agencies, however, have and must continue to play a significant role in clean energy innovation. These include the National Science Foundation (NSF), Department of Defense (DOD), the

FIGURE 5

Aligning the Key Players, Policies, and Programs Can Optimize Clean Energy Innovation



Source: Energy Futures Initiative (EFI), 2018

Department of Transportation (DOT), and the Department of Agriculture (USDA); portfolios at these agencies have different areas of focus—each important to support the overall innovation system. Figure 5 depicts how the alignment of key players in both the public and private sector, policies and programs can help optimize clean energy innovation.

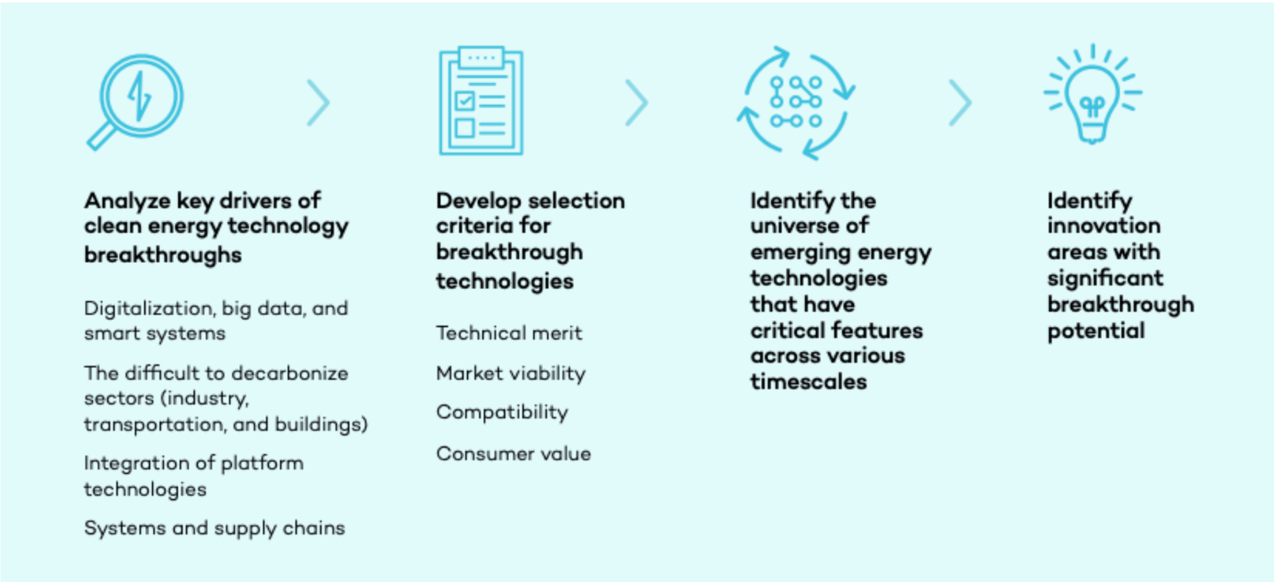
At the core of success in developing the technologies and systems needed to reach a carbon neutral economy by midcentury is a robust clean energy innovation portfolio. Developing a portfolio based on any single variable, such as cost, may be inadequate. Some sectors, such as aviation and manufacturing, are more difficult to decarbonize than others but will require significant attention, innovation spending, and other types of policy, regulatory, and business model support. There are also significant systems integration needs that cannot be met if innovation investments are too narrowly focused.

Breakthrough Technology Evaluation Criteria

Advancing the Landscape of Clean Energy Innovation study described the importance of a systematic method for planning a comprehensive RD&D portfolio. The report provided a four-step methodology for identifying

FIGURE 6

Aligning the Key Players, Policies, and Programs Can Optimize Clean Energy Innovation[3]



Source: Energy Futures Initiative (EFI), 2018

breakthrough technologies to address national and global challenges and help meet near-, mid-, and long-term clean energy goals as seen in Figure 6.

The following are expanded definitions of these technology selection criteria:

- **Technical Merit** includes energy or environmental performance, especially GHG reduction, leading to systems-level performance improvements. It also includes enabling innovations or knowledge and heuristic gains for cost, risk, and performance across a variety of technologies or systems.
- **Market Viability** includes manufacturability at scale with adequate and secure supply chains; a viable cost-benefit ratio for providers, consumers, and the greater economy; maturity to support very large scale-up; economic and environmental sustainability from a life-cycle perspective; significant market penetration; and revenue generation.
- **Compatibility** includes potential to interface with a wide variety of existing energy infrastructures (interoperability); potential to adapt to a variety of possible energy system development pathways

3. https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5e56b4e66212a045e9892505/1582740734147/Advancing+th e+Landscape+of+Clean+Energy+Innovation.2+2019.pdf Page 78

(flexibility); potential to expand or extend applications beyond initial beachhead applications (extensibility); and the ability to minimize stranded assets.

- **Consumer Value** takes into consideration potential consumer preference issues, such as expanded consumer choice (by facilitating the introduction of new or improved products and services) and ease of use.

Shortlist of Breakthrough Technology Areas

The EFI/IHS-Markit study identified five broad technology areas deemed to have high breakthrough potential, including:

1. Advanced battery and long-duration energy storage technologies;

2. Deep decarbonization: large scale carbon management;
   a. Carbon capture, use and storage at scale
   b. Sunlight to fuels
   c. Biological sequestration

3. Technology applications of industry and buildings as sectors that are difficult to decarbonize;
   a. Hydrogen
   b. Advanced Manufacturing Technologies
   c. Building Energy Technologies

4. Advanced nuclear reactors;

5. Platform technologies, such as AI, machine learning and big data analytics;

6. Systems: electric grid modernization and smart cities.

The process of technology innovation is dynamic, and over the past several years several other new technology areas with breakthrough potential have emerged including:

1. Technological and technologically enhanced carbon dioxide removal;

2. Nuclear fission micro-reactors; and

3. Nuclear fusion technologies

Progress is being made. The Energy Act of 2020 marks a significant move to advance and accelerate the energy innovation agenda. The Act also authorized a series of measures to improve DOE management of the innovation process. In addition, the Act authorized new energy RD&D efforts in seven major titles that largely mirror the breakthrough technology areas identified above, including:

- Energy Efficiency

- Nuclear Energy

- Renewable Energy and Storage

- Carbon Management

- Carbon Removal
- Industrial and Manufacturing Technologies
- Critical Materials; and
- Grid Modernization.

The Energy Act of 2020 also emphasized the importance of federal support for demonstration projects as a critical need in the end-to-end innovation (i.e., RD&D) cycle for next generation clean energy technologies. Government policies and programs that enhance learning across the innovation chain should be built out and encouraged. The authorizations in the Energy Act were accompanied by increased appropriations to translate these directives into action. For example, more than $400 million dollars was appropriated to demonstration projects across these key technology portfolio elements, including $250 million for the Advanced Reactor Demonstration Program; and $115 million for SMR development, design, and demonstration. The consideration of the supply chain and jobs needs—both are key to later stages of the innovation system— promote long-term success. Wind energy programs, for example, received significant funding for offshore and distributed systems, advanced manufacturing of component parts, grid integration, and job training.

Enabling Platform Technologies

The 2019 EFI/HIS-Markit study also identified the importance of so-called platform technologies as an enabler of energy technology innovation. The rapid development of digital, data-driven, and smart systems—largely from outside the energy sector—has unlocked the potential of other platform technologies that could be scalable across the entire energy value chain. Key platform technologies include:

- Additive manufacturing, enabling more efficient and customized fabrication of products at smaller production scales;
- Materials by design, utilizing computational methods to enable more rapid prototyping of materials to meet specialized requirements;
- Artificial intelligence and big data analytics to provide new insights into many applications ranging from optimization of industrial processes to improved reliability of the electricity grid;
- Genomic science and synthetic biology, to develop new biomass energy sources, enhanced carbon capture pathways and to substitute biological for chemical processes; and
- Blockchain, to enhance the integrity of databases and provide better tracking of transactions throughout

the supply chain.

A greatly enhanced focus on these platform technologies could be led by NSF, with important contributions from DOE, DOD Commerce/NIST, HHS/NIH and others in a whole of government approach.

Priority Areas of Emphasis

Federal agencies must work closely with the private sector to ensure the evolving policy environment, climate science, and financial and investment trends factor into the innovation programs and the technology portfolio. RD&D areas that merit additional support include cross-cutting technologies that reduce emissions in multiple sectors and strengthen the foundation of the innovation infrastructure. A few examples are: clean hydrogen; sustainable supply chains; climate risk analysis tools; and carbon dioxide removal.

Clean Hydrogen

Hydrogen is a clean energy carrier with multiple applications across every sector of the economy. Clean hydrogen could play an essential role in a low carbon economy as a zero-carbon "fuel" and was identified as one of ten technologies with significant breakthrough potential in *Advancing the Landscape of Clean Energy Innovation.*

EFI analysis in 2019 also concluded that hydrogen was one of four cross-cutting clean energy pathways that could help California meet its mid-century net zero targets. The Energy Act of 2020 provides a strong foundation to build a robust hydrogen ecosystem in the United States through appropriations to study the benefits of blue hydrogen, research methods to reduce hydrogen transportation costs, and advance fuel cell technologies, among others.

There is significant interest among investors, utilities, oil and gas companies, and heavy industry to be part of the hydrogen solution. Opportunities for clean hydrogen end uses include industrial processes, heavy transportation, and power generation. Hydrogen from natural gas steam methane reforming (SMR) processes are already mature and meet almost all current domestic hydrogen demand. Producing "blue hydrogen" by capturing the carbon emitted via this hydrogen production approach is an off-the-shelf clean hydrogen solution. Using clean electricity to produce "green hydrogen" is also commercially available but requires further innovation to reduce costs.

As with carbon capture and sequestration, large hydrogen users may have the business expertise and capital availability to support an end-to-end hydrogen supply chain for their own uses. For clean hydrogen to scale, however, new infrastructure investments will likely be required to enable market hubs where several producers and consumers are co-located and benefit from economies of scale.

The infrastructures needed for hydrogen market formation tend to be highly regional. Potential large-scale consumers, such steel, and power generation, tend to be in close-proximity, and are already supported by pipelines, power lines, roads, and other infrastructures needed for the clean energy transition. Finding similar synergies with other infrastructure needs for achieving deep decarbonization, including carbon capture and storage from a range of facilities, could lower the overall development costs of a hydrogen-fueled economy at the same time they provide pathways for a net zero future. These potential "hubs" could be formed in regions where various users of hydrogen across industrial, transport and energy markets are co-located and could benefit from shared infrastructure.

Targeted additional support would allow the U.S. to accelerate the development of clean hydrogen as a versatile energy source and the resultant decarbonization benefits. Regional-based studies of the range of hydrogen production pathways and viable market and regulatory structures is an important area that deserves additional support. Green hydrogen production pathways, which use clean electricity resources to produce hydrogen, are an important option for regions that lack suitable geologic storage capacity. Deploying hydrogen transport, storage, and fueling infrastructure will be critical to realize U.S. decarbonization goals, and region-specific plans will likely be needed to account for variable regional aspects such as geological storage potential and energy demand. A transition to clean hydrogen will also require preparing a workforce trained to handle hydrogen from production through end-use and ensuring that such jobs provide competitive wages. Finally, a national, economy-wide roadmap for the deployment of hydrogen across all relevant sectors should be developed, establishing multi-year goals and R&D initiatives focused both on technology advances and accelerating market penetration.

Sustainable Supply Chains

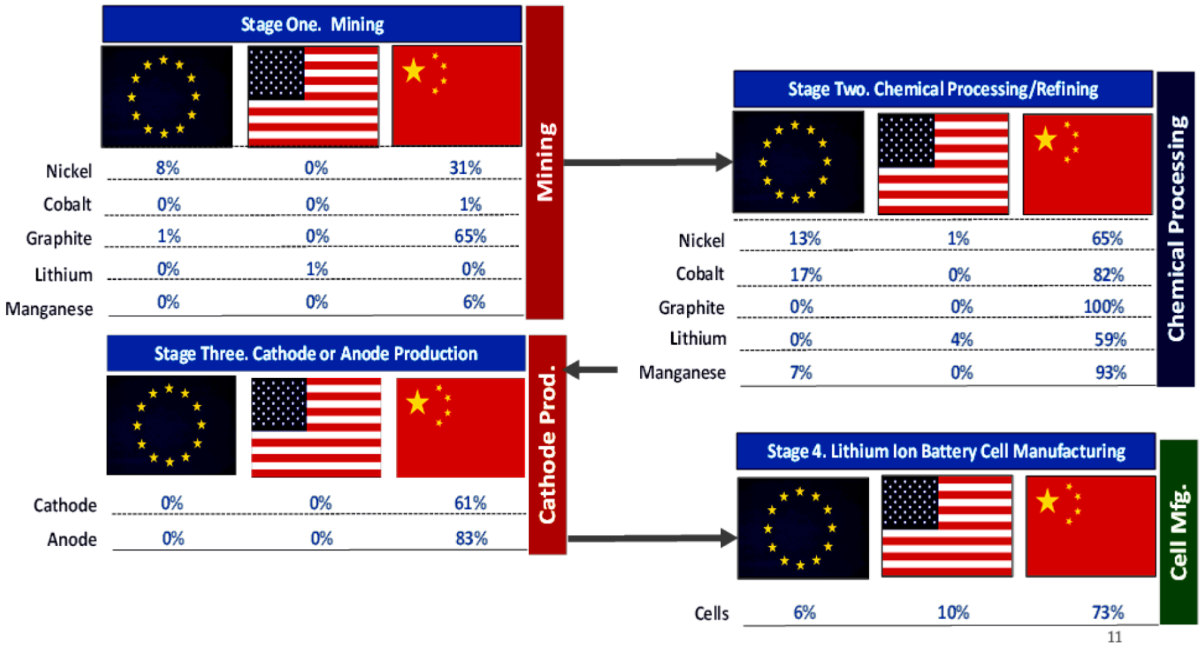
Supply chain issues of new clean energy technologies must be evaluated and factored into policy plans. Favoring certain clean energy pathways without considering the potential material and process limitations could delay or hinder U.S., and global, decarbonization efforts.

Policies and programs that could enhance US capacity in these areas include:

- Protection of global supply chains for minerals/metals needed for wind, solar and batteries;
- Support for innovation to support new domestic, environmentally responsible, net-zero mining activities for key minerals/metals, including associated infrastructures;
- An increase in the capacities, capabilities, and associated infrastructures needed for key mineral chemical processing/refining and battery manufacturing;

FIGURE 7

Select Process for Key Metals and Minerals Needed for EV Battery Production: EU, US, and China Shares, 2019



Source: Modified from Benchmark Mineral Intelligence.

- Significant recycling programs for key metals and minerals; and

- Research into substitutions for key minerals by earth-abundant metals and minerals.

Much of the innovation in this area has been led by the private sector, and additional private investment in these areas is much needed. A key requirement to foster increased private sector innovation is the protection of intellectual property rights. Federal policy to protect the rights of innovators has its roots in the U.S. Constitution, which calls for the government "to promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries." This principle was recently tested in the dispute between LG Energy Solutions (LGES) and SK Innovation (SKI) over the misappropriation of proprietary LGES EV battery trade secrets by SKI and destruction of pertinent records. Fortunately, the Biden Administration stepped in to facilitate a settlement between the two companies that maintained the integrity of IP protection policy while enabling the expansion of domestic manufacturing of EV battery systems and protecting jobs to support the electrification of the U.S. light duty vehicle market.

Figure 7 underscores the need for innovation throughout the supply chain for the metals and minerals supply chain for EV battery manufacturing. The heavy reliance on foreign supply at key points in the supply chain point to the need for RD&D and associated deployment policies to support net-zero domestic mining, chemical processing and refining, and manufacturing of electric vehicle lithium-ion batteries.

Title VII of the Energy Act of 2020 promotes a robust effort to rebuild domestic supply chains, emphasizing responsible production and efficient use, recycling, and development of alternatives for critical metals and minerals. In particular the establishment of a robust program for assessment of critical metals and minerals is an essential first step. The Act also authorizes DOE to conduct a comprehensive program of RD&D as well as commercial application for critical materials, including development of alternatives, recycling and efficient production and use. These efforts should expand to include all materials vital to the clean energy transition. Onshoring offshore wind supply chains, for example, including raw material extraction, manufacturing, and final assembly could generate thousands of good jobs that would generate significant regional economic activity.

New Climate Risk Frameworks

While Earth has seen major climate variation over its history, the pace of change today is well beyond that attributable to natural phenomena and is driven by human activity, especially from energy. The UN's 2019 Climate Action Summit brief noted that the last four years were the four hottest on record, and winter temperatures in the Arctic have risen by 3°C since 1990. The growing intensity and frequency of floods, hurricanes, and droughts across the country and the world have underscored both the ferocity and costs of a changing climate. As noted, a recent example is the winter storm in mid-February 2021 that affected large regions of the southern U.S., including Texas, with sustained subzero temperatures and snow. In Dallas, in February temperatures were -2 degrees F, while the average low for this time of year was around 40 degrees. Because two-thirds of Texans rely on electric heating, this led to a surge in electricity demand throughout the state of about 20 GWs, or one-third of the winter peak, far exceeding ERCOT's worst case planning scenario, based on the 2011 winter storm. In other words, we can no longer look at the past to predict the future.

It is critical that we develop a new, flexible climate risk profile for energy systems and the broader economy, including the associated analytical tools. This is an area that needs significant innovation investments in new models, techniques, and approaches for considering climate change-based risk into the system. It is critical that multi-agency efforts, with support from universities, the national labs, and other research institutions continue to develop tools, programs, and partnerships that closely monitor climate conditions, feeding into decision making processes in both the public and private sectors. The risk profiles need to be developed with regional granularity not just for polar vortices but for the entire spectrum of weather and other climate change extremes.

Carbon Dioxide Removal

CDR is an essential complement to CO_2 emissions reductions, and a critical part of achieving net-zero emissions goals and subsequently net-negative emissions, thereby providing the opportunity to reverse some of the effects of historical GHG emissions. In EFI's 2019 report *Clearing the Air*, EFI outlined a 10-year, $10.7-billion RD&D program to bring more CDR approaches to deployment readiness—a necessary step to scaling up CDR to the point where it can make a meaningful difference. We believe that CDR is a necessary and material contributor to any successful pathway to net zero, and certainly for achieving a net negative emissions economy.

The Energy Act of 2020 establishes a broad-based CDR RD&D program to "...test, validate, or improve technologies and strategies to remove carbon dioxide from the atmosphere on a large scale." The Act also established prize program for direct air capture and authorized the Secretary of Energy to establish an interagency task force and report to Congress on additional CDR measures. These provisions track closely with the EFI Report recommendations. In addition, Congress made a historic investment in CDR RD&D in the December omnibus, with appropriations totaling over $90 million for RD&D on technological and technologically enhanced natural CDR pathways.

A significant increase in appropriations will be needed in future years to reach the funding levels recommended by the 2018 National Academy of Sciences Report and the 2019 EFI Report. Furthermore, current authorization and appropriations for CDR emphasize DOE programs for direct air capture as the principal CDR pathway. Additional emphasis should be extended to other CDR pathways, and other federal agency roles, including bioenergy with carbon capture (BECCS), and bioengineered plants, forestry, and soil pathways (with USDA); in situ and ex situ carbon mineralization (with Interior and EPA); and ocean-based CDR involving both biological and chemical methods (with NOAA). In December 2020, EFI issued a series of three supplemental reports on terrestrial CDR, oceans-based CDR and carbon mineralization.[4]

Targeted pilot testing and demonstration programs will be a critical element for assessing the feasibility and suitability of CDR for large scale deployment. EFI proposed a competitive, technology-neutral demonstration projects fund in Clearing the Air. And while the extension of the

4. The three reports are: From the Ground Up: Cutting-Edge Approaches for Land-Based Carbon Dioxide Removal; Uncharted Waters: Expanding the Options for Carbon Dioxide Removal in Coastal and Ocean Environments; and Rock Solid: Harnessing Mineralization for Large-Scale Carbon Management.

45Q tax credit in the Energy Act of 2020 was critical to provide necessary incentive for deployment of both CDR as well as carbon capture, utilization and storage (CCUS) from point source emissions, proposals for expanding 45Q, enhancing its credit for CDR projects, and new tax credits for natural CDR pathways such as expanded tree-planting should be further explored.

Cyber Security

Ensuring cybersecurity must be a fundamental consideration when modernizing and expanding U.S. energy infrastructures. The modern energy system—including the electric grid, natural gas systems, on-road and air transport, and manufacturing—will become increasingly dependent upon cyber-physical systems. As the energy system becomes smarter through the integration of information and operational technologies, the risks posed by cyber-attacks will increase.

There are, however, also opportunities to engineer cybersecurity into the future energy infrastructure in a way that supports decarbonization, operational resilience, and security. This will include developing intrusion detection systems into critical components, expanding our capability to monitor and track the supply chains for critical components, embedding cybersecurity into training across the entire workforce, building on our strong information sharing programs between the government and private sector and among industry itself. The recently revealed SolarWinds attack shows how cybersecurity must be applied along the entire supply chain for infrastructures. These and other measures should be integrated into how we build energy infrastructure in the United States.

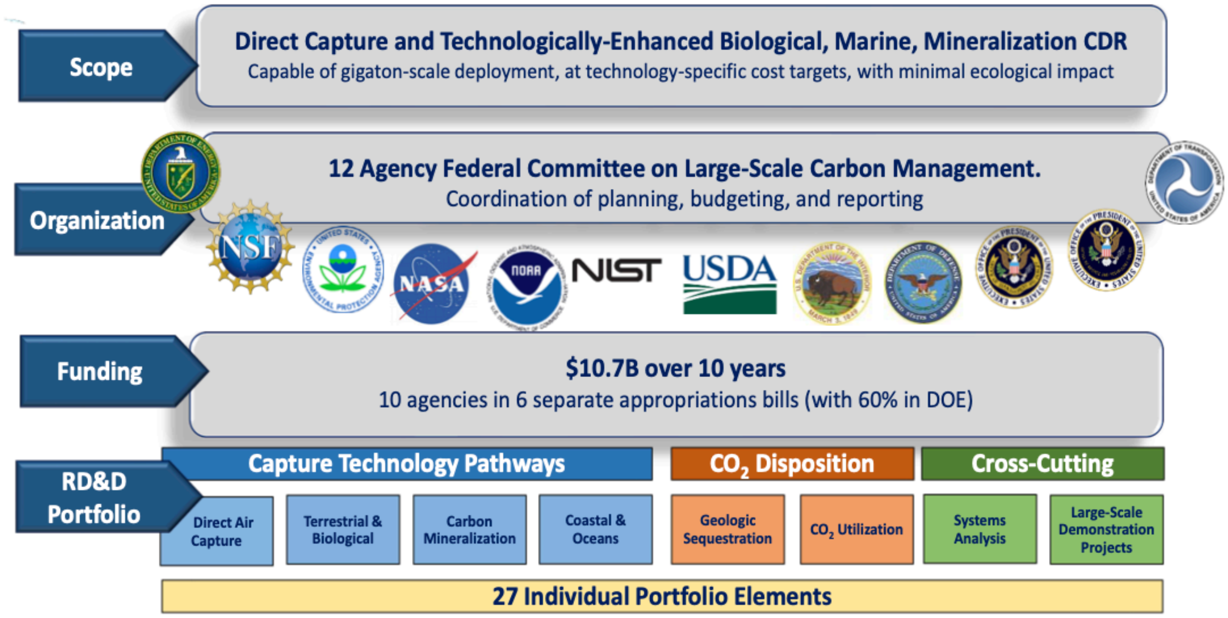
Implementation Framework for a Super-Charged Clean Energy Innovation Portfolio

The architecture and processes for implementation of a federal energy innovation investment program are as important as the content of the portfolio itself. Drawing upon my experience in academia, government and now in the private sector, I offer several general principles for consideration.

First, innovation investment programs should build upon and better integrate the existing unparalleled innovation capacity in the U.S. across private industry, universities, research institutions, entrepreneurs and federal, state and local government entities. Stepping up the pace of energy innovation requires building upon the collaborative strengths of this innovation ecosystem. Increased federal investment in innovation can best accelerate the clean energy transition by leveraging all of the players into closer alignment. This can be accomplished through federal policies that encourage public-private partnerships, formation of regional innovation ecosystems and alignment of innovation investment with market formation policies.

The private sector is central to clean energy innovation, providing

FIGURE 8
Comprehensive Carbon Dioxide Removal RD&D Initiative



Source: Energy Futures Initiative (EFI), 2020.

entrepreneurial vision, channeling financial resources, and connecting innovation to the rest of the energy system and the economy. The private sector is not only a key player in innovation, but also is key to testing and early adoption of innovations emerging from government and academia. Public private partnerships, leveraged by federal cost sharing and other policy initiatives, can expand and accelerate the ability of the private sector to deliver innovative energy products and services to consumers.

States, Cities and Tribal governments play a very important role in the energy innovation process, particularly as supporters of initial commercial adoption of new energy technologies and products. Expanded policy innovation in state electricity and natural gas regulatory practices also could play an important role in accelerating energy innovation.

As noted, at the federal government level, a key focus is the Department of Energy, which in FY 2016 administered three-quarters of Federal investment in clean energy innovation. Other agencies with significant clean energy innovation budgets include the Department of Defense (DOD), the Department of Transportation (DOT), and the Department of Agriculture (USDA); portfolios at these agencies are mission-focused, as opposed to being broadly based across all energy sectors. It is imperative that major energy innovation programs will utilize a whole-of-government approach. Carbon dioxide removal (CDR) represents a case in point. The EFI 2019 Report, Clearing the Air, provided a set of recommendations and detailed implementation plans for a comprehensive, 10-year, $10.7 billion research, development, and demonstration (RD&D) initiative in the U.S. to bring new pathways for technologically enhanced CDR to readiness for widespread application. The wide range of scientific challenges requires an interagency effort spanning the mission responsibilities of 12 federal departments and agencies, with DOE, the Department of Agriculture and the National Oceanic and Atmospheric Administration playing key roles (Figure 8).

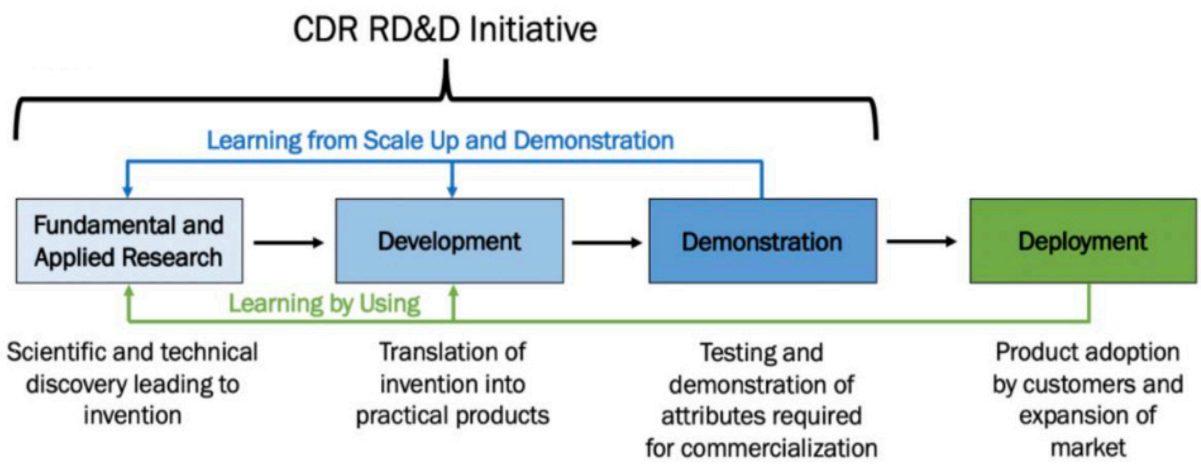
The effective planning, budgeting, and execution of the CDR RD&D initiative will require effective coordination led by the Office of Science and Technology (OSTP) and the Office of Management and Budget (OMB). This coordination effort is modeled from the highly successful U.S. Global Change Research Program. Similar interagency coordination mechanism may need to be strengthened in other areas of energy innovation such as advanced manufacturing technology.

Within the federal energy innovation establishment, the 17 DOE National Laboratories play a critical role. The National Laboratories provide world-class research facilities that are too expensive and specialized to be developed by universities or most companies acting alone, and by providing sustained attention to scientific issues with long time horizons and multidisciplinary complexity. Notably, five of the world's ten fastest supercomputers are housed in National Laboratories. The National Laboratories also play an important integration role among the participants in the energy innovation process, through various collaborative programs that help connect the early scientific discovery emphasis of research universities with the needs of industry for near-term solutions.

Second, it is essential that the innovation portfolio support the entire innovation spectrum, from use-inspired fundamental research through learning-by-doing demonstrations and pioneering commercialization. As shown in Figure 9, the innovation process is not a simple, linear process of (i.e., early-stage government research followed by private sector development, demonstration, and commercialization), but rather a complex process where the feedback loops can be as or more significant. A federal system that is focused solely on discovery and invention leaves the door open to other countries to translate the fruits of this research into new products, industries and jobs that are based offshore.

It is essential that the federal investment portfolio support innovation in all areas. Additional investment is needed in fundamental research that will feed the pipeline for future innovation. Within DOE, the Office of Science has supported a broad program of fundamental research, including operation of large scientific user facilities that are used by university and

FIGURE 9
Focus of a CDR RD&D Initiative



The process of moving innovations into the marketplace generally follows these four stages; however, this process can be non-linear as a result of feedbacks stemming from technology scale up, demonstrations, and knowledge by using. Source: EFI, 2019.

private sector researchers (many of the university users are NSF supported). Over the past decade the Office of Science has developed a program of use-inspired fundamental research5 through the establishment of Energy Frontier Research Centers (EFRCs). The design of this program was the outgrowth of a series of in-depth workshop meetings of the science community convened by DOE beginning in 2001 to identify areas of fundamental research needed to support energy technology breakthroughs. The workshops led to the 2007 Basic Energy Sciences Advisory Committee Report, *Directing Matter and Energy: Five Challenges for Science and the Imagination.*

It should be noted that the EFRCs were largely university based with some partnerships with the private sector and other research participants. While the focus of the EFRC program was on fundamental research, it produced significant advancements in the technology base to support subsequent commercialization. This connection is illustrated by the fact that DOE reports that EFRC research has led to more than 650 invention disclosures and 180 patents, with 100 companies having directly benefited from EFRC direct partnerships, patent licensing, and transfers of scientific findings to technology developers.

In this regard, the National Science Foundation (NSF) also can play a critical role through its established network of research university-based principal investigators and collaborative research centers. While the NSF is appropriately focused on fundamental research, and should remain so, there is an opportunity to further expand the NSF role beyond discovery science to support use-inspired fundamental research in areas of science and engineering that can accelerate technology innovation, especially in platform technologies, such as advanced computation, synthetic biology, cybersecurity, risk assessment and decision science that underpin many potential inventions of and applications to new products and services. Adding a major focus on technology development and commercialization to NSF's mission, however, would pose a major risk to the nature and culture of the agency and would need to be circumscribed with great care. The provisions in the draft House bill, *The National Science Foundation for the Future Act*, to erect a firewall between a new NSF Directorate for Science and Engineering Solutions and the existing organization are reflections of such risk.

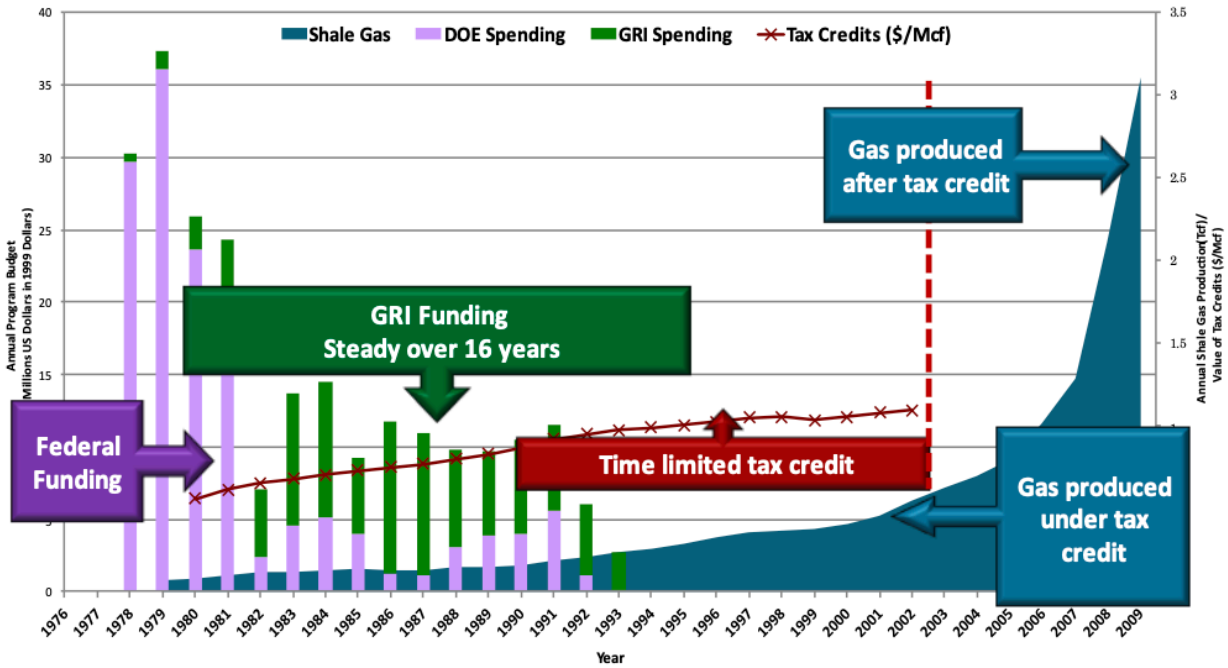
The DOE and its system of National Laboratories play an important role in planning and implementing use-inspired fundamental research initiatives. DOE has provided leadership in platform technology areas including high performance computing, the National Quantum Initiative, artificial intelligence, cybersecurity, biotechnology and genomics. In addition, DOE has the ability to manage both open science and classified applications concurrently, a critical programmatic feature. The future role NSF in use-inspired fundamental research should be complementary to, and closely coordinated with, similar fundamental research in DOE and other federal mission departments and agencies, including joint programs, to enhance opportunities for translation of research into applied technology development, demonstration, and ultimate commercialization by the mission agencies and the private sector.

At the other end of the spectrum, government cost shared support for prototyping and demonstration projects at or near commercial scale are equally important to test the operational viability and commercial attractiveness of new technologies. The expanded list of advanced energy technology demonstration projects authorized in the Energy Act of 2020 underscores the important federal role in supporting technology scale-up and demonstration projects, and implementation of these provisions will provide significant momentum for energy innovation over the coming years.

Finally, the role of the Advanced Research Projects Agency—Energy (ARPA-E) is noteworthy for its unique role in bridging between the stages of fundamental and applied research into development and scale-up. ARPA-E, established in the America COMPETES Act of 2007 pursuant to a recommendation by the National Academies of Science, Engineering and Medicine in the *Rising Above the Gathering Storm Report*, has been given more program flexibility than other DOE applied energy R&D programs to spur acceleration of innovation in cutting edge areas of energy technology. The success of ARPA-E has been widely acknowledged in various metrics on patents, follow-up investment and

FIGURE 10

Federal Investments, Policy, and Industry Support: US is Now the Number One Gas Producer in the World



Source: MIT Future of Natural Gas Study.

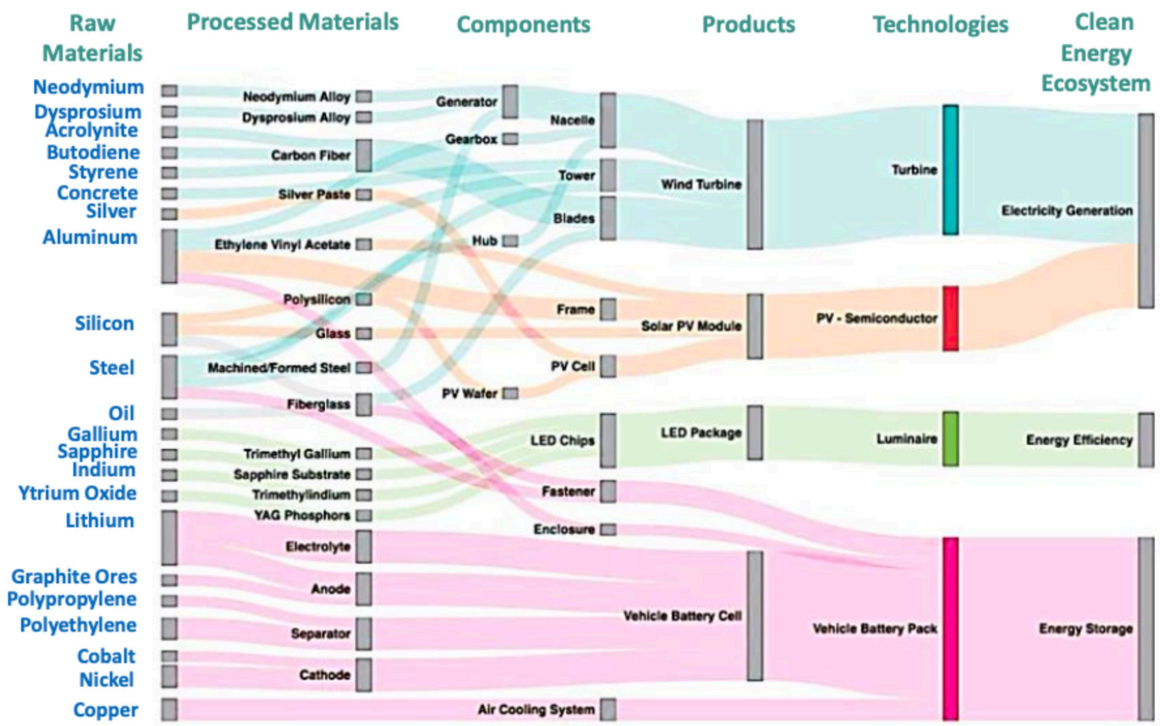
formation of new companies.

The ARPA-E mission and functions were favorably evaluated in the June 2017 report by the National Academies, An Evaluation of ARPA-E. The FY 2021 Energy and Water Development Appropriations Act raised the annual funding level to $427 million, but it is still less than half the level recommended at the time of its establishment over a decade ago. This has led to suboptimal award rates, with many good ideas left on the table. Increased funding for ARPA-E should be considered as one of the highest priorities for Congress in the new budget cycle. Consideration also should be given to broadening its programmatic reach, by allowing ARPA-E for example to increase the length and size of grant awards. The Biden Administration request for FY 2022 discretionary funding includes a total of $1 billion combined for both ARPA-E and the proposed Advanced Research Projects Agency—Climate (ARPA-C). No additional details are yet available as to the allocation between the two entities or to the proposed portfolio for ARPA-C.

Third, the innovation portfolio needs to be closely coupled to deployment incentives. The development of the U.S. shale gas industry offers a textbook

FIGURE 11

Sankey Diagram of Clean Energy Technology Supply Chain

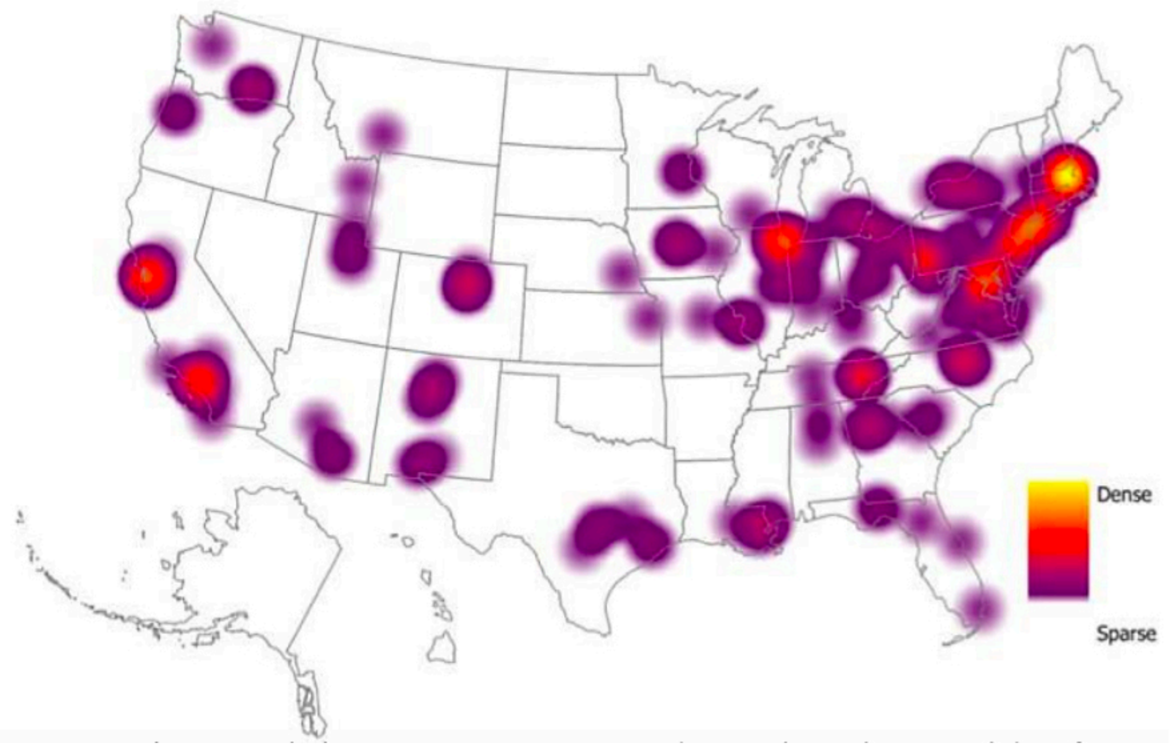


The clean energy technology supply chain is vast and complex but also includes numerous interconnections between raw materials and technologies. Source: McCall, 2017. Clean Energy Manufacturing Analysis Center.

example of how strategic investments in innovation, coupled with public-private partnerships and targeted, time-limited financial incentives, can work together to successfully launch a major energy transition. As seen in the Figure 10, federal investments in technology development in drilling technology and federally funded resource assessments provided the foundation for development of shale gas (and oil) technology. Follow-on applied R&D investment, through a public private partnership involving DOE, the Gas Research Institute (now the Gas Technology Institute) and the private sector achieved proof of concept of shale gas drilling techniques. The availability of the nonconventional gas tax credit provided an important incentive to encourage the initial deployment. The industry then matured on the basis of learning-by-doing improvements in productivity. This same model may be relevant to the development of the advanced nuclear technology and the offshore wind industries.

Fourth, energy innovation programs

FIGURE 12
EFI's Regional Clean Innovation Index



EFI's Regional Clean Energy Innovation Index combines locational data for energy RD&D resources across the country to analyze the potential benefits to innovation of regional clustering. Source: Energy Futures Initiative (EFI), 2017. Compiled using data from Hersch, 2014; Manufacturing USA; NASA; NSF; DOE.

need to provide greater emphasis on supply chain issues. As noted earlier, advanced clean energy technologies are increasing dependent upon critical metals and minerals, as shown in Figure 11.

Meeting the increased demand for critical metals and minerals will likely require a corresponding- increase in domestic mining, albeit mining that employs environmentally sustainable practices. It will also require the development of stable, strategic international supply chains. Targeted RD&D activities can supplement these strategies. Opportunities for materials substitution and materials recycling, as well as alternative approaches for materials processing and equipment manufacturing should become a requirement for all DOE funded RD&D for clean energy technologies. Strategies for commercial deployment should take into consideration security and reliability of supply chains and develop appropriate acquisition strategies.

Fifth, the implementation of energy innovation programs needs to be cognizant of regional variations and needs to exploit regional innovation strengths. Nurturing energy innovation ecosystems at a regional scale can be the critical catalyst for aligning the key players, policies and programs among the private sector, universities and governments. Energy resources, expertise and markets vary significantly by region of the country, and many of the issues facing the energy sector can be better managed by strategies tailored to each region's specific needs.

Analysis of national data on energy innovation reveals strong regional clustering. Combining data on the location of Department of Energy (DOE) national laboratories and Energy Innovation Hubs, the DOE-funded Energy Frontier Research Centers, the National Network for Manufacturing Innovation Centers, NASA laboratories and facilities, the top 100 research universities, and the major Federally Funded Research and Development Centers (FFRDCs) into a single heat map shows significant clustering of innovation capabilities (see Figure 12). What the heat map shows is that there is a robust system of innovation enablers in many, but not all, parts of the United States.

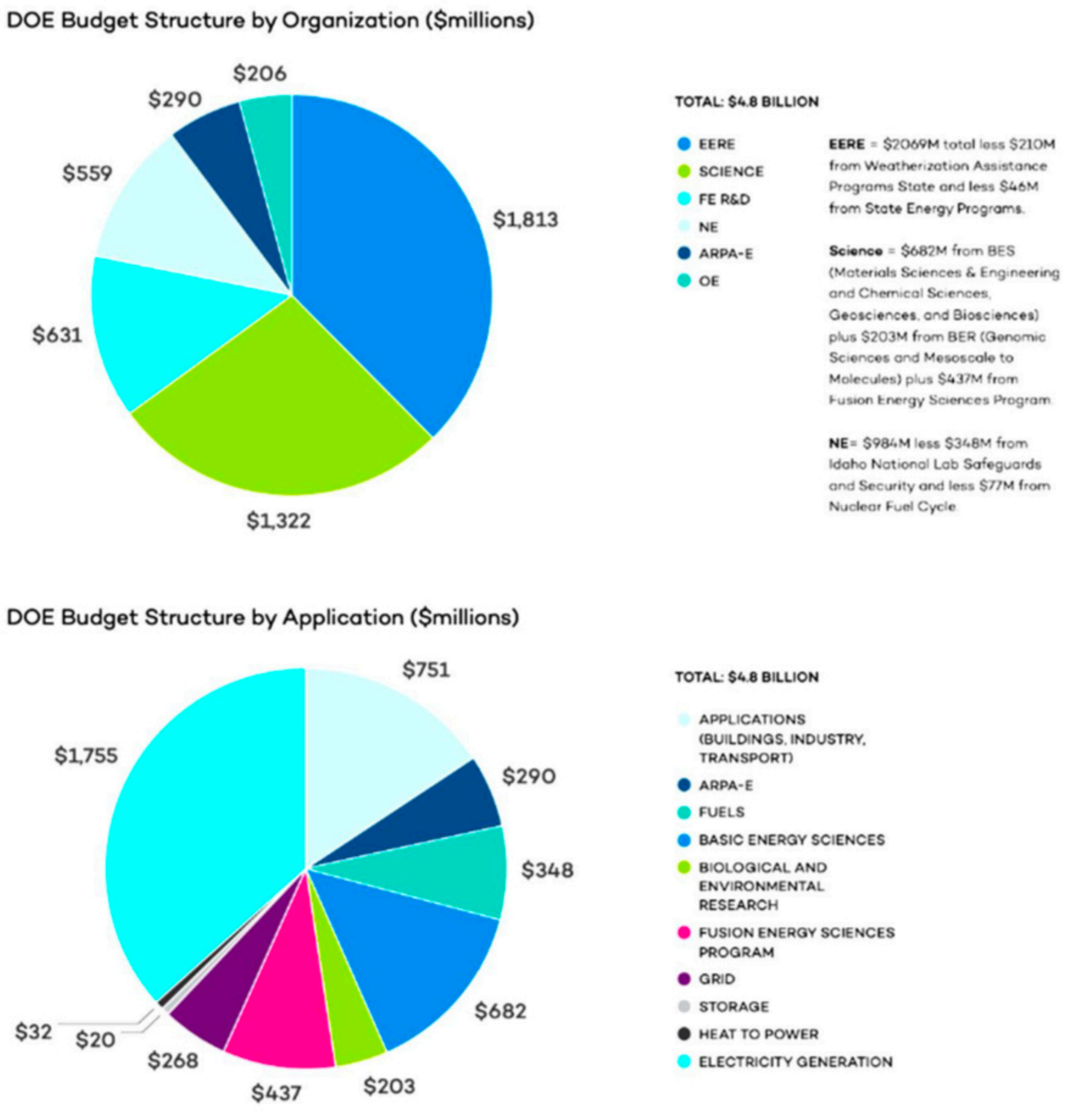
Federal policies and programs should be cognizant of these developments and seek to nurture further evolution. The DOE National Laboratories and other federally funded research institutes, working with universities, can play a major role in catalyzing regional energy innovation ecosystems.

Finally, the federal energy innovation research portfolio needs to be better planned and managed for performance. The DOE applied energy research programs are currently organized around a fuel centric framework that has its origins in the 1970s, a structure that inherently skews its programs and budgets. It tends to lead to budget allocations by fuel, resulting in gaps and budget distortions, rather than prioritization by innovation potential. The 2019 study Advancing the Landscape of Energy Innovation, included an analysis of the FY 2017 DOE budget comparing the budget allocations by organization with a budget allocation by application, shown in Figure 13.

The comparison highlights the relative lack of attention to several key technology areas such as energy storage, grid modernization, heat to power, and hydrogen and other clean fuels. Emerging areas of research needs, such as carbon dioxide removal, had no clear organizational home. The DOE Quadrennial Technology Reviews of 2012 and 2016 represented steps toward better portfolio planning. These efforts should be reinvigorated. In particular, the Conference Report accompanying the Energy and Water Development Appropriations Act for 2021 underscored the need for better multi-year R&D portfolio planning, noting that "The Department is still not in compliance with its statutory requirement to submit to Congress, at the time that the President's budget is submitted, a future-years energy program that covers the fiscal year of the budget submission and the four

FIGURE 13

Comparison of DOE Budget Structures by Organization and Application



Source: Energy Futures Initiative (EFI), 2017. Compiled from DOE Fiscal Year 2018 Budget Documents.

succeeding years."

The current structure also lacks clear direction for supporting all stages of the innovation process from fundamental research through commercial demonstration. Demonstration projects are an essential element of the innovation process for testing new technologies at scale with full integration of components and sub-systems. The learning by doing achieved through demonstration projects is an essential two-way street, enabling any necessary fine tuning as technologies enter commercial deployment as well as providing important feedbacks to guide further research priorities. The management of DOE large-scale demonstration projects has a checkered history, leading some critics to propose the proverbial "throw out the baby with the bathwater." Adopting a more rigorous project management guidelines to demonstration projects along with stronger project management oversight, modeled after those applicable to DOE internal construction projects, will be necessary to ensure effective implementation of the new demonstration projects authorized in the Energy Act of 2020.

All of this points to the need for, and ability of the U.S. to sustain its preeminence in clean energy technology innovation but requires far-sighted and sustained action to better align the policies, players and programs that are the key building blocks of our national energy innovation ecosystem. It is my pleasure—once again—to appear before this Committee. I have always found that Members from both sides of the aisle are willing to work together to support U.S. energy innovation, and I would be happy to support your efforts in any way.

Conclusion

All of this points to the need for, and ability of the U.S. to sustain its preeminence in clean energy technology innovation but requires far-sighted and sustained action to better align the policies, players and programs that are the key building blocks of our national energy innovation ecosystem. It is my pleasure—once again—to appear before this Committee. I have always found that Members from both sides of the aisle are willing to work together to support U.S. energy innovation, and I would be happy to support your efforts in any way.

Madam Chair, Ranking Member Lucas, members of the Committee, I appreciate the opportunity to testify today on critical clean energy innovation needs. I look forward to your questions.

Endnotes

i. https://www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx

Written Testimony

LIFT America: Revitalizing Our Nation's Infrastructure and Economy

On March 22, 2021, the House Committee on Energy and Commerce convened a hearing entitled, "LIFT America: Revitalizing Our Nation's Infrastructure and Economy."

Witnesses included: The Honorable Ernest Moniz, President and CEO, Energy Futures Initiative; Tom Frieden, Former Director, Centers for Disease Control and Prevention; Michael O'Rielly, Former Commissioner, Federal Communications Commission; and Tom Wheeler, Former Chairman, Federal Communication Commission.

Mr. Chairman, ranking member Rodgers, members of the Committee, thank you for the opportunity to testify today and to discuss the LIFT America Act.

Coming on the heels of the disaster in Texas, this hearing and the LIFT America Act's focus on improving the nation's energy infrastructure, is very timely. The recent events in Texas serve as a wakeup call for many things Congress should consider and address as it works to help modernize the nation's energy infrastructure.

The Texas experience puts an exclamation point on a broad range of domestic and global activities and actions now underway. As we all know, the Biden Administration has re-joined the Paris Agreement and is working to develop a new NDC for the United States. In addition, roughly 130 of 196 nations around the world have committed to or are actively considering net zero emissions targets by mid-century. More than half of the U.S population lives in a state or city with an emissions reduction target of 80% or greater by midcentury. Also, the European Union is developing a carbon border adjustment policy scheduled to be released this summer. And finally, the COVID pandemic serves as a constant and critical reminder of the ongoing need for jobs and the almost unparalleled need to support an economic recovery plan.

We made energy infrastructure an early priority in my tenure as Secretary at DOE with the drafting and publication of the first installment of the Quadrennial Energy Review, or QER, which was focused on energy infrastructures, including shared infrastructures. This installment made 63 recommendations for building a smarter, cleaner electric grid; promoting workforce training and development; reducing emissions from natural gas systems; supporting the re-investment into our critical waterborne transport systems; and enabling improved siting and permitting issues that are critical steps for deploying innovative systems to the market. By the end of my tenure, 29 of QER1.1's 63 recommendations had been implemented fully, with 21 more underway. It is worth noting that that the first installment of the QER included a section specifically focused on the 2011 cold snap in Texas and New Mexico, emphasizing the growing interdependencies of the electricity and natural gas infrastructures, borne out by events in Texas 10 years later (see Text Box 1).

The second installment of the QER focused specifically on the grid: "Transforming the Nation's Electricity System". This installment evaluated the centrality of the electric grid to the nation's economic health, national and energy security, and the social lives of our citizens. It recommended flexible financing for developing a clean, modernized grid; ensuring the electric grid is prepared for growing risks of anthropogenic climate change and cyber-attacks; building capacity at the federal, state, and local levels to support the grid's regulatory and policy requirements; and maximizing consumer equity and economic value of the system.

I am pleased to see that some of the provisions of the LIFT America Act align with QER recommendations, including the establishment of a Strategic Transformer Reserve and the natural gas infrastructure grant program. A summary of recommendations from both QER installments has been entered into the record as attachments to this testimony. The non-profit Energy Futures Initiative (EFI) that I founded with two colleagues from DOE has continued work on some of the QER recommendations, in particular the development and release of the annual U.S. Energy & Employment Report.

Only four years have passed since we issued the last installment of the QER in January 2017 but the urgency of upgrading our energy infrastructure in service of a deeply decarbonized economy has become even clearer. The advances in climate science and the realities of extreme weather call for action, as advocated by this committee with the LIFT America Act and other initiatives, such as the CLEAN Future Act introduced earlier this month.

In looking ahead to infrastructure needs, it is useful to focus on a number of technologies that will almost certainly play major roles in a deeply decarbonized economy:

- **Electricity and the grid:** The electric sector is leading the way on decarbonization and will continue in that role. A reliable and resilient grid will also continue to be the central infrastructure on which other infrastructures depend. How that grid is configured will have to be matched to the mix of critical generation and storage technologies:

BOX 1

QER 1.1 Highlighted Growing Gas/Electric Interdependencies

The Big Chill: A Disruptive Event Made Worse by Infrastructure Interdependencies[1]

The "Big Chill" of 2011 illustrates the complicated relationship between natural gas and electric power, which had compounding effects during a period of extreme weather.

During the first week of February 2011, the U.S. Southwest was hit by an arctic cold front that was unusually severe in terms of its low temperatures, gusting winds, geographic extent, and duration. From January 31 to February 4, temperatures in Texas, New Mexico, and Arizona were the coldest experienced within the region since 1971. Dubbed the "Big Chill" in the media, it overwhelmed the routine preparations for cold weather that had been put in place by electric generators and natural gas utilities located in those states.

Within the Electric Reliability Council of Texas (ERCOT) Interconnection, starting in the early morning hours of February 2, the cold temperatures and wind chill caused a significant number of outages at generating plants, with approximately one-third of the total ERCOT generating fleet unavailable at the lowest point of the event. With electricity demand soaring because of the cold weather, ERCOT and some utilities in New Mexico instituted rolling blackouts to prevent collapse of their electric systems. For the Southwest as a whole, 67 percent of electric generator failures (by megawatt-hour) were due directly to weather-related causes, including frozen sensing lines, frozen equipment, frozen water lines, frozen valves, blade icing, and low-temperature cutoff limits on equipment.

Gas producers and pipelines were also affected in Texas, New Mexico, and Arizona. Natural gas production was diminished due to freeze-offs and the inability to reach gas wells (due to icy roads) to remove produced water and thereby keep them in operation. When rolling electricity blackouts hit gas producers and gas pipelines, it had the effect of causing further losses to natural gas supply. The ERCOT blackouts or customer curtailments caused or contributed to 29 percent of natural gas production outages in the Permian Basin and 27 percent of the production outages in the Fort Worth Basin, principally as a result of shutting down electric pumping units or compressors on gathering lines. As a result of all these factors, natural gas deliveries were affected throughout Texas and New Mexico. More than 30,000 customers experienced natural gas outages at some point during this period.

The majority of the problems experienced by the many generators that tripped, had their power output reduced, or failed to start during the event were attributable, either directly or indirectly, to the cold weather itself. However, at least another 12 percent of these problems were attributed afterward to the interdependencies between gas and electricity infrastructures (such as lost electricity generation due to natural gas curtailments to gas-fired generators and difficulties in fuel switching).

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1. Federal Energy Regulatory Commission and North American Electric Reliability Corporation. "Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1-5, 2011: Causes and Recommendations." August 2011. http://www.ferc.gov/legal/staff-reports/08-16-11-report.pdf. Accessed February 2, 2015.

variable renewables wind and solar, batteries and long duration storage, advanced nuclear technologies (fission and fusion), fossil power plants with carbon capture, utilization, and sequestration (CCUS).

- **Electrification of other economic sectors, especially transportation:** Momentum has continued to build for electric vehicles (EV), a fact that is underscored by recent announcements from major automakers. An elaborate continental scale charging infrastructure will be needed. In turn, vehicles connected to the grid might make a major contribution to grid services.

- **Large scale carbon management:** CCUS at gigaton scale from power plants and industrial facilities will require a major CO_2 pipeline infrastructure and significant hubs for geological CO_2 storage. In addition, reaching net zero emissions—and eventually net negative emissions—throughout the economy will require carbon dioxide removal (CDR) from the atmosphere and upper ocean layers. Many CDR pathways—direct air capture (DAC)biomass energy with CCS (BECCS), and in-situ mineralization—will depend on large scale carbon management infrastructures.

- **"Fuels" to complement clean electricity:** It is very unlikely that efficiently decarbonizing the economy can be fully achieved through electrification only. A low-carbon fuel will be needed, and the general view today is that hydrogen is the most likely candidate. This will require yet another major infrastructure for the use of hydrogen—a highly flexible fuel that could assume the critical role currently played by natural gas—in multiple sectors over the next decades. Blue hydrogen (i.e., made from natural gas with the emitted CO_2 undergoing CCUS) will also utilize the large-scale carbon management infrastructure in addition to the hydrogen infrastructure needed for green hydrogen (i.e., made by electrolysis of water).

While only a partial list, this set of new infrastructure needs has a clear connection to decarbonization while maintaining the reliability and resilience of the grid and supporting the significant economic activity and essential services that are currently associated with conventional fuel use. These critical needs cannot be met without a major commitment to infrastructure, and the LIFT America act sets us on that pathway.

The Central Role of Electricity

First and foremost, the recent Texas experience underscores the critical and central role electricity plays in our lives, the economy, and the nation's security. No systems in Texas were fully operational without electricity, the "uber" infrastructure.

This experience, the rolling blackouts in California due to the Western heat wave last August and numerous other

FIGURE 1

California Wind and Solar Generation fo Each Day of 2017, CA Installed Capacity, 2019

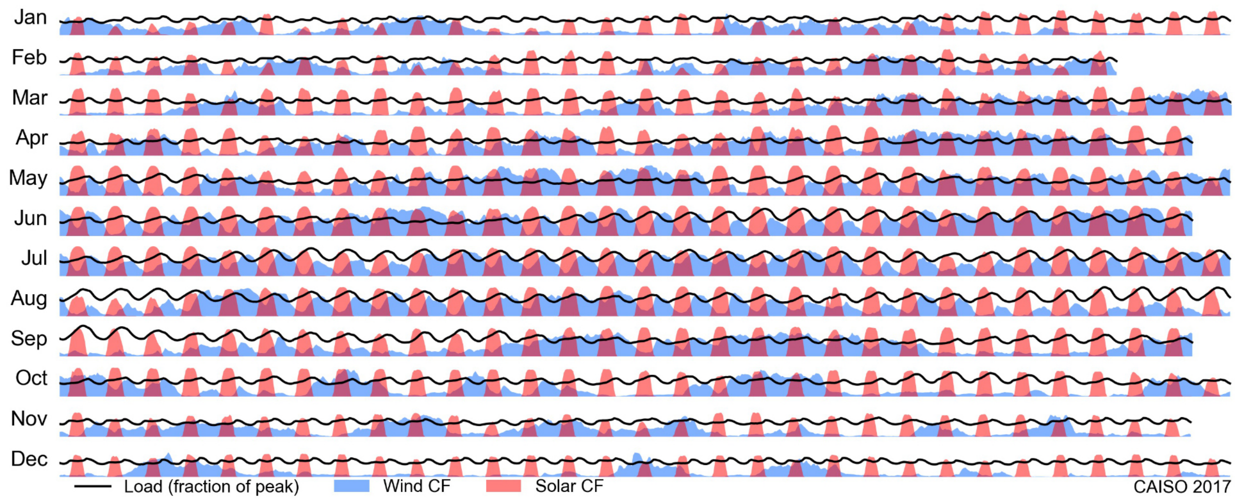


Figure 1 shows the hourly wind and solar generation for every day in 2017. Numbers in green count the days in the year where there was little to no wind generation in the state. The inset shows the installed battery storage capacity and duration in California which is currently insufficient to provide longer duration storage during multi-day periods with little to no wind generation. Source: CAISO data, EFI analysis.

weather-driven catastrophes, drive home an essential consideration going forward: energy infrastructures, especially the grid, are very exposed to the impacts of climate change. As we increase our focus on the electrification of several sectors and subsectors—a key decarbonization strategy—the Texas experience and this exposure reminds us that the reliability and resilience of the grid is a critical consideration and need. Research, development, and demonstration of grid resilience technologies will be critically important to preserving reliability, an essential role of the federal government.

It also drives home another key point: climate change means that the weather patterns of the past are not adequate to inform those of the future. This changed risk profile affects infrastructure from design, to investment, to buildout, to insuring the system. As we increase electrification of key sectors, we must thoughtfully approach these requirements for, and risks to, a modernized electric grid.   In addition, increased electrification of other parts of the economy necessitates a substantial buildout of the grid system, from transmission lines to substations and transformers, to distribution systems and EV charging stations, all the way to heat pumps for homes.

Another critical part of the future grid will be a set of technologies that supply large scale, long duration storage to support wind and solar generation. As seen in Figure 1, in 2017, California had 90 days with little to no wind, sometimes 10-11 days in a row. Deployed grid-scale battery storage has a duration of around four hours.

Even with continued innovation, batteries will likely be used for intraday storage needs. We need innovation in long duration storage—days, weeks, and seasonal—complemented by different generation technologies (such as advanced nuclear and CCS) and market structures that support clean firm power as well.

Modernizing the Existing Electricity Grid Infrastructure

As noted, the electric grid is the "uber infrastructure"—the backbone of our economy and social interactions, central to meeting health and safety needs, and critical to our national security. It touches everything and will be a critical enabler of, and contributor to, decarbonization. Due to its outsized importance, combined with emerging trends, electric grid modernization must meet multiple objectives: providing clean, reliable service to growing demand; promoting social equity and inclusion; ensuring resilient performance in the face of a changing climate and increasing cyber threats; integrating distributed sources of clean electricity; and supporting broad connectivity throughout the system to enable smarter cities and communities.

Managing an electric grid that is the size and complexity of the U.S. system is a major challenge. There are already 642,000 miles of high voltage transmission lines and 6.3 million miles of distribution lines in the U.S.[1] As the US transitions to a clean energy future, the electric grid will require many billions of dollars of investment over the coming years.

Connecting renewable energy from remote areas to urban centers, for example, will require a significant transmission system buildout. Expanding the role of federal power marketing authorities in building out new transmission could help add long-distance bulk transmission capacity. EFI and Energy and Environmental Economics (E3) completed a study last year on decarbonizing New England's economy and electric grid. The study found that by mid-century, electricity demand would grow by 60-90% from current levels. This would require massive investments in the associated buildout of the grid infrastructure, especially to access more Canadian hydropower and to accommodate a massive new offshore wind development.

There are several actions that could facilitate the deployment of new transmission that will be necessary for deep decarbonization. Permitting could be streamlined in a number of ways in a broad stakeholder process: a pre-approval optional process for state and local authorities; centralizing certain kinds of transmission permitting in a single authority (such as FERC); harnessing existing rights of way for rail,

1. Quadrennial Energy Review, Department of Energy, 2015.

pipelines, interstate highways, and other infrastructure so as to minimize eminent domain requirements and public opposition; tailoring permitting procedures for new kinds of infrastructure like CO_2 transport/DAC; empowering decisionmakers to resolve intragovernmental dispute; conducting multiagency reviews in parallel rather than sequentially; and ensuring Tribal sovereignty/input.

Modernizing the grid will also depend on updating today's electricity market design. The current wholesale electricity market design is increasingly challenged to reconcile the integration of intermittent generation sources with the need to ensure reliability by maintaining clean firm power generation. Moving to a net zero electricity generation regime will further amplify these challenges. Rectifying this problem could involve redesigning the electricity market to better accommodate existing subnational and proposed national decarbonization policy initiatives, lower barriers to new technology, encourage demand-side participation, value more attributes of resources, and better meet reliability needs. Congress could initiate a review of federal policy on wholesale market design.

Electric Vehicle Infrastructure

Over a quarter of US emissions come from the transportation sector, the nation's largest emitting sector; on-road vehicles comprise 23% of US emissions. Moving to a mid-century net-zero economy will require electrification of nearly all light-duty vehicles, as well as significant percentages of other transportation subsectors.

Foreign and domestic manufacturers have announced substantial investments in electric vehicles, with General Motors, for example, committing to discontinuing new internal combustion models by 2035. Infrastructure options and associated policy support will likely have to accommodate battery electric vehicles and plug-in hybrids, hydrogen fuel cell vehicles and vehicles that run on biofuels. Emissions-free liquid fuels likely will garner some market share, and policies to improve fuel economy of new models and encourage mode-switching will continue to be important.

On a global scale, the IEA Sustainable Development Scenario estimates an increase in EVs from five million in 2019 to about 140 million by 2030. This would require a rapid scaleup from the current global battery manufacturing capacity of 193 GWh (41 of which are in the U.S.) by an order of magnitude. Likewise, public chargers would need to scale by orders of magnitude to numbers in the millions by 2030, compared to around 100,000 today. It would also require vastly more supply of cobalt and lithium, supplies of which currently depend on imports. There is also global competition for these critical supplies of mineral and metals, as well as a concentration in China of the processing needed, for lithium-ion batteries.

To support this enormous demand growth—essential for meeting climate imperatives—EV infrastructure must be scaled up rapidly in the next three to five years. This buildout includes supply infrastructure, private and public chargers, as well as the electricity system and building upgrades needed to accommodate them. Additional infrastructure will be needed to support vehicle-to-grid integration and managed charging, which can mitigate the potential impacts of vehicle charging on electricity demand.

Federal policy will be necessary to accelerate the development and deployment all three types of EV infrastructure at a pace sufficient to meet deep decarbonization targets. Supply infrastructure could be supported by a combination of incentives, such as rebates and grant programs; or mandates, such as inclusion in state energy plans or building codes. Federal programs for zero-emissions vehicles have been designed around biofuels, and some of these programs can be reoriented to reflect the growing dominance of EVs in the energy transition. As the Federal government incentivizes and supports buildout of an EV charging network, a core design element must include serving areas where individual home charging stations are not possible (e.g., urban areas with predominantly on-street parking).

It is also crucial to ensure that EV infrastructure is deployed equitably. In the past, vehicle electrification incentives have benefited people at higher incomes, due to EV's higher upfront costs and the requirements of at-home charging; new policies can shift this dynamic as EVs become cheaper and more widespread.

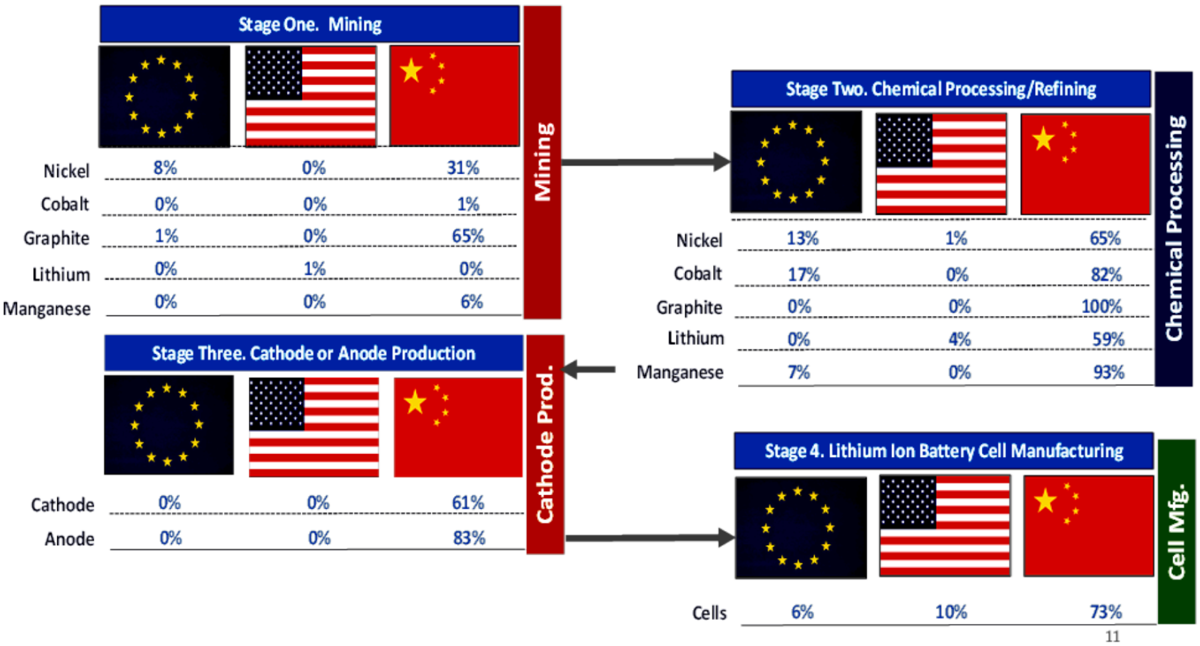
Battery supply is also a critical need. Federal incentives like the DOE Advanced Technology Vehicles Manufacturing Loan Program have already supported the growth of domestic battery manufacturing, funding battery factories for Tesla and Nissan. More incentives will be important, as well as RD&D investment to reduce battery cost and improve performance. IP protection is also essential to create the necessary environment for innovation and investment.

Battery supply considerations must also accommodate supply chains for the metals and minerals necessary to manufacture batteries, such as lithium and cobalt; domestic net-zero mining, and the buildout of the infrastructure needed for battery manufacturing itself, will become essential. This will be an area of increasing global competition, and support for domestic supply chains and protection of the intellectual property of innovators will be essential.

The metals and minerals supply chain requires development of a framework for sustainable domestic mining, as well as RD&D on new sources for these materials. Innovation can also help develop substitutes, as well as batteries with lesser critical material needs. Policies that establish producer responsibility for used batteries can encourage the development of new technologies, chemistries, and systems. Innovation could enable cost reduction, reduce dependence on imports of critical metals and minerals, and open the door to the development of new battery technologies.

FIGURE 2

Select Process for Key Metals and Minerals Needed for EV Battery Production: EU, US, and China Shares, 2019



Source: Modified from Benchmark Mineral Intelligence.

EFI is undertaking research on supply chain issues, with a focus on expanding domestic supplies of metals and minerals. New domestic sources of lithium are already being explored, and innovation could develop alternatives and/or additional supply, such as geothermal brines in places like California's Salton Sea. More domestic mining would allow for a bigger push to make battery supply chains more environmentally sustainable, as well as provide a bulwark against the frequent price fluctuations of these commodities. Innovation could also make improvements further down the supply chain, by reducing the quantities of critical materials required and increasing recycling options and opportunities.

Figure 2 shows the steps in EV battery production for the EU, US and China, and the relative shares of each country/ region in supplying those steps.

Offshore Wind: Renewable Electricity with Major Infrastructure and Supply Chain Needs

ffshore wind (OSW) is poised to significantly contribute to decarbonizing the power sector by 2035, boosting the reliability and resiliency of a modernized national electric grid infrastructure. It provides a good example of the importance of infrastructure planning to enable a critical low-carbon pathway and create lots of good jobs.

Offshore wind projects face significant barriers to adoption, however, including: 1) long and uncertain permitting processes that increase costs and threaten access to tax incentives for project investment; 2) high costs and insufficient financial incentives to build transmission lines to connect offshore wind to shore; and 3) potential opposition from local stakeholders including property owners who have raised sight and noise concerns, and fishermen who are concerned about impacts on their businesses. Reducing these barriers can unlock tremendous investment in clean energy and promoting domestic supply chains will ensure the investment and job creation is made in America. In developing offshore wind infrastructure, the US has an opportunity to support high-paying domestic jobs in the steel, manufacturing, and utility sectors.

It is critical that any offshore wind policy—perhaps with a phase-in period for domestic content—be designed to encourage a build out our domestic supply chain capabilities to support this new industry. Current commitments for Atlantic Coast wind development total 32GW—about three percent of total current U.S. capacity. This capacity could require deployment of about 4,000 turbines, creating tens of thousands of new jobs. About 20 GW of projects are in various stages of planning and development, implying up to $68 billion in capital investments, not including necessary investments in supporting infrastructure, shipping and port capacity, or workforce development.[2]

New federal policy for transmission system build-out could include expanding DOE's Loan Program funding to include offshore wind transmission network infrastructure and associated upgrades of coastal grid infrastructure, including public-private partnerships. Congress could also expand the investment tax credit to include transmission components from offshore collector platforms to onshore substation points of interconnection.

Other policies to encourage development of domestic supply chains could include reinstating the 48C Advanced Energy Manufacturing Tax Credit program to help spur development of a robust U.S. manufacturing capacity for American-made offshore wind turbines, nacelles, blades, subsea cables, and other equipment. In addition to domestic supply of steel and component parts, policies to encourage domestic supply base of critical metals and minerals for offshore wind turbines and structures could both preserve and increase jobs across the supply chain. A reinstated 48C tax credit would also benefit many other clean energy technologies.

Building out seaport facilities and related marine infrastructure is an important part of OSW implementation and the domestic supply chain. There are several financial incentives pathways that could incentivize the buildout of port facilities. One pathway is to expand

2. Special Initiative on Offshore Wind, "Supply Chain Contracting Forecast for U.S. Offshore Wind Power," March 2019.

the Maritime Administration's Port Infrastructure Development Grants Program, Small Shipyards Grant Program, and America's Marine Highway Program. A second pathway would be to increase funding for BUILD grants to upgrade U.S. ports for offshore wind installations, including heavy-duty cranes, turbine assembly areas, lay-down yards, deep draft berth and multi-modal transport connections. Decarbonization of port infrastructure operations, through electrification, or use of hydrogen or other net zero carbon fuels, should be integral to infrastructure modernization and should be strongly incentivized.

Building out the shipping fleet needed to construct, transport, and maintain offshore wind turbines is another opportunity for creating good paying American jobs. The government could provide financial incentives, grants, and loan guarantees for U.S. shipbuilders' construction of vessels that will install and provide maintenance to OSW farms, transmission platforms, and seabed cables. These incentives may require some short-term Jones Act waivers as the domestic fleet is built.

EFI is working within the Labor Energy Partnership (LEP) with the AFL-CIO to further delineate key issues, develop an analytical agenda and pursue in-depth study of domestic supply chain. This in-depth study will seek to understand how the domestic supply chain for offshore wind can create robust and competitive global supply chains for this new industry. The analysis will map out the network of existing domestic companies, potential technology clusters, and timelines, and will catalogue incentives that are needed to ensure that public investments in offshore wind result in maximizing domestic, high-quality job creation.

Cross-Sectoral Technology Options with Infrastructure Needs

Net zero targets around the world—including what might be included in the new US NDC—are placing additional policy, innovation, infrastructure, and competitive pressures on all major economic sectors—transportation, electricity, buildings, industry, and agriculture—to deeply decarbonize.

In this regard, the US industrial sector is one of the most difficult sectors to decarbonize. The industrial sector and many subsectors, e.g., refining, chemicals, steel, cement, iron, and ammonia production, are essential to the US economy, its export markets, and jobs. The US iron and steel industry for example, while a major emitter, supported almost two million US jobs and $523 billion in economic output in 2019. The industrial sector is also a major consumer and producer of hydrogen and in many instances relies on both natural gas and oil as feedstocks or fuels for a range of processes.

Decarbonization options for the industrial sector include some electrification and increased efficiency, as well as carbon capture and sequestration and increased use of hydrogen—a clean energy carrier that can support the decarbonization of many critical sectors. Policy support for the buildout of the associated infrastructures that could be compatible, co-located or re-purposed, will reduce their emissions while helping to enable the ongoing economic benefits of these industries and ensuring they meet new requirements of export markets that may include the calculation of embedded emissions.

This buildout would also support the decarbonization of other sectors—the power sector, for example, could use both CCUS infrastructure as well as hydrogen—with an end state that could include a green hydrogen future, supported by natural gas and blue hydrogen with CCUS. Policy incentives, infrastructure investment, and market formation regulatory support will aid in this buildout that could ultimately support zero emissions industry, transportation, and power generation. Key cross-sectoral technologies and infrastructures include natural gas, hydrogen and CCUS, discussed in detail in this section of my testimony

Improving and Transitioning Existing Natural Gas Infrastructure

Natural gas has become a major part of the U.S.—and global—energy mix over the last three decades, displacing higher emitting fuels and lowering greenhouse gas emissions. As many regions of the country begin to shift their policy targets toward net zero emissions, the emissions from natural gas, including methane emissions, must be reduced, or eliminated. I understand there are major proponents of "keeping it in the ground". Responsible actions, however, acknowledge that natural gas currently provides the fuel needed for clean firm power (recall the 90 days with no wind in California), and is an essential fuel for industry, a major energy consuming sector that is difficult to decarbonize.

There are significant opportunities to leverage the natural gas system's infrastructure to accelerate economywide decarbonization. Natural gas fired generation provides the electric grid with firm, dispatchable power. It also enables a lower-cost transition. EFI's study of New England showed that the cost of reaching a deeply decarbonized electric grid by midcentury was cut in half when natural gas with carbon capture and storage is included as a technology pathway. In many projected futures, a renewables-heavy electric grid would dispatch power from natural gas units only to maintain reliability and resilience.

EFI is currently assessing the global future of natural gas in a deeply decarbonized world, including the critical issues of supporting economic development. Initial findings from workshops held with think tanks in key world regions suggest that all regions have a significant interest in reducing emissions, and there are competing priorities that must also be considered. There is an emerging consensus that there will be a role for natural gas in a decarbonized global economy, specifically as an enabler of—and complement to—intermittent renewables for power generation, as a near-term "transition fuel" for fuel switching (especially away from coal and oil in power generation), as a feedstock in industry and for sectors that require high temperature process heat, and as a backup fuel in multiple end-use sectors.

For the natural gas system to be leveraged as part of the clean energy transition, however, its emissions must be reduced to meet climate policy targets. While there is a significant amount of debate around the current emissions from the gas sector, it is critical that the system's owners and operators monitor, detect, and eliminate methane leaks and other direct and indirect emissions associated with its operations. New standards to regulate methane leakage are possible within existing authorities. Also, the Interior Department could update its regulations for methane emissions from infrastructures on federal lands; EPA can revise its rules on methane under the Clean Air Act; and FERC could consider the establishment of new end-to-end standards for methane leakage for all gas ultimately entering interstate commerce or seeking LNG export authorization. EFI is evaluating opportunities to create an improved data and analysis framework for better modeling methane leakage from the natural gas infrastructure, as a foundation for future policy and regulations to manage its emissions.

Natural gas, as noted, is also an essential fuel for the U.S. industrial sector, that currently has few options for mitigating CO_2 emissions. Also, as noted, key industries—chemicals, plastics, iron, and steel—use natural gas as a fuel for process heat, and to produce the hydrogen used in a range of other industrial processes. These industries represent a major portion of U.S. GDP and employ hundreds of thousands of workers, across many regions of the country. Many of these industries will also be essential making the cement and steel needed for the grid, roads carrying EVs, and highly efficient buildings. Greatly reducing methane emissions along the supply chain deserves full commitment from industry.

Congress could also take a carrot-and-stick approach, pairing this regulation with financial support to offset rate impacts of gas pipeline improvements, as recommended in the QER. This policy could also specifically target improvements in communities that have a disproportionate pollution burden through carve-outs or other measures. In tandem with these programs, the federal government could also work to improve methodologies for measuring and estimating fugitive methane emissions.

Federal policy could also help propel innovation in natural gas infrastructure. Incentives for improvements could be strengthened if the improvements are particularly novel or effective at reducing emissions. Federal funding for RD&D could also help transform natural gas infrastructure for the net-zero world, including regional demonstration projects for hydrogen/natural gas blending or incentives for biogas.

U.S. LNG production and exports also have significant infrastructure needs, including ports and pipelines. Destinations for U.S. LNG include Brazil, Japan, South Korea, Mexico, India, the EU, and several other countries and regions. In many cases, this has supported climate change mitigation by gas substitution for coal. Analysis by the International Energy Agency concluded that coal to gas fuel switching reduced global emissions from the power sector by four percent. In China reduced emissions from its power sector by eight percent in 2018 alone and in the US by 14% that year.

Hydrogen: Both a Transition Option and an End State

Hydrogen is a clean energy carrier with multiple applications across every sector of the economy. Clean hydrogen could play an essential role in a low carbon economy as a zero-carbon "fuel" and was identified as one of ten technologies with significant breakthrough potential in EFI's 2019 report, "Advancing the Landscape of Clean Energy Innovation." EFI analysis in 2019 also concluded that hydrogen was one of four cross-cutting clean energy pathways that could help California meet its mid-century net zero targets.

There is significant interest among investors, utilities, oil and gas companies, and heavy industry to be part of the hydrogen solution. Opportunities for clean hydrogen end uses include industrial processes, heavy transportation, and power generation. Hydrogen from natural gas steam methane reforming (SMR) processes are already mature and meet almost all current domestic hydrogen demand. Producing "blue hydrogen" by capturing the carbon emitted via this hydrogen production approach is an off-the-shelf clean hydrogen solution. Using clean electricity to produce "green hydrogen" is also commercially available but requires further innovation to reduce costs.

The infrastructures needed for hydrogen market formation tend to be highly regional. Potential large-scale consumers, such steel, and power generation, tend to be in close proximity, and are already supported by the pipelines, power lines, roads, and other infrastructures needed for the clean energy transition. Finding similar synergies with other infrastructure needs for achieving deep decarbonization, including carbon capture and storage from a range of facilities, could lower the overall development costs of a hydrogen-fueled economy at the same time they provide pathways for a net zero future. These potential "hubs" could be formed in regions where various users of hydrogen across industrial, transport and energy markets are co-located and could benefit from shared infrastructure.

As with carbon capture and sequestration, large hydrogen users may have the business expertise and capital availability to support an end-to-end hydrogen supply chain for their own uses. For clean hydrogen to scale, however, new infrastructure investments will likely be required to enable market hubs where several producers and consumers are co-located and benefit from economies of scale.

Figure 3 offers a snapshot of where joint CCUS-hydrogen market hubs might form based on existing industrial clusters that are major GHG emitters, produce or consume hydrogen, have substantial fossil-generated power generation, and

FIGURE 3

Select Process for Key Metals and Minerals Needed for EV Battery Production: EU, US, and China Shares, 2019

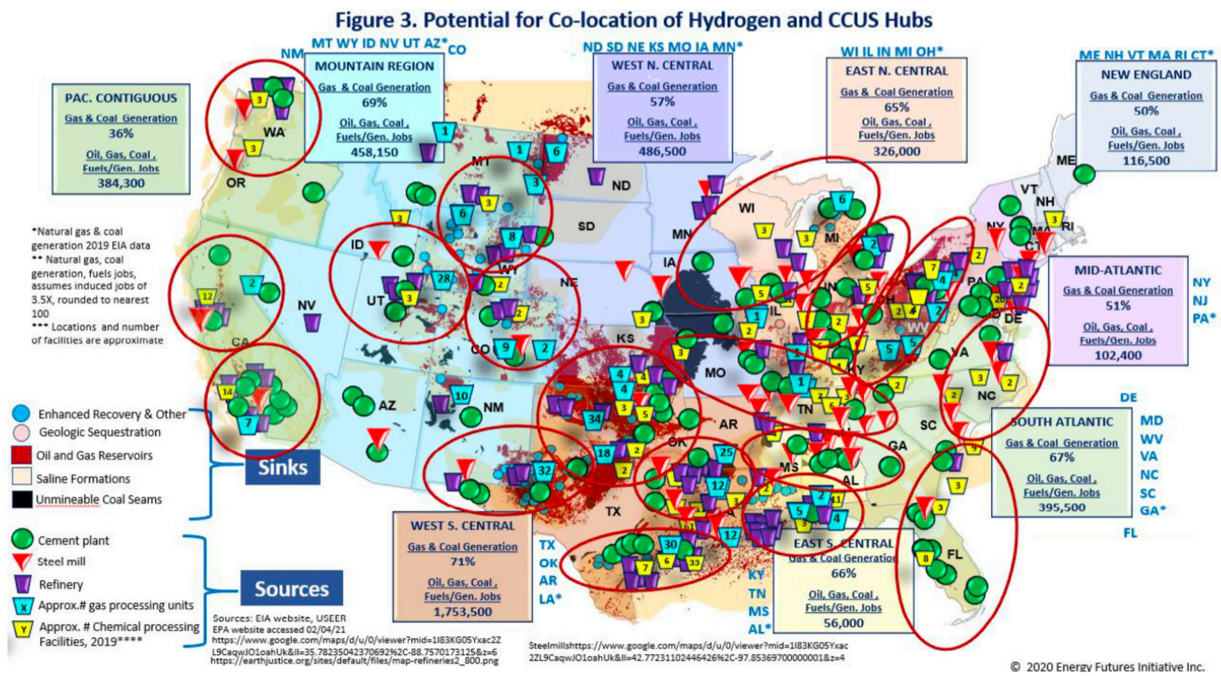


Figure 3 is an overlay of EIA power generation regions (e.g., CA/WA/OR) on top of potential sequestration sites from NETL. It also shows the spatial clustering of major industrial and power sector emissions sources, actual or potential producers/consumers of hydrogen, e.g., refineries, chemical processing, and their proximity to geological formations that are suitable for permanent geologic storage of captured CO_2. The clusters represent opportunities for potential CCUS/hydrogen hubs that could share a range of infrastructures, indicated by the larger red circles. Source: EFI, 2020. Adapted from EIA, USEER, and EPA.

potential sequestration sites for captured CO_2. Within one hub, there could be a mix of blue hydrogen and CCUS for different categories of industrial plants.

The formation of hydrogen hubs may develop along a similar path to natural gas distribution systems, requiring policy enablers, regulatory frameworks, and new business models. EFI is investigating the policies needed for hydrogen market formation in the United States, actively working with major stakeholders to profile current investments in clean hydrogen across the emerging hydrogen value chain: production, transport, and end use. This will help EFI to develop regional case studies to evaluate the specific opportunities and challenges of building out hydrogen infrastructure and markets. Federal and state governments should work together to incentivize early-mover hydrogen-CO_2 hubs, perhaps through approved multi-state regional compacts.

Federal financial incentives will be a key part of developing hydrogen infrastructure. These could include tax incentives for production, installation of supply infrastructure, purchase of hydrogen-fueled vehicles, or use in industrial and commercial contexts. Infrastructure-specific incentives will be key to solving the chicken-and-egg problem of hydrogen supply. Another form of incentive could be use of public procurement power, such as purchase targets for fuel-cell vehicles. A carbon border adjustment for energy-intensive goods could also encourage industrial producers to be early hydrogen adopters.

Federally funded innovation will also be key to developing a hydrogen economy. One possible path forward toward hydrogen hubs is the establishment of a federally assisted demonstration program, which would create two to three hubs that could be used as examples for the rest of the country. Expanded RD&D could reduce cost of blue or green hydrogen production, and further develop new configurations like nuclear-powered production. Innovation could also be important to developing alternative forms of hydrogen carriers.

CO_2 Transportation and Storage

Carbon capture utilization and storage (CCUS) will be an essential element in any portfolio of actions for meeting a mid-century net zero goal. As one indicator of scale—the EFI study of the California decarbonization policies and plans found that CCUS could contribute to a reduction of around 60 $MMTCO_2$, representing nearly 30% of the State's 2030 emissions reduction target. Scaling CCS projects nationwide will require significant quantities of CO_2 that must be captured and transported for geologic storage or other disposition. CO_2 transport and storage also will be required to support carbon removal technologies including biomass with carbon capture and storage (BECCS), Direct Air Capture (DAC), and in-situ carbon mineralization.

Very large carbon management projects, such as at some power generation facilities or large industrial emitters, may deploy CCUS as a single, wholly owned and operated project. Many other CCUS and direct carbon capture projects, however, will need to rely upon the economies of a large-scale carbon management hub, where CO_2 transport and storage is provided by a 3rd party deployment of a spoke-and-hub architecture. Congressional action can provide needed stimulus for the formation of such regional CO_2 hub infrastructures.

Building a CO_2 pipeline infrastructure raises the challenges of obtaining rights of way and the complexity of permitting. The EFI analysis of CCUS deployment opportunities in California showed that project permitting is one of the most significant impediments to progress for new CCS project developers. CCS projects involve permitting for at least two processes (capture and storage) and each process may include multiple—and up to a dozen—state and federal agencies that may not be familiar with CCS permitting processes. CO_2 transportation needs add to the complexity when projects have widely separated source and sink. Congressional action to encourage repurposing of existing rights of way to allow for CO_2 pipelines to co-locate with other infrastructures would be beneficial. Policy direction to improve coordination of permitting, such as the provisions of the proposed USEIT Act, also would be very beneficial. Finally, additional financing incentives, such as an expanded application of the DOE Title XVII loan guarantee program or new financial incentives such as those in the SCALE Act, could accelerate the pace of buildout of CO_2 pipeline infrastructure.

In addition to pipeline infrastructure, the other key element of CO_2 infrastructure is the buildout of geologic storage hubs. The DOE Carbon Storage Assurance Facility Enterprise (CarbonSAFE) program has supported the characterization studies needed to assess the feasibility of storage hub locations. This work could be accelerated with additional funding and expanded in scope to enable the build out of several of the CarbonSAFE sites into regional storage hubs. The September 2019 EFI Report, Clearing the Air, discussed in more detail the opportunity to expand and accelerate the storage hub concept.

Finally, creating a large-scale CO_2 management infrastructure will require the development of new business models and regulatory frameworks. The creation of 3rd party carbon management entities—perhaps a CO_2 utility model—provides a substantial new business opportunity for firms with expertise and experience in managing fossil fuel production and processing; the 3rd party could be organized as a regulated utility due to the non-competitive nature of shared transportation and storage infrastructure. New regulatory structures, with an emphasis on encouraging deployment on a regional scale, also will be needed. Management of liability, particularly in cases where the entity managing the CO_2 storage is different from the entity that generated the CO_2, will be critical. The monitoring, reporting and verification (MRV) requirements of the current EPA Class VI permitting program may need to be supplemented with some form of an insurance pool to address liability for CO_2 leakage from third party sequestration sites that are managing CO_2 from multiple sources. An insurance pool could more appropriately balance risks between generators of CO_2 and owner/operators of CO_2 storage sites, lowering an impediment to project finance and development.

Other Cross-cutting Needs for Expediting Clean Energy Infrastructure Buildout

There are other issues, policies and potential options that should be considered in the context of infrastructure incentives and policies to aid in the clean energy transition. These include protection of global supply chains and incentives for building domestic capacity; the growing interdependencies of key infrastructures; broadband access; the generic need for expedited infrastructure siting; and cyber-security.

Protecting Global Supply Chains, Building Domestic Options

Increased electrification, new clean energy technologies, LNG exports to allies, and COVID have raised issues about the security of global supply chains and the need to focus on creating, building, and reinvigorating domestic options. As noted, electrification and the buildout of transmission lines, and variable renewable generation technologies, will mean dramatic increases in demand for steel, EV battery manufacturing, the mining, processing, and refining of key metals and minerals including lithium, cobalt, manganese, and nickel, and cathode and anode production.   And this demand growth is not occurring in a vacuum. Net zero targets are increasing demand—and competition—for steel, EVs, batteries, and other key materials and technologies around the world.

The need to address these issues was underscored by President Biden's Executive Order 14017, America's Supply Chains, which notes that "More resilient supply chains are secure and diverse—facilitating greater domestic production, a range of supply, built-in redundancies, adequate stockpiles, safe and secure digital networks, and a world-class American manufacturing base and workforce. Moreover, close cooperation on resilient supply chains with allies and partners who share our values will foster collective economic and national security and strengthen the capacity to respond to international disasters and emergencies."

Figure 3 underscores some of the critical issues that drive the need for such an order and highlights key areas of focus for building up domestic supply chain infrastructures. From an energy perspective, the EO focuses on two key areas: batteries and industrial supply chain needs. Creating domestic options for both batteries and critical industry needs should be considered essential components of a clean energy future.

Protecting global supply chains, growing domestic industries and options, and investing in innovation, are all critical to providing the energy and associated infrastructures for a clean energy future. This should, in fact, inform and broaden the definition of both energy infrastructure and energy security to help ensure policymakers are providing adequate direction and incentives to support the supply chains and industries needed for a clean energy future

Policies that could enhance US capacity in these areas include:

- Protection of global supply chains for minerals/metals needed for wind, solar and batteries;
- Support for new domestic, environmentally responsible mining activities for key minerals/metals, including associated infrastructure;
- An increase in the capacities, capabilities, and associated infrastructures needed for key

mineral chemical processing/refining and battery manufacturing; and

- The promotion of humane mining conditions around the world.

Infrastructure Interdependencies

The Texas experience also highlights the growing interdependencies of critical infrastructures and points to a key need going forward. In the case of the Texas deep freeze, it was the electricity, gas, and water infrastructures. These three infrastructures—and other critical infrastructures—do not sit neatly together in law, regulation, oversight and, relevant to today's discussion, within either committee or federal agency jurisdictions. This needs significant analysis to identify changes in policy and program structures that might be needed to accommodate the new realities of clean energy systems and the interdependencies of critical infrastructures.

Broadband Access

Energy infrastructures are also increasingly dependent on digital technologies, making broadband access a critical part of modernizing those infrastructures. In fact, the COVID-19 pandemic has demonstrated just how dependent we are on internet access in all facets of modern life. The increasing IT connectivity of energy systems could also help accelerate the low-carbon transition, facilitating digital infrastructures that allow for more efficient energy use and integration of new kinds of resources. Increased public investment can mitigate existing inequities in broadband access and close the gap to universal deployment. There are also possible synergies between broadband and energy infrastructure: pursuing the physical improvements and expansions required for each system in parallel can create opportunities for cost savings and more efficient permitting.

Infrastructure Siting Challenges

In addition, the urgency of climate change and the need for a range of new infrastructures begs siting questions and the speed at which new infrastructure can be built. The list of delays in siting key energy infrastructures is long and includes the Northern Pass Project, Cape Wind, the Winder Catcher project, Sun Zia and the Clean Line Energy project that we worked on at DOE when I was Secretary.[3] There are existing rights of way, e.g., for railroads, interstate highways, gas and oil pipelines, and existing electricity transmission that might be re-purposed to help expedite the siting of new clean energy infrastructures. It is possible that such re-purposing could also be monetized, aiding in reducing financial losses to industries that have relied on revenues from conventional energy. Coal transport, for example, has been a significant source of revenue for freight rail, but coal demand has declined

3. https://www.greentechmedia.com/articles/read/9-transmission-projects-laying-the-paths-for-cross-country-clean-energy

significantly over the last several years; with federal support and guidance, railroad rights of ways might be valuable for more rapidly siting new infrastructures needed for a clean energy future. An examination of existing authorities and the development of new authorities to support the re-purposing or multi-purposing of existing rights of way could help accelerate the transition to a clean energy future.

Cyber Security

Ensuring cybersecurity must be a fundamental consideration when modernizing and expanding U.S. energy infrastructures. The modern energy system—including the electric grid, natural gas systems, on-road and air transport, and manufacturing—will become increasingly dependent upon cyber-physical systems. As the energy system becomes smarter through the integration of information and operational technologies, the risks posed by cyber-attacks will increase. There are, however, also opportunities to engineer cybersecurity into the future energy infrastructure in a way that supports decarbonization, operational resilience, and security. This will include developing intrusion detection systems into critical components, expanding our capability to monitor and track the supply chains for critical components, embedding cybersecurity into training across the entire workforce, building on our strong information sharing programs between the government and private sector and among industry itself. The recently revealed SolarWinds attack shows how cybersecurity must be applied along the entire supply chain for infrastructures.

These and other measures should be integrated into how we build energy infrastructure in the United States.

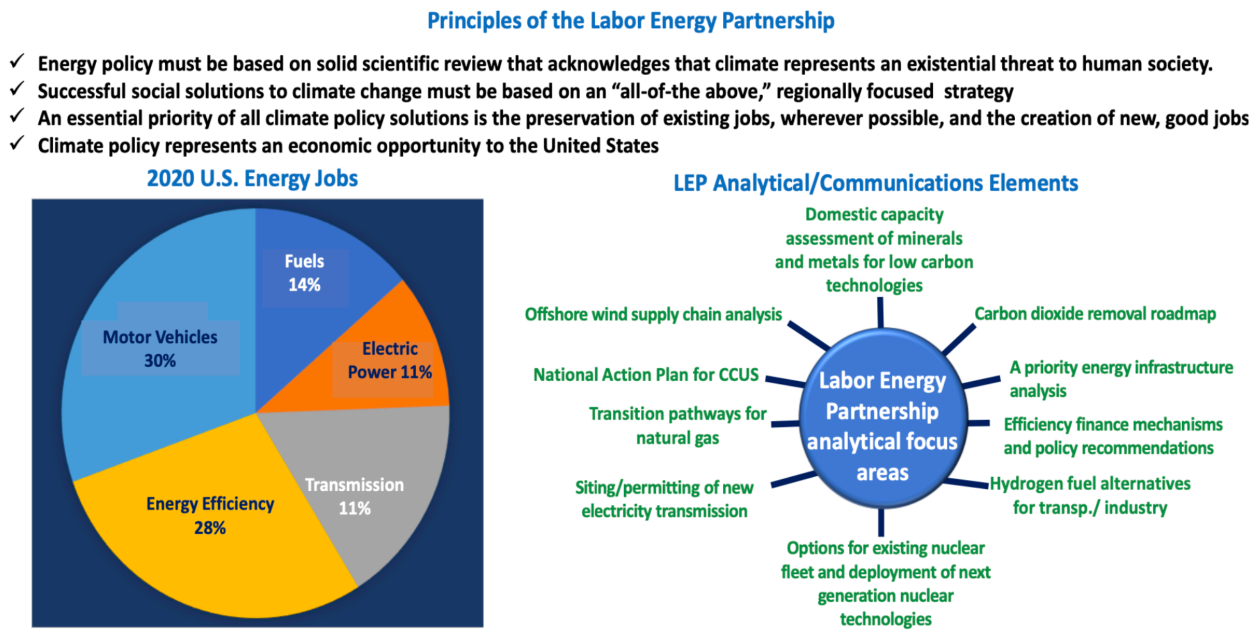
Transitioning Conventional Energy Jobs to the Clean Energy Jobs of the Future

Another significant activity we are engaged in that relates directly to the topic of today's hearing is the establishment of the Labor Energy Partnership (LEP). Last Earth Day, the Energy Futures Initiative (EFI) and the AFL-CIO formed the LEP. This is a joint effort of both organizations to develop a framework the 21st Century energy system that creates and preserves quality jobs while addressing the climate crisis.

The LEP's four guiding principles demonstrate its approach to a range of issues, including grid modernization, offshore wind, CCUS, and hydrogen. These principles are: 1) Energy policy must be science-based; 2) We need an "all-of-the-above" energy strategy that is regionally focused, flexible, and preserves optionality; 3) preserving jobs, while creating new ones, is essential to climate policy; and 4) there are significant economic opportunities in the development and deployment of clean technologies and infrastructure. Figure 4 below highlights these principles as well as the 10 areas of analytical and outreach focus that guide the activities of the LEP. It also shows the distribution of energy jobs in 2020.

The Labor Energy Partnership is currently analyzing the policies needed

FIGURE 4
U.S. Energy Jobs by Sector, the Labor Energy Partnership



to site and permit new electricity infrastructure projects in the near-term. It is also evaluating policy solutions to ensure rapid development of offshore wind resources along the east and west coasts, and in the Great Lakes region. In line with its wholistic approach to policy analysis, the LEP is considering local economic impacts, the opportunity to onshore the offshore wind manufacturing and supply chains, the social equity and environmental justice concerns, and the lessons learned from the existing global market.

In addition to its work with the AFL-CIO, the Energy Futures Initiative, in partnership with the National Association of State Energy Offices, conducts an annual energy jobs survey that we started at DOE when I was Secretary. The previous Administration discontinued this survey. Understanding its importance, EFI and NASEO have sustained this critical work and released a five-year trend analysis of energy jobs last year. The data in this summary analysis (all pre-COVID) indicated that energy jobs were created at twice the rate of overall jobs in the economy, a critical consideration as we work on COVID recovery.

Special attention needs to be paid to conventional energy jobs and providing the training and cross-walking to clean energy jobs. Again, offshore wind provides an example. The skills of oil and gas workers who have experience with building and maintaining offshore drilling platforms can be transferred to offshore wind platform construction and maintenance. CCUS offers another opportunity to apply the subsurface and pipeline construction and maintenance knowledge and skills of oil and gas workers to work on large scale decarbonization infrastructures. This underscores some of the key reasons why we formed the Labor Energy Partnership with the AFL-CIO last year.

Transforming our Energy Systems: Regional Infrastructure Options are Critical

Last, and perhaps most important for the members who represent varied constituencies across the country, we need to encourage and provide policy support for regional solutions to climate change and the associated infrastructure needs. EFI has undertaken multiple projects on regional decarbonization, including reports on California and New England (in collaboration with E3), and a forthcoming report on New York City (along with ICF and Drexel University). The resources, infrastructures, emissions profiles, innovation, and policy needs vary greatly by region of the country—a "one size fits all" approach to policy and financial support will likely impede, not accelerate progress towards deep decarbonization. EV charging infrastructures will, for example, look very different in both rural and urban areas, where the typical "suburban EV model mindset" and its associated infrastructure will have little relevance.

Access to broadband offers another example, affecting the degree to which a city, town or region could be considered for any policy support as a "smart community". Smart Community initiatives must be understood and guided by digitization as the foundation for economic growth and entrepreneurial activity. While important to focus on initial apps (e.g., smart streetlights), a critical focus should be ensuring the buildout and protection of the digital backbone infrastructure that is the basis for an entrepreneurial economy in cities and communities. This backbone starts with the integrated cutting-edge smart electricity and telecommunications systems linked to big data, sensors, real-time modeling, and artificial intelligence capabilities. The backbone infrastructure will provide unforeseen entrepreneurial advances in the smart city/community and act as a magnet for talent. In addition, all these issues and considerations must accommodate regional, state, and local needs and differences, including urban and rural differences.

Mr. Chairman, Ranking Member Rodgers, members of the Committee, I appreciate the opportunity to testify today on critical energy infrastructure issues. The Lift America Act is a very important and necessary step towards supporting the infrastructure we need for deep decarbonization of energy systems and consuming sectors and for building resilience into our infrastructures in anticipation of increasingly extreme weather patterns. I look forward to your questions.

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