Testimony of Secretary Ernest Moniz, CEO, Energy Futures Initiative
before the House Committee on Science, Space and Technology
April 15, 2021

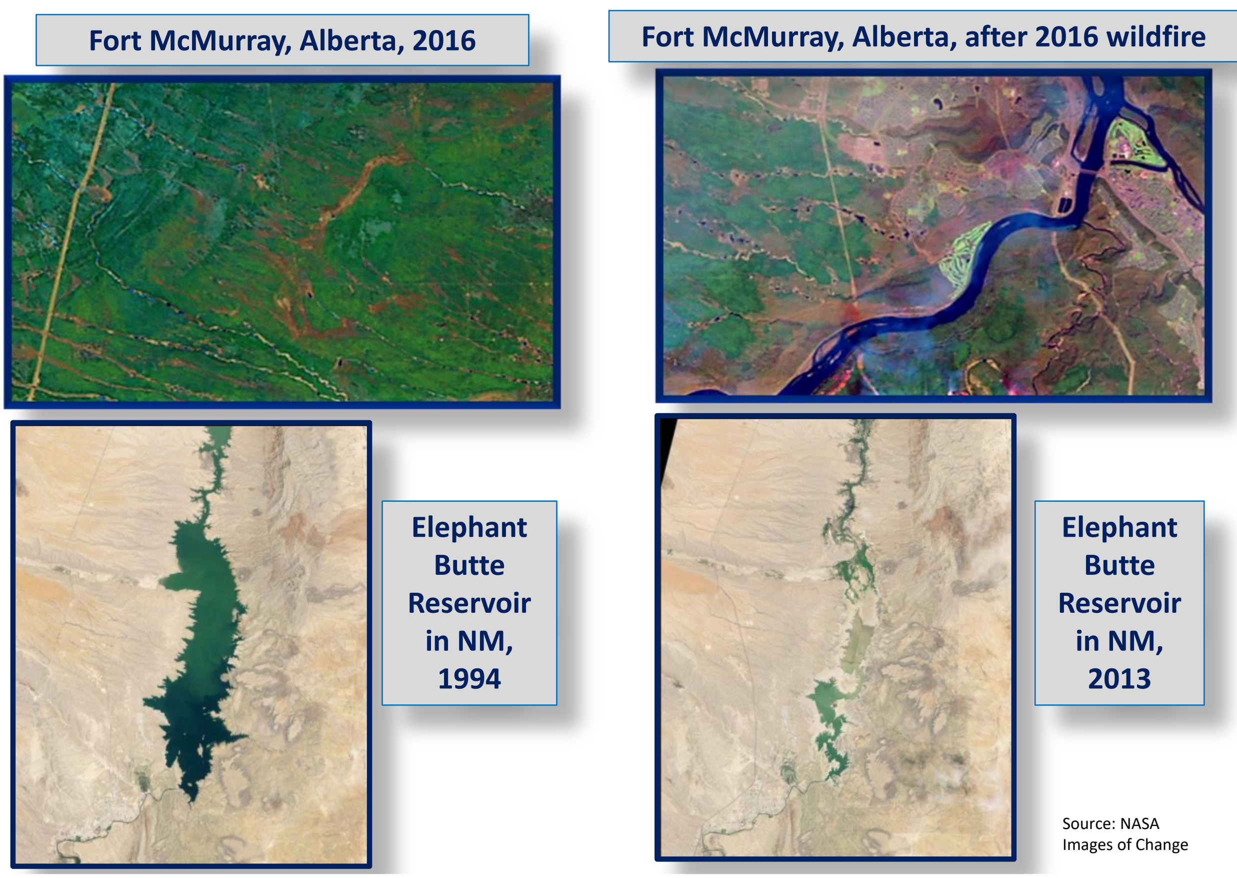
Madam Chair, Ranking Member Lucas, members of the Committee, thank you for the opportunity to testify before you today.

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.

Figure 1. Examples of the Impacts of Climate Change In N. America: Increased Wildfires, Severe Drought



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 UNFCC, 191 countries have submitted their first Nationally Determined Contribution (NDC) and eight have submitted their second.[i] 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.

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.

Text Box 1. QER 1.1 Highlighted Gas/Electric Infrastructure 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 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.

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.

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

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 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.

Figure 2. California Wind and Solar Generation for Each Day of 2017, CA Installed Storage Capacity, 2019

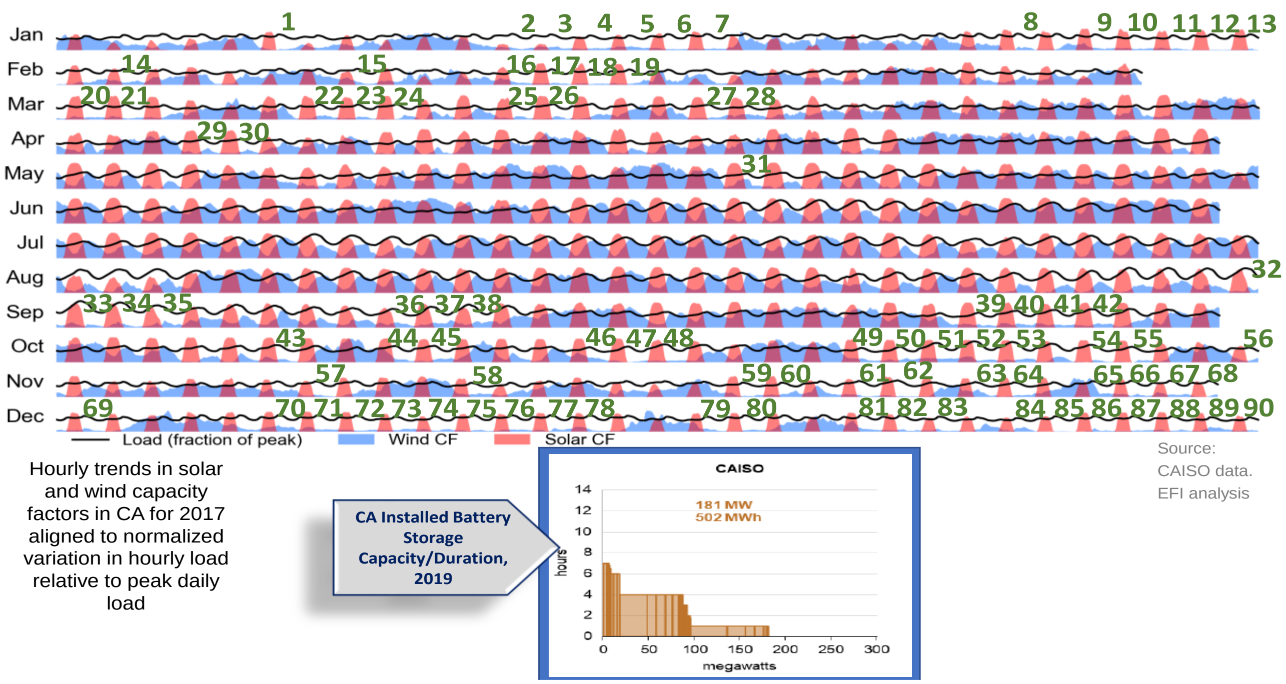


Figure 2 shows the hourly wind and solar generation for every day in 2017. Numbers in green count the days in the year where there was little to no wind generation in the state. The inset shows the installed battery storage capacity and duration in California which is currently insufficient to provide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

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]

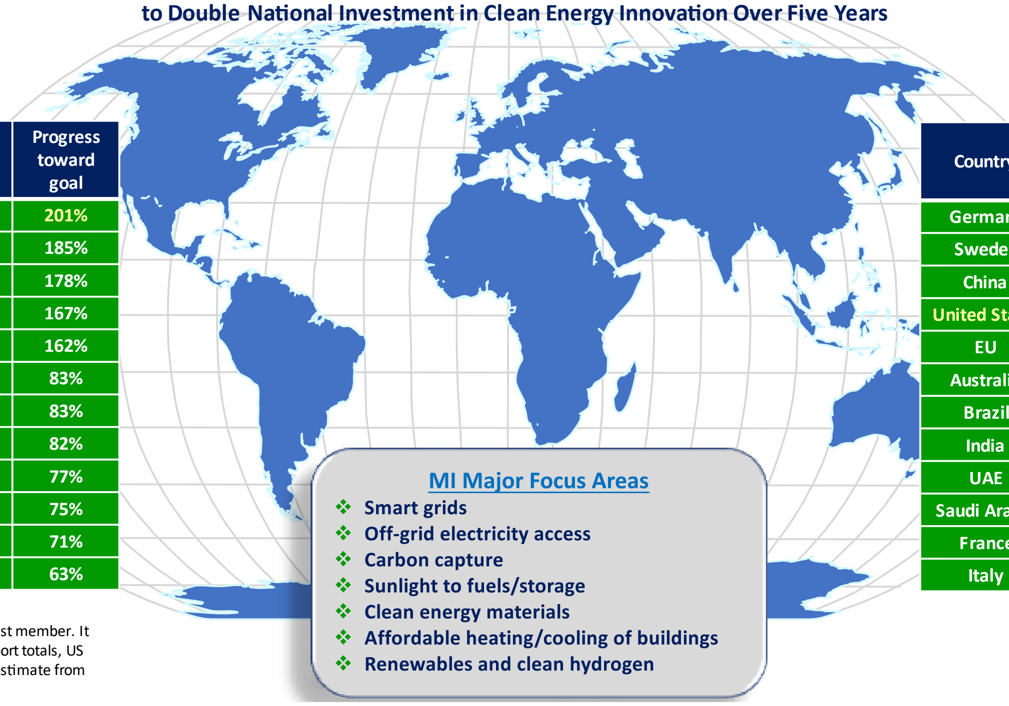
There is significant consensus from these and other reports on recommendations for federal energy innovation support that include:

- 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.

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

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



Country	Progress toward goal
Norway	201%
Netherlands	185%
Japan	178%
UK	167%
Mexico	162%
Chile	83%
Austria	83%
Indonesia	82%
Canada	77%
Denmark	75%
South Korea	71%
Finland	63%

Country	Progress toward goal
Germany	63%
Sweden	60%
China	52%
United States	43%*
EU	41%
Australia	36%
Brazil	34%
India	26%
UAE	22%
Saudi Arabia	20%
France	17%
Italy	14%

MI Major Focus Areas
- Smart grids
- Off-grid electricity access
- Carbon capture
- Sunlight to fuels/storage
- Clean energy materials
- Affordable heating/cooling of buildings
- Renewables and clean hydrogen

*Morocco is newest member. It and US did not report totals, US percentage is an estimate from EFI analysis

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 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 G-7/EU Leaders, 2014

- Flexible, transparent and competitive energy markets, including gas markets, should be developed.
- Infrastructure modernization will improve energy system resilience. Promoting supply and demand policies will help withstand systemic shocks.
- Energy fuels, sources and routes should be diversified and development of indigenous sources of energy supply should be encouraged.
- Reducing our greenhouse gas emissions and accelerating the transition to a low carbon economy are key contributors to enduring energy security.
- 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.**
- Emergency response systems, including reserves and fuel substitution for importing countries, should be put in place to manage major energy disruptions.

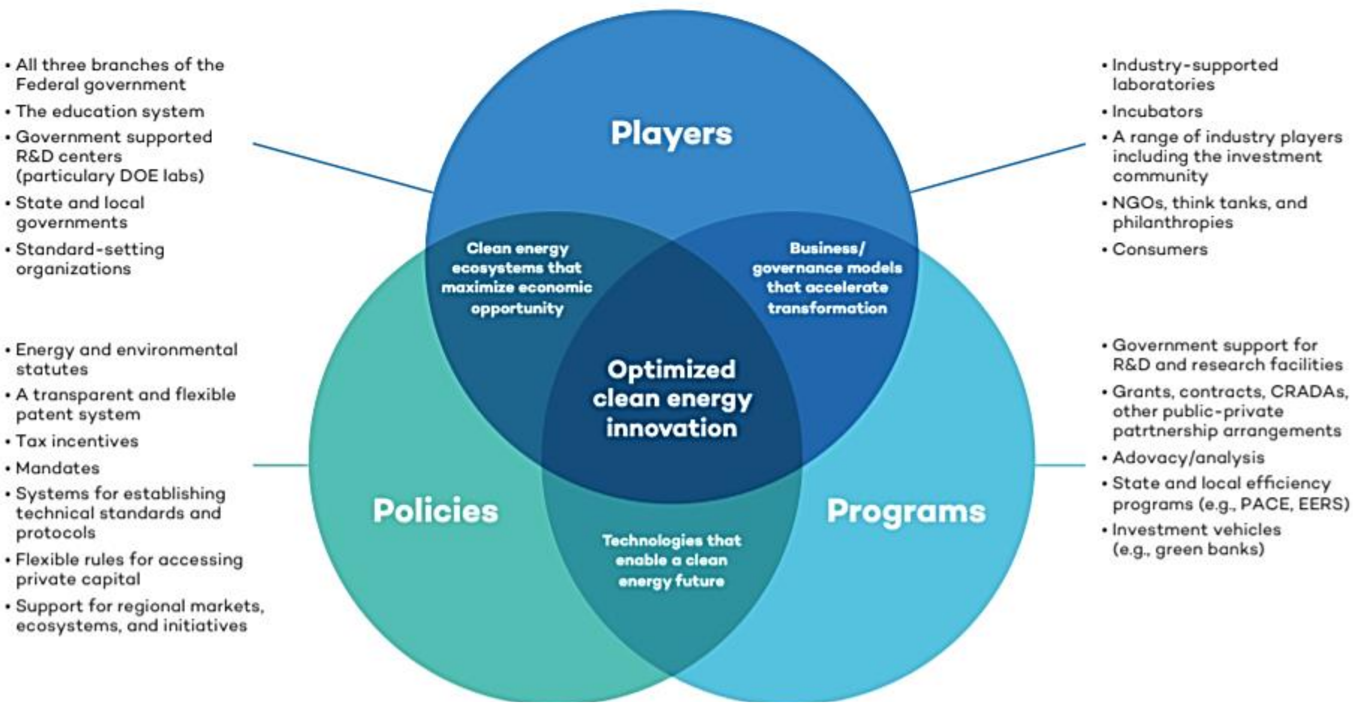
Adapted from Joint Statement, Rome G7 Initiative for Energy Security, May, 2014

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 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.

Figure 5. Aligning the Key Players, Policies, and Programs Can 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 breakthrough technologies to address national and global challenges and help meet near-, mid-, and long-term clean energy goals as seen in Figure 6.

Figure 6. EFI's Four-Step Methodology for Identifying Breakthrough Technology Areas[3]

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 (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

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

    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.

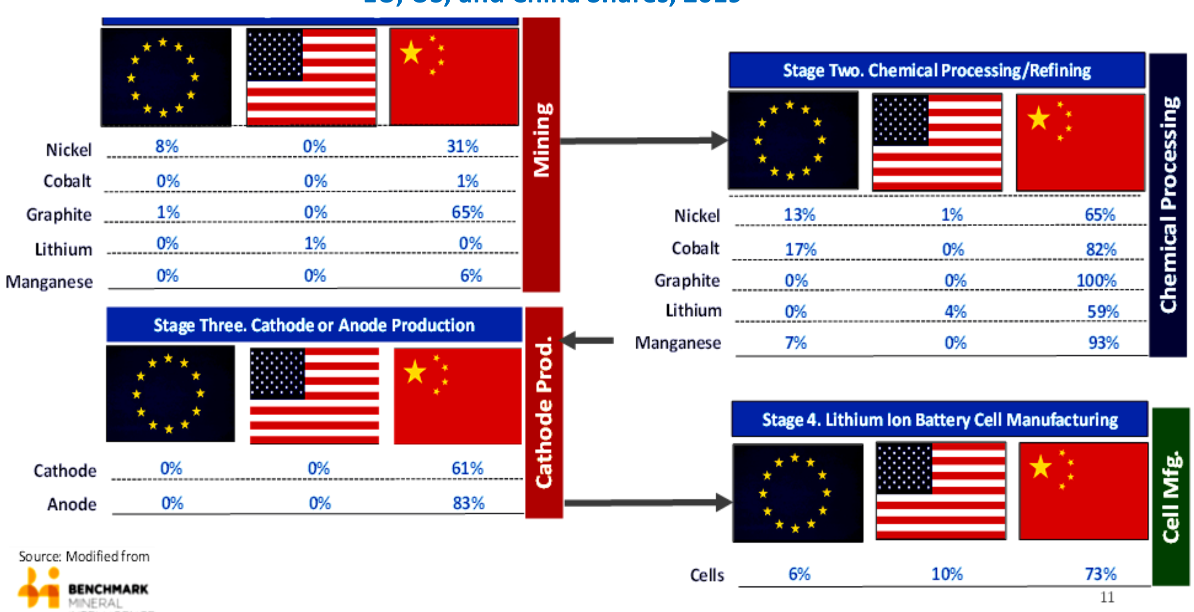
Policies and programs that could enhance US capacity in these areas include:

- 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;
- 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.

Figure 7. Select Process for Key Metals and Minerals Needed for EV Battery Production: EU, US, and China Shares, 2019



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 CO2 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 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 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.

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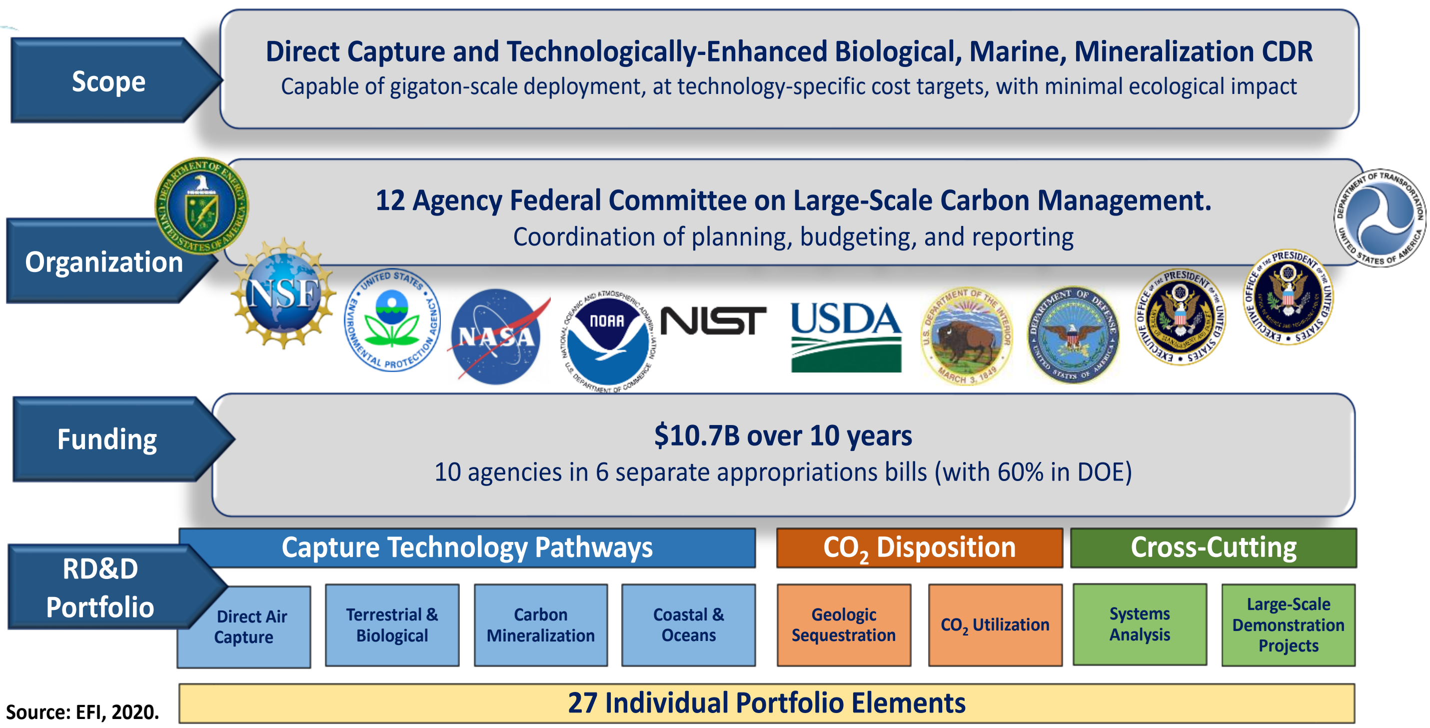
[4] The three reports are*: From the Ground Up: Cutting-Edge Approaches for Land-Based Carbon Dioxide Removal; Uncharted Waters: Expanding the Options for Carbon Dioxide Removal in Coastal and Ocean Environments; and Rock Solid: Harnessing Mineralization for Large-Scale Carbon Management.*

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).

Figure 8. Comprehensive Carbon Dioxide Removal RD&D Initiative



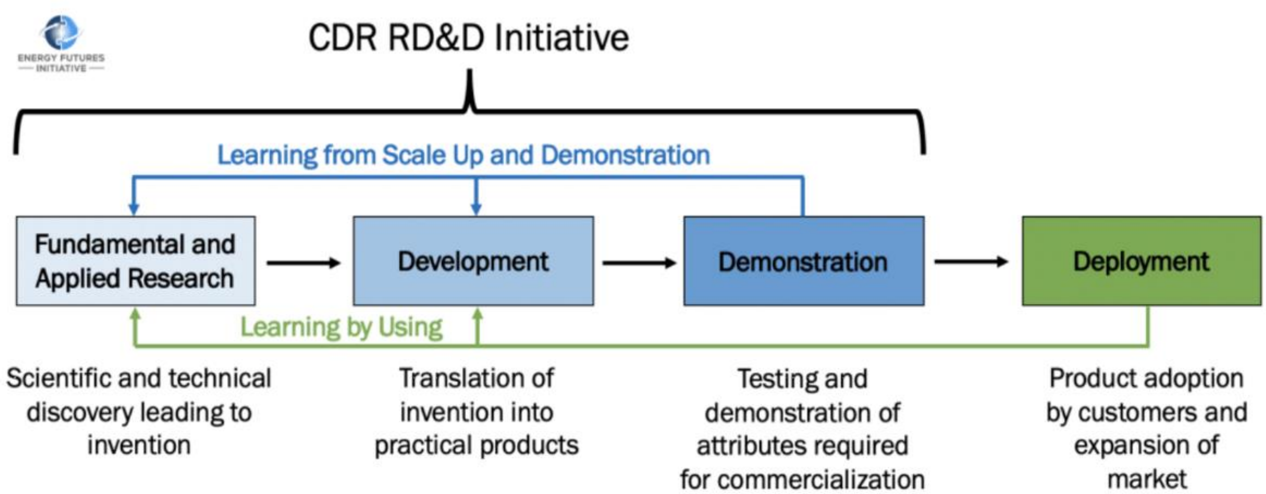
Source: EFI, 2020.

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.

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 learning by using. Source: EFI, 2019.

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 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 research[5] 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.*

[5] Use-inspired science has been referred to as Pasteur's Quadrant—an approach fitting to DOE and Mission Agencies. See Donald E. Stokes, Pasteur's Quadrant: Basic Science and Technological Innovation, Washington, DC, Brookings Institution Press, 1997.

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.

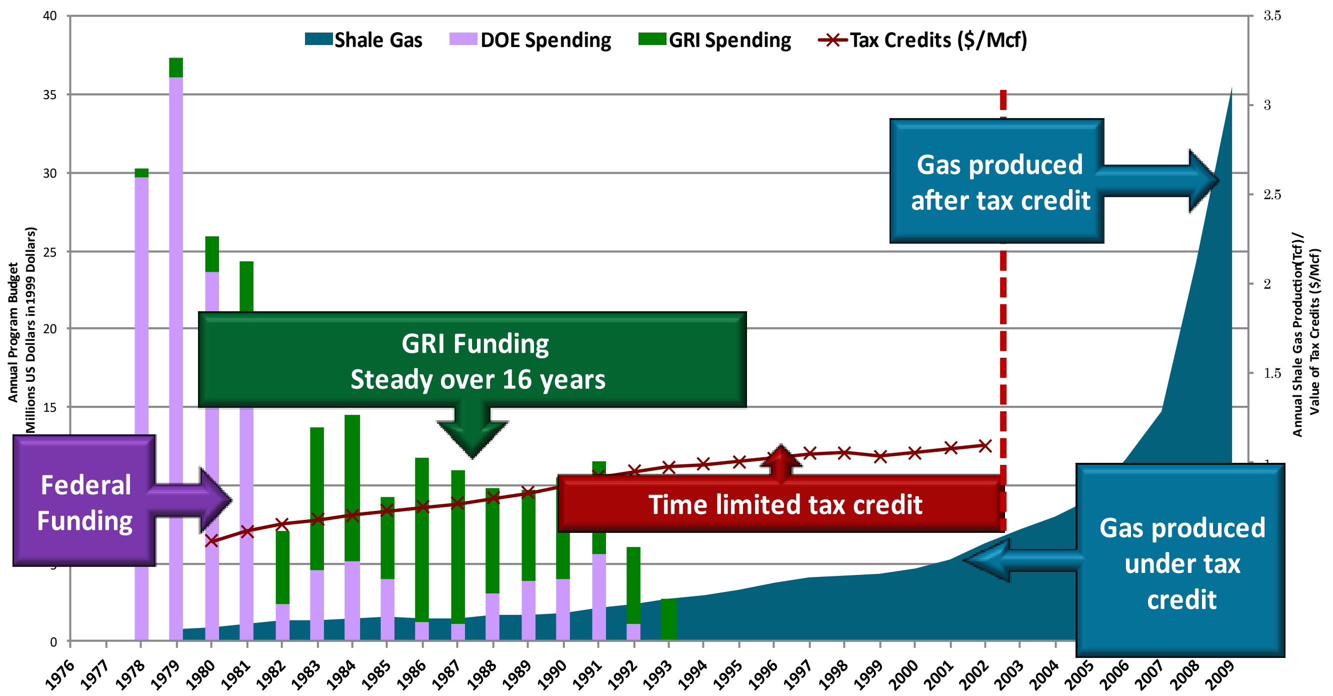
Finally, the role of the Advanced Research Projects Agency—Energy (ARPA-E) is noteworthy for its unique role in bridging between the stages of fundamental and applied research into development and scale-up. ARPA-E, established in the America COMPETES Act of 2007 pursuant to a recommendation by the National 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 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 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.

Figure 10. Federal Investment, Policies, Industry Support: US is Now the Number One Gas Producer in the World



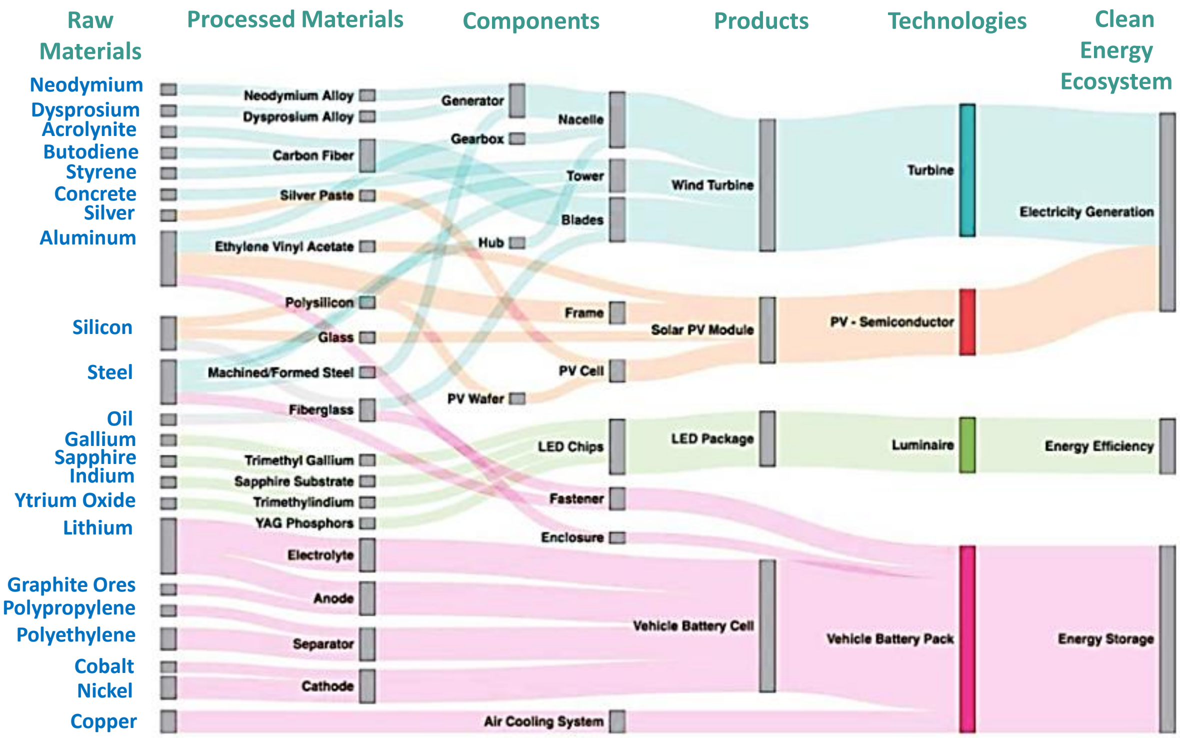
Follow-on applied R&D investment, through a public private partnership involving DOE, the Gas Research Institute (now the Gas Technology Institute) and the private sector achieved proof of concept of shale gas drilling techniques. The availability of the nonconventional gas tax credit provided an important 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 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 strategie

Fifth, the implementation of energy innovation programs needs to be cognizant of regional variations

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.

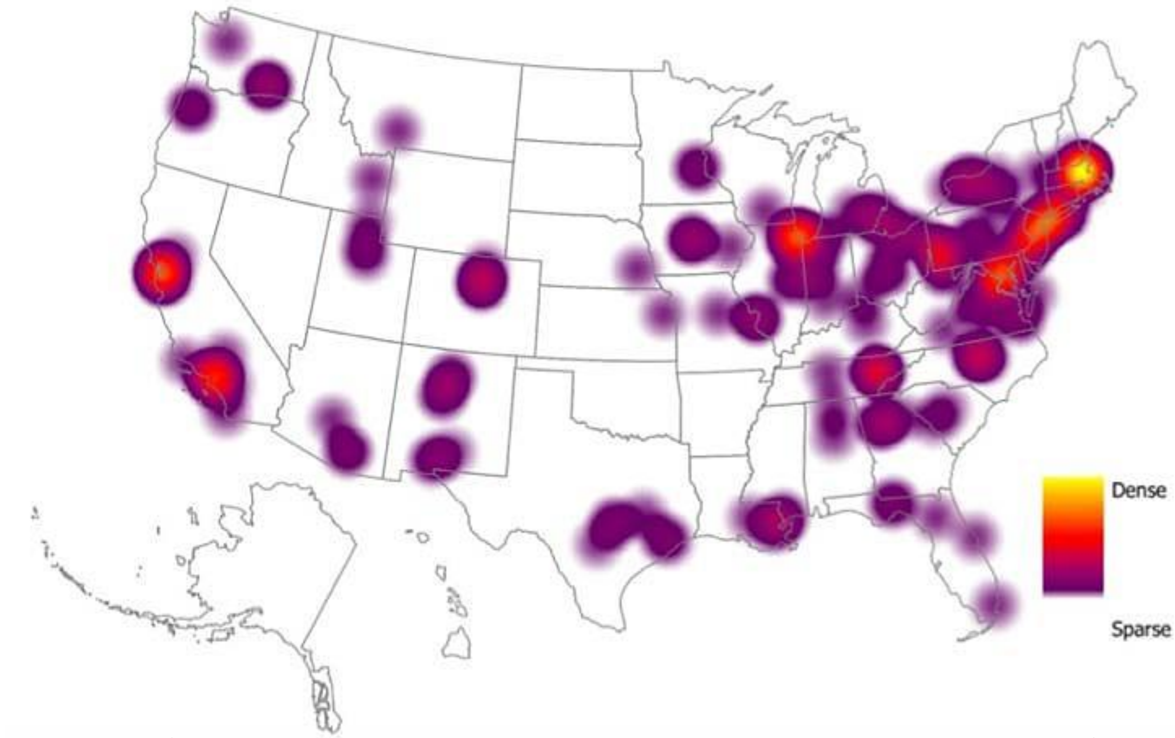
Source: McCall, 2017, Clean Energy Manufacturing Analysis Center

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.

Figure 12. EFI's Regional Clean Innovation Index



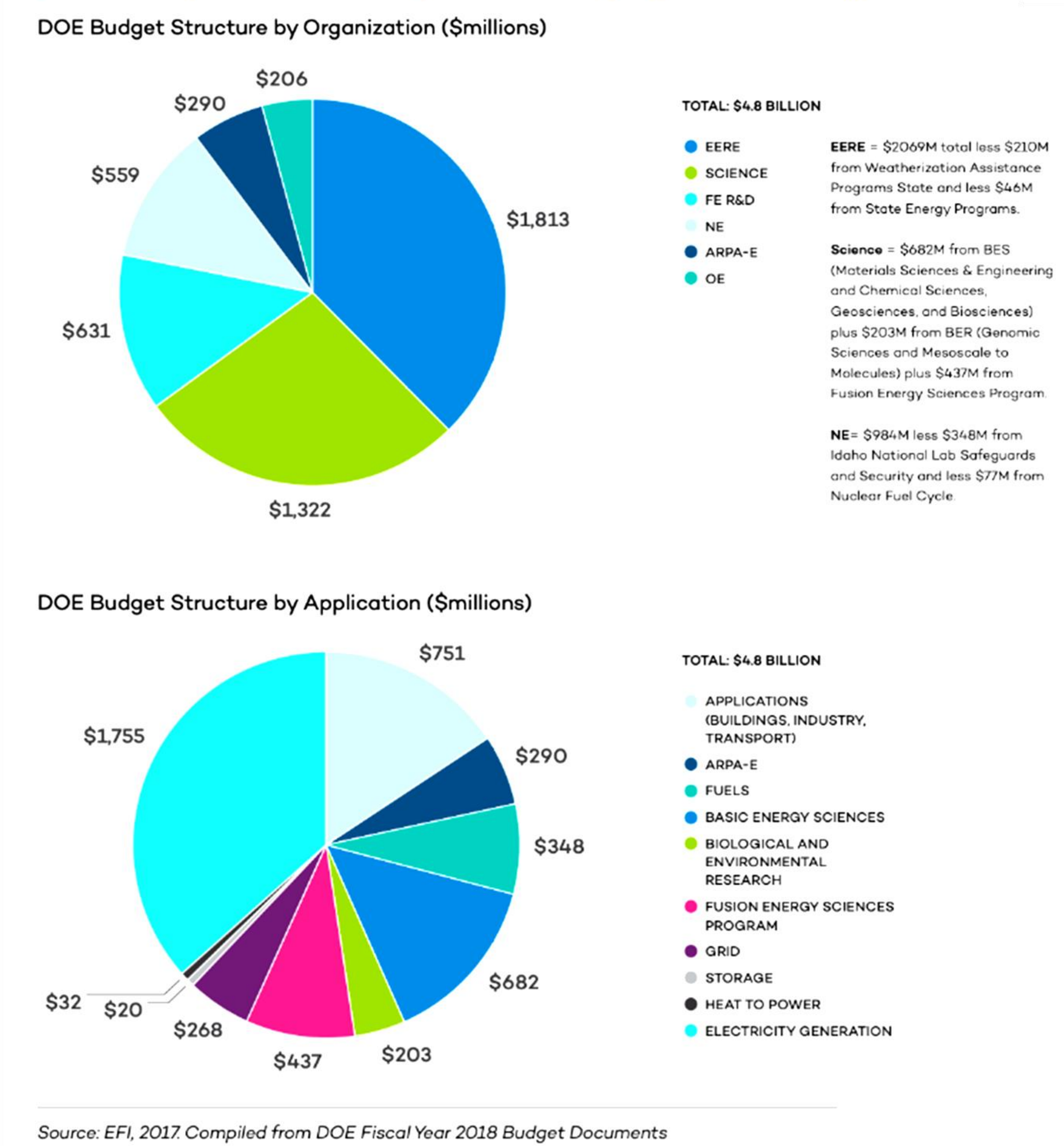
EFI's Regional Clean Energy Innovation Index combines locational data for energy RD&D resources across the country to analyze the potential benefits to innovation of regional clustering.

Source: Energy Futures Initiative (EFI), 2017. Compiled using data from Hersch, 2014; Manufacturing USA; National Aeronautics and Space Administration; National Science Foundation; DOE

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 succeeding years."

Figure 13. Comparison of DOE Budget Structures by Organization and Application



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.

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.

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