ENERGY FUTURES INITIATIVE

EFI's Portfolio for Accelerating the Clean Energy Transition

A Guide for the Biden-Harris Department of Energy (DOE) Transition Team

December 2020

900 17TH ST. NW, SUITE 1100, WASHINGTON, D.C. 20006

December 23, 2020

To Members of the DOE Transition Team:

We are pleased to submit this compendium of work by the Energy Futures Initiative (EFI) to serve as a reference for the Biden-Harris administration as it re-joins the Paris Agreement and charts a course to net-zero carbon by midcentury. International leadership must, of course, rest on the solid foundation of domestic accomplishment.

Since it was established in 2017, EFI has analyzed many policies, programs and technologies needed for deep decarbonization. As the science of climate change has advanced, this analysis has increasingly focused on those qualities that are central to any climate action plan that can succeed in reaching the aggressive—but essential—net-zero goal:

- ✓ **Jobs, Jobs, Jobs**: We need to create millions of good jobs coming out of COVID and into the future. EFI research has identified the high-leverage opportunity of clean energy investment for job creation that can effectively translate conventional energy jobs into clean energy jobs without stranding workers, communities or assets. The Labor-Energy Partnership formed between EFI and the AFL-CIO will continue to identify and amplify opportunities for good job creation while addressing climate risks.
- ✓ **Optionality, Flexibility, and Innovation**: 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. Breakthroughs will be needed, and EFI has and will engage the breadth of technology development, demonstration, and deployment needed for a mid-century zero-emissions economy, including:
    - Energy efficiency
    - Advanced renewables, such as offshore wind
    - Electricity storage from minutes to seasons
    - Advanced modular nuclear technologies, both fission and fusion
    - Carbon capture, utilization, and sequestration
    - Hydrogen
    - Carbon dioxide removal from the atmosphere and upper ocean layers
    - Associated infrastructure
- ✓ **Secure and Sustainable Supply Chains**: COVID demonstrated the importance of secure supply chains for our health care system and the entire economy. We are rapidly establishing new, un-tested supply chains of critical component parts that enable our clean energy transition. EFI is committed to helping develop sustainable and secure supply chains needed for dramatic scale-up of clean energy technologies, especially renewables and their enabling technologies.
- ✓ **Regional Solutions with Social and Environmental Justice**: EFI has emphasized the important regional differences that must be accommodated in building climate and social equity solutions. Local and regional resources, expertise, and infrastructures are important catalysts for rapid and significant innovation. EFI will continue to identify

novel recommendations for advancing policy solutions that support social equity and environmental justice concerns in the emerging clean economy.

Finally, and perhaps most important in today's highly charged and divided politics, we need policies, technologies and programs that enable the formation of:

- ✓ **Strong and Sustainable Coalitions**: We cannot address climate change at an accelerated pace and at the scale needed to transform massive energy systems without doing the hard work of building broad coalitions of support. EFI has worked with labor, business, other NGOs, financial institutions, foundations, religious leaders, and Federal, State and local officials on both sides of the political divide to provide analytically-based solutions that can change how we produce and consume energy at the pace needed for deep decarbonization by mid-century.

All of the EFI work to-date underscores the need for a decade of supercharged innovation—starting now—as a necessary component of a successful climate change risk mitigation program.

We believe that these qualities are integral to the stated Biden-Harris approach to the climate crisis. EFI stands ready to assist the Administration's efforts to reawaken American leadership and hopes that this synthesis of several years of work will be helpful during the next few months and beyond for setting a significantly different direction commensurate with the climate challenge.

Ernest J. Moniz	Joseph S. Hezir	Melanie A. Kenderdine	Alex Kizer
Founder & CEO	Managing Principal	Managing Principal	Research Director

Introduction

For nearly four years, the Energy Futures Initiative (EFI) has focused on conducting pragmatic, technically grounded analyses to inform federal, regional, state, and local stakeholders on how to address the climate challenge: significantly reducing emissions of greenhouse gases to mitigate largescale economic, environmental, and cultural losses associated with an increase in mean global temperatures. Since its founding, EFI has become a leading voice on technology and policy pathways to deep decarbonization. In addition to the public messaging of its principals at events around the world, EFI has published several major studies:

1. Carbon Dioxide Removal Frontiers Series (Dec. 2020)
2. Net-Zero New England: Ensuring Electric Reliability in a Low-Carbon Future (Nov. 2020)
3. An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions (Oct. 2020)
4. Energy Transitions: The Framework for Good Jobs in a Low-Carbon Future (Sept. 2020)
5. The U.S. Energy and Employment Reports (Mar. 2020, May 2019, May 2018)
6. Regional Clean Energy Innovation: Regional Factors for Accelerating the Development and Deployment of Climate Mitigation Technologies (Feb. 2020)
7. Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies (Sep. 2019)
8. The Green Real Deal: A Framework for Achieving a Deeply Decarbonized Economy
9. Optionality, Flexibility, and Innovation: Pathways for Deep Decarbonization in California (May 2019)
10. Carbon Removal: Comparing Historical Federal Research Investments with the National Academies' Recommended Future Funding Levels (Apr. 2019)
11. Advancing the Landscape of Clean Energy Innovation (Feb. 2019)
12. Promising Blockchain Applications for Energy: Separating the Signal from the Noise (Jul. 2018)
13. Investing in Natural Gas for Africans: Doing Good and Doing Well (Aug. 2018)
14. Advancing Large Scale Carbon Management: Expansion of the 45Q Tax Credit (May 2018)
15. Leveraging the DOE Loan Program: Using $39 Billion in Existing Authority to Help Modernize the Nation's Energy Infrastructure (Mar. 2018)
16. The U.S. Nuclear Energy Enterprise: A Key National Security Enabler (Aug. 2017)

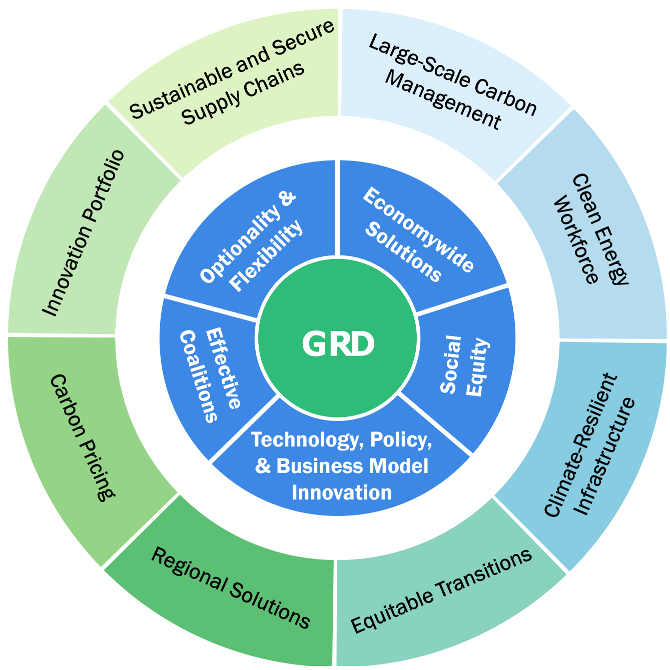
EFI has become a leading voice on deep decarbonization. Since its founding in 2017, EFI's work has generated more than 1,000 news articles and 6 million Twitter impressions (likes and comments), and our published reports (20 studies and white papers) are free for download on the EFI website. In the 116th Congress, EFI staff briefed more than 55 Representatives, 35 Senators and testified at six Congressional hearings. Public outreach includes more than 20 thought leadership articles (including The Wall Street Journal, The Boston Globe, The Houston Chronicle, Politico, The Hill and Bloomberg) and more than 100 public workshops and events. EFI is rapidly expanding its global network of experts and champions for an equitable, low-carbon transition. The work underscores a critical imperative: a science-based, coalition-building framework is urgently needed to turn deep decarbonization ambitions into actions.

EFI's Framework for Achieving a Deeply Decarbonized Economy

Building on the high-level goals of the Green New Deal—deep decarbonization and social justice—EFI has developed an actionable framework for meeting deep decarbonization of energy and associated systems by midcentury in ways that minimize costs, maximize economic opportunities, accelerate solutions, and promote social equity. This framework, referred to as the Green Real Deal (GRD) (Figure 1)—starting from five broad-based principles and organized around eight high-level key elements—is designed to provide policymakers, stakeholders, and industry with the tools necessary for prioritizing, selecting and implementing energy policy, technology, and business model innovations to effectively accelerate economywide decarbonization.

Figure 1

A Framework for Achieving a Deeply Decarbonized Economy



The five GRD principles are represented in the inner blue ring and its eight elements are represented in the outer ring. Source: EFI, 2019.

EFI's approach to deep decarbonization builds on the Paris Agreement and the commitments of the range of subnational players dedicated to deep decarbonization. Advances in science and observed environmental changes in the short time since Paris have, however, caused a reevaluation of the stringency of the targets. A 40% economywide emissions reduction target by 2030 and net zero greenhouse gas emissions by 2050 are increasingly seen as essential for avoiding the most serious impacts of climate change. Operationally, this means that multiple pathways to economywide decarbonization must be implemented simultaneously, and breakthrough innovations are needed at scale by midcentury. This framework emphasizes innovation, optionality, flexibility, regional solutions, and coalition building as key to addressing the urgency, range of pathways, policy support and consensus that are needed to meet these targets.

EFI's Research Priorities in Support of Deep Decarbonization

This document provides the Biden-Harris transition team with a catalog of EFI's research priorities in support of deep decarbonization. This catalog consists of EFI's completed and ongoing work focused on timely policy-relevant research that tackles some of the most challenging issues of deep decarbonization. It can provide a blueprint for policymakers of demonstrably successful policies and create new and innovative policy solutions. Some of EFI's completed and ongoing activities are shown in Table 1.

Table 1
EFI's Research Priorities in Support of Deep Decarbonization

Guiding Principles	Social Equity	Optionality and Flexibility	Tech, Policy, and Biz. Model Innovation	Effective Coalitions	Economywide Solutions

Research Element	Research Sub-element	Principal Activities
Large-Scale Carbon Management	CO_2 Removal RD&D	•Collaborated with the Bipartisan Policy Center on Carbon Removal: Comparing Historical Federal Research Investments with the National Academies' Recommended Future Funding Levels, published in April 2019 •Released September 2019, Clearing the Air details a federal RD&D initiative and management plan for CDR •EFI's Frontiers of CDR Series provides technology roadmaps, needs assessments, and pathways prioritization to advance and deploy terrestrial, oceans, and mineralization CDR technologies.
	Carbon Sequestration Policies and Programs	•Explored carbon sequestration policy in Clearing the Air and Advancing Large Scale Carbon Management: Expansion of the 45Q Tax Credit •Developed strategies for deploying carbon capture and storage by 2030, focusing on policy and business model innovation in An Action Plan for Carbon Capture and Storage in California •The Frontiers of CDR Series report on mineralization outlines how those technologies can tap into existing sequestration incentives, and how mineralization can draw on sequestration programs as inspiration for RD&D collaboration
Workforce for a Clean Energy Future	Regional Energy Workforce Analysis	•Established the Labor Energy Partnership with the ALF-CIO and released Energy Transitions, which provides a comprehensive overview of a suit of climate and labor policies that will accelerate America's transition to a low carbon economy while preserving and creating access to high quality jobs •Conducted U.S. Energy and Employment Report in 2018, 2019, and 2020. The 2019 edition was the first to include state and city deep dives, and the 2020 edition provides an exclusive section on five-year trends •Analyzed options for saving existing carbon jobs and developing new skills to support the clean energy transition in An Action Plan for Carbon Capture and Storage in California
	Socioeconomic and Demographic Analysis of Energy Workforce	•Included demographic questions in U.S. Energy and Employment Report surveys in the 2018, 2019, and 2020 editions
	Energy Workforce Development Programs	•Analyzed the evolution of the nuclear engineering workforce, including federal education programs in The U.S. Nuclear Energy Enterprise
Modernized, Innovative, and	Expanded Investment Programs	•Published Leveraging the DOE Loan Program, a report on key existing mechanisms for mobilizing energy infrastructure investment

Climate-Resilient Infrastructures	Strategies to Support Transformation of Physical and Human Infrastructures	•Analyzed opportunities for repurposing existing infrastructure in California as part of Optionality, Flexibility, and Innovation •Energy Transitions: The Framework for Good Jobs in a Low-Carbon Future assesses opportunities for infrastructure modernization and policy solutions for repurposing existing systems for low carbon
	Strategy for Universal Broadband	•Advancing the Landscape of Clean Energy Innovation emphasizes the importance of universal broadband access in unlocking innovative clean energy platform technologies
Social Equity in the Distribution of Costs and Benefits of Deep Decarbonization	Effectiveness of Policies and Programs Addressing Social Equity	•Forthcoming report on Energy Infrastructure Pathways for New York City analyzes the social equity implications of various low carbon solutions throughout the report •Provided equity-focused policy recommendations in An Action Plan for Carbon Capture and Storage in California •EFI's analytical team developed an internal Justice and Equity Framework that will be utilized in all future EFI research projects to ensure that impacts of policies, programs, and technologies on disadvantaged communities are assessed
	Equity Issues in Electricity Decarbonization Planning	•Assessed the equity implications of decarbonizing the electricity sector in the northeastern US in Net-Zero New England
	Social Equity in Carbon Pricing	•EFI Principals advance public discussions on the merits of the Climate Leadership Council's 2017 CO_2 Pricing Plan
Subnational and Corporate Decarbonization Strategies	Technoeconomic Case Studies of Subnational Decarbonization Strategies	•Published Optionality, Flexibility, and Innovation which looked at bottom-up pathways to meeting California's 2030 climate target across electricity, transportation, industry, buildings, and agriculture. •Forthcoming Energy Infrastructure Pathways for New York City study includes modeled pathways to meet NYC's mid- and long-term emissions reduction targets •Net-Zero New England analyzed policy and technology options for New England based on its resources potential, policy landscape, and local industries.
	Deep Dive Policy Options Analyses	•An Action Plan for Carbon Capture and Storage in California found that nearly 60 $MtCO_2$ per year could be reduced by 2030 through widescale CCS deployment and recommended a policy action plan to unlock this potential •Established underlying principles for the Labor Energy Partnership in Energy Transitions: The Framework for Good Jobs in a Low-Carbon Future
	Improve Corporate Climate Disclosures	•Sec. Moniz participated in Vatican dialogue hosted by the Pope that resulted in shared statements from multiple corporate participants on climate disclosures and carbon pricing
	CO_2 Price Border Adjustment Methodology	•EFI proposes to analyze and evaluate key design elements of carbon border adjustment schemes, using the U.S. steel industry as a case study given its energy intensiveness, exposure to trade, and importance for creating clean energy infrastructure.
	Socioeconomic Effects of Economywide Carbon Charges	•Sec. Moniz participated in Vatican dialogue hosted by the Pope that resulted in shared statements from multiple corporate participants on climate disclosures and carbon pricing, emphasizing mitigating economic impact •EFI plans to conduct state-level studies of distributional impacts, evaluations of scenarios for allocating funds, and identification of regulations that could augment CO2 pricing to improve carbon pricing design, implementation, and social equity impacts
National Technology, Policy, and Business Model	National Energy Technology Innovation Program Portfolio	•Technologies with breakthrough potential identified in EFI and IHS Markit's Advancing the Landscape of Clean Energy Innovation •Identified innovation portfolio for California to meet its midcentury climate goals in Optionality, Flexibility, and Innovation and Net-Zero New England

Innovation Program Portfolios		•The Labor Energy Partnership is working to establish national roadmaps for CCUS, offshore wind, and clean energy infrastructure
	Alternative Funding Mechanisms for the National Innovation Portfolio	•Clearing the Air recommended a new federal RD&D initiative, which would put $10.7 billion over 10 years toward scaling up CDR •The Frontiers of CDR Series reports recommended new funding arrangements to promote cutting-edge CDR, and an updated allocation of funding for marine CDR based on current research •Refocusing tax revenues to support innovation was discussed in EFI and IHS Markit's Advancing the Landscape of Clean Energy Innovation •Recommended that California, with its significant economy, climate leadership, and innovation capacity should support innovation at its research institutions and laboratories in An Action Plan for Carbon Capture and Storage in California
	Flexible Business Models to Improve Innovation Effectiveness	•New business models for innovation discussed in Advancing the Landscape of Clean Energy Innovation and in Carbon Removal: Comparing Historical Federal Research Investments with the National Academies' Recommended Future Funding Levels •Identified pathways for cleaner fuels in California's electricity and industrial sectors in An Action Plan for Carbon Capture and Storage in California following on to previous EFI analysis that shows that fuels will remain critical to the energy system through midcentury
	Regional Innovation Ecosystems	•Regional Clean Energy Innovation measures levels of success across the US and provides deep dives into Colorado and Maryland to identify best practice to accelerate climate mitigation technologies •Identified regional CCS hubs the Los Angeles and San Francisco Bay areas in An Action Plan for Carbon Capture and Storage in California that could minimize infrastructure buildout, lower costs, maximize emissions reductions and provide local benefits •The Frontiers of CDR Series report on mineralization recommends a new federally funded program for creating regional RD&D collaboration hubs and multipurpose field labs
	Regulatory and Financial Policy for Market Deployment	•Analyzed opportunities to utilize $39 billion in available loan funding for infrastructure modernization in Leveraging the DOE Loan Program • Provided a comprehensive overview of the opportunities for applying the expanded federal tax credit for CCUS in Advancing Large Scale Carbon Management: Expansion of the 45Q Tax Credit •Recommended regulatory adjustments and financial incentive opportunities to catalyze the deployment of CCS in An Action Plan for Carbon Capture and Storage in California •The Frontiers of CDR Series reports outline considerations for large-scale deployment of new CDR methods, including the need for a new enabling governance framework for oceans CDR •Evaluates wholesale electricity market constructs compatible with deep decarbonization in on-going work
Sustainable and Secure Clean Energy Technology Supply Chains	Case Studies of the Supply Chain for Clean Energy Technology	•Analyzed supply chain dynamics in The U.S. Nuclear Energy Enterprise •Released a report on energy blockchain technologies and supply chain considerations in Separating the Signal from the Noise
	Environmentally Sound and Sustainable Mining Practices for Critical Materials	•Analyzing the sustainability and security of clean energy technology supply chains, focusing on critical metals and minerals required in a rapid clean energy transition and identifying R&D needs for mitigating supply chain vulnerabilities.

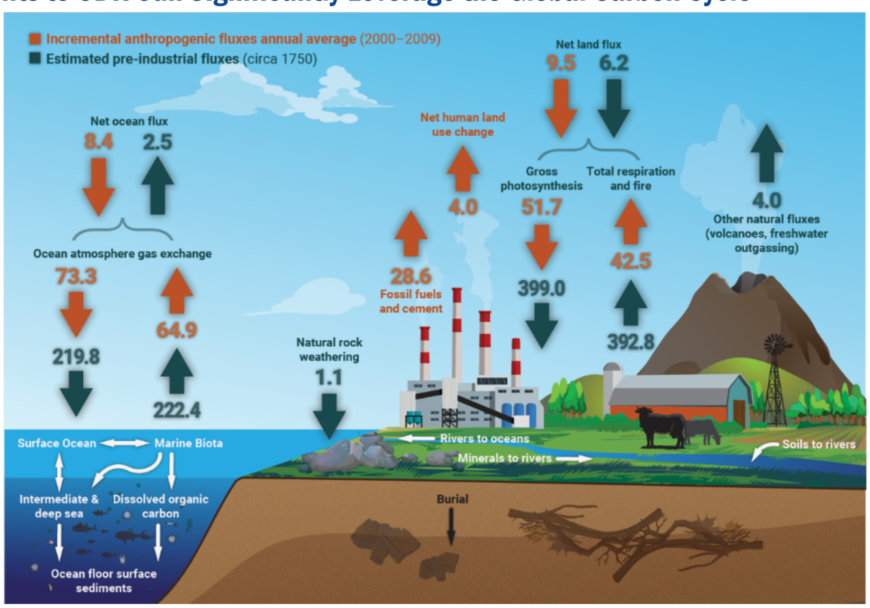
REPORT SUMMARIES

1. Frontiers of Carbon Dioxide Removal Series

In September 2019, EFI published *Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies*, a major report that outlined a 10-year, $11-billion research, development, and demonstration (RD&D) program to bring more CDR approaches to deployment readiness. Several of these approaches, such as bioenergy with carbon capture and storage (BECCS) and direct air capture (DAC) are garnering increased funding support in Congress, but other pathways have received much less attention. Building on the work of the *Clearing the Air* report, EFI identified three CDR "frontiers" deserving of deeper evaluation: **(1) technologically enhanced biological and terrestrial CDR; (2) marine CDR; and (3) carbon mineralization.** The need for a broad portfolio of CDR options at Gt scale, compatible with the geography and geology of different regions of the U.S. and the world, underscores the need for increased investment in these relatively underexplored CDR "frontiers."

Figure 2

Enhancements to CDR Can Significantly Leverage the Global Carbon Cycle

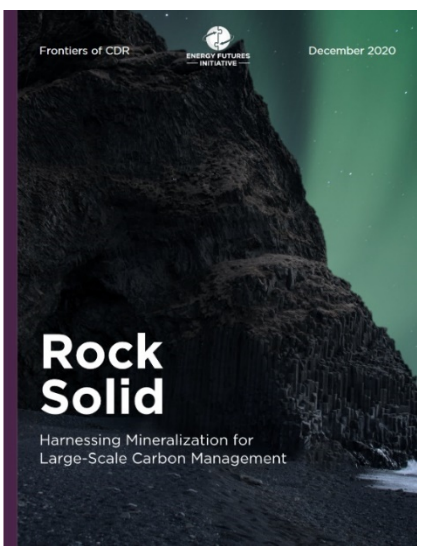


The global carbon cycle involves the exchange of CO2 among the atmosphere, land, water, and subsurface. Green arrows denote estimated natural fluxes prior to the Industrial Era (circa 1750). Orange arrows denote anthropogenic fluxes averaged over the time period 2000-2009. Frontier CDR options can increase the existing negative fluxes—including terrestrial photosynthesis, rock weathering, and ocean fluxes—to combat climate change. Source: EFI, 2020. Compiled using data from Intergovernmental Panel on Climate Change, 2013.

EFI organized six virtual workshops, involving more than 75 scientific and technical experts, to address these pathways. The workshops identified the range of CDR approaches, their respective stages of development, and high-priority RD&D needs and opportunities ("big ideas"). This series of reports combines the findings of those workshops with analysis from EFI to provide policymakers with new insight into the potential benefits of these frontier CDR pathways and detail key priority research areas to promote their development.

Carbon dioxide removal (CDR) refers to methods to remove carbon dioxide (CO_2) from the atmosphere and upper levels of the oceans and sequester or convert the CO_2 into an inert form. CDR is a necessary complement to CO_2 emissions reductions to achieve net-zero emissions goals. CDR also can help achieve net-negative emissions, thereby providing the opportunity to reverse some of the effects of historical greenhouse gas (GHG) emissions and "restore" the climate. The 2018 Intergovernmental Panel on Climate Change (IPCC) *Special Report on Global Warming of 1.5°C (SR1.5)* outlined the importance of reaching net-zero emissions by 2050 in order to limit warming to 1.5 degrees. *SR1.5* estimated that 3 to 7 billion metric tons (gigatons, or Gt) of CDR per year would be required globally by 2050 and up to 15 Gt per year by the end of the century.

There are a variety of well-established **natural CDR pathways** that involve increasing the size of natural carbon sinks, such as planting more trees, adopting sustainable agricultural soil management, and enlarging coastal ecosystems. Expanding natural CDR methods, while necessary, will not be sufficient to meet the SR1.5 goals. The carbon removal capacity of natural systems can be **technologically enhanced** through the application of modern technology—including use of biotechnology to enhance CDR in trees and crops, enhancing the reactivity of CO_2-absorbing minerals, increasing ocean biomass through cultivation or artificial fertilization, and neutralizing ocean acidity. **Direct technological capture** pathways include direct air capture (i.e., atmospheric scrubbing) and direct ocean capture through electrochemical conversion, which produce a concentrated stream of gaseous CO_2. The captured CO_2 can then be injected into subsurface saline aquifers or mineralizing rock formations or converted into inert carbon-based materials.

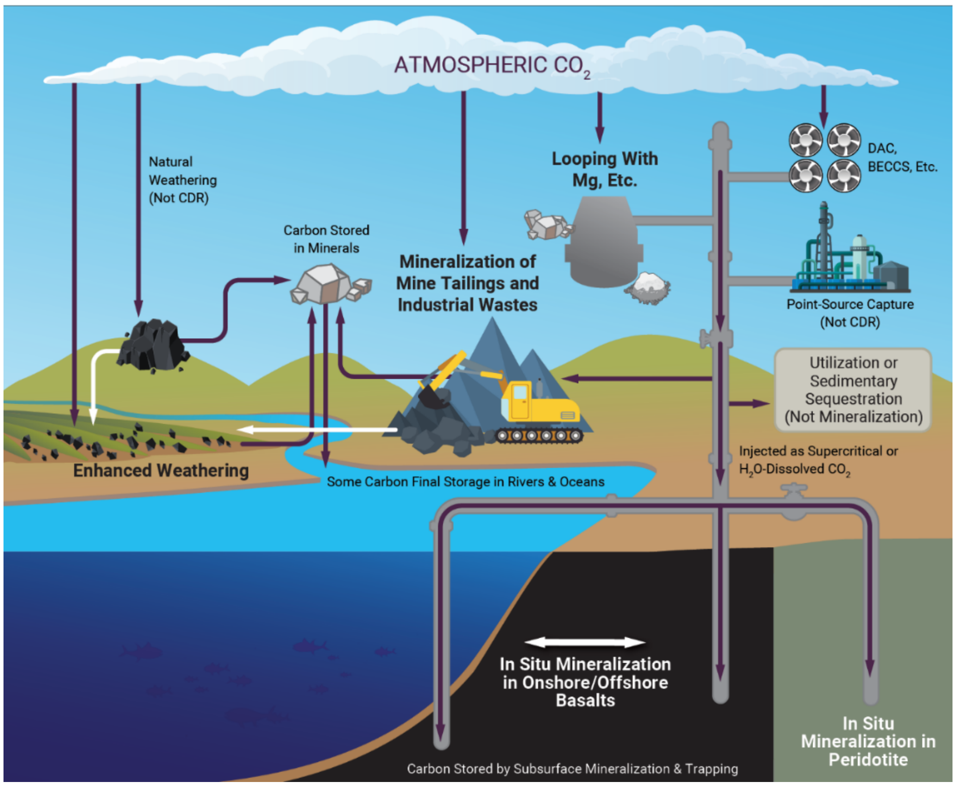


Rock Solid: Enhancing Mineralization for Large-Scale Carbon Management

CO_2 mineralization is the transformation of atmospheric CO_2 into carbonate minerals by a multi-step process that starts with rocks and minerals at the Earth's surface slowly dissolving into weakly acidic rainwater and groundwater. This dissolution process is also referred to as "rock weathering." Dissolved rock material is transported to the oceans by rivers, adding calcium, magnesium, and other minerals to ocean water, and eventually causing carbonate minerals to form and accumulate on the ocean floor as limestone. Carbon mineralization is a continually occurring foundational process in the global carbon cycle that has contributed to the historical stability of atmospheric CO_2, climate and the biosphere.

The limitation of the natural carbon mineralization process is that it removes CO_2 from the atmosphere at a rate of just over 1 Gt per year, which is about the same rate that natural processes such as volcanism add CO_2 to the atmosphere. A wide variety of methods have been proposed for technologically enhancing the rate and scale of carbon mineralization as a means to complement efforts to mitigate anthropogenic CO_2 and help stabilize and ultimately reverse adverse climate change. To do so, new approaches to technologically enhancing carbon mineralization on a gigaton scale, multiple times the natural rate, will be needed in order to have a material impact in combating climate change.

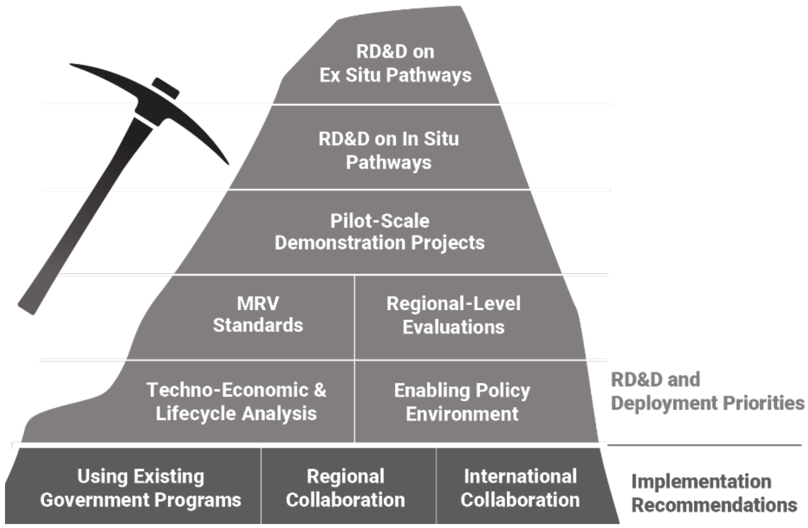
Figure 3
Overview of CDR and Non-CDR Pathways for Mineralization



This figure shows pathways for ex situ and in situ mineralization, including those that do and do not contribute to CDR. Purple arrows show movement of carbon; white arrows show where transportation of mineralization feedstocks is necessary. This figure does not include in situ CDR approaches that remove carbon without the need for DAC or another source of CO_2. Source: EFI, 2020.

Technologically enhanced carbon mineralization methods include both surface and subsurface processes. Surface, or ex situ mineralization, involves the application of finely ground, quickly reacting minerals that can result in direct formation of carbonate minerals in the soil, rivers, and oceans. Subsurface, or in situ mineralization, involves the injection of captured CO_2 into subsurface reactive mineral deposits that can result in conversion to a solid phase material. In situ mineralization is qualitatively different from ex situ mineralization because in most cases it requires a separate CO_2 capture process—either another CDR method or point-source carbon capture. A key attribute of carbon mineralization is its ability to convert atmospheric CO_2 to a solid form; mineralization is attractive because it effectively returns carbon permanently to the Earth.

Figure 4
RD&D, Policy, and Implementation Opportunities for Carbon Mineralization



This figure shows the major priorities identified in this report for pathway-specific RD&D, cross-cutting RD&D, large-scale deployment, and implementation. Source: EFI, 2020.

Key findings and recommendations:

- Carbon mineralization provides a pathway to near permanent isolation of CO_2 from the environment. Mineralization is a naturally occurring process that reacts atmospheric CO_2 with certain types of rocks to form relatively inert carbonate minerals. The reaction can take place either at the surface of the Earth (ex situ mineralization) or through the capture of CO_2 and injection into underground rock formations (in situ mineralization).

- Technological enhancements can expand and accelerate natural carbon mineralization, making it feasible to achieve gigaton-scale CDR. Natural rock weathering currently removes about 1 Gt of CO_2 per year globally, and technologically options could increase the rate of natural mineralization by a factor of five to ten.

- Carbon mineralization has several co-benefits that enhance its attractiveness. These benefits include the addition of carbon absorbing minerals as an agricultural soil amendment, potential beneficial use of certain mining and industrial process wastes as carbon absorbing material, and synergies between in situ carbon mineralization with point source carbon capture and direct air capture CDR pathways.

- Increased federal investment in RD&D should include both *ex situ* and *in situ* pathways:

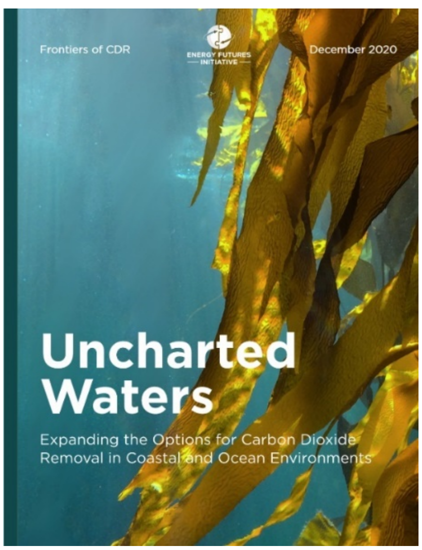
  - ✓ Surface carbonation of mineral wastes from mining and materials processing;

  - ✓ Enhanced rock weathering and carbonation in soils;

  - ✓ Surface capture of CO_2 via calcium and magnesium oxide carbonation and subsequent “looping”; and

  - ✓ Subsurface injection into mineral formations (basalt and ultramafic rocks) of CO_2-bearing water or CO_2 captured via various means.

- Determining technical and economic feasibility of carbon mineralization RD&D for potential deployment at a gigaton scale requires scale up to larger field-scale pilot projects.
- Location-specific climate, geological and land use considerations requires a regional approach to carbon mineralization RD&D. Regional carbon mineralization RD&D collaboration hubs, modeled after the Department of Energy Regional Carbon Sequestration Partnerships (RCSP) and the Carbon Storage Assurance Facility Enterprise (CarbonSAFE) programs, would provide an effective programmatic structure for advancing carbon mineralization methods and practices.
- Fundamental research supporting carbon mineralization, including further validation of co-benefits, should be incorporated into existing federal research and development programs at DOE, USDA, and DOI.
- Deployment of carbon mineralization at Gt scale also will require development of new methodologies for techno-economic analysis (TEA), life cycle assessments (LCA) and monitoring, reporting, and verification (MRV) standards.
- Large scale (i.e., gigaton-scale) deployment of carbon mineralization also will require parallel policy analysis and development. The application of environmental regulatory requirements and financial incentive polices such will need to be addressed.

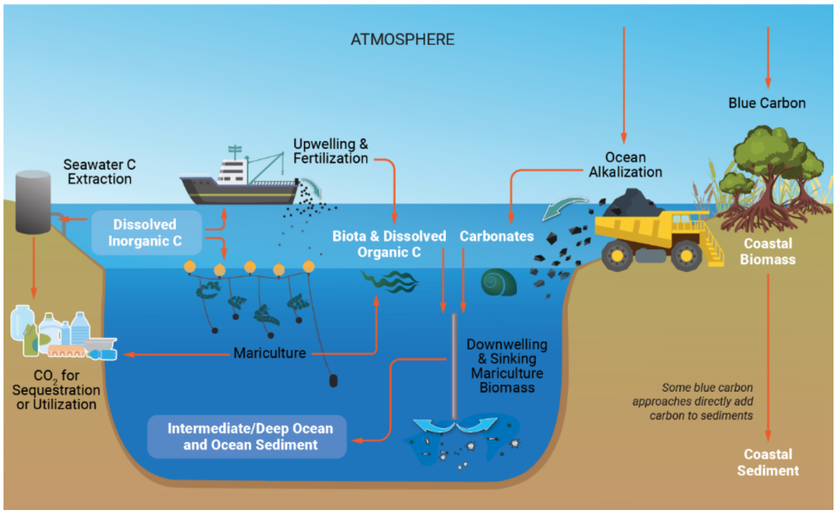


Uncharted Waters: Expanding the Options for Carbon Dioxide Removal in Coastal and Ocean Environments

The oceans are an obvious place to look for additional CDR capacity given their sheer size and major global role in cycling atmospheric CO_2. The already massive contributions of oceans to natural carbon removal suggest that high-capacity, cost-effective CDR opportunities can be found by mimicking and enhancing natural processes, by finding and employing novel engineered methods, and by the coupling of these two approaches. Most of the marine CDR research to date has focused on coastal ecosystems (often known as “blue carbon”), and on iron fertilization, with relatively little RD&D on other marine CDR pathways that may have much larger CDR potential.

The increased absorption of CO_2 by ocean waters, combined with the absorption of the excess heat created by atmospheric CO_2 levels, has come at a significant cost to marine ecosystems. The oceans have become 30% more acidic; 50% of tropical coral reef systems have been lost; and extreme ocean heating has led to sea level rise, changing weather patterns, deoxygenation, interrupted ocean mixing, and poleward migration of fish and other marine species. Marine CDR could provide viable means to help reverse these impacts. Importantly, due to the interplay within the marine ecosystem, marine CDR pathways may also provide significant benefits to marine conservation efforts and have synergies with marine economic development as CDR removes CO_2-induced stress on the oceans and the planet.

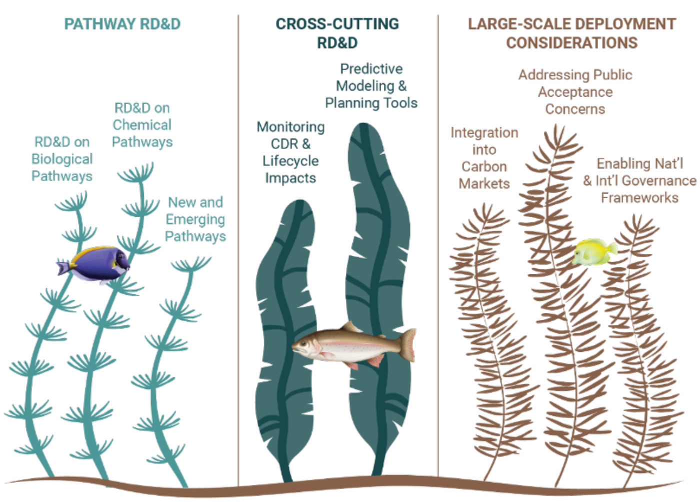
Figure 5
CDR and the Ocean Carbon Cycle



This figure shows representative CDR pathways discussed in EFI's report, with carbon fluxes shown by red arrows. These CDR methods harness existing carbon "pumps" in the ocean. Source: EFI, 2020.

Marine CDR also requires special attention to enable governance and legal frameworks because the oceans are a global commons and collective heritage, playing a central role in the viability of the biosphere and the planet. A key tension to be addressed in creating and enabling an effective and efficient governance framework for the deployment of marine CDR is the dynamic between the urgent need to find new, effective ways to combat climate effects while avoiding further adverse collateral impacts on ocean ecosystems.

Figure 6
RD&D Opportunities for Marine CDR



The priorities for marine ocean CDR RD&D fall under a range of categories that involve scientific discovery, proof of concept, optimization of cost-effective management potential and development of monitoring, reporting and verification protocols to enable governance frameworks. Source: EFI, 2020.

Key findings and recommendations:

- Elevated atmospheric CO_2 concentrations have adversely affected the marine environment in three ways—ocean warming, ocean acidification and deoxygenation—all of which have had deleterious effects on the ocean's living resources.
- Marine CDR, the removal of CO_2 from upper ocean waters, is a key element of the CDR portfolio and, in particular, is an essential complement to reducing atmospheric CO_2 levels. Without corresponding enhanced marine CDR, reducing atmospheric CO_2 levels will cause oceans to respire a portion of this absorbed CO_2 back into the atmosphere.
- Marine CDR pathways have significant potential to scale. Marine CDR pathways can capture and sequester CO_2 at Gt scale because of the sheer amount of available space in the ocean and the absence of land use complications. Additionally, there are numerous marine CDR pathways available.
- Marine CDR pathways capture and store CO_2 in ways that may avoid deleterious environmental impacts and in fact have significant co-benefits for ocean ecosystems and fisheries.
- Questions of public acceptance are among the most critical challenges facing marine CDR at present. Well-controlled and documented research projects, beginning with smaller-scale experiments, will be critical for building public understanding. Efforts should also be made to pilot CDR in areas where co-benefits can directly help local communities.
- Increased Federal investment in marine CDR RD&D is merited and should include a broad portfolio of emerging marine CDR methods that include both biological and non-biological approaches.

  Biological pathways include:

  ✓ coastal ecosystem restoration (blue carbon);
  ✓ enhanced microalgae cultivation, including boosting surface ocean nutrients through fertilization or upwelling;
  ✓ increased cultivation and harvesting of marine-based plants; and
  ✓ downwelling of seawater as a means of sequestering CO_2 dissolved in upper ocean waters.

  Chemical pathways include:

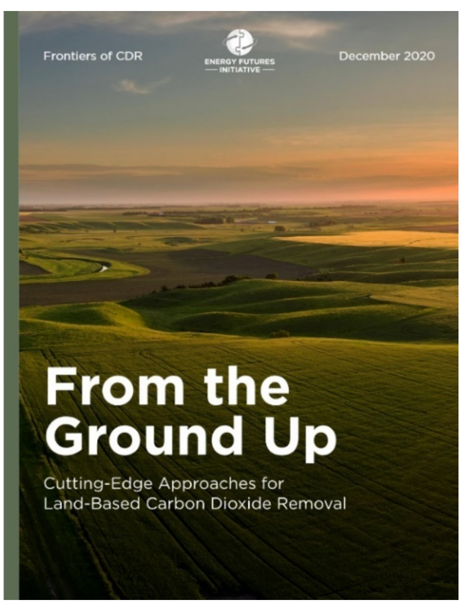
  ✓ ocean alkalinization; and
  ✓ electrochemical extraction of carbon from seawater.

- An expert panel convened by the Energy Futures Initiative highlighted six key areas for emphasis in an interagency federal marine CDR RD&D initiative:

  1. Defining the RD&D portfolio of specific CDR pathways, including anticipating new and emerging pathways;
  2. Improving the methods for monitoring, quantifying, and verifying CDR benefits, ecosystem effects, and lifecycle impacts;
  3. Developing predictive modeling and planning tools for siting and operations;

4. Creating markets for co-products from ocean CDR pathways and integration into carbon markets;
5. Enhancing public engagement and support; and
6. Creating enabling national and international governance frameworks

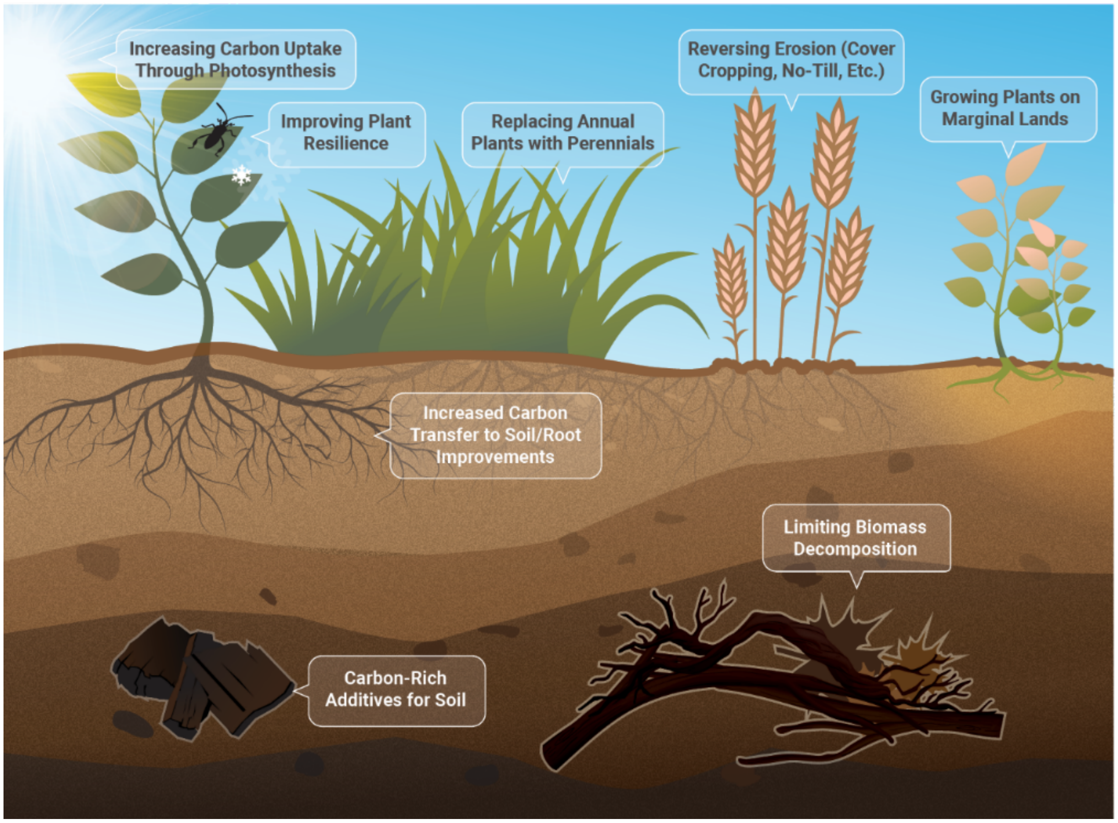
- Federal funding of over $2 billion over the next decade will be required for research and development, field experiments and large-scale demonstration of the most promising marine CDR approaches.
- The federal government, with extensive input from the scientific community, should adopt a protocol for open ocean marine CDR experimentation in order to open the door to necessary large scale research opportunities, while also starting to bring the U.S. in line with international agreements.
- Marine CDR RD&D represents an important arena for international scientific collaboration, and the U.S. should seek to join ongoing international CDR research efforts, such as the EU OceanNETs program, as well as seek international participation in planning carefully controlled, limited-scale experiments within U.S. territorial waters.
- The National Atmospheric and Oceanic Administration (NOAA) should lead coordination efforts for the federal interagency marine CDR RD&D effort and should establish a new high-level office within NOAA to manage marine CDR RD&D and to coordinate with other federal agencies.
- Marine CDR RD&D will require extensive coordination and integration across the federal executive branch. DOE and the National Science Foundation (NSF) will be key contributors to marine CDR RD&D, with potential key roles for the Navy, Coast Guard, Army Corps of Engineers, and NASA.



From the Ground Up: Cutting-Edge Approaches for Land-Based Carbon Dioxide Removal

Increasing the level of natural methods of CDR from biological and terrestrial ecosystems is feasible and desirable but subject to limitations. For example, forestry pathways—including afforestation, reforestation, and improved forest management—are among the most well-established and can be expanded with appropriate policy support. There are, however, practical limitations, such as land area needs and competing demands for food and fiber, which ultimately constrain their scale of deployment. For example, the United Nations Trillion Tree Initiative, if fully implemented, could require foresting a global landmass nearly equivalent in size to the entire United States. Exciting new scientific research opportunities in terrestrial CDR pathways have the potential to supercharge land-based ecosystems. Technologically enhanced biological and terrestrial CDR can greatly expand the range of options for capturing and storing carbon in terrestrial ecosystems.

Figure 7
Biological and Terrestrial CDR Pathways

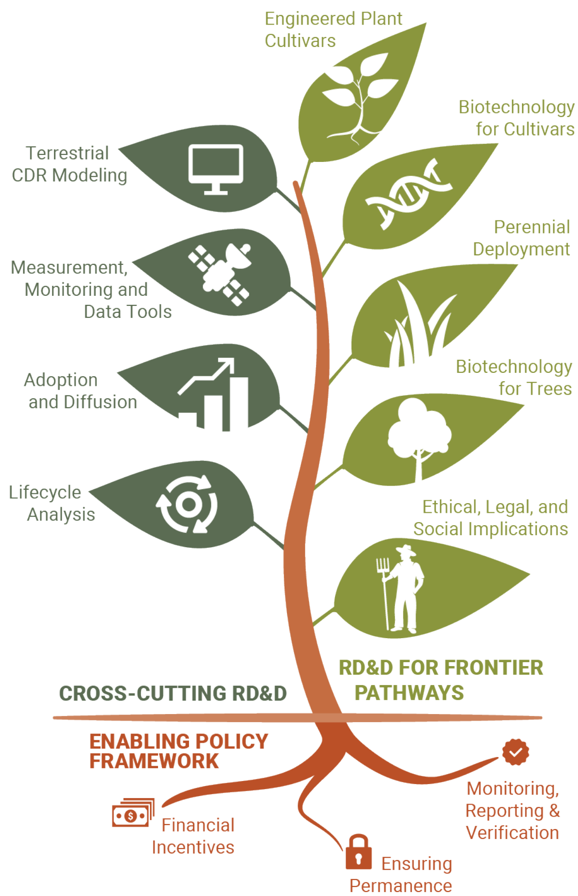


Purpose-engineered crop cultivars can develop and deploy a variety of terrestrial CDR techniques that improve subsurface and aboveground systems. Source: EFI, 2020.

Purpose-engineered plant varieties (cultivars) are a primary means for developing and deploying terrestrial CDR techniques. New and improved cultivars can also help modern food production systems confront the contemporary challenges of a growing human population, climate change stressors, rapid topsoil erosion, reduced soil fertility, and a decline in natural pollinators. Once traits are identified, they can be introduced through traditional breeding methods and by biotechnology techniques. These improvements may include whole plant traits (e.g., increased photosynthetic efficiency), root system traits (e.g., larger, deeper, more branched, and decomposition-resistant roots); sustainability traits (e.g., water and nutrient efficiency, stress tolerance).

Figure 8

Biological and Terrestrial CDR RD&D Opportunities and Enabling Policy Framework



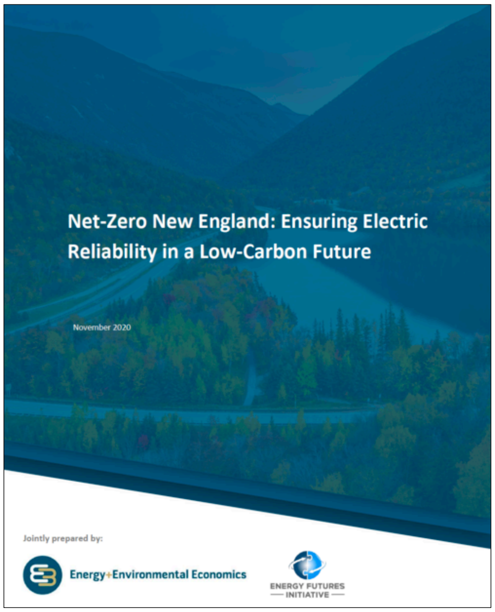
A combination of enabling policies and increased RD&D in priority areas is necessary to achieve terrestrial and biological CDR at scale. Source: EFI, 2020.

Key findings and recommendations:

- Innovations across several areas of science and technology open the door to new pathways for biological and terrestrial CDR.
- Increasing the CO_2 uptake in soils and terrestrial ecosystems can have significant co-benefits, including replenishment of soil organic carbon (SOC), higher crop yields, reduced demand for water and fertilizer, improved nutritional quality, and new revenue streams for farmers.
- Cross-cutting RD&D opportunities can help close data gaps for terrestrial and biological CDR and accelerate deployment, including more robust models; new measurement, monitoring, and data tools; lifecycle analysis; and strategies for incentivizing adoption and diffusion of new crops.

- Increased federal investment in biological and terrestrial CDR RD&D should support a broad portfolio of approaches extending across the entire biological and terrestrial ecosystem, including soils, plants, and trees. The priority areas for increased biological and terrestrial CDR RD&D include:
  - ✓ Enhancement of SOC through various approaches;
  - ✓ Fundamental research to identify plant organism traits that govern the absorption and conversion of CO_2 and develop methods to enhance those traits;
  - ✓ Purpose-engineered plant cultivars employing both conventional breeding and biotechnology techniques; and
  - ✓ Transformation of annual crops to perennial crop systems.
- The application of biotechnology to advancing biological and terrestrial CDR approaches should proactively address the ethical, legal, and social concerns raised by biotechnology innovation.
- Biological and terrestrial CDR RD&D efforts should emphasize co-benefits wherever possible to enable rapid deployment and diffusion, which in turn offers the potential to achieve significant impacts on net CO_2 emissions within a relatively short timeframe.
- The biological and terrestrial CDR RD&D portfolio should also focus on development of improved methodologies for measurement of carbon reduction impacts to support new revenue streams as well as advance carbon policy objectives.
- The Department of Agriculture (USDA) should be the lead agency on biological and terrestrial CDR efforts. USDA houses several research agencies with expertise in the biological and terrestrial sciences, as well as conservation and extension efforts that can help with demonstration and deployment. USDA could accelerate RD&D by adding CDR by establishing a strong internal coordination process under the auspices of the Under Secretary for Research, Education, and Economics.
- USDA should implement the Agriculture Research and Development Agency (AGARDA), dedicated to high-risk, high-reward research, with an initial priority emphasis on CDR. Existing cutting-edge research organizations, such as the DOE Advanced Research Projects Agency—Energy (ARPA-E) and the DOE Office of Science, can support novel or more innovative concepts for biological and terrestrial CDR but may otherwise be outside the framework of existing research entities.

2. Net-Zero New England: Ensuring Electric Reliability in a Low-Carbon Future



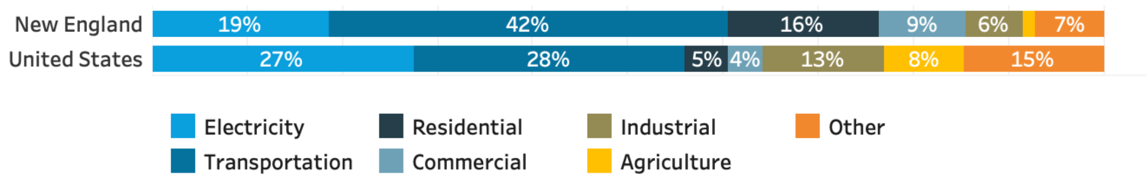
The six New England states have adopted economy-wide greenhouse gas (GHG) reduction targets of at least 80% economy-wide emissions reductions by midcentury, with Massachusetts recently adopting a net-zero commitment. The electricity system will play a key role in achieving these targets through near-complete decarbonization of electricity supply and supporting the electrification of transportation, buildings, and industry.

This study shows that cost-effectively meeting the dual challenge of growing electricity demand—increasingly characterized by peak winter heating demand—and reducing emissions to nearly zero will involve the addition of large amounts of wind, solar, and battery storage resources, complemented by firm capacity to provide generation during extended periods of low wind and solar availability. Firm capacity includes natural gas power plants, nuclear, hydrogen generation, or other yet-to-be commercialized options such as long-duration storage. Achieving carbon goals with natural gas generation will require operating natural gas power plants at suitably low-capacity factors, capturing their emissions, and/or utilizing low/zero-carbon fuels such as hydrogen.

E3 and EFI conducted this study to evaluate net-zero economy-wide decarbonization pathways that meet New England's long-term goals while maintaining electric system reliability. Reliable electricity supplies are critical to the functioning of the modern economy and for the health and safety of people everywhere. This will increasingly be true in an electrified future in which New Englanders rely at least in part on electricity for heating and mobility on the coldest winter days. At the same time, decarbonizing the electricity system will require New England to deploy significant quantities of wind, solar, and energy storage resources. While these intermittent and/or energy-limited resources can make significant contributions to reliable electric system operations, numerous studies in other regions have demonstrated that complementary resources will be needed to provide essential grid services and to generate electricity during extended periods of low wind and solar generation. This study assesses in detail the resources needed to maintain reliable electric service in a New England electricity system with high penetrations of renewable energy resources.

New England's GHG emissions in 2016 (the latest year with published estimates for all states) equaled 170 million metric tons of CO_2-equivalent (MMT CO_2e), roughly 3% of the U.S. total. Massachusetts accounts for roughly 44% of total New England emissions, primarily due to its larger population. Figure 9 provides a comparison of 2016 emissions profiles for New England and the United States. New England will not be able to attain its GHG reduction goals with an exclusive focus on electricity production; it will be necessary to implement aggressive decarbonization on an economy-wide basis.

Figure 9
2016 Greenhouse Gas Emissions Profile of New England and United States



Notes: Other includes waste, non-combustion, and industrial processes and product use (IPPU). Source: EIA, 2016; state emissions inventories, 2016.

New England's unique economy, resource availability, and geography will shape its path to decarbonization. The proportion of emissions attributable to transportation is higher than the national average, while the emissions from industrial sources are lower. Fossil fuel use for residential and commercial heat contributes a quarter of New England's emissions, and New England is the only region in the country where oil is the most common heating fuel. A successful clean energy transition will require sector-specific solutions that navigate difficult issues related to planning, financing, and siting electricity transmission and other new energy infrastructure, while at the same time protecting environmentally sensitive lands, preserving natural landscapes, and alleviating the environmental burden on disadvantaged communities.

New England's electricity supply is already less carbon-intensive than much of the rest of the country. Natural gas fuels 40% of the region's electricity generation today, and its displacement of oil and coal over the past decades has contributed to halving power sector emissions since 2005. Nuclear generation is currently New England's largest source of carbon-free power, producing over seven times as much electricity as all the region's wind and solar combined. Prospectively, solar represents a relatively low-cost source of clean electricity in New England, despite capacity factors roughly half of those in the Southwestern United States. Solar can be complemented by high-quality offshore wind resources that are available in significant quantities, and New England states are already in the process of procuring significant amounts of offshore wind through long-term contracts. As prices fall, batteries also provide a useful complementary resource by shifting generation.

Key Findings

The following key findings provide insight into how New England can provide affordable and reliable electric power that achieve net-zero economy-wide GHG emissions by 2050.

1. **Decarbonizing New England requires transformational change in all energy end-use sectors.** New England has long been an environmental policy leader, with progress in recent decades aided by the region's transition from oil and coal to natural gas. Today, direct energy use for transportation and buildings makes up two-thirds of the region's emissions. Key strategies for mitigating economy-wide greenhouse gas emissions are: (1) aggressive deployment of energy efficiency; (2) widespread electrification of end uses in the building, transportation and industrial sectors; (3) development of low-carbon fuels; and (4) deep decarbonization of electricity supplies.

2. **Electricity demand will increase significantly in New England over the next three decades under the net-zero scenarios studied.** In the two primary bookend scenarios, annual electricity demand grows by 70 to 110 Terawatt-hours (TWh), roughly 60 to 90% from today. Electric peak demand reaches 42 to 51 Gigawatts (GW) as the system shifts from summer to winter peaking in the 2030s. This demand growth is primarily due to electrification of transportation, building and industrial end-uses that currently rely on direct combustion of fossil fuels. This large increase in electricity demand occurs despite significant energy efficiency included in the scenarios. Absent energy efficiency, demand growth would be even higher.

3. **Renewable electricity generation will play a major role in providing zero-carbon energy to the region.** The Base Case scenarios select a diverse mix of 47 to 64 GW of new renewable generation capacity by 2050, including land-based solar and wind, offshore wind, and distributed solar, along with 3.5 GW of new incremental Canadian hydro. Renewable generation is needed to displace fossil fuel generation in the electricity system and to provide zero-carbon energy for vehicles, buildings and industry. New England's constrained geography, slow pace of electric transmission planning, and historical difficulty siting new infrastructure are significant challenges that the region must overcome.

4. **A cost-effective, reliable, and decarbonized grid requires firm generating capacity.** Firm capacity is capacity that can provide electricity on demand and operate for as long as needed; today, natural gas and nuclear generation are the primary sources of firm capacity in the region. While today's renewable generation and battery storage technologies will play large roles in the future New England system, relying on these resources alone would require very large quantities of renewables and storage (Figure 10) and would be extremely costly (Figure 11). In practice, as much as 46 GW of firm capacity could be needed in 2050 to ensure resource adequacy. Significant gas capacity is retained even though the gas plants operate far fewer hours and contribute less energy (and emissions) to the region than today. New resources may be developed and deployed in the future to provide low-carbon firm capacity such as advanced nuclear, natural gas plants with carbon capture and sequestration (CCS), long duration energy storage, or generation from carbon-neutral fuels such as hydrogen. Until one or more of these technologies is widely and commercially available, natural gas generation is the most cost-effective source of firm capacity, and some reliance on gas generation for resource adequacy is consistent with achieving a 95% carbon-free electricity grid in 2050 as long as the generation operates at a suitably low capacity factor.

Figure 10

Installed Capacity Across Base Case and Key Sensitivities in 2050 (High Electrification)

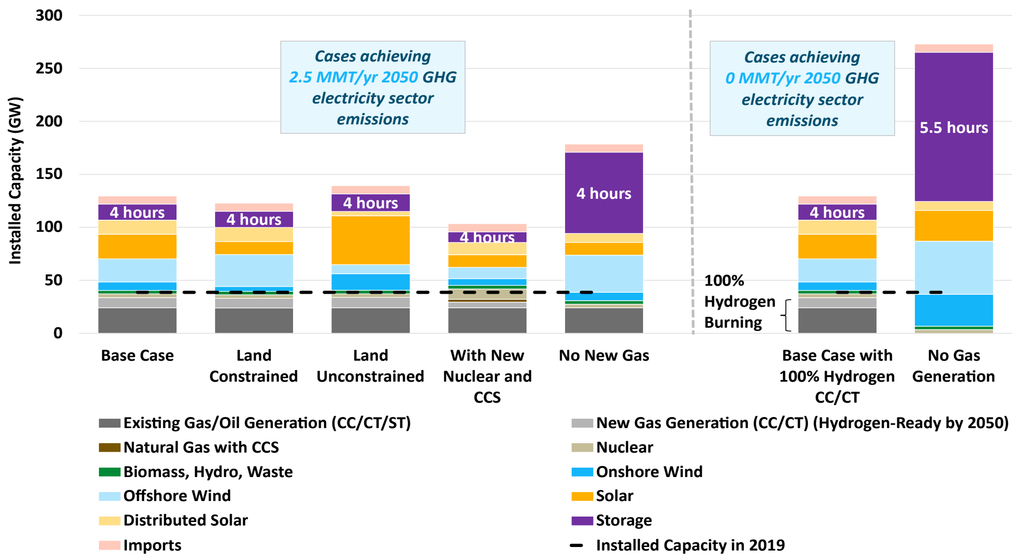
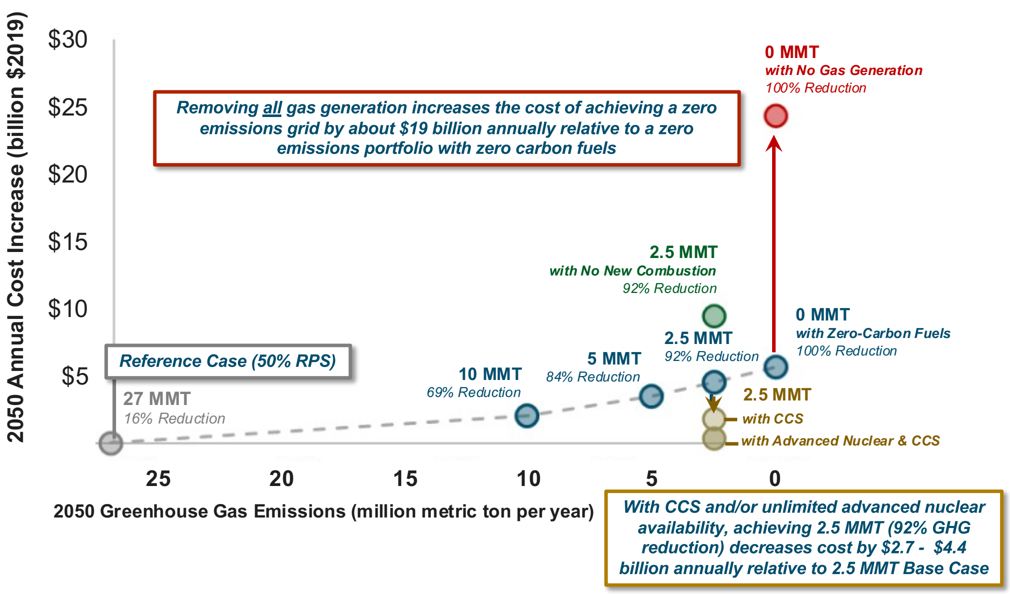


Figure 11

Increase in Electricity System Modeled Costs Relative to Reference Case Across Selected Set of Scenarios in 2050 (High Electrification)



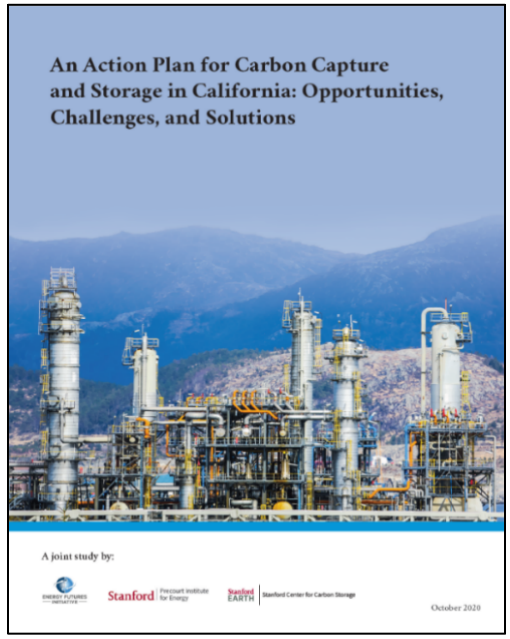
5. **A broader range of technology choices lowers costs and technology risks.** The availability of low-carbon firm generation technologies – such as advanced nuclear or natural gas with CCS – could provide significant cost savings and reduce the pressure of renewable development on New England's lands and coastal waters. The 2050

incremental cost to achieve an electricity sector target of 2.5 million metric tonnes (MMT CO_2e) relative to a Reference Case (50% renewables) falls roughly in half when natural gas with CCS is made available, assuming technology cost declines are achieved. When advanced nuclear technology is also available at scale, the cost of decarbonization declines further (Figure 11).

6. **Achieving net-zero GHGs requires carbon dioxide removal (CDR), and New England's extensive stock of healthy forests and local forest management expertise provide an ideal local opportunity for CDR.** While CDR alone will not be enough to achieve economy-wide decarbonization or meet the region's policy targets, it supports achieving full carbon neutrality and potentially net-negative emissions in New England and beyond. The lack of suitable geology for carbon sequestration make direct air capture and bioenergy with carbon capture and storage poorly suited to the region, but a large stock of forests provides a good opportunity for in-region CDR. A more purposeful and explicit consideration of the carbon sequestration potential of New England's forests would help the region better manage tradeoffs between preserving forest land and new greenfield renewable energy development. Policymakers should consider incorporating practices that promote CDR across its forest lands, as well as other natural CDR options, which are the best candidates for near-term deployment.

7. **Achieving the commercialization of emerging technologies can be aided by leveraging regional innovation capacity.** New England's innovation ecosystem is one of the most robust in the world. Local policymakers can increase the likelihood of commercializing emerging technologies by orienting the homegrown efforts of private, public, and academic researchers already developing science and business innovations relevant to decarbonization. Specifically, advanced nuclear, long-duration storage, and renewable fuels are innovation areas that have tremendous regional potential and could play a role in supporting a low-carbon power sector, especially when local innovation efforts are coordinated with federally funded programs.

3. An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions



This study provides policymakers with options for near-term actions to deploy carbon capture and storage (CCS), a clean technology pathway well suited for rapidly reducing emissions from economically vital sectors in California that have few other options to decarbonize. CCS, like all other emission reduction technologies, is not a "silver bullet" technology for decarbonization. Carbon capture paired with permanent geologic storage offers a viable and important option for reducing emissions from the industrial and electricity sectors that are key contributors to California's economy and the reliability of its grid.

The report built on the finding from EFI's May 2019 report, Optionality, Flexibility and Innovation*: Pathways to Deep Decarbonization for California (detailed below)*, that identified CCUS as one of most significant pathways to reaching the state's 2030 GHG target.

Technoeconomic analysis done for this study identified 76 existing electricity generation and industrial facilities in California as candidates for CCS, representing close to 15% of the state's current GHG emissions. To put this in perspective, in 2017, California's power sector emitted 16% of the total. The analysis also analyzed geologic storage potential for the state of California by developing an exclusion zone to avoid consideration of areas with sensitive habitats, population zones, and a history of geologic vaulting, among other criteria.

CCS is a strong complement to other decarbonization strategies, and geologic carbon dioxide (CO_2) storage is a critical enabler of prominent carbon dioxide removal (CDR) pathways, including direct air capture (DAC) and conversion of waste biomass to zero- or negative-carbon transportation fuels and electricity. For California's cement industry, CCS is considered one of the most cost-effective carbon reduction options and a complement to other strategies like increased energy efficiency, clinker substitution, and fuel switching.

As of September 2020, there are five announced CCS projects in varying stages of planning and development in California. These projects will provide valuable lessons learned for future project developers, policymakers, and regulators. The design of these early projects provides insight into the opportunities and challenges of pursuing CCS in California today.
A robust regulatory environment can advance CCS deployment by providing certainty and environmental and safety assurances to CCS developers, investors, and local and regional communities. In contrast, the absence of a sound regulatory environment or one that is unclear and/or unpredictable can act as a barrier to CCS development.

Opportunities for CCS in California

California has opportunities to advance its decarbonization and economic goals by leveraging CCS due to its sizeable geologic storage resources; the suitability of its emissions sources for carbon capture; its need for clean firm electricity generation as the renewable energy profile grows; the need for decarbonized transportation fuels, such as hydrogen; and its experience advancing strong climate policies and innovative industries.

- California has one of the largest geologic storage potentials in the United States, with over 70 gigatons (Gt) of storage potential, the majority of which is located in the Central Valley.
- There are 76 existing energy and industrial facilities [51 industrial and 25 natural gas combined cycle (NGCC) plants] identified by this analysis to be candidates for CCS retrofit in California. These facilities emit 59 Mt CO_2e/yr (Table 2)

Table 2

Sources of Emissions, Potential Capturable Emissions, Costs, and Incentive Eligibility

Metric	NGCC	Hydrogen	CHP	Refining	Cement	Ethanol
Number of Facilities	25	16	15	9	8	3
Total Emissions, 2018 (MtCO_2e)	21.6	11.2	10.1	6.3	7.8	.43
Assigned Capture Rate	90%	90%	90%	90%	90%	100%
Total Capturable Avoided Emissions (MtCO_2)	27.5	10.1	9.1	5.2	7.0	.43
Weighted Average Capturable Emissions (tCO_2 per facility per year)	1,100,000	630,000	600,000	575,000	880,000	142,000
Estimated Capture Cost Range ($/t$CO_2$)	$62 -$96	$58-$101	$60-$131	$58 -$73	$48 - $75	$20 - $23
LCFS Eligibility	No*	Yes**	Yes***	Yes**	No	Yes

* Elk Hills Power is considered 40% LCFS eligible as some of the electricity will be used for oil field operations
**Hydrogen and Refining were considered 80% LCFS eligible as some refined product is exported out of state.
*** CHPs associated with refining operations were considered 60% LCFS eligible due to rationale in ** yet reduced another 20% because some power generated by CHPs is sold to the grid. CHPs associated with upstream oil and gas production activities were considered to be 50% LCFS eligible.

- Roughly 50 MtCO_2e/yr of capturable emissions require development of up to 1150 miles of new pipeline connecting emissions sources with suitable geologic storage. Although pipelines have relatively low capital and installation costs, permitting and building a new CO_2 pipeline in California is expected to be a formidable task.
- There are potential CCS hubs in the Los Angeles and San Francisco Bay areas, which could result in emissions reductions of 25. 2 MtCO_2/yr and 14 MtCO_2/yr, respectively (Figure 12). Regional CCS hubs offer 'economy of effort", where FEED, permitting and construction could be economized due to co-location of emission sources. Project returns may also be enhanced with centralized storage facilities managing flows from multiple sources.

Figure 12

CCS Project Development Opportunities

Map illustrates potential project development opportunities which together abate 59 Mt CO_2/yr. Pipeline routings are 'notional' and follow existing pipeline right-of-ways. Sink locations are not intended to be exact locations for geologic storage.

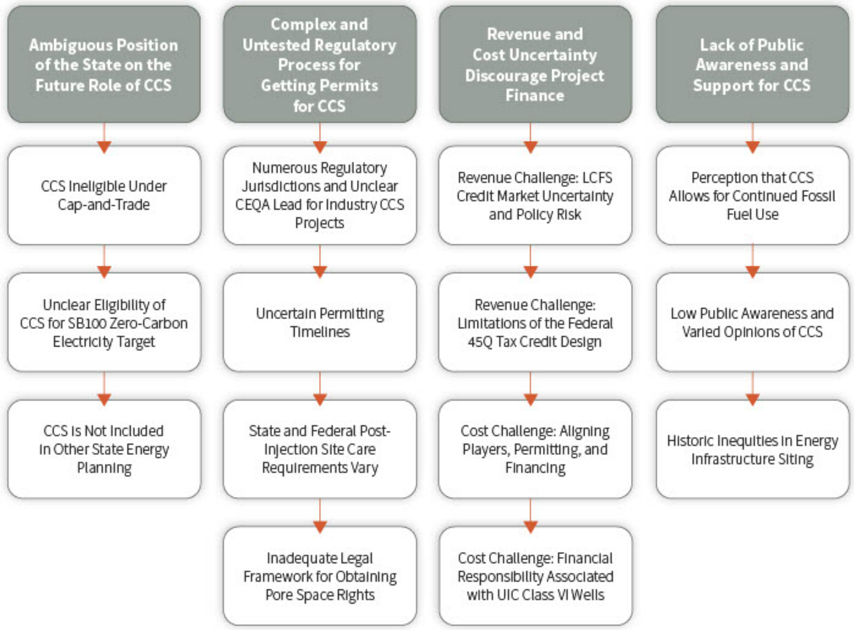
- While the primary objective of CCS is to reduce CO_2 emissions and mitigate climate change, post-combustion capture can also result in the reduction of criteria air pollutant emissions from certain facilities.

Challenges for CCS Project Development in California

Informed by interviews with project developers, financiers, and industry stakeholders, this analysis identified existing barriers to CCS project development, including ambiguous state support for CCS, complex and untested regulatory process; revenue and cost uncertainty, and lack of public awareness and support (Figure 13).

Figure 13

Challenges to CCS Project Development

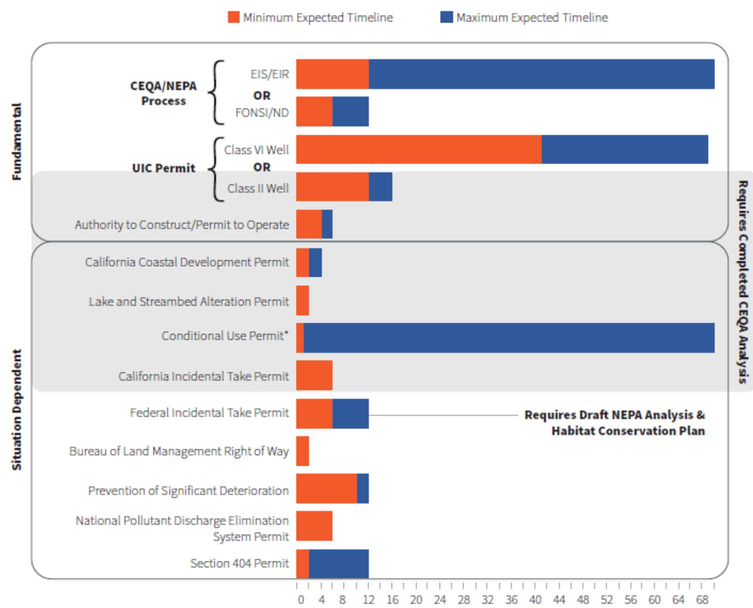


This analysis identified key challenges for CCS project development in California through interviews with project developers, financiers, and industry stakeholders, as well as archival research and analysis of California's policy landscape.
Source: Energy Futures Initiative and Stanford University, 2020.

- A stable and consistent policy environment is critical for developing and deploying greenhouse gas mitigation technologies at scale. CCS has received some state policy incentives—namely eligibility under the LCFS—but it remains ineligible for some of the state's largest decarbonization policies and strategies.
- Every CCS project is unique from a planning and permitting perspective. The location and project type will impact what permits are necessary and which local, state, regional, and/or federal agencies would be involved.
- CCS projects in California require at least three fundamental permits from different regulatory processes: Authority to Construct and Permit to Operate; either a Class VI or Class II well permit; and either a CEQA or a joint CEQA/NEPA review. The notional permitting timelines depicted in Figure 14 show two key permits that will impact the total permitting timeframe: the Class VI well application, and the CEQA process.

Figure 14

Estimated CCS Project Permitting Timelines



**Conditional Use Permits (CUPs) must be in accordance with the city or county's General Plan (i.e. meet the development objectives) to be approved. General Plans are not updated often, so this should be taken into careful consideration by a developer.*

This figure illustrates timelines of permitting process that may be required to develop a CCS project in California. The timelines are notional estimates based on federal and state guidelines, project case studies, and agency reports. The orange bars are a minimum estimated permitting duration from application to permit issuance, while the blue bars indicate how long the process could potentially take. Blue bars that extend to the end of the graph represent processes that could have an indefinite timeframe. Source: Energy Futures Initiative and Stanford University, 2020.

- Public acceptance can make or break a CCS project, and opinions on CCS are wide ranging and highly variable. This is due in part to the fact that these are relatively new infrastructures and technologies with which the public is unfamiliar. Analysis suggests that individuals are influenced by relationships with their communities; better community relationships translate into greater individual support for CCS.

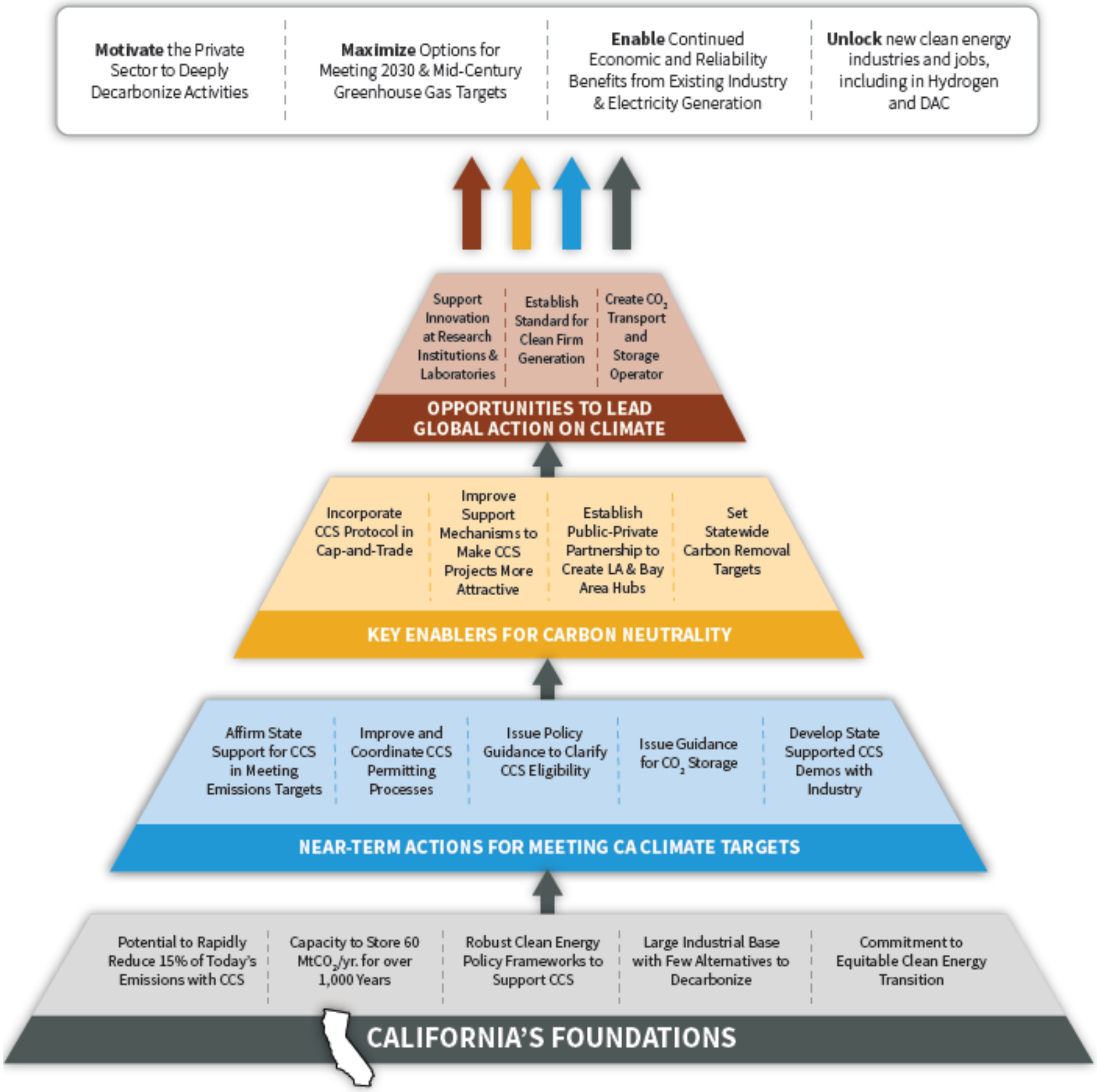
An Action Plan for CCS in California & Policy Recommendations

A combination of policy actions supported by broad coalitions can maximize the value of CCS for meeting the state's economywide decarbonization goals, motivating the private sector to decarbonize, enabling economic and reliability benefits from existing industries and power generation, and unlocking new clean energy industries and jobs.

CCS is a critical decarbonization pathway for helping California meet its 2045 carbon neutrality goal, while also supporting related goals that are fundamental enablers of the clean energy transition and key to building the necessary coalitions. Figure 15 details the following goals: 1) Maximizing options for meeting 2030 and 2045 greenhouse targets to reduce overall abatement costs, improve the likelihood of achieving the targets, and foster innovation. 2) Motivating the private sector to deeply decarbonize its activities and products. 3) Enabling continued economic and reliability benefits from existing industries and power generation. 4) Unlocking new, potentially multi-billion-dollar, clean energy industries—such as hydrogen, CO_2 utilization, DAC, and fuels from biomass waste—creating new jobs in the process.

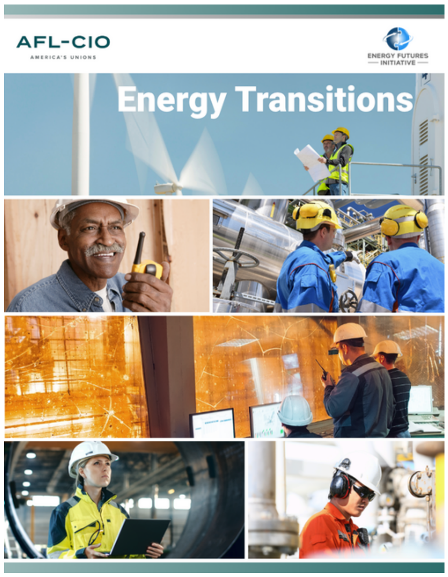
Figure 15

A Policy Action Plan for CCS in California to Meet the High-Level Goals



The analysis in this report helped form the high-level goals for CCS in California, described at the top of the figure. California can build on its strong foundation for CCS to develop and implement the specific recommendations. Each row of the figure above California's Foundations is organized by key drivers that increase in potential impact on CCS project development from the bottom to the top. Source: Energy Futures Initiative and Stanford University, 2020.

4. Energy Transitions: The Framework for Good Jobs in a Low-Carbon Future



Industrial transitions have rarely been smooth. They have been typically marked by community and worker dislocations with significant regional disparities, disproportionate impacts on minority communities, and the fraying of existing social institutions, including public education systems, local government services, unions, and even religious organizations.

Today's imperative for a transition to a low carbon economy is grounded in the need to address the existential threat of climate change and is being driven in large part by public actions, programs, policies and investments, designed and implemented by federal and state governments to regulate and subsidize the growth of low carbon technologies. As such, *it is the duty and obligation of policymakers to embrace solutions to industrial dislocation as fundamental to a clean energy economy transition's design and implementation, technological evaluation, and how regions and localities are supported.*

It is in this context that the AFL-CIO and EFI announced the formation of the Labor Energy Partnership (LEP). The LEP's inaugural document, Transition Pathways—The Framework for Good Jobs in a Low-Carbon Future, summarizes ten key areas of analysis, the results of which will help guide the LEP as it launches a multi-decadal effort to create a clean energy economy that is more equitable for all Americans and can be sustained across our diversity of political views, regional differences, and economic challenges for the next thirty years.

The leadership of the LEP has identified ten key areas that are critical to creating a unified path forward for the implementation of climate solutions in the United States. Each element requires an unbiased analysis that identifies challenges, opportunities, needed investments, and policy options. Over the course of the Biden-Harris Administration, the LEP intends to conduct analyses on the following 10 critical elements:

1. A national action plan for the deployment of carbon capture, utilization, and sequestration technology. Carbon capture, utilization, and sequestration technologies (CCUS) removes carbon dioxide, the primary greenhouse gas (GHG) emission from combustion streams, preventing it from being released into the atmosphere and allowing it to be permanently stored underground or used in other chemical or manufacturing processes. CCUS is the only technology currently capable of decarbonizing the high-grade process heat required in energy intensive industries, including steel, aluminum, pulp and paper, chemicals, cement, and a handful of others. These five industries produce 70% of industrial GHG emissions both in the U.S. and globally. Industrial emissions make up about 20% of all emissions. Energy intensive industries in the United States employ over 1.7 million Americans, and capital-intensive, durable manufacturing industries have high job multiplier impacts in the communities where they are located, generally creating 7.4 indirect jobs in addition to each direct job.

2. A priority energy infrastructure analysis that provides a roadmap for key energy infrastructure needs, financing mechanisms, and approval and permitting pathways. The quadrennial American Society of Civil Engineers (ASCE) report card on American infrastructure in 2017 gave U.S. energy infrastructure a D+. Currently, the electricity portion of energy infrastructure would need to spend $177 billion dollars over a decade in addition to the $100+ billion it already spends annually to raise electricity infrastructure to a B level. This additional spending would improve the efficiency and reliability of the system, but it does not include a focused plan to decarbonize the electrical system over the coming decades.

Table 3

Opportunities for Using Existing Carbon Infrastructure for Decarbonization

	Oil Refining & Natural Gas Processing	Natural Gas Generation	Oil & Gas Pipelines	Waterborne Transport & Ports	Storage
Biofuels	Conversion of oil refineries to bio-refineries Upstream blending of oils with drop-in biofuels Applying industry expertise	See renewable natural gas example 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 using hydrogen safety 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 expect efficiency ≥ 60 percent	Doping in NG pipelines (≤ 15 percent with minor pipeline upgrades needed) Leveraging pipeline right-of-way	Using fuel storage and transportation hubs	Using salt caverns and other geologic formations Capitalizing on industry expertise with NG storage
Negative Emissions Technologies, CCUS	Applying industry expertise to CCUS technologies for DAC and BECCS	Applying industry expertise: CCUS technologies for DAC and BECCS	Using compression technologies similar to those in NG infrastructure for CO2 Rail and roadway = existing infrastructure Leveraging pipeline rights-of-way	Using industry expertise in liquefaction and transport of LPG/LNG for liquid CO2 Marine vessels for CO2 using the same technology as existing LPG or LNG tankers Port infrastructure for loading Offshore facilities for subsea injection	Using saline formations, depleted O&G reservoirs, un-mineable coal seams, basalt formations Using industry expertise in large-scale CO2 separation and sequestration Applying technologies for drilling and injection, subsurface characterization, and site monitoring, same as in the O&G sector Leveraging similarities with NG storage, acid gas disposal, and CO2EOR
Renewable Natural Gas	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 refinery performance	Creating smart generation solutions: NG-battery and NG-solar hybrids	SCADA expertise Improving the efficiency of transport of RNG, H2, CO2 Leverage pipeline rights of way	Using transport management systems and other IoT applications Data tracking of supply chains	Optimizing revenues from grid-scale systems

3. Policies needed to site and permit new electricity transmission projects in the near-term. One of the impediments to the rapid ramp-up of clean, new, and modernized energy infrastructure and technologies is the cumbersome and lengthy review process for permitting infrastructure projects. Currently, many proposals have been floated to expedite permitting. Among these are the reform of the National Energy Policy Act, the creation of a pre-approval optional process for state and local authorities, and the transfer of certain kinds of transmission permitting to a single authority such as FERC. This LEP analysis will identify policies and procedures on expediting or restructuring transmission permitting.

4. Options for safe and affordable preservation of the existing nuclear fleet and the deployment of next generation nuclear technologies. Nuclear generation provides carbon-free, baseload power for a wide range of U.S. consumers with significantly different needs. For instance, some industrial customers, operating 24 hours a day, 365 days a year, require reliable sources of electricity and could not operate if forced to consume only variable sources of electricity. The rapid and unplanned retirement of the existing nuclear fleet would most likely result in a large expansion of natural gas-fired generation, thus driving up the rate of GHG emissions at the precise moment that climate solutions demand their reduction. Currently, the workforce in the nuclear power generation sector provides the highest average pay rates, employs the greatest percentage of women, and is the most diverse workforce in the entire electric generation sector. It is also highly unionized at twice the national rate.

5. Development of technology and policy pathways for the use of natural gas consistent with meeting climate goals. An important consideration in the future will be the role of natural gas in a low carbon economy. Currently, 40% of natural gas is consumed by industry, both for process heat and as a feedstock, while 37% is used for electric generation. The balance is used in commercial and residential buildings. Across its entire value chain, the natural gas sector directly employs over 636,000 Americans. The utility sector is the largest industry sector for natural gas, which employs almost 184,000 people, followed by mining and extraction, and construction with 166,000 and 110,000, respectively. Current limitations on the reliability of wind and solar generation due to their inherent variability underscore the role of natural gas in both our energy transition to a low carbon economy and in meeting our energy requirements in the post-2050 period. The LEP will examine natural gas use in a future low carbon economy.

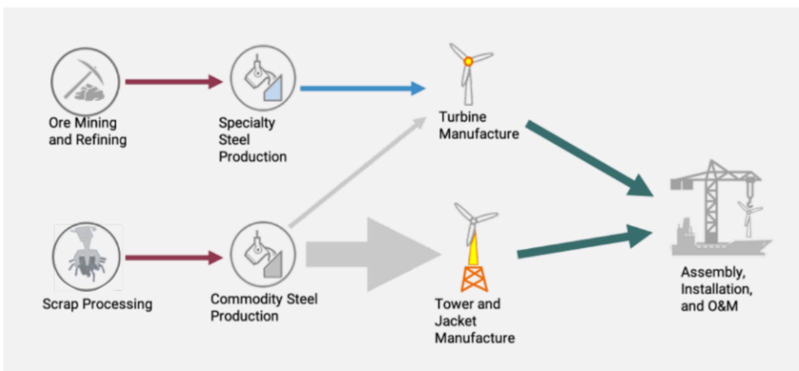
6. An exploration of the economic challenges and costs and benefits of developing alternatives to hydrogen fuel for transportation, power, and industrial sectors. Current challenges to the wide-scale deployment of hydrogen as an industrial and transportation fuel include its relatively high cost of production either from electrolysis or methane reforming and its safe and efficient storage and distribution. One possible pathway to more wide-spread utilization of hydrogen to reduce GHG emissions would be the creation of "hydrogen hubs" where geographically concentrated end users such as ports with warehousing and manufacturing assets could easily benefit from hydrogen usage without significant transmission requirements.

7. The expansion of energy efficiency finance mechanisms and policy recommendations to enable the full utilization of energy efficient technologies in commercial and residential buildings, industrial processes, and transportation. As a result of the wide-scale adoption of energy efficiency technologies across the economy, "energy efficiency jobs" have become an important component of economic development strategies. 75% of all utilities in the United States today operate or finance energy efficiency programs. Over 30 states have set energy efficiency standards or targets.

8. An assessment of the capacity of the United States to mine, process, and manufacture the critical minerals and materials necessary for the domestic production of low-carbon technologies including, but not limited to, rare earths, lithium, cobalt, copper, nickel, and palladium. In 2017, the World Bank estimated the demand for critical minerals in the solar, wind, and electric vehicle technologies if the global economy were to meet the emission reduction requirements of the Paris Agreement. That study found significant increases would be required in the production of rare earths, lithium, cobalt, copper, nickel, and palladium. Even more common minerals such as iron ore would also be needed in significantly increased volumes for the expansion of products such as wind turbine towers. In addition, the recent global experience with supply chain vulnerability for personal protective equipment during the COVID-19 pandemic has underscored that the U.S. cannot allow its energy system to be overly dependent on minerals that we no longer mine in the U.S.

9. An analysis of the offshore wind supply chain, including its raw material requirements, manufacturing technologies, and geographical differences between the East Coast, West Coast, and Great Lakes' resources and policy options to encourage domestic development. The pipeline for offshore wind power contracts in the Northeastern United States through 2030 implies up to 20 GW of capacity and $68 billion capital investment in the major components of wind turbines, not including necessary investments in supporting infrastructure, shipping and port capacity, or workforce development. The creation of a new offshore wind sector in the Northeast and followed, potentially, by similar industry developments in the Southeast, Great Lakes, and Pacific Coast provide the U.S. with the opportunity to create robust and competitive global supply chains for this new industry.

Figure 16
Offshore Wind Industry Steel-Related Supply Chains



10. A roadmap for implementing natural and engineered carbon dioxide removal at scale. Most scientific reviews of climate policy acknowledge that some level of direct carbon dioxide removal will be necessary to achieve the most aggressive goals of emission reductions, such as net zero by 2050. A recent workforce assessment of direct capture technologies performed for the Carbon Capture Coalition by the Rhodium Group estimated that, when brought to scale, these new technologies could create between 100,000 and 140,000 jobs in construction and operations. The most pressing need today is the development of a clear roadmap that integrates the necessary policy supports with the RD&D funding, timeline, and implementation architecture.

Conclusion: Creating Quality Jobs and an Inclusive Workforce

The LEP initiatives delineated above will enable the U.S. to move forward in a manner that creates new, quality jobs and an inclusive workforce. At the core of each of these initiatives is a set of key social policies that should be linked to the regulations and economic incentives that will encourage that transition. Some of these are currently in law, covering some government procurement policies, while others represent best practices in the private sector. All of them should be expanded to provide maximum opportunity for quality job creation and ease of access to those jobs by all demographic groups. They include:

- **Davis-Bacon Prevailing Wage Standards.** Davis-Bacon requires that prevailing wages be paid for federal government-funded projects, thus diminishing labor rates from the competitive bidding process.
- **Project Labor Agreements.** Project labor agreements promote pre-hire agreements between union contractors and labor unions to ensure appropriate skills, labor availability, adequate training, and labor peace during project construction.
- **Labor Standards Requirements for Energy Tax Credits.** Federal tax incentives have been critical for the growth of clean energy technologies. In 2020, the House of Representatives passed HR2, which included the GREEN Act, which for the first time requires the Department of Labor to certify that bonus tax credits for renewable energy tax credits only go to employers who comply with labor and civil rights laws.
- **Buy America Provisions.** Buy America provisions require that public funds use American-made products on government-funded projects, thus ensuring the development of domestic supply chains for new technologies. Currently, Buy America provisions only apply to the Departments of Transportation and Defense.
- **Buy Clean Standards.** Pioneered by the State of California, Buy Clean standards require carbon accounting of the products used in government contracts, thus encouraging the purchase of the least carbon intensive products, almost always domestically produced.
- **Border Adjustments for Energy Intensive Industries.** Energy-intensive industries produce 70% of industrial GHG emissions in the U.S. Border adjustment tariffs on imported energy intensive products such as steel, aluminum, pulp and paper will prevent carbon leakage and reward American companies for their high environmental performance.
- **Community Benefits Agreements.** Community Benefits Agreements provide insurance that government funded projects will support minority-owned businesses, provide training and hiring guarantees to disadvantaged communities, and lead to greater social equity as a result of climate-related projects.
- **Good Neighbor Agreements.** Good Neighbor Agreements are legally enforceable agreements in labor- and environmentally sensitive industries and projects necessary for the low-carbon transition, such as mining or multi-state high voltage direct transmission lines. GNA's provide community input and social buy-in for environmentally sensitive projects.

5. The U.S. Energy and Employment Report Series

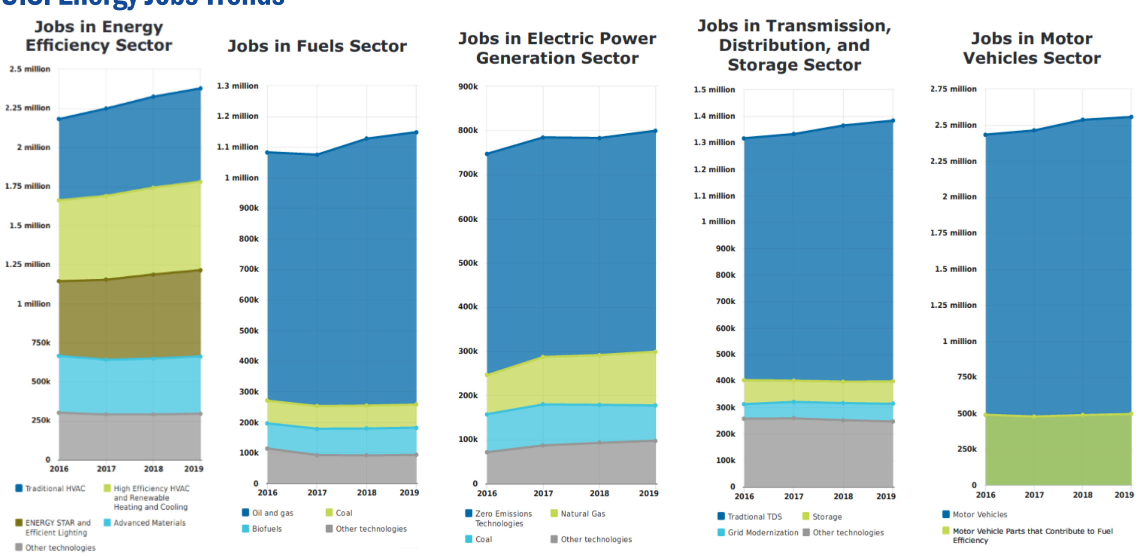
The U.S. Energy and Employment Report (USEER) was first published in 2016 by DOE "to reform existing data collection systems to provide consistent and complete definitions and quantification of energy jobs across all sectors of the economy." Although DOE elected not to undertake similar reports 2018, 2019, and 2020, EFI and the National Association of State Energy Officials (NASEO) have organized and implemented to provide continuity with the previous editions of the USEER in data collection and accuracy in year-to-year comparisons. The 2018-2020 reports utilize near-identical methodology to the survey instrument developed by DOE and approved by the Office of Management and Budget (OMB Control No. 1910-5179).

The USEER studies analyze the following five sectors of the U.S. economy: Fuels; Electric Power Generation; Transmission, Distribution and Storage (TDS); Energy Efficiency; and Motor Vehicles. The first three of these sectors make to the Traditional Energy sector. Each USEER from 2018 onward includes a 50-state supplement that provides state-level trends and data.

USEER Five Year Trends

Because 2020 marked the fifth year that the USEER report was initially launched at DOE in 2015, a special report on five-year trends was also published. Overall, there was a 12.4% increase in employment in the five sectors assessed through USEER between 2016-2019. The breakdown of employment growth in energy efficiency, fuels, electric power generation, transmission, distribution, and storage, and motor vehicles is shown in Figure 17.

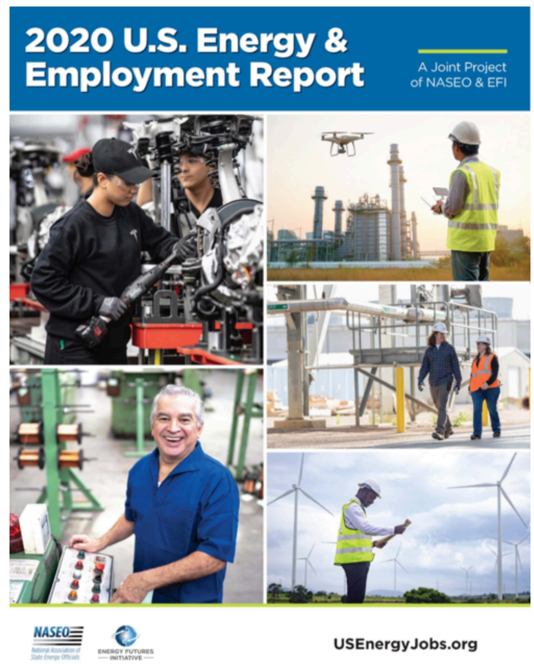
Figure 17
U.S. Energy Jobs Trends



The decoupling of energy consumption from job growth is one of the important trends noted in the 2016-2020 USEERs. A second trend is the fact that the deployment of new technologies in all five sectors has driven net job growth, even while the displacement of old technologies has led to job loss in specific subsectors. The transition from coal-fired generation as the largest source of electricity in the United States in 2015 to natural gas in 2017 is the clearest example of such displacement.

Finally, the role of energy efficiency, both in the built environment and in transportation, cannot be overstated as a contributor to job growth. While fuel efficiency jobs data in the motor vehicles sector was not collected in 2015, energy efficiency and fuel efficiency contributed to over 400,000 new jobs in the last five years.

The 2020 U.S. Energy and Employment Report



It is our hope that the 2020 USEER, its 50-state supplement, and future editions will be used to better inform federal, state, and local policymakers; academic decision-makers; and the private sector in developing integrated energy, security, economic development, and workforce plans. This kind of integration is key to maximizing the benefits of the nation's abundant energy resources, rapid pace of energy innovation, and dynamic energy markets. We further hope that the data presented in these and future reports will help advance the understanding of the economics of emerging energy industries.

Some of the findings from the 2020 report include:

- In 2019, the Fuels sector, which includes oil, gas, coal, nuclear, and various biofuels, employed nearly 1.15 million people and added more than 26,100 jobs, with the most growth in oil, natural gas, mining, extraction, and biofuels (excluding corn ethanol).
- The Electric Power Generation sector employed nearly 900,000 people, seeing high growth in natural gas generation (9,100 new jobs), good growth in solar (5,700 new jobs) and wind (3,600 new jobs), and a decline in coal generation (7,700 jobs lost)
- TDS operations employed more than 2.4 million people, with over 1 million working in retail trade (e.g., gas stations, fuel dealers). 17,800 non-retail jobs were added, most significantly in TDS-related construction work, which experienced 4% year-on-year growth.
- Jobs involved in the design, installation, and manufacture of Energy Efficiency products and services totaled 2.38 million, adding 54,000 jobs year-on-year. More than half of this job growth was in Energy Efficiency construction, which comprises more than 1.3 million jobs.
- Jobs related to motor vehicle and associated parts construction amounted to 2.55 million, adding 20,000 jobs year-on-year. However, employment declined in jobs related to alternative fuel vehicles (2%), as well as hybrids and electric vehicles (2.5%).

- Natural gas jobs spanning utilities, construction, and extraction collectively employed more than 636,000 people, a growth of 1.7%.
- Petroleum jobs encompassing extraction, trade, distribution, transport, and manufacturing totaled more than 824,000 people, a growth of 3.1%.
- Coal industry jobs including mining, trade, distribution, transport, and utilities employed nearly 186,000 people, a decline of 5.9%.
- The nuclear industry collectively employed more than 70,000 people across utilities, professional and business services, and manufacturing, down 2.5% from 2018.
- Traditional fossil fuel sectors employed 1.2 million people (down 2% year-on-year), while zero emissions technologies employed nearly 510,000 and low emissions technologies employed more than 227,000 people.
- The gender balance across all sectors surveyed ranged from 23% women to 32% women, compared to a general national workforce composition of 47% women.
- Most sectors showed higher racial diversity than the general national workforce, though specific racial categories may be underrepresented.
- Veterans represent eight to ten% of energy workforce jobs, compared to general workforce representation around six%.
- Persons aged 55 or older comprised from 13% to 21% of energy sector jobs, a lower percentage than the national average of 23%.
- All energy sector jobs except for fuels show a higher unionization rate than the national private sector average.

The 2019 U.S. Energy and Employment Report

The 2019 USEER used similar methodology to collect data on energy employment in 2018 but included the differentiation of jobs in oil and gas pipeline construction, an expansion of energy storage technologies, and an energy and energy efficiency jobs wage data survey to be published as a separate report. This also included state-level data in its 50-state supplement.

Some of the key findings from the 2019 report include:

- The Fuels sector had 1,127,600 total jobs with an increase of 52,00 or 4.8% in 2018. There was strong growth in petroleum fuels jobs, amounting to 33,500 new positions, an increase of nearly 6%, and natural gas extraction employment increasing by 17,000 new jobs, an increase of 6.8%.

- Electric Power Generation had 875,600 total jobs with a decrease of about one percent, losing jobs in solar, nuclear, and coal generation that were partially offset by gains in natural gas, wind, and CHP.
- Solar energy firms employed 242,000 employees who spent the majority of their time on solar. An additional 93,000 employees spent less than half their time on solar-related work. The number of employees who spend the majority of their time on solar declined by 3.2% or more than 8,000 jobs in 2018. There were an additional 111,000 workers employed at wind energy firms across the nation in 2018, an increase of 3.5% or 3,700 jobs.
- All-natural gas employment in Electric Power Generation increased by over 5,200 (4.9%), for almost 113,000 jobs, reflecting that gas now produces more electricity in the United States than any other fuel type.
- Advanced/low emissions natural gas, wind, and CHP generation were the fastest growing new sources, increasing employment by more than 4,500 (7.0%), 3,700 (3.5%), and 2,000 (7.4%), respectively.
- The TDS sector employed more than 2.3 million Americans, with just over 1 million working in retail trade (gasoline stations and fuel dealers). Excluding retail trade, this represents an increase of 33,000 new jobs or 2.6%. Utilities and construction were the two strongest industry sectors in TDS, adding over 30,000 new jobs in 2018 and battery storage added over 9,500 new jobs for an 18% growth rate in 2018.
- Overall, 48% of respondent employers working in the TDS sector reported that a majority of their revenues come from grid modernization or other utility-funded modernization projects, an increase of 10 percentage points over 2017.
- Energy Efficiency employed 2.35 million Americans, in whole or in part, in the design, installation, and manufacture of Energy Efficiency products and services, adding 76,000 net jobs in 2018 (3.4%), an increase over the 67,000 jobs added in 2017.
- 79% of employees who work on Energy Efficiency in the construction sector report spending at least half their time on Energy Efficiency-related work, virtually unchanged from the number reported last year (1.024 million) up from 797,500 in 2015 and 1.017 million in 2016.

- Manufacturing jobs, producing ENERGY STAR® certified products and energy efficient building materials in the United States, increased by 6,000 jobs or 2%.
- Motor Vehicles employed over 2.53 million workers, excluding automobile dealerships and retailers, adding 74,000 jobs in 2018, an increase of 3%.
- In 2018, almost 254,000 employees worked with alternative fuels vehicles, an increase of nearly 34,000 jobs. Hybrids, plug-in hybrids, and all-electric vehicles made

up over 90% of this number, supporting 231,000 employees. The number of jobs supported by hydrogen or fuel cell vehicles declined, while jobs in all other alternative vehicle technologies increased.

The 2019 USSER highlighted that 2018 marked another year in the evolution of the U.S. energy system, one in which market forces, technology development and maturation, tax policy, and declining federal regulation (countered by increased regulation in some states) affected the changing profile of our energy workforce. In spite of one of the highest levels of employment in recent U.S. history, the traditional energy and energy efficiency sectors continued to outperform the economy as a whole, adding 152,000 new jobs.

The 2018 U.S. Energy and Employment Report

The 2018 USEER used similar methodology to collect data for 2017, with EFI and NASEO taking up the task for the first time. In the 2018 study, Fuels and Electric Power Generation were grouped together. The 2018 USEER was the first time that the USEER included a 50-state supplement.

Some of the key findings include:

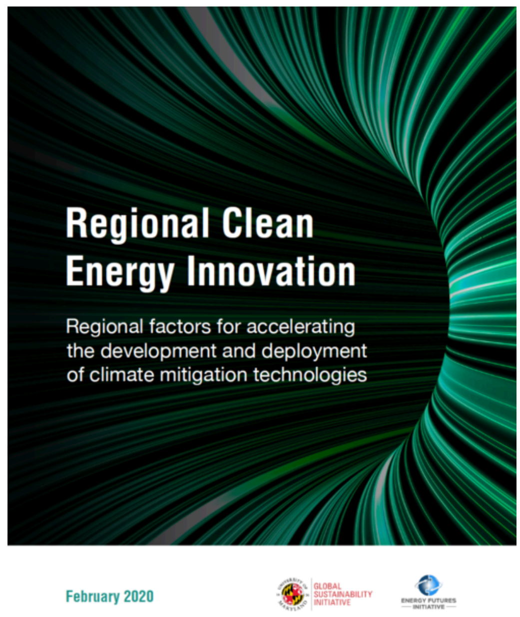
- Electric Power Generation and Fuels directly employed more than 1.9 million workers in 2017, up 15,000 jobs from 2016. In this sector, 55%, or 1.1 million, of the employees in this sector worked in traditional coal, oil, and gas, while almost 800,000 workers were employed in low-carbon emission generation technologies.
- Natural gas, wind, and CHP employment increased in 2017. There were an additional 107,000 workers employed at wind energy firms, an increase of nearly 6%.
- Solar employment declined and solar energy firms employed, in whole or in part, 350,000 individuals in 2017, with more than 250,000 of those employees spending the majority of their time on solar. That represents a reduction of 6% or 24,000 jobs in solar in 2017, with 9,000 in utility-scale solar and 15,000 in residential solar.
- Natural gas employment in Electric Power Generation increased by over 19,000, reflecting that gas now produces more electricity in the United States than any other fuel type. Bioenergy and CHP Generation were the fastest growing new sources, increasing employment by over 4000 and 9000 each or 55% and 51%.
- Transmission, Distribution, and Storage employed more than 2.3 million Americans, with just over 1 million working in retail trade and another 869,000 working across utilities and construction. Overall, 38% of respondent employers working in TDS reported that a majority of their revenues come from grid modernization or other utility-funded modernization projects, an increase of 6.5 percentage points over 2016.
- Energy Efficiency employed 2.25 million Americans, adding 67,000 net jobs in 2017. Almost 1.3 million Energy Efficiency jobs are in the construction industry, a decline

from 2016. However, Energy Efficiency jobs in manufacturing, trade, and professional services all grew, more than offsetting the decline in construction.

- Motor Vehicles employed over 2.46 million workers, adding 29,000 jobs in 2017. Almost 220,000 employees worked with alternative fuels vehicles, a decline of almost 40,000 jobs. Hybrids, plug-in hybrids, and all-electric vehicles made up over 90% these jobs, supporting 197,000 employees. The number of jobs supported by hybrid and plug-in hybrids both declined, while jobs supported by all-electric vehicles rose sharply.

Overall, firms covered by the survey anticipate roughly 6.2% employment growth for 2018. Energy Efficiency employers project the highest growth rate over 2018 (9%), followed by Electric Power Generation (8%); Motor Vehicles (almost 7%, including a 6% increase in manufacturing), Transmission, Distribution, and Storage (3%), and the Fuels sector (2%).

6. Regional Clean Energy Innovation

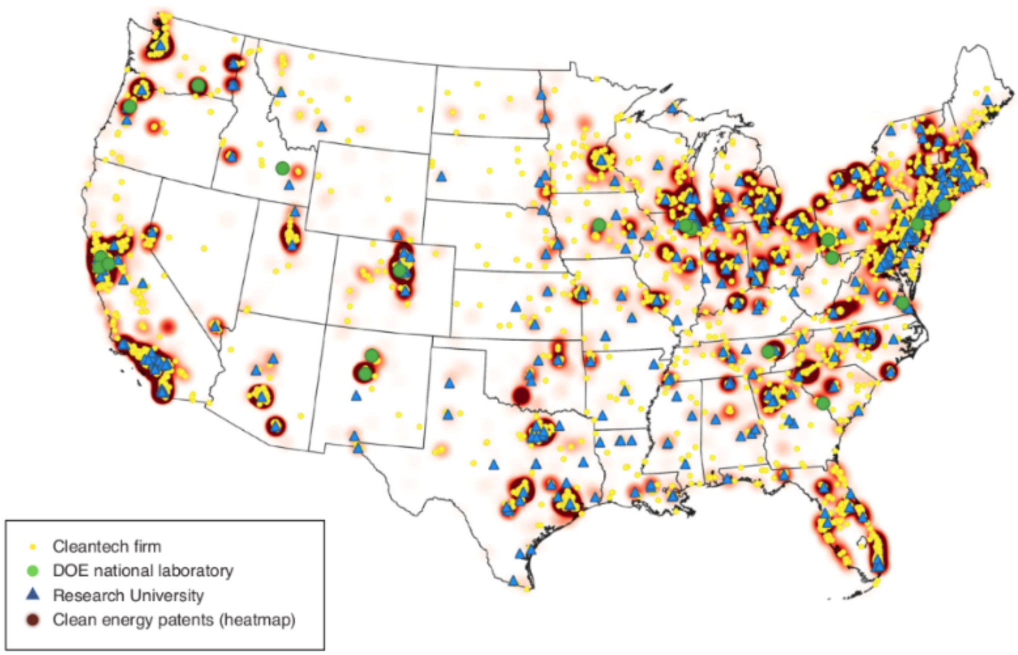


This report, conducted in partnership with the University of Maryland Global Sustainability Initiative, uses a data-driven approach to explore regional characteristics, defined at the state-level, in clean energy innovation. Clean energy is defined broadly to cover technologies that either contribute to climate mitigation or to modernizing the energy system. The exploration of data is presented in two stages: a 50-state assessment and detailed case studies comparing Colorado and Maryland.

The cleantech firms revealed

Figure 18 are a key focus of the analyses in this report. Cleantech firms are vital elements in robust, long-term clean energy based economic development. Such firms are valuable because they can create long-term export generating assets from the technology strengths of a state's research, development, and demonstration (RD&D) activities and create long-term employment opportunities through the development of new, competitive industries.

Figure 18
Clean Energy Innovation Activity is Dispersed Across the United States



Data on state-level clean energy innovation allows an exploration of activities related to research, development, and demonstration (RD&D) and deployment by different stakeholders. Using these datasets, the 50-state assessment categorizes the motivations for regional clean energy innovation activity in terms of 1) the potential for economic development; 2) goals for social and environmental benefits; and 3) local technology capacity in RD&D (i.e., technological, intellectual, and financial capacity).

Table 4

Categories of 50-State Data Used for Exploring Correlations Among Factors and outcomes Related to Clean Energy Research and Development, Demonstration, and Deployment

Description	Examples of Metrics
Economic Development	Natural resources – e.g., fossil fuels, biofuels, wind and solar State RD&D funding – energy, environment and natural resources
Energy and Environment	Energy efficiency standards and incentives Renewable Portfolio Standards (RPS) Other state clean energy policies
Technology Capacity	Overall innovation ranking and overall RD&D spending Department of Energy RD&D grants Number and technical areas of clean energy Small Business Innovation Research (SBIR) grants Number and technical areas of clean energy patents
Outcomes	Number and technical areas of clean energy firms Employment in clean energy sectors Deployment of clean energy technologies Reduction in greenhouse gas emissions

Relatively few states have an idealized regional clean energy innovation system with a coordinated process of research, development, demonstration, and deployment. Instead, specialization maps reveal that states' individual choices about advancing different technology areas have often led to growth of individual stages of clean energy innovation (measured through metrics like patenting activity, cleantech firms, or deployment) with variable levels of coordination between stages.

This report presents an analysis of two states, Colorado and Maryland, that have similar overall innovation capabilities (i.e., not specific to clean energy), yet have remarkably different clean energy innovation outcomes. There are a number of possible factors contributing to the differences between Colorado and Maryland: these include the states' natural resources and industrial bases, state energy policies and how they are implemented, the stakeholders involved in these processes (e.g., state agencies, universities, laboratories, private sector), and the state governments' distribution of spending or incentives across the stages of RD&D and deployment.

Table 5

Outcomes Related to In-State Clean Energy RD&D in Maryland and Colorado

State	Overall innovation ranking (ITIF[13])	Number of cleantech firms (i3[1] and others)*	Energy efficiency ranking (ACEEE[14])	Wind and solar power generation (in state, 2018)[15]	Clean energy employment (USEER[6])**	Energy-related per capita CO_2 emissions reductions since 2005[16]
Colorado	Rank 7th of 50 states	513 firms in expanded dataset; 288 firms in best available industry dataset	Rank 14th of 50 states	10.8 million MWh (19.5% of total)	12 jobs per thousand people	21.7%
Maryland	Rank 6th of 50 states	189 firms in expanded dataset; 94 firms in best available industry dataset	Rank 7th of 50 states	0.97 million MWh (2.2% of total)	14 jobs per thousand people	34.9%

*Estimated using the i3 cleantech database[1] and expanded using additional datasets (clean energy patent assignees in state, cleantech firms that received SBIR funding, cleantech firms that received state grants)

**Maryland's clean energy employment is dominated by the buildings sector, while Colorado has a balanced representation across most technology areas, with greatest specializations in biofuels and wind.

A crucial difference observed between Colorado and Maryland is in how they integrate clean energy innovation with economic development goals.

Colorado has identified clean energy innovation as an important component of its economic development priorities. The governor-led policy push initiated a coordinated engagement of multiple state agencies and other public and private stakeholders who shared similar goals for clean energy. Coordination between state agencies for energy (Colorado Energy Office) and economic development (Colorado Office for Economic Development and International Trade) helped the state attract wind manufacturing facilities and also, over time, deploy wind energy (and other forms of clean energy) to address its renewable energy standards. Such policy signals contributed to the development of an industry association (Colorado Cleantech Industries Association) and the emergence of state-sponsored programs for coordination among RD&D stakeholders (including universities and the National Renewable Energy Laboratory) that supported innovative clean energy firms in the state.

Maryland's clean energy activities have predominantly been administered through the energy office (Maryland Energy Administration) and through substantial investment in utilities' programs encouraging energy efficiency (EmPOWER). State government incentives have focused on deployment of mature technologies rather than RD&D or deployment of early-stage clean energy technologies. The emphasis on mature energy efficiency products is a factor for Maryland's relatively strong clean energy employment in service and construction in the buildings efficiency sector and its strong energy efficiency ranking. Also, prior to the recent formation of the Maryland Energy Innovation Institute (MEI), no program offered targeted seed funding or mentoring support for clean energy RD&D and cleantech firms, although some seed funding had been available from general innovation programs.

Table 6

Comparison of Spending by the State Governments in Colorado and Maryland on Clean Energy RD&D and Deployment

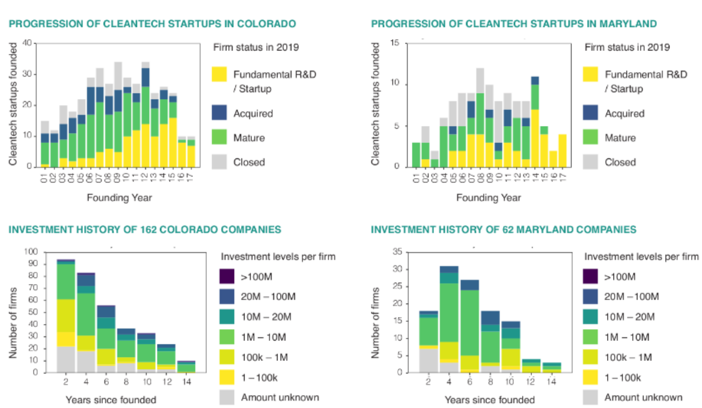
Innovation stages	Colorado Average annual per capita (population 5.7 million)	Maryland Average annual per capita (population 6.04 million)
Late deployment, market growth, mature companies	$12.31/year (78.2%)	$44.90/year (90.6%)
Early deployment, companies shipping product or developing pilots	$2.91/year (18.5%)	$4.31/year (8.7%)
Research, development, and technical demonstration, companies developing prototype and product	$0.52/year (3.3%)	$0.33/year (0.7%)
Total per capita	**$15.74/year**	**$49.55/year**
Total dollars	**$90 million/year**	**$310 million/year**

The quantitative comparisons of actual state government spending on clean energy innovation show that Colorado spends significantly less than Maryland overall. However, Colorado spends about 50% more than Maryland on the early stages of research, development and technical demonstration. The higher funding for early-stage technologies in Colorado (compared to Maryland) undoubtedly influenced its striking advantage in the number of cleantech firms.

Statistics reveal that Colorado has nearly three times as many cleantech firms as Maryland. Maryland's cleantech firms show a larger failure rate (24%) than Colorado (14%), and a smaller acquisition rate (7%) than Colorado (17%). Colorado's cleantech startups were also more successful on a per-company basis than Maryland's in attracting the private-sector investments needed to cross the 'valley of death' and growing subsequently to deliver economic benefits to the state.

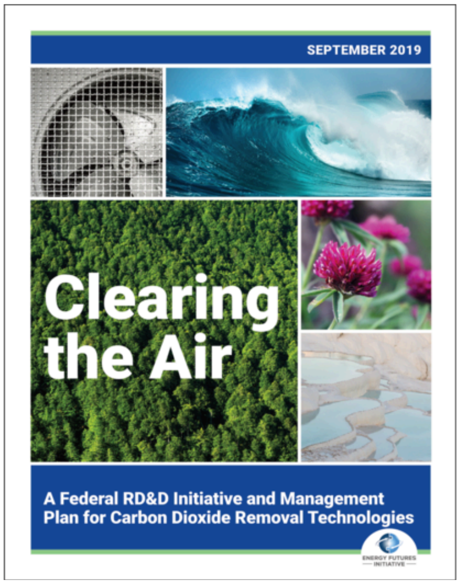
Figure 19

Comparison of Cleantech Startups in Colorado and Maryland



The data approaches and types of analyses presented here demonstrate a process that can inform federal and state planning efforts to accelerate clean energy innovation by aligning programs with regional resources, economic development goals, and environmental priorities.

7. Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies

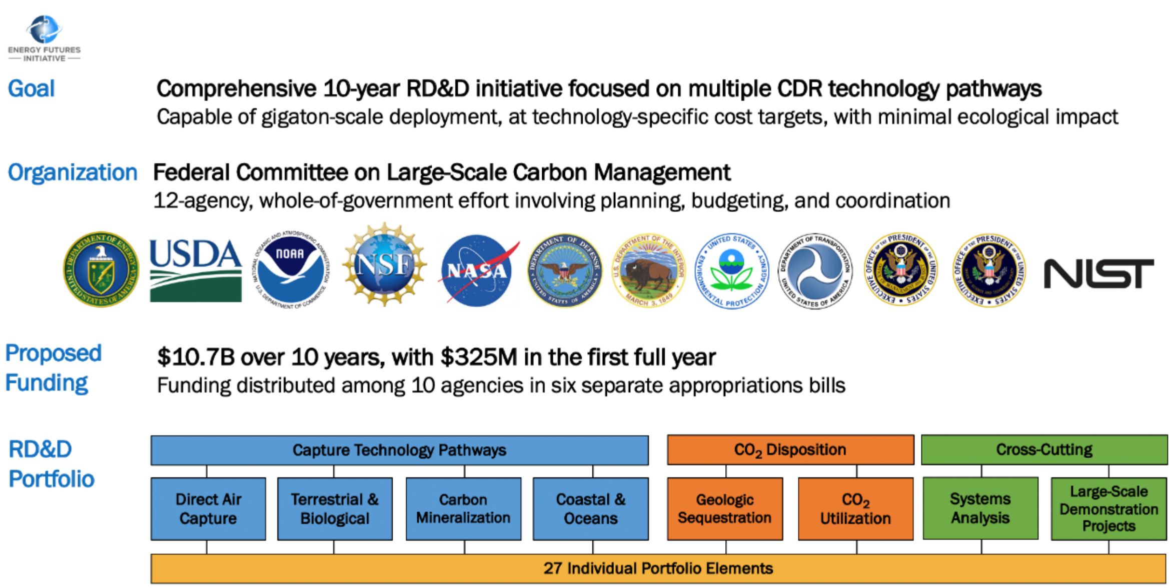


In September 2019, EFI released *Clearing the Air,* which proposed the first largescale RD&D portfolio for CDR based on the technical potential of each pathway and the opportunity to leverage existing capacity of federally-funded R&D. This report provides a set of recommendations and implementation plans for a comprehensive, 10-year, $10.7 billion research, development, and demonstration (RD&D) initiative in the United States to bring new pathways for technological carbon dioxide removal (CDR) to commercial readiness (Figure 20).

The CDR RD&D initiative encompasses a broad range of technological pathways and technologically-enhanced natural processes that can remove CO_2 from the environment including direct air capture (DAC); technologically-enhanced carbon uptake in trees, plants, and soils; capture and isolation of CO_2 in coastal and deep ocean waters; and carbon mineralization in surface and subsurface rock formations. Geologic sequestration and CO_2 utilization will also be included in the CDR RD&D initiative to provide CO_2 disposition options for CDR pathways such as DAC and bioenergy with carbon capture and sequestration (BECCS).

Figure 20

Overview of CDR RD&D Initiative



The CDR RD&D initiative is proposed to span 10 years and involve multi-agency collaboration and coordination. Source: EFI, 2019.

The wide range of scientific challenges requires a whole-of-government approach that reaches the mission responsibilities and research expertise of 12 federal departments and agencies, with the Department of Energy (DOE), Department of Agriculture (USDA), and the National Oceanic and Atmospheric Administration (NOAA) playing key roles. The planning, budgeting, execution, and performance aspects of the CDR RD&D initiative will require effective coordination led by the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) within the Executive Office of the President (EOP). At an international level, the CDR RD&D initiative should seek to collaborate with similar efforts in other countries under an expanded Mission Innovation (MI) initiative, which was launched at the 21st Conference of the Parties (COP21) in 2015.

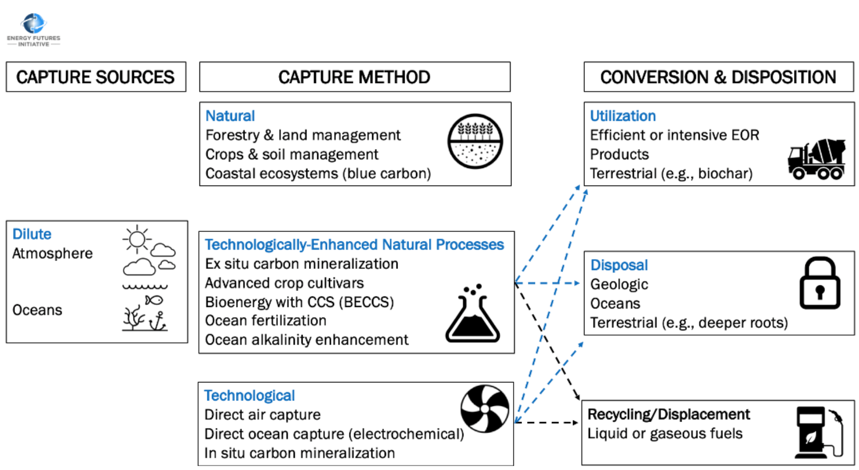
Scope of Technological CDR Approaches

The three broad approaches to CDR are **natural**, **technologically-enhanced natural processes** (or hybrid), and **technological** CDR from the atmosphere and oceans (Figure 21).

- **Natural CDR** includes pathways such as afforestation, reforestation, soil carbon sequestration, and coastal ecosystem carbon uptake ("blue carbon"). Natural CDR pathways remove carbon from the atmosphere at gigaton (Gt) scale but are currently insufficient to offset anthropogenic emissions and thus cannot keep the carbon cycle in a net-neutral balance.
- **Technologically-enhanced natural processes** include elements of both natural and technological CDR and include pathways such as ex situ carbon mineralization, advanced crop cultivars, ocean alkalinity enhancement, and BECCS. The technologically-enhanced CDR options (other than BECCS) also have the advantage or providing both capture and sequestration in the same process.
- **Direct technological capture**, including DAC and electrochemical separation of CO_2 from seawater. These pathways do require some form of sequestration or utilization in order to achieve permanent disposition of the captured CO_2.

Figure 21

Selection of Pathways for CDR from Dilute CO_2 Sources

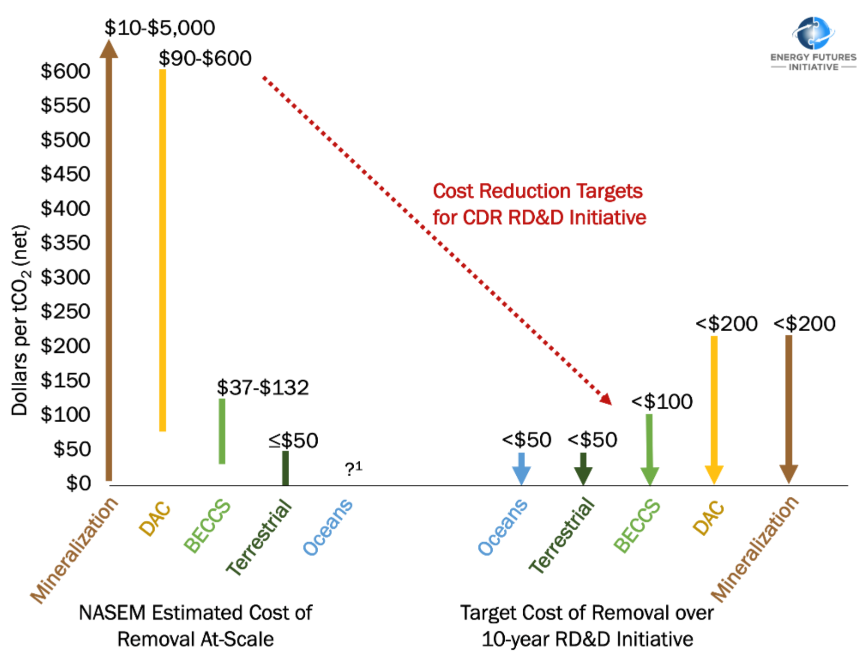


There are a variety of natural, technologically-enhanced natural processes, and technological pathways that can facilitate CDR through the capture of CO_2 from dilute sources. Source: EFI, 2019.

Technology-Specific Cost Objectives

The ultimate challenge in setting the RD&D cost objective is to strike a balance between the necessary (bringing costs down to where policy or market factors can drive deployment) and the realistic (establishing a target that can potentially be achieved). The proposed programmatic cost objective is to drive down the cost of multiple CDR technology pathways (at material scale) to technology-specific cost targets (Figure 22) defined as dollars per tCO_2 (net), where the use of net tons reflects the fact that it is only meaningful from a climate perspective to use a full lifecycle analysis of the CO_2 removal amount (including emissions due to energy or materials consumption in the removal process). The cost targets are technology-specific and will narrow the range of cost uncertainties reported in the literature that are defined by large variations within and across CDR technologies. There will also be a need to establish a rigorous process for estimating costs on an equal footing across the range of energy technologies.

Figure 22
CDR RD&D Initiative Cost Targets



The CDR RD&D initiative cost targets are technology-specific given the high degree of cost uncertainties for various CDR capture technology pathways. [1]Cost estimates were available for blue carbon but not for other oceans-related CDR pathways. Source: EFI, 2019. Compiled using data from the National Academies of Sciences, Engineering, and Medicine.

Portfolio Structure for the CDR RD&D Initiative

The proposed technological CDR RD&D portfolio framework consists of:

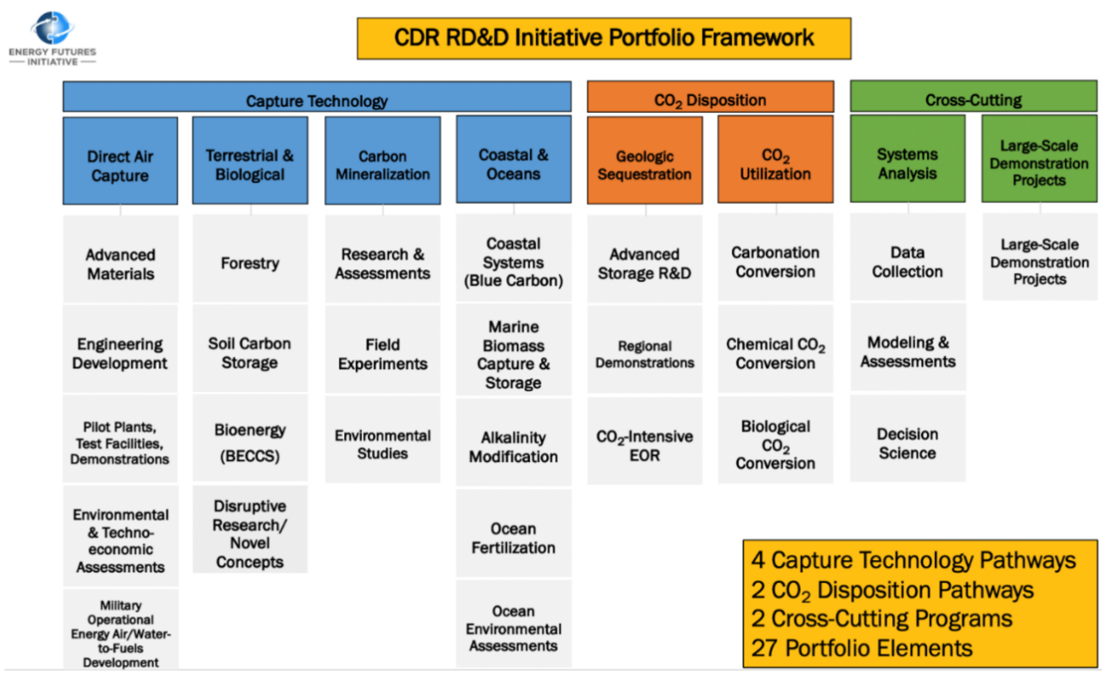
- Four capture technology pathways (DAC, terrestrial and biological, carbon mineralization, coastal and oceans). For the terrestrial and biological, carbon mineralization, and many coastal and oceans CDR pathways, sequestration is an integral part of the capture mechanism;

- Two CO_2 disposition pathways (geologic sequestration, CO_2 utilization). The two CO_2 disposition pathways are needed primarily to support DAC, BECCS, and oceans direct capture options; and
- Two cross-cutting programs (systems analysis, large-scale demonstration projects) that provide holistic or common services applicable to all of the CDR pathways.

Figure 23 illustrates the portfolio design. The organization of the four capture technology pathways largely stems from those discussed in the NASEM report but were expanded to include CDR in the deep oceans. Each of the capture technology pathways and CO_2 disposition pathways contain specific RD&D needs and challenges at different stages of the research process, which are explained in detail in the subsequent chapters. In total, the RD&D portfolio comprises 27 separate elements.

Figure 23

CDR RD&D Initiative Portfolio Framework



The CDR RD&D portfolio consists of four capture technology pathways, two CO_2 disposition pathways, and two cross-cutting programs. Source: EFI, 2019.

Recommended Budget Planning Estimates

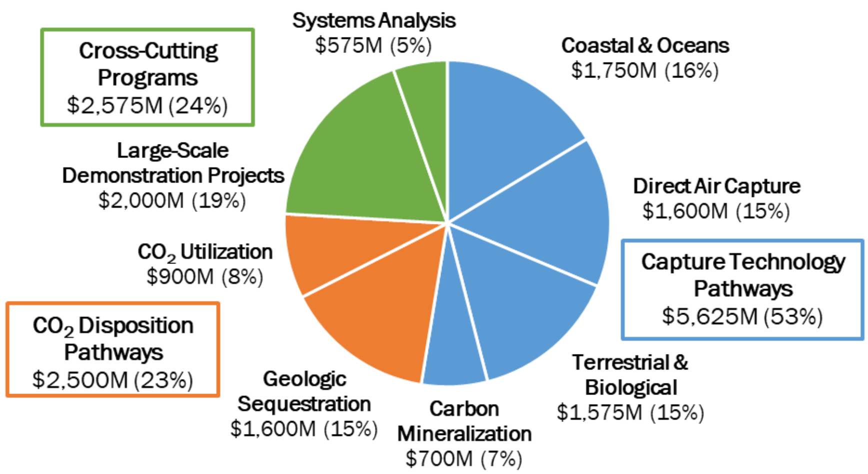
Budget planning estimates were developed for each of the 27 portfolio elements. One or more agencies were identified to lead the RD&D work within each element, and the budget planning estimates reflect the proposed scope of work for that element.

The total RD&D initiative budget is estimated at $10.7 billion over the proposed 10-year span of the program. The distribution of funding by portfolio component is illustrated in Figure 24.

Funding for the four capture technology pathways totals $5,625 million over 10 years (53%), while funding for the two CO_2 disposition pathways and two cross-cutting programs totals $2,500 million (23%) and $2,575 (24%), respectively.

Figure 24

CDR RD&D Initiative Proposed Total Funding by Portfolio Categories



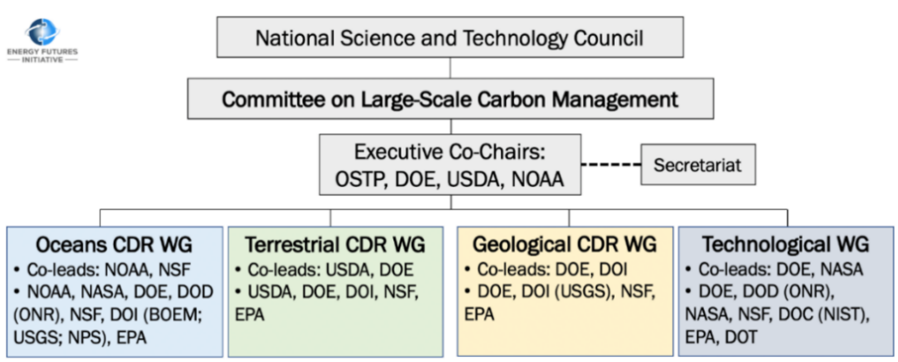
Proposed funding is divided between four capture technology pathways, two CO_2 disposition pathways, and two cross-cutting programs. Source: EFI, 2019

Federal Agency Organization and Management

The broad scope of the technological CDR RD&D initiative requires a whole-of-government approach involving numerous federal agencies that work in a coordinated manner to bring the alternative technological CDR pathways to commercial readiness. Best practices from the implementation of prior federal RD&D initiatives informed the recommended organizational framework for the technological CDR RD&D initiative in Figure 25.

Figure 25

Interagency Integration and Coordination



The CDR RD&D initiative would be governed by a new entity within the National Science and Technology Council. Source: EFI, 2019.

The proposed initiative would be governed by a new entity, the ***Committee on Large-Scale Carbon Management***, to be established within the National Science and Technology Council (NSTC). The new committee would be co-chaired by an Executive Committee comprised of the OSTP Associate Director for Science, and senior officials from DOE, USDA, and NOAA. Co-leadership is essential to reflect the key roles and responsibilities of these organizations in the overall planning of the initiative.

Value Added from the Proposed CDR RD&D Initiative

The proposed initiative is designed to offer significant value in several ways:

- The proposed initiative is highly focused to deliver commercial-ready CDR innovations within a decade to address the mounting climate crisis. A $10.7 billion investment is small compared to the potential range of economic damage resulting from unchecked climate change.
- The CDR technological pathways provide additional optionality and flexibility to help limit temperature increases in the most cost-effective manner possible, as well as reverse atmospheric CO_2 concentrations resulting from past emissions.
- CDR RD&D innovations can also benefit other national research objectives in ocean ecosystems and fisheries restoration and management, forest and agriculture productivity, and resource conservation; and national security.
- The large-scale deployment potential for CDR innovation offers significant economic benefits in terms of new industries and new jobs on a global scale.

8. The Green Real Deal: A Framework for Achieving a Deeply Decarbonized Economy

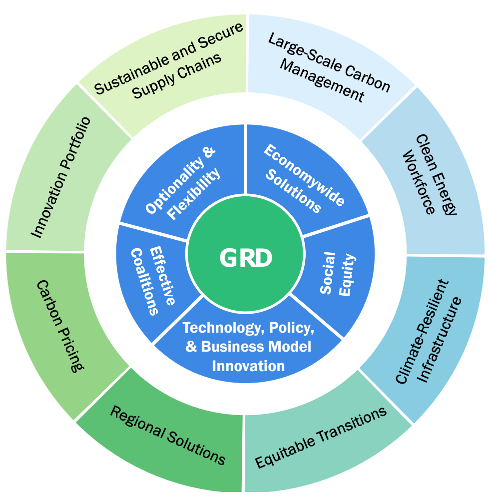
The Green New Deal put an important spotlight on the climate crisis by articulating ambitions. The Green Real Deal (GRD) builds on the aspirations of the Green New Deal and provides an actionable framework for meeting deep decarbonization of energy and associated systems by midcentury in ways that minimize costs, maximize economic opportunities, accelerate solutions, and promote social equity.

Operationally, this means that multiple pathways to economywide decarbonization must all be implemented while breakthrough innovation success will be needed at scale by midcentury. The GRD is designed with the emphasis on innovation, optionality, and flexibility to respond to new and better understanding of the science.

The GRD rests on five fundamental principles:

- a strong, ongoing commitment to and reliance on innovation;
- the need to attract and build strong and inclusive coalitions;
- a commitment to social equity in all deep decarbonization policies;
- economywide solutions to the climate challenge that are both sector specific and crosscutting; and
- technology and regional innovation options and flexibility supported by policies that enable each.

Figure 26
GRD Principles



The five GRD principles are represented in the inner blue ring and its eight elements are represented in the outer ring. Source: EFI, 2019.

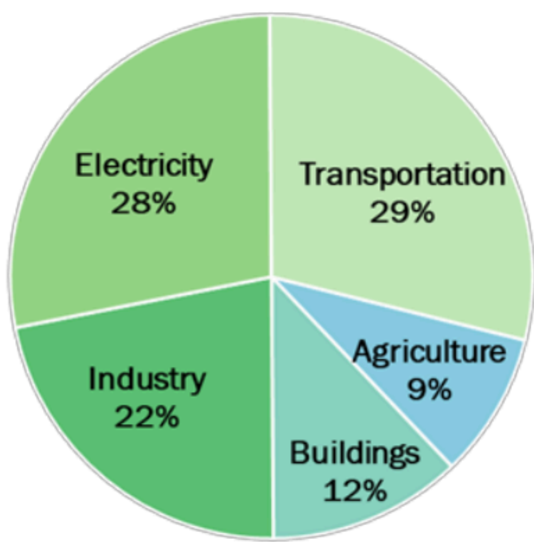
Technology, Business Model, and Policy Innovations Are Essential. Innovations in technology, business models, and policy are essential for meeting deep decarbonization targets by midcentury. Incremental and breakthrough innovations must be developed to meet the challenges of deep decarbonization, including the rising marginal costs of GHG abatement.

Broad and Inclusive Coalitions Must Be Built. Solutions for addressing the climate challenge cut across all portions of the economy and require participation of businesses, consumers, governments, and advocacy groups. Finding common cause, proactively addressing conflict, and ensuring all members of society benefit from a transformation to a low-carbon economy will put wind in the sails of meaningful action.

Social Equity Is Essential for Success. The transformation of energy and associated systems must also improve lives, grow public acceptance of the widespread change required to address climate change, and provide meaningful, well-paying jobs. The GRD subscribes to the National Academy of Public Administration's definition of social equity: "The fair, just and equitable management of all institutions serving the public directly or by contract, and the fair, just and equitable distribution of public services, and implementation of public policy, and the commitment to promote fairness, justice, and equity in the formation of public policy."

All GHG Emitting Sectors Must be Addressed in Climate Solutions. Much of the academic and policy carbon abatement work to-date has focused on the electricity sector. Electricity is, however, only 28% of U.S. emissions and is arguably the easiest to decarbonize. Sectoral analyses—electricity, transportation, industry, buildings and agriculture—will be central to identifying solutions and advancing innovation and net zero emissions targets. Reaching economywide emissions reductions targets will require progress in every sector of the economy, including those that are difficult to decarbonize due to technical, cost, and performance barriers.

Figure 27
2017 U.S. GHG Emissions by Sector



This figure shows the breakdown of GHG emissions by sector in the United States. Source: EFI, 2019. Compiled using data from EPA Greenhouse Gas Inventory, 2017.

Optionality and Flexibility are Needed for Technologies, Policies, and Investments. There are no clear "silver bullet" solutions to decarbonization at the present time. Multiple clean energy technology options are needed for each sector of the economy and region of the country—this requires technology and policy options and flexibility.

The GRD principles are designed to guide efforts to make deep decarbonization a reality. The principles form the basis for eight key elements—areas of focus that, if supported by analyses and actions, will help forge broadly acceptable, equitable, and practical solutions to help mitigate the impacts of climate change by transforming our energy systems. These elements could support a range of efforts that offer stakeholders analytically sound and operationally focused strategies—essential building blocks for deeply decarbonizing the U.S. economy as rapidly as is technologically and politically feasible. They are also capable of garnering coalition support. These eight elements detailed in full in the GRD are:

- National innovation program portfolios;
- Regional decarbonization strategies;
- Equitable distribution of energy transition costs and benefits;
- Effective carbon pricing;
- A skilled clean energy workforce;
- Large-scale carbon management;
- Climate-resilient modernized energy infrastructures; and
- Sustainable and secure clean energy supply chains.

Each of the five principles and eight elements of the GRD is critical for translating climate mitigation ambitions into actions. Such an ambitious undertaking will require compressive analyses beyond those listed here and an across-the-board approach to aggressive decarbonization, while building broad coalitions from disparate parts of society. However, time is not on our side. Meaningful progress—that must be accountable to current and future generations—will require urgent, concerted efforts across policy and politics, business, science and technology, providers and consumers, and other stakeholders.

9. Optionality Flexibility and Innovation: Pathways to Deep Decarbonization in California

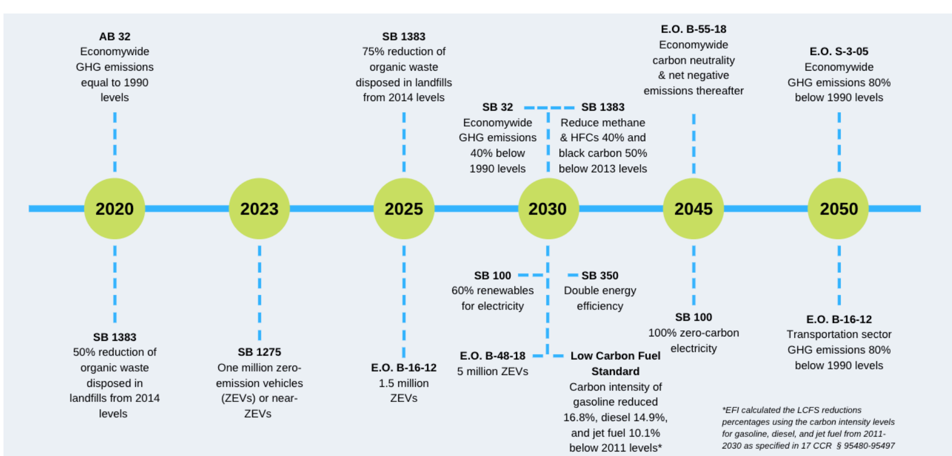
California is a global leader in climate policy. It has adopted aggressive goals to reach a low-carbon future at a scale and pace needed to meet the underlying Paris commitment of keeping temperature increases to two degrees Celsius, or even significantly lower, by the end of the century. If California meets its aggressive goals, it will enhance its leadership status, setting an example for the world where, unfortunately, carbon dioxide emissions continue to rise. As the world's fifth largest economy, what happens in California is critical for shaping the global response to climate change, reinforcing the importance of California's leadership.

This study analyzes the options—described as "pathways"—for meeting California's near- and long-term carbon emissions reduction goals. This analysis is designed to work within the parameters of existing state policy; it does not offer explicit policy recommendations.

California's decarbonization goals include both economywide and sector-specific policy targets (Figure 28): Executive Order S-3-05 (2005) calls for an economywide emissions reduction of 80% by 2050 (from 1990 levels); Executive Order B-55-18 establishes a statewide goal of carbon neutrality by 2045; SB 100 (2018) requires 60% renewable electricity generation (excluding large hydro) by 2030, and net-zero-emissions electricity by 2045. Some policies are more prescriptive (e.g., five million zero emissions vehicles by 2030), while others are less so (e.g., 40% reduction of emissions economywide by 2030).

Figure 28

California's GHG Emissions Reductions Policy Timeline



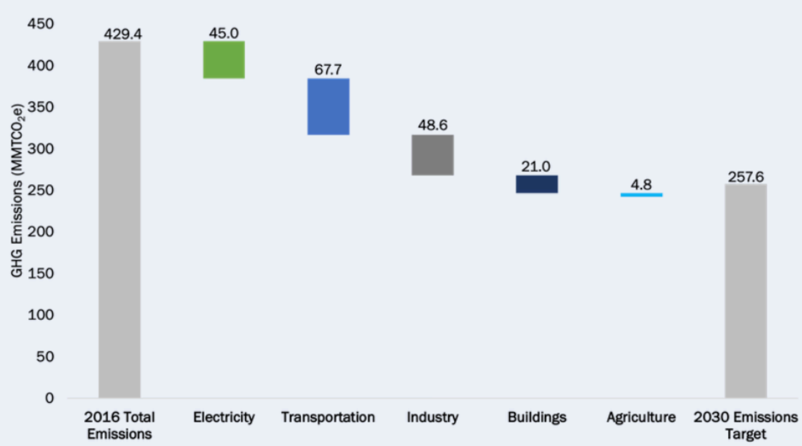
To meet its aggressive GHG emissions reduction goals, California has a number of policies aimed at reducing emissions from various sectors and end uses. Note that bill numbers were used as a shorthand. Source: EFI, 2019

To develop decarbonization pathways and technology options for California, this study focuses on two targets, identifying separate but overlapping tracks: aggressive decarbonization by 2030 and deep decarbonization by midcentury, both from a 2016 baseline. Each target presents its own unique challenges and opportunities. To support these different tracks, the analysis emphasizes the value of technology optionality and flexibility. Over the longer term, managing an economy that has the scale and sector diversity of California's, and is deeply decarbonized, presents dynamic challenges that have not been addressed previously. For both the near and long term, engaging a range of stakeholders is key; energy incumbents and legacy infrastructures may slow the deployment of existing clean technologies in the near term.

The top-level outcome of the analysis: ***California can indeed meet its 2030 and midcentury targets***. Figure 29 shows meeting the 2030 target will require success across economic sectors with multiple technologies contributing in each.

Figure 29

Identified Emissions Reduction Potential for Meeting the 2030 Targets by Sector



California can meet its 2030 target of a 40 percent emissions reduction with commercially available technology pathways. Emissions reduction strategies will have to contend with policy interactions, however, as well as the projected emissions growth in certain sectors. Source: EFI, 2019.

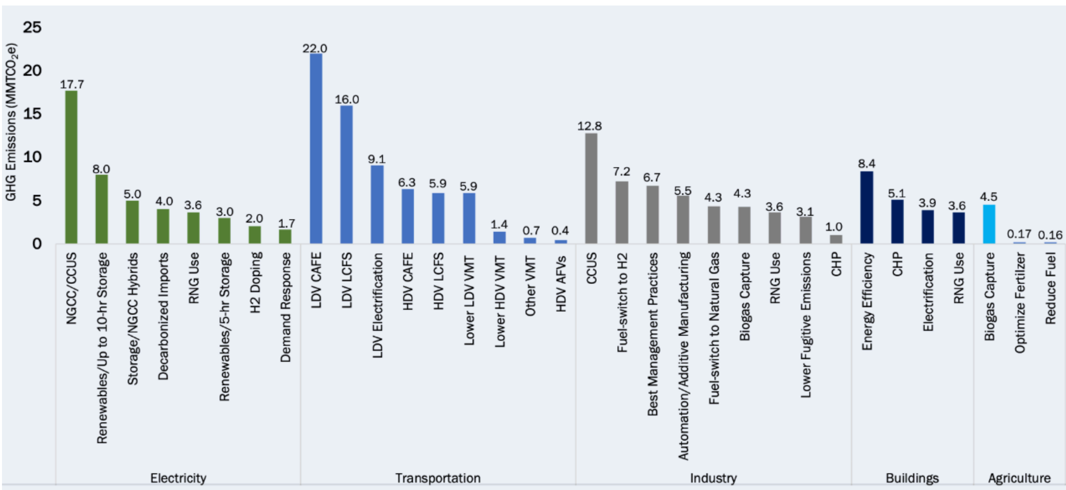
Achieving deep decarbonization in the midcentury timeframe will depend on innovation, including in clean energy technologies that cut across sectors. Meeting both goals and managing the costs will require a strong focus on, and commitment to, technology optionality, flexibility, and innovation. This focus is essential for several critical reasons:

- The energy system must provide essential services (light, heat, mobility, electricity, etc.) reliably at all times;
- The current cost of many important low- and zero-carbon technologies is too high;
- Energy delivery infrastructure must be available, reliable and secure as the system transforms;
- Affordable negative emissions technologies will ultimately be important at large-scale for deep decarbonization and acceptable stabilization of the earth's temperature; and
- Success will require aligning the interests and commitment of a range of key stakeholders.

Looking to 2030, this analysis provides a comprehensive analysis of 33 clean energy policy and technology pathways across California's economic sectors and assesses the emissions reduction potential of each (Figure 30). The portfolio prioritizes technologies with strong technical performance and economics; pathways that augment existing energy infrastructure are emphasized as they offer significant cost and market readiness benefits.

Figure 30

Identified Emissions Reduction Potential for Meeting the 2030 Targets by Pathway



The estimated emissions reduction potential for each pathway is shown by sector. They are based on an attempt to meet California's target to reduce emissions economy wide by 40 percent. This approach attempts to meet the target with an equal share from each economic sector. Source: EFI, 2019.

The growing impacts of climate change on energy systems and new and changing supply chains for sustainable energy technologies must be accommodated in policies and planning. Certain clean energy pathways are more susceptible to disruption, such as hydroelectric generation or power lines exposed to wildfires. Materials and metals needed for clean energy technologies may see price spikes or supply disruptions in the future.

These factors imply that detailed, bottom-up analysis of specific pathways, while instructive for meeting 2030 goals, have little value for informing the technologies needed to operate low- to zero-carbon energy systems by midcentury. The near-term focus should be on working as hard as possible to develop as many viable options as possible, making it clear that innovation must be at the heart of a decarbonization strategy.

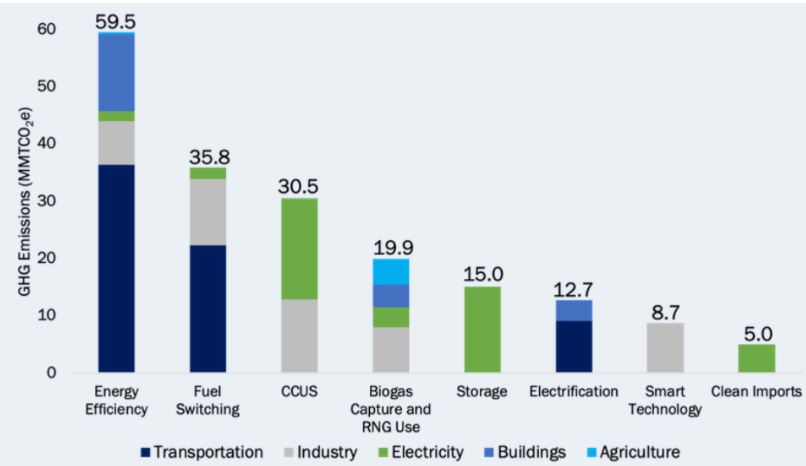
This report presents a "success model" for the longer term, strictly to illustrate both one of the many strategies that could meet long-term goals as well as to demonstrate the overall difficulty of achieving midcentury goals without having a range of options for doing so. It identifies an analysis-based innovation portfolio for California, focused on technologies with long-term breakthrough potential. Technologies were screened based on California's existing policies and programs, energy system and market needs, and other distinctive regional qualities that position California to be a technological first mover and global leader. Eleven breakthrough technologies were identified as major potential contributors to California's deep decarbonization over the long-term, including hydrogen produced by electrolysis, smart systems, floating offshore wind, seasonal energy storage, and clean cement, among others. Research and development on these technologies with breakthrough potential must pick up the pace today and be sustained to support their development.

Major Findings for Aggressive Decarbonization by 2030

- Meeting California's carbon reduction goals by 2030 will require a range of clean energy pathways across all economic sectors—Electricity, Transportation, Industry, Buildings and Agriculture (Figure 31). This is due to the uncertainty of each pathway and the fact that there are no "silver bullet" solutions. There are sufficient commercially available pathways to meet 2030 targets, though some technologies are less expensive and more advanced than others. To meet the 2030 target, however, it is expected that there will be incremental improvements and cost reductions in key technologies, for example, CCUS at industrial facilities and natural gas power plants.

Figure 31

Identified Emissions Reduction Potential for Meeting the 2030 Targets by Cross-Cutting Technologies



Some decarbonization strategies are applicable to multiple sectors of the economy. Of these, energy efficiency/demand reduction is most significant, representing the largest emissions reduction potential and cutting across all five sectors. Source: EFI, 2019.

- California's ambitious policy to double economywide energy efficiency is an important step for meeting 2030 decarbonization targets. Energy efficiency, defined broadly, is likely to be the most cost-effective approach to decarbonization in the energy end-use sectors in California. This includes technologies and processes that increase fuel efficiency of vehicles; demand-response mechanisms in the Electricity, Transportation, and Buildings sectors; highly efficient end-use technologies in all sectors, especially Buildings and Industry; and measures that help reduce energy consumption in sectors that have high non-combustion emissions, such as Industry and Agriculture.
- Transportation is the single largest emitting sector in California and requires transformational change to achieve aggressive decarbonization by 2030. Existing policies will have a major impact on the sector's emissions reduction by 2030. Transportation subsectors that are difficult to decarbonize—heavy-duty vehicles, aviation, marine, and rail—options for achieving deep decarbonization over the long

term have to extend beyond energy/fuel-based technologies, including new infrastructure systems, platform technologies, behavioral incentives, urban design, and advancements in materials science.

- Clean fuels (e.g., renewable natural gas [RNG], hydrogen, biofuels) are critical clean energy pathways due to the enormous value of fuels in providing flexibility to energy systems. Fuels that are durable, storable, and easily transportable play a fundamental role in ensuring that all sectors can operate at the scale, timing, frequency, and levels of reliability that are required to meet social, economic, and stakeholder needs.
- California can meet its 60% renewable energy target by 2030 with continued expansion of wind and solar resources; some geothermal and increased imports of clean electricity (mostly hydro) will play a role as well. Natural gas generation will continue to play a key role in providing California's grid with operational flexibility and enabling the growth and integration of intermittent renewables.

Major Findings for Deep Decarbonization by Midcentury

Meeting California's deep decarbonization goals by midcentury will be extremely difficult (if not impossible) without energy innovation. This is due to many challenges inherent to deep decarbonization planning, including:

- **Predicting the mix of clean energy technologies needed by 2050.** While many studies explore technology pathways over the long term, they should not be used to prescribe the optimal energy mix by midcentury.
- **Rising marginal costs of abatement.** It is highly likely that costs will increase over time as the lowest cost opportunities to reduce emissions are widely deployed.
- **Performance issues of deeply decarbonized energy systems.** Managing a large, carbon-free electric grid offers challenges in terms of operation, design, size, and the growing, climate change-related uncertainty concerns about wind and hydro availability, for example. Also, scalable clean technologies are not readily available for meeting deep decarbonization goals in several key applications.
- **Cost-effective and efficient negative emissions technologies are needed by 2045.** Technologies that could help achieve net neutrality are in relatively early stages of development and include carbon dioxide capture from dilute sources; massive utilization of captured carbon dioxide in commodity products; and both geological and biological sequestration at very large scale.

There are technology priorities with long-term innovation breakthrough potential that California should develop; these include hydrogen production with electrolysis, advanced nuclear, green cement, and seasonal storage, among others. These technology priorities were screened based on California's policies and programs, energy system and market needs, and other distinctive regional qualities that position California to be a technological first mover: a strong resource base, relevant

Technology Priorities with Long-term Breakthrough Potential

Technologies were identified as having longterm breakthrough potential for California based on EFI-developed screening criteria. Source: EFI, 2019.

workforce expertise, and robust scientific and technological capacity. A broader list of candidate technologies was also developed and organized by energy supply (electricity and fuels), energy application (Industry, Transportation, and Buildings), and cross-cutting technology areas (e.g., Large Scale Carbon Management).

A Repeatable Framework for Decarbonization

This report is meant to advise California's near- and long-term decarbonization strategy. It offers insights on decarbonization pathways, timescales, technology utilization, energy system operational needs, costs, and energy innovation. It provides a comprehensive review of on-the-ground issues that may aid or slow the state's progress toward deep decarbonization. In addition to benefitting California, there are high-level findings that may also provide a framework for decarbonization strategies that can, and should, be repeated in other economies around the world, including:

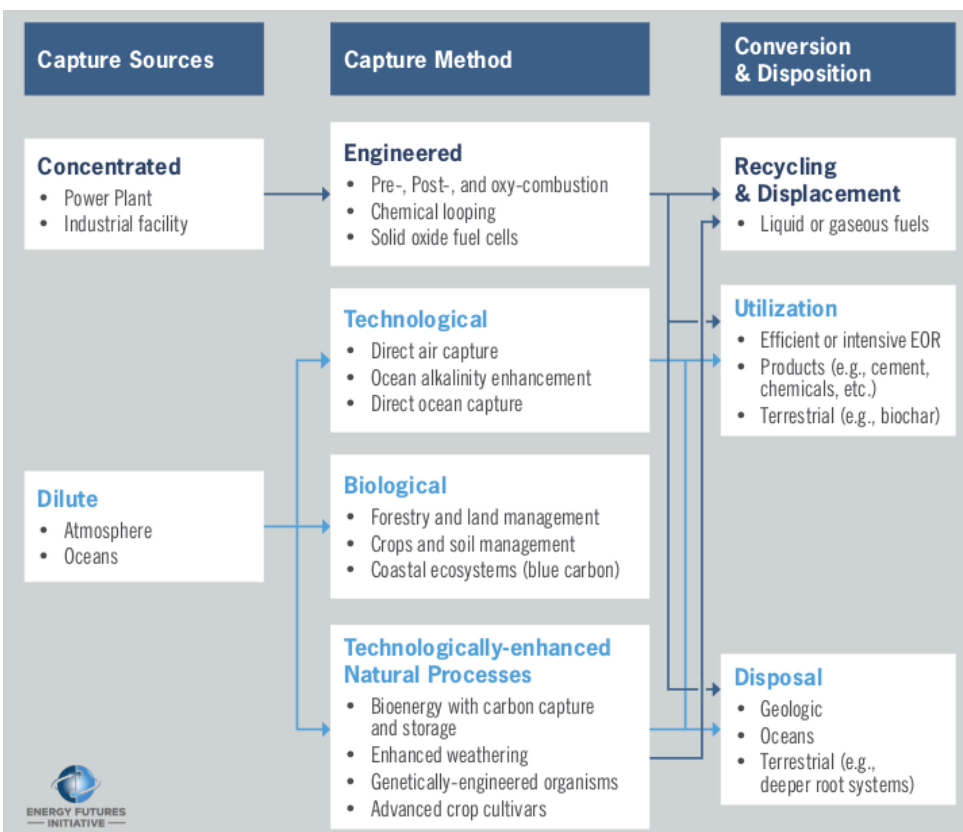
- Energy system "boundary conditions," including considerable system inertia that works against rapid change, complex supply chains, long-duration of technology development, and commodity business models must be taken into consideration when developing decarbonization strategies.
- There is no "silver bullet" technology for deep decarbonization. Technology optionality and flexibility are critical to any decarbonization strategy, especially for the difficult-to-decarbonize sectors.
- Existing carbon infrastructure and expertise must be aligned with deep decarbonization goals to prevent the creation of strong and dilatory political and business opposition to decarbonization pathways when acceleration is called for.
- Decarbonization pathways should address multiple timescales, emphasizing commercially available technologies in the near-term and developing (and/or supporting the development of) new technologies with long-term innovation potential.
- Decarbonization pathways should support local and regional energy capacity that includes the existing workforce, the structure of economic sectors, clean technology firms, natural and scientific resources, and many other factors that shape the opportunities and challenges on the ground.

10. Carbon Removal: Comparing Historical Federal Research Investments with the National Academies' Recommended Future Funding Levels

Carbon dioxide removal (CDR) approaches—also referred to as negative emission technologies (NETs)—complement mitigation efforts to protect the environment while opening new opportunities for U.S. businesses in a growing global marketplace as many countries move toward a lower-carbon economy.

The United States has a long history of leveraging its scientific and technological capabilities at national laboratories, universities, and the private sector to pioneer advances in technology that move the economy forward. Just as decades of federal research investment drove efficiency and cost improvements for many of the technologies Americans enjoy today—including fuel-efficient vehicles, lithium-ion batteries, and natural gas production—so, too, will it be necessary to advance the next generation of technologies involving carbon removal (Figure 32).

Figure 32
Technical Pathways for Carbon Dioxide Removal



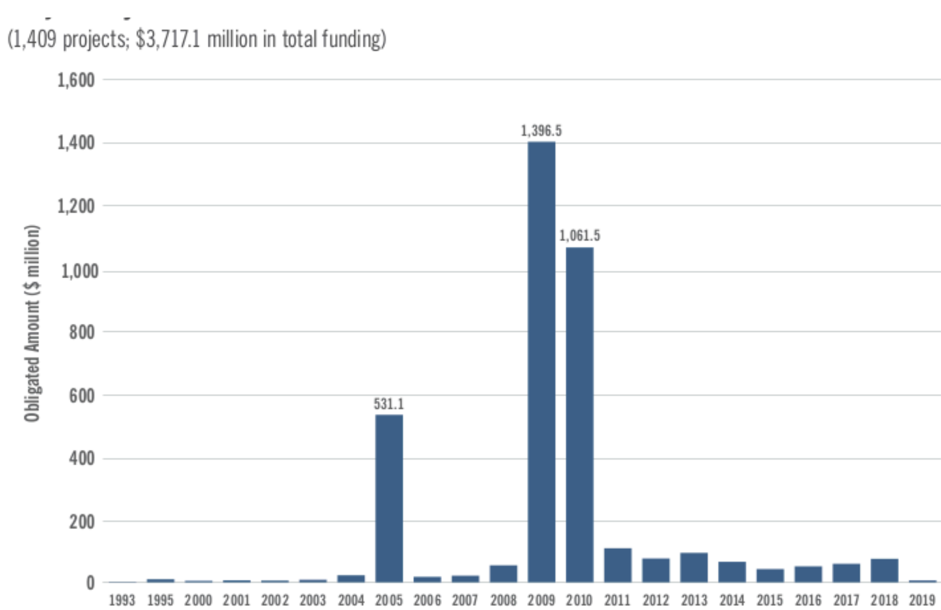
In October 2018, the National Academies of Sciences, Engineering, and Medicine (NASEM) released a report, Negative Emissions Technologies and Reliable Sequestration: A Research Agenda, that examined the state of carbon removal technology. The NASEM report identified barriers to land-based carbon removal approaches (for example, afforestation/reforestation and bioenergy with carbon capture and storage) at the level needed to achieve global climate targets and concluded that significant federal research investment is necessary across a portfolio of carbon removal approaches. The report recommended specific levels of future funding at key federal science agencies that are necessary to advance six types of carbon removal and enabling technologies.

The objective of this analysis is to review the historical baseline estimates of federal RD&D investment related to carbon removal and assess how they compare with the recommended future funding levels from the 2018 NASEM report. The analysis employed two approaches: (1) a top-down analysis to identify federal agency appropriations accounts and major program elements within those accounts that could support RD&D activities related to carbon removal; and (2) a bottom-up analysis to search a database of historical federal spending to identify specific RD&D projects funded in prior years that may have directly or indirectly supported carbon removal scientific and technical objectives.

The top-down analysis identified 23 separate appropriations accounts within nine federal departments and agencies that contain program elements with sufficiently broad research program scope that they could encompass RD&D support for carbon removal. The bottom-up analysis identified cumulative federal funding totaling $3,717.1 million across 1,409 carbon removal-related RD&D projects over a 27-year period from 1993 to 2019 (Figure 33).

Figure 33

Historical Federal Investment for All Carbon Removal-Related RD&D Projects by Year



Sources: Energy Futures Initiative, 2019.[35] Compiled using data from USAspending.gov.[36]

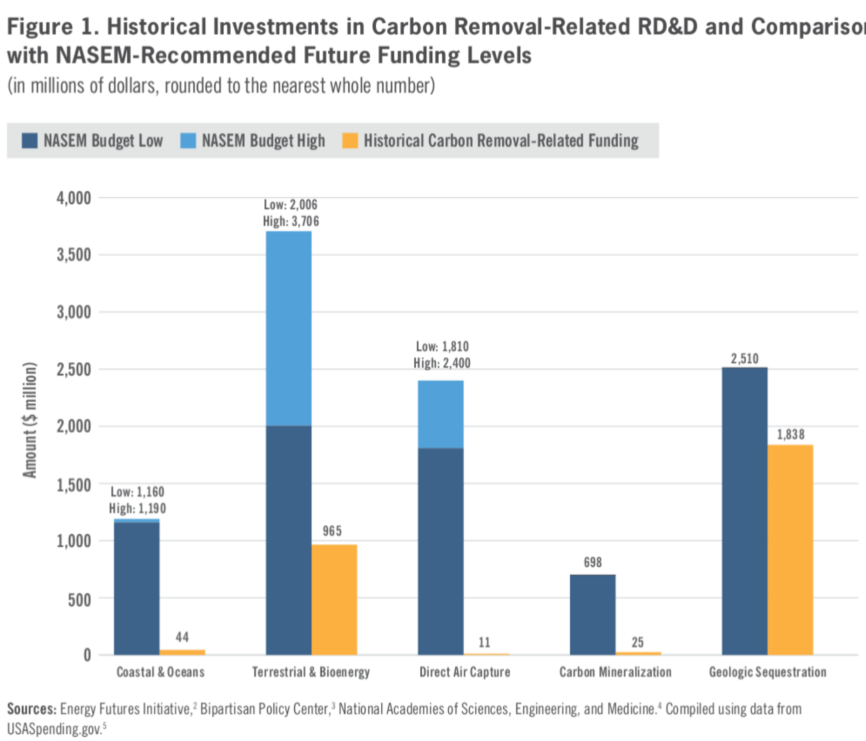
This historical record is very small relative to the recommended funding levels by NASEM—$8.1 to $10.5 billion—over the next one to two decades. It is especially small given that the research projects identified in the historical baseline primarily targeted other science and technology objectives and may only tangentially address potential carbon removal applications.

Nonetheless, comparing the historical levels of investment with recommended future funding levels does illustrate the scale of future funding challenges to the implementation of the NASEM report. The challenges are particularly acute for implementing the NASEM recommendations for RD&D on direct air capture, mineralization, and coastal and oceans carbon removal:

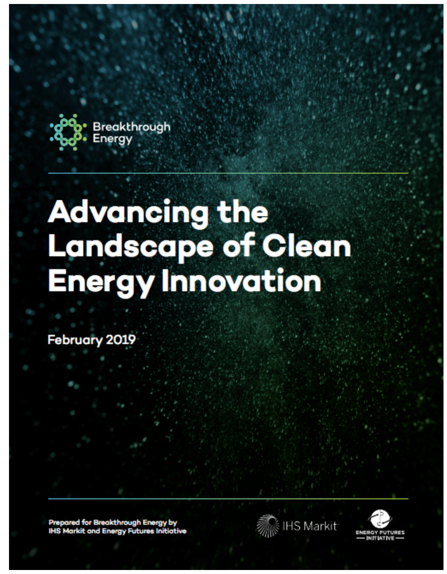
- NASEM-recommended future funding needs for direct air capture are 100 to 200 times the historical baseline level
- NASEM-recommended future funding needs for carbon mineralization are nearly 30 times the historical baseline level
- NASEM-recommended future funding needs for coastal and oceans carbon removal-related research are nearly 30 times the historical baseline level
- Even in the categories of terrestrial and bioenergy and geologic sequestration, the future funding levels recommended in the NASEM report represent significantly higher future funding levels compared with the historical baseline estimates.

Figure 34

Historical Investments in Carbon Removal-Related RD&D and Comparison with NASEM-Recommended Future Funding Levels



11. Advancing the Landscape of Clean Energy Innovation



Clean energy innovation supports multiple national goals: economic competitiveness, environmental responsibility, energy security, and national security. Key features of energy systems, however, impede accelerated innovation. Energy is a highly capitalized commodity business, with complex supply chains and established customer bases, providing essential services at all levels of society. These features lead to systems with considerable inertia, focus on reliability and safety, aversion to risk, extensive regulation, and complex politics. Existing innovation processes face challenges as they work within these boundary conditions.

Successful clean energy innovation on a large scale in the U.S. requires alignment of key players, policies, and programs among the private sector, the federal government, and state and local governments. This report considers these alignment needs through an assessment of the roles of these various groups. It also identifies critical clean energy technologies. It further suggests the value of regional efforts to advance innovation and discusses ways in which federal tax policy could accelerate innovation.

Investments are needed from foundations and from federal, state, and local governments to expand the availability of open-access testbeds and strengthen the effectiveness of incubators in accelerating commercialization of innovative technologies. Some of these investments could fund research into best practices and performance results of incubators and testbeds and of state and local programs supporting innovation.

Because clean energy innovation incentivizes only modest financial investments at precommercial stages, and because strategic corporate investment is focused primarily on those innovations recognized as useful to business objectives, strategic philanthropic investors, and coalitions of industry investors with long-term horizons could play an important role in identifying and supporting promising technology ventures that are otherwise not commercially viable in the near term.

A shared agenda of primary technology objectives can help ensure that programs pursued by multiple stakeholders in the clean energy space are timely, durable, and mutually supportive. It can give entrepreneurs and creative innovators a framework for assessing the prospects of a particular area of initiative and the steps needed to sustain critical innovations over long time spans, and it can give corporate adopters, financial investors, and policymakers visibility into the evolving future of clean energy.

A four-step methodology is suggested for identifying breakthrough technologies to address national and global challenges and help meet near, mid- and long-term clean energy needs and goals. These steps consider technical merit, potential market viability, compatibility with other elements of the energy system, and consumer value. Application of these considerations to a list of 23 potential technology candidates yields a key technology shortlist (Figure 35).

Figure 35

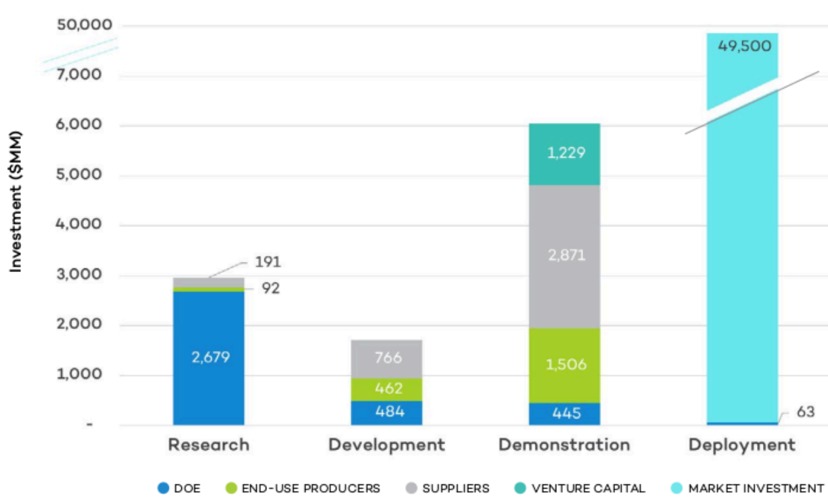
Technologies with Breakthrough Potential

- **Storage and battery technologies**
- **Advanced nuclear reactors**
- **Technology applications for industry and buildings as sectors that are difficult to decarbonize**
  - Hydrogen
  - Advanced manufacturing technologies
  - Building energy technologies
- **Systems: electric grid modernization and smart cities**
- **Deep decarbonization/large-scale carbon management**
  - Carbon capture, use, and storage at scale
  - Sunlight to fuels
  - Biological sequestration

The principal agency funding clean energy innovation is the Department of Energy (DOE), which administers about 75% of all Federal energy R&D spending. DOE performs its role in partnership with its 17 national laboratories, academia, states, regions, other agencies, and the private sector. As the primary Federal funder of energy R&D, DOE has played a critical role in changing the U.S. energy landscape over several decades. Shortly after its establishment in 1977, DOE characterized U.S. shale basins and supported the development of key drilling technologies that enabled horizontal drilling. It has had an ongoing and central role in developing supercomputing, an enabling technology for digitalization, artificial intelligence, smart systems, and subsurface characterization. Its investment in phasors and sensors support the smart grid. The Advanced Research Projects Agency-Energy (ARPA-E), a DOE program, has led to the creation of dozens of clean energy start-up companies which have raised more than $2.6 billion in private-sector follow-on funding.

Figure 36

Investment Sources Across the Technology Readiness Stages of Clean Energy Innovation, 2016



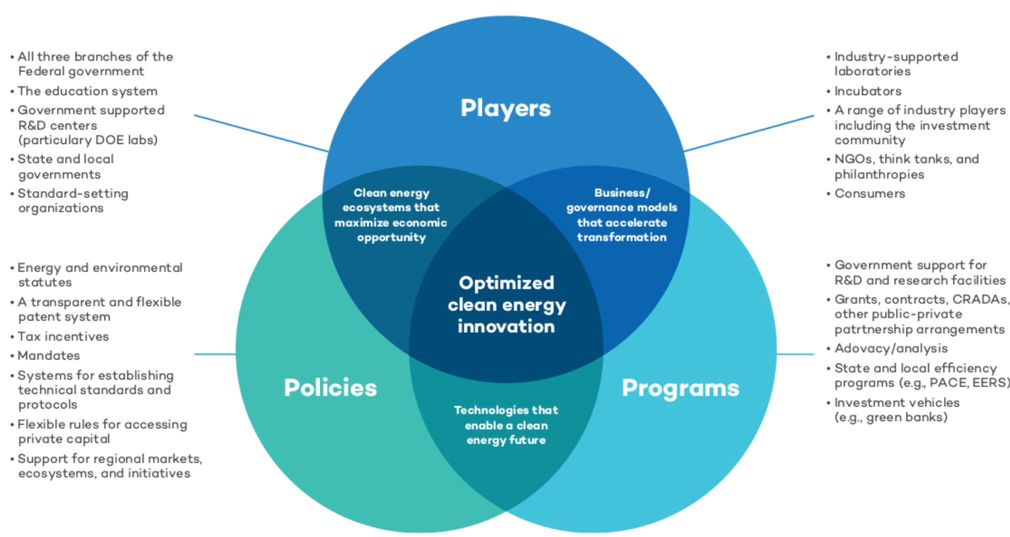
However, DOE's performance in advancing clean energy innovation would benefit from several institutional modifications. For example, the fuels-based organizational structure of the DOE, which has been in existence since 1979, is not optimized for modern energy systems and needs. Congress and the Administration should initiate efforts to reorganize the Federal energy RDD&D portfolio and the Department of Energy toward a fuel- and technology-neutral structure that (1) aligns with the highest priority opportunities, (2) enables systems-level integration, and (3) avoids gaps in crosscutting programs. Moreover, Congress and the Administration should consider dedicated funding sources for energy innovation to ensure predictable and increasing levels of clean energy RDD&D funding based on international and cross-sectoral benchmarks.

State and city governments have regulatory authority over most of the myriad consumer, commercial, and industrial activities that collectively shape the country's patterns of energy use. The contribution of state, local, and tribal governments to clean energy innovation could be further strengthened by development of program best practices and standardization, capacity and resource enhancement, increased funding, and modernization of ratemaking and business models.

Many energy innovation clusters in the U.S. are in the process of evolving into fully integrated innovation ecosystems. While federally funded RDD&D historically has not been well connected to state and regional economic development, activating these regional clusters to break down the barriers among federal, state, and local resources will create new synergies. National labs could serve as anchors for these efforts. Universities, private industry, philanthropies, state and local governments, and DOE should seek to expand and strengthen incubator capabilities within regional clusters to provide additional tools to enable innovators to conduct R&D and prototyping.

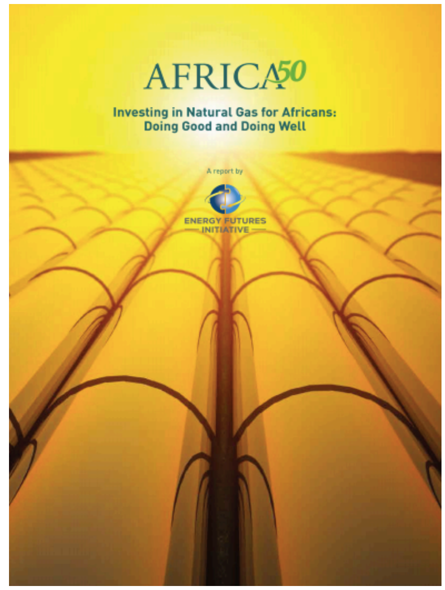
Figure 37

Aligning Players, Policies, and Programs to Accelerate Clean Energy Innovation (Illustrative)



Source: Energy Futures Initiative (EFI), 2018

12. Investing in Natural Gas for Africans: Doing Good and Doing Well



Africa is at an inflection point: its population is burgeoning, energy resources and demand are growing, its economic outlook is improving, and its national, regional, and continental governance entities are focused on a range of policies and structures to support economic growth. Given the right set of policies and incentives, natural gas could provide a sound foundation to support and accelerate this growth, at the same time it helps African nations meet their key electrification, health, and environmental goals.

There are significant natural gas resources across the African continent. Natural gas is also an extremely flexible fuel. It can be used in all sectors of modern economies – industry, buildings, transportation, and power generation. Natural gas can be an essential source of liquid fuels like propane and is an important building block for industrial products -- fertilizer, plastics, and pharmaceuticals. It is a heat source for the manufacture of glass, cement, ceramics and more.

While the flexibility of gas is attracting well-deserved attention, the inflexibility of the infrastructures for its transportation and distribution can diminish its uses in developing regions like sub-Saharan Africa. A suite of technologies can be used to address a range of demand-limiting infrastructure issues, creating new natural gas options for both urban and rural consumers. In particular, innovation in distributed technologies can positively impact the delivery of new energy services in rural settings and grow national economies.

Implications of Investment in Large-Scale Gas Turbines for Africa50 Countries

- Historically, the desirability of natural gas generation has been tempered by widely fluctuating natural gas prices; however, with the conventional and unconventional long-term gas supply, this constraint is no longer perceived to exist.
- For large, sustained daily demand, natural gas combined cycle technology offers a low cost, reliable option.
- For meeting variable demand, natural gas peaking technology offers an economical, flexible option.
- Large-scale gas generation can replace more carbon-intensive fuels like coal and oil, while complementing zero-carbon fuels by providing more stability of supply.

Implications of Investment in Virtual Pipelines for Africa50 Countries

- Modified small-scale shipping containers for LNG or compressed natural gas (CNG) for intermodal transportation offer affordable, technologically feasible alternatives to traditional natural gas pipeline infrastructure.
- LNG virtual pipelines would feature small-scale regasification (vaporizer) facilities.

- CNG or LNG carried by virtual pipeline would be primarily used for small-scale power generation, but could serve other end uses such as transportation, heating, and cooking.
- New airborne technologies, tailored to Africa's needs, are being developed that could provide an alternative to overland transport of natural gas products associated with Africa's flared/stranded gas.
- Given the multiple technologies associated with the virtual pipeline, from source to use, the economics of each project will vary significantly.

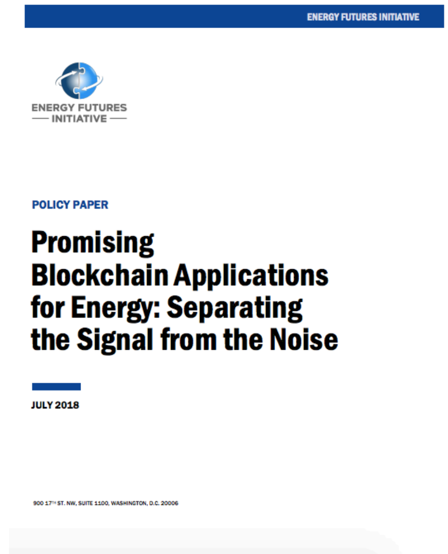
Implications of Investment in Floating Regasification Storage Units for Africa50 Countries

- Low costs (compared to land-based regasification facilities) reduce barriers for new market entrants, especially those without established infrastructure and which have lower volumes of gas demand.
- Reduced construction schedules increase ability to respond to emerging market conditions and/or energy needs.
- The ability of FSRUs to be moved to new, more favorable locations reduces risks to investors and promotes regional development.
- FSRUs can accelerate the LNG-to-Power Sector when integrated with natural gas turbines.
- FSRUs can be a bridge or temporary approach while a conventional land-based terminal is explored.
- The complexity of the transactions and individual attributes of each marine location require major due diligence at the front end.
- Floating Storage Units (FSUs) without regasification are cheaper and can facilitate the creation of an LNG virtual pipeline, allowing for small scale regasification at point of use.
- A range of factors must be considered when deciding between FSRUs and an onshore terminal including port space, water depth, and vessel size, among others.

Implications of Investment in Small-Scale Gas Processing for Africa50 Countries

- The processing of wet natural gas, which consists of methane along with natural gas liquids, creates commodity byproducts such as liquefied petroleum gas (LPG) that can be used for cooking and heating; as well as ethane, that can be used as a feedstock for petrochemical production.
- A significant amount of associated and non-associated natural gas in Africa is flared because of lack of access to gas processing facilities or because the resource is of sub-optimal size, making it uneconomic to transport.
- Small scale, skid mounted gas processing units have been developed to produce LPG units can condition dry gas for power generation and can also process gas to produce CNG.

13. Promising Blockchain Applications for Energy: Separating the Signal from the Noise


ENERGY FUTURES INITIATIVE

ENERGY FUTURES INITIATIVE

POLICY PAPER

Promising Blockchain Applications for Energy: Separating the Signal from the Noise

JULY 2018

Energy sector stakeholders are managing a range of rapid changes: the need for deep decarbonization, flat or declining demand, integrating variable generation technologies, evolving measures of reliability, increasing customer choice, and the growing national security implications of electricity reliance. New blockchain applications for energy may assist energy players in managing these and other changes -- at the same time, these applications may signal even greater changes to come, enabling new entrants and functions that could have disruptive potential.

It is important, as energy applications of blockchain are developed and deployed, to separate the "signal from the noise. The increased adoption of distributed generation, energy storage, and other smart devices are working in concert to create new complexities and challenges for operations and energy markets that are designed for centralized control. These and other energy sector trends are also most likely to benefit from technologies, like blockchain, that seek to optimize the use of information in order to save time, reduce cost and risk, and increase trust. The five use cases assessed in this report are shown in Table 7.

Table 7

Alignment of Emerging Energy Issues and Core Blockchain Capabilities Result in Promising Energy Sector Applications of Blockchain

Emerging Energy Sector Issues	Core Blockchain Capabilities	Promising Energy Sector Applications
Falling Technology Costs; Decentralization; Changing U.S. Energy Supply System; Evolving Grid Control Capabilities	Decentralized Systems can be Self-Administered; Architecture Sets Permissions, Regulated by Rules-based System	**Distributed Energy Resources**
Vehicle Electrification; Falling Battery Costs; Decentralization; Decarbonization	Enables "Smart" Contracts for Streamlining and Automating Contract Terms (i.e. Deposits, Payments, Proof of Performance Actions); Removes Need for Trusted Third-Parties; Regulators and Governments Can Observe or Record Details;	**Electric Vehicle Deployment**
Decentralization; Digitalization; Changing U.S. Supply System; Emerging Global Natural Gas Markets	Businesses Partners can Access Records; Removes Need for Trusted Third-Parties; Regulators and Governments Can Observe or Record Details;	**Energy Trading**
Decarbonization; Digitalization; Changing U.S. Supply System; Evolving Carbon Markets	Removes Need for Trusted Third-Parties; Regulators and Governments Can Observe or Record Details; High Process Transparency and Enforceability, Opening Access to Emerging Markets	**Carbon Tracking and Registries**
Global Population Growth; Shifting Global Markets; Decarbonization; Electrification	Supports Digital Payments; High Process Transparency and Enforceability, Opening Access to Emerging Markets	**Energy Transactions for Emerging Markets**

Source: Energy Futures Initiative

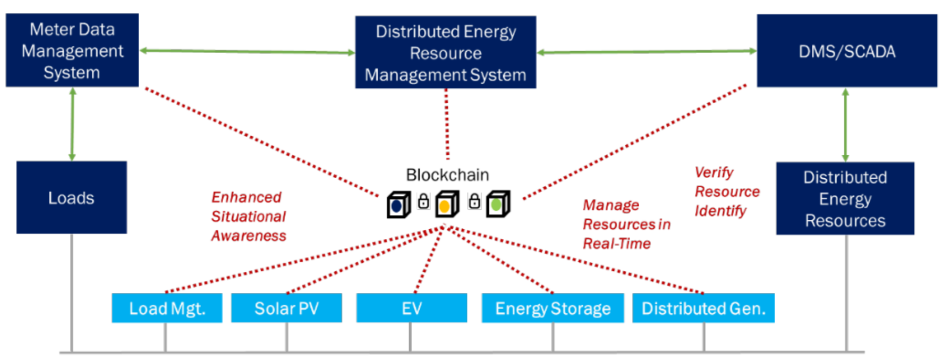
Distributed Energy Resources

Distributed energy resources (DER) are physical and virtual assets characterized by their small capacity and connection to low and medium voltage grids. Examples of DERs include rooftop and community solar, electric vehicles, energy storage, and demand response. Because most DERs do not follow a dispatch signal and are generally not visible to operators, significant and unexpected DER supplies coming online can often result in high levels of system inefficiency and unnecessary cycling from other generating units (e.g., natural gas).

Blockchain can help create a framework for improving visibility and control of DERs to meet increasingly complex grid operations needs as variable renewables and other DER are added to the electricity system. A blockchain leveraged by DER entities, grid operators and utilities can create a trusted, secure system for managing the record, status, and transaction of DERs. This benefits the grid by providing operators with critical information to enhance the situational awareness needed to manage unnecessary ramping, load forecasting, interconnection requirements as well as the other primary task of ensuring reliability (Figure 38).

Figure 38

Blockchain-Supported DER Management[38]



ENERGY FUTURES INITIATIVE

Blockchain can be integrated into DERMs to create new mechanisms for managing DER resources in real-time with smart contracts, verifying resource identify, and enhancing situational awareness of DER entity intentions

Source: Adapted from Kley, Holger, "What is a Distributed Energy Resource Management System?"

Electric Vehicle Markets

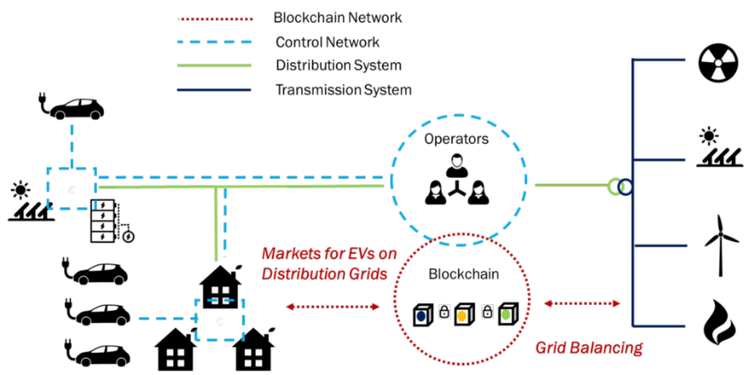
The global electric vehicle (EV) stock surpassed two million in 2016—only one year after crossing the one million vehicle mark. Blockchain can support the infrastructure needed to create and build this critical market.

Blockchain enables and provides economic incentives for owners of private chargers to bring them online for public use. The vast majority of existing chargers deployed globally remain idle for most of the day. Blockchains are being developed to create simple, peer-to-peer transactions on private chargers so that owners can set their own prices (flat, time-based, or electricity-based) and use the blockchain to handle all billing, payment, and authentication.

Blockchain's core technology—efficient and secure management of large volumes of transactions in distributed networks—coupled with the lack of a robust EV charging infrastructure and no accepted standard for billing, scheduling, and payments software make blockchain a viable solution for EVs to "leapfrog" the build-out of a massive new wires network for managing transactions.

Figure 39

Multiple Opportunities Exist for Blockchain to Support EV Charging Networks



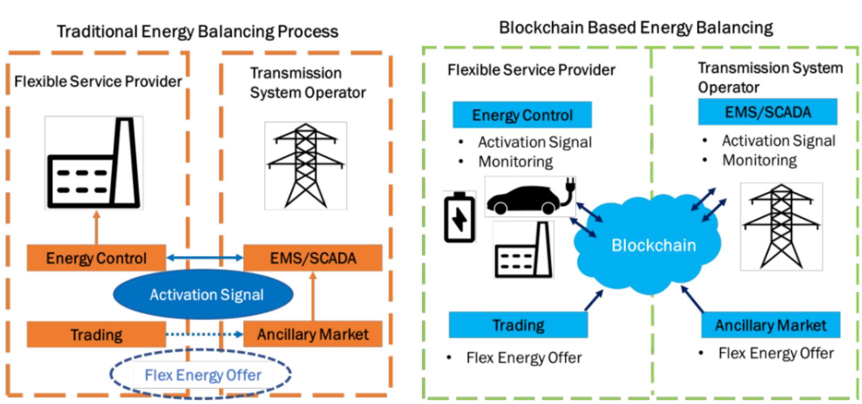
ENERGY FUTURES INITIATIVE Blockchain can support the growth of EV markets by incentivizing owners of private chargers to bring them online for public use and by assisting grid operators to better manage EV demand on the grid

Advanced Energy Trading Platforms

Energy and commodity trading firms are increasingly relying upon the use of big data analytics and cloud-based storage to optimize their processes. Blockchain applications can build on this platform. In wholesale electricity markets, for example, throughout a transaction lifecycle there may be clearinghouses that mitigate counterparty risk; brokers and exchanges that give market access and provide liquidity; and operations managers who book and settle deals physically and financially with counterparties and the transmission system operator (TSO). A blockchain-based platform can help integrate current market participants and incentivize new ones. With smart contracts on the blockchain, more resource types, including electric vehicles, can receive payments for active participation as sources of supply or as demand response.

Figure 40

Blockchain-Based Energy Balancing Can Better Integrate the Players



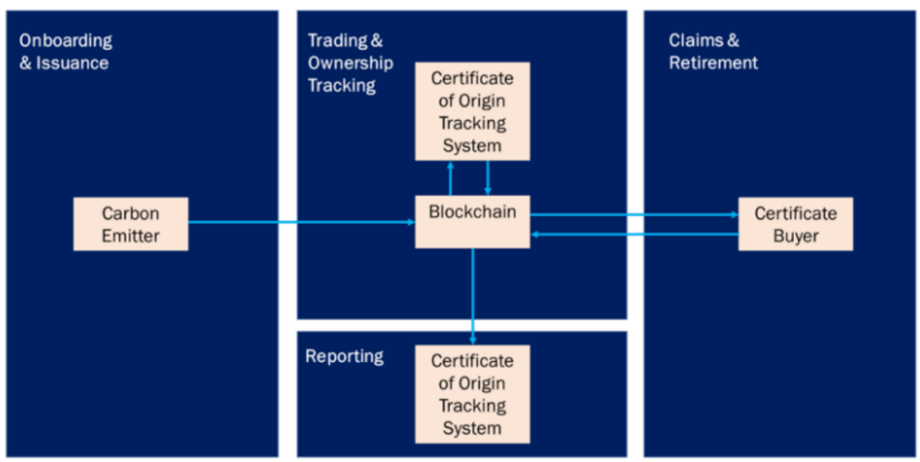
ENERGY FUTURES INITIATIVE Blockchain benefits energy balancing by offering a transparent mechanisms for receiving flex energy offers and an auditable record of flex energy demand. Blockchain also does not replace past investments

Emissions Tracking and Carbon Registries

A prominent mechanism for managing economy-wide carbon is an emissions trading system (ETS). An ETS establishes a mandatory cap on emissions and allocates tradeable permits to participating entities who can use them to cover their allowable emissions during a specified reporting period. A successful ETS requires substantial resources, meticulous design, and a commitment to best practices in monitoring, reporting, and verification (MRV). Globally, there were 21 ETS in operation in 2018; the total cost to administer these systems was an estimated $980 million.

Blockchain's core capabilities directly align with the many challenges around developing, deploying, and managing emissions tracking and trading systems. As a trusted repository of transaction data, blockchain can be used to streamline trades, strengthen the verification process, and eliminate the need for costly centralized management.

Figure 41
Example of Blockchain's Streamlined Process



Source: Adapted from Energy Web Foundation

ENERGY FUTURES INITIATIVE

Blockchain can help address many of the current challenges facing carbon markets, including validating MRV, harmonizing market rules, and ensuring transparency of processes across members.

Another major benefit of blockchain for carbon tracking and registries is the opportunity to create an immutable and transparent record of the market data. This could provide an accountability mechanism for mitigation efforts such as the Paris Agreement where countries are responsible for executing their Nationally Determined Contributions (NDCs) in a rigorous and transparent manner. These blockchain benefits could also help facilitate the tracking of carbon emissions across the range of carbon capture, utilization, and storage (CCUS) activities.

Energy Transactions in Emerging Markets

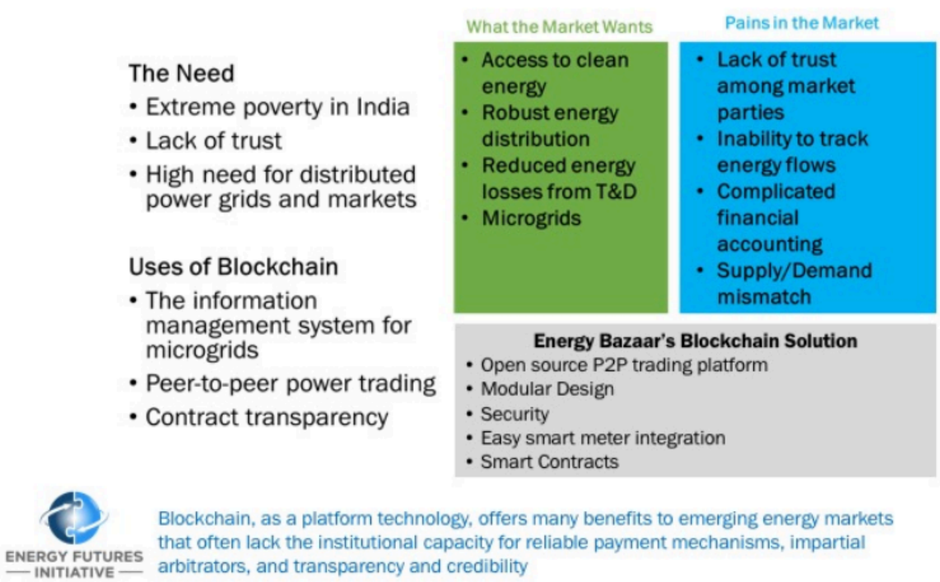
Many emerging economies lack the institutional capacity to build and sustain robust, traditional energy markets. Blockchain offers a framework for automating many fundamental institutional capacities that are generally handled by large organizations with many employees.

Blockchain creates a trusted system for handling energy transactions, including billing and settlement, and can do so without the need for a central authority.

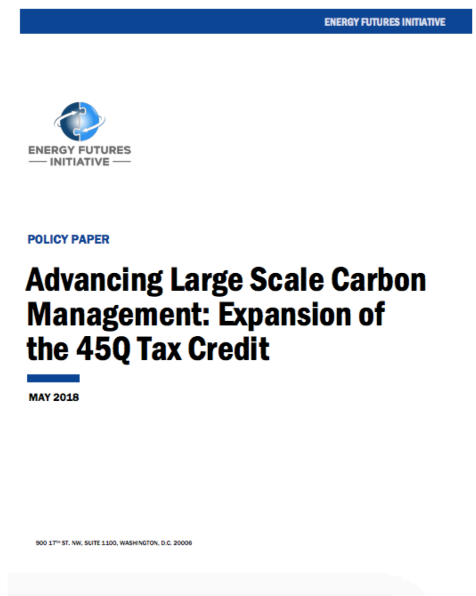
An effort is underway by Energy Bazaar, a firm that is developing blockchain to support the development of microgrids in rural India, where 244 million people lack energy access. A major challenge that Energy Bazaar seeks to manage with blockchain is the lack of trust in economic transactions. Rooftop solar PV deployments in India are expected to triple by 2021; it is anticipated that blockchain can provide a way to effectively trade and share electricity. The blockchain offers an easy-to-use system for automating energy exchanges, while accounting for and providing a public record for every exchange.

Figure 42

The Energy Bazaar Example: Using Blockchain for Microgrids in India



14. Advancing Large Scale Carbon Management: Expansion of the 45Q Tax Credit


ENERGY FUTURES INITIATIVE

ENERGY FUTURES INITIATIVE

POLICY PAPER

Advancing Large Scale Carbon Management: Expansion of the 45Q Tax Credit

MAY 2018

900 17TH ST. NW, SUITE 1100, WASHINGTON, D.C. 20006

The Bipartisan Budget Act (BBA) passed by Congress on February 8, 2018 included expanded provisions for carbon dioxide (CO_2) capture, utilization, and storage (CCUS). They include an increase in the credit value for qualifying projects, a longer time horizon for developers to claim the credit, a more expansive definition of qualifying utilization projects beyond enhanced oil recovery (EOR), and eligibility of direct air capture.

In total, an estimated ~50-100M tons CO_2 per year may be captured and stored through expanded 45Q-related deployment. This number will be sensitive to many factors, including public acceptance, the ability to transfer tax credits, the availability of CO_2 pipeline infrastructure, and the readiness of storage sites.

Figure 43

Tax Credit Value Available for Different Sources and Uses of CO_2

	Minimum Size of Eligible Carbon Capture Plant by Type ($ktCO_2$/yr)			Relevant Level of Tax Credit in a Given Operational Year (USD/tCO_2$)									
Type of CO_2 Storage/Use	Power Plant	Other Industrial Facility	Direct Air Capture	2018	2019	2020	2021	2022	2023	2024	2025	2026	Beyond 2026
Dedicated Geological Storage	500	100	100	28	31	34	36	39	42	45	47	50	Indexed to Inflation
Storage via EOR	500	100	100	17	19	22	24	26	28	31	33	35	Indexed to Inflation
Other Utilization Processes[1]	25	25	25	17[2]	19	22	24	26	28	31	33	35	Indexed to Inflation

[1] Each CO_2 source cannot be greater than 500 $ktCO_2$/yr

[2] Any credit will only apply to the portion of the converted CO_2 that can be shown to reduce overall emissions

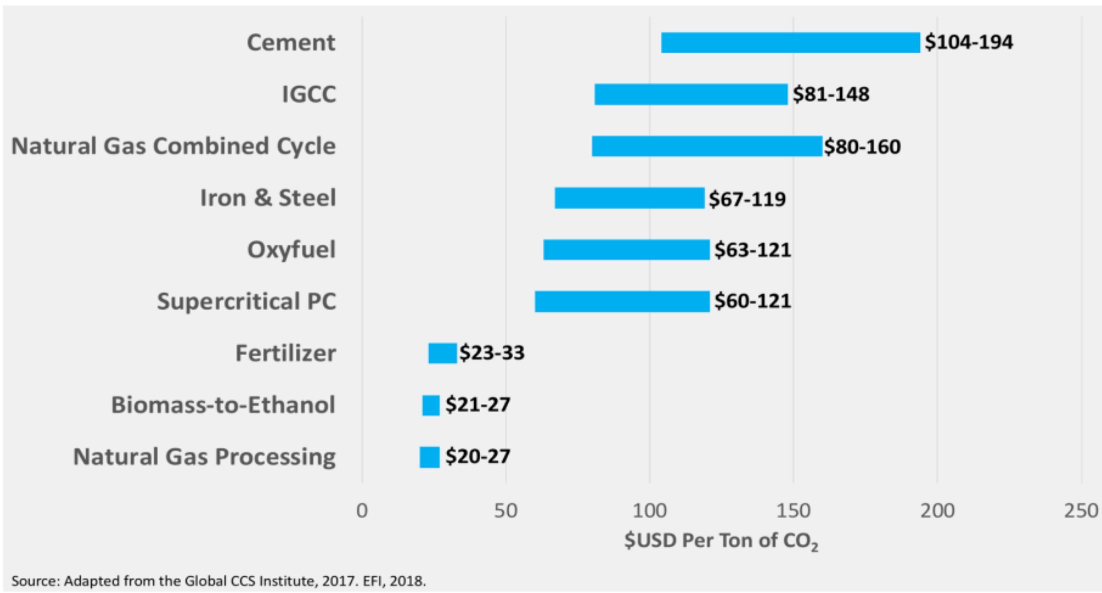
ENERGY FUTURES INITIATIVE

Source: Closely adapted from Simon Bennett and Tristan Stanley, Commentary: US budget bill may help carbon capture get back on track, International Energy Agency.

While the 45Q provisions represent a major step forward for emissions reductions, the size and duration of the credits may be insufficient to incentivize retrofits for the variety of facilities that are eligible, including many coal and natural gas plants. The below chart illustrates the first-of-a-kind cost ranges associated with different classes of industrial and power facilities; although operators indicate that subsequent projects could achieve operating cost reductions of 20 to 30%, those cost savings would still leave many CCS projects unprofitable at the current 45Q tax credit rates.

Figure 44

Estimated and Measured First-of-a-Kind Costs for CCS Applied to Different Plants

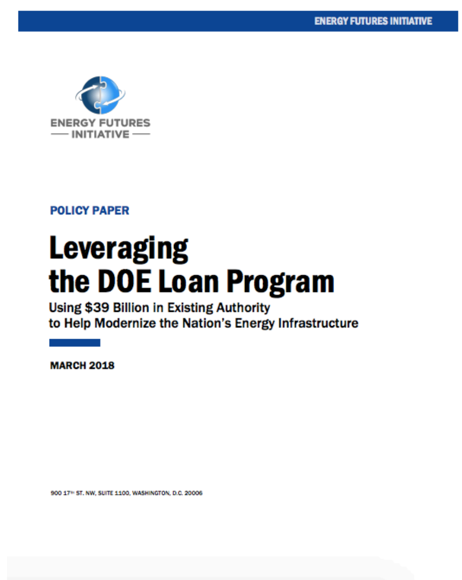


The costs of implementing CCS technologies can vary considerably across different plant types, technology mix, and geographies in the power and industrial sectors. These costs are for new-build systems and retrofits with current technology, and include capture, compression, transportation, and storage costs. They do not include revenues from EOR or utilization. Source: Global CCS Institute, The Global Status of CCS: 2017

To address these and other issues, a more comprehensive policy framework may be needed to maximize the value of the credits. Indeed, the comprehensive approach for policy support proved effective for renewable entry into power markets, and included tax credits, portfolio standards, feed-in tariffs, renewable energy certificates (REC), investment in innovation, loan guarantees, net metering, and preferred loading priority.

The 45Q credits could be made even more effective through additional policy measures or actions by companies and investors to address these issues. Congress should consider additional measures to facilitate and accelerate CCUS deployment, including addressing uncertainties regarding long-term post-injection carbon management, including monitoring, reporting and verification. Although most studies recognize that the risks are very low (both low probability and low consequence), questions about long-term obligations for long-term post-injection site monitoring could impede CCUS deployment; this could be problematic when operators lease subsurface rights and must make separate arrangements with landowners to conduct post-injection MRV activities. Long-term post-injection management could be organized through new institutional arrangements ranging from an industry-led voluntary agreement or a statutory risk-sharing initiative. Financial support could be organized in a fund (not unlike the Oil Spill Liability Trust Fund) financed by a small fraction of the 45Q credit value. A backstop mechanism to address long-term post-injection MRV would provide additional assurance that the 45Q credit results in permanent carbon removal from the environment, while providing greater certainty for private sector business models to proceed with CCUS projects.

15. Leveraging the DOE Loan Program


ENERGY FUTURES INITIATIVE

ENERGY FUTURES INITIATIVE

POLICY PAPER

Leveraging the DOE Loan Program

Using $39 Billion in Existing Authority to Help Modernize the Nation's Energy Infrastructure

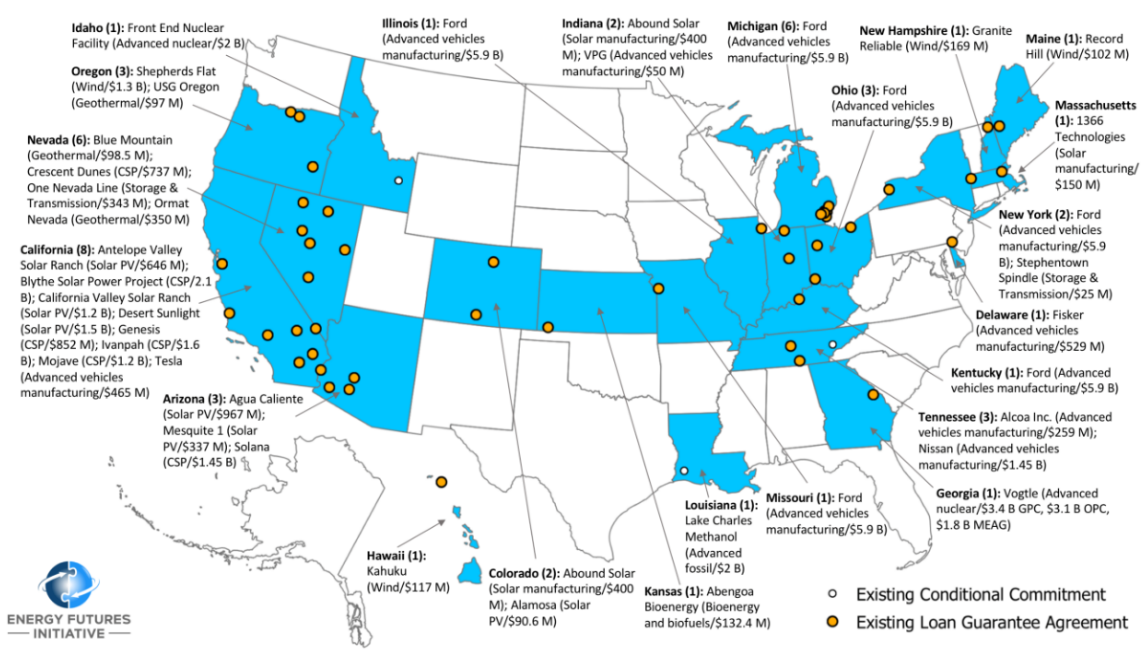
MARCH 2018

900 17th ST. NW, SUITE 1100, WASHINGTON, D.C. 20006

There is currently a great deal of interest in modernizing the Nation's infrastructures – a suite of actions and investments that are essential for the economic growth, security, health and well-being over the long run, but expensive in the near-term. One available tool to help address both infrastructure modernization needs, as well as deficit concerns, is the Department of Energy's Loan Programs. These programs currently have $39 billion in available loan and loan guarantee authority that could be used, all or in part, to finance innovative energy infrastructure projects without the need for any new appropriations.

The DOE Loan Programs Office (LPO), initially authorized and signed into law in 2005 by President Bush, manages a $30 billion portfolio and provides a credit backstop that has been used to leverage $50 billion in investments in commercial projects that deploy innovative energy technologies (Figure 45). The LPO portfolio has a default rate of just over two%, a record that compares favorably to private lending institutions even though its principal objective and success lies with first-time, commercial scale deployments of innovative energy technologies.

Figure 45
DOE's LPO Project Portfolio: Diverse, Regional, High Impact



Assuming a similar track record of success going forward, the LPO's estimated $39 billion remaining loan and loan guarantee authority could leverage as much as $100 billion of investments in innovative approaches to modernizing energy infrastructures across all energy sectors.

This report provides an overview of the important role LPO has played in advancing energy innovation in America and how, going forward, the program can be used to finance the next generation of major energy infrastructure projects in the United States. The report examines a range of issues, including current energy infrastructure investment needs; ways to deploy LPO's existing loan authority; trends that underscore the need for innovative investments in energy infrastructure; ways both programs could be used for funding critical energy- and transportation-related infrastructure needs; and recommendations for process improvements. It also provides an overview of the Tribal Energy Loan Guarantee Program, for which LPO manages the credit underwriting. The benefits described in this report can be realized with minor changes in current eligibility requirements and, as noted, *with no new appropriations*.

To date, the $50 billion in total project investment has created or saved 56,000 American jobs, boosted local economies and accelerated multiple new energy markets in the United States. In addition to these metrics, as of December 2016, LPO projects resulted in 34.7 million metric tons of avoided CO2 emissions, produced enough clean energy to power over 1 million average American homes annually, and saved 1.7 billion gallons of gasoline. These estimates will continue to increase as completed projects continue operations and more projects complete construction and become fully operational.

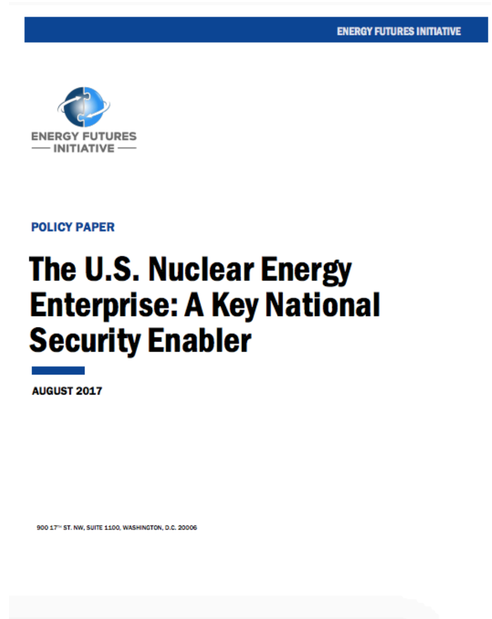
To help fund the next wave of energy and transportation infrastructure, Congress could amend the Title XVII and ATVM programs to significantly expand their use and deploy LPO's existing $40 billion in loan authority, without the need for additional appropriations in the federal discretionary budget.

EPACT (2005) requires that projects eligible for loan guarantees employ innovative technology. Clarifying that an innovative technology can consist of a *system of technologies* that can combine existing technologies in an innovative manner could enable eligibility for example, of smart transportation systems that combine state-of-the-art technologies for sensors, big data analytics and artificial intelligence in new and innovative ways. Clarifying that an innovative technology can include projects that incorporate new and innovative *platform technologies* developed outside the energy sector could enable, for example, smart sensors and controls that enable automation of electricity distribution systems, microgrids, and the integration of large-scale distributed energy resources (DER). Additionally, explicit characterization of *software innovation* as innovative technology could enable new approaches for addressing cybersecurity.

EISA (2007) requires that ATVM loans be provided for manufacturing facilities that produce advanced technology light duty autos and trucks, as well as manufacturing facilities for qualifying components for advanced technology light duty autos and trucks. The program eligibility requirements were clarified in January 2017 to include *manufacturing of fueling infrastructure equipment* for advanced technology vehicles. This could cover, for example, manufacturing of equipment for electric vehicle charging stations, hydrogen fuel distribution equipment and manufacturing of equipment for methanol, compressed natural gas (CNG), liquefied natural gas (LNG) and other alternative fuel systems. The current scope of the program could be even more supportive of infrastructure modernization by expanding the definition of advanced technology vehicles to *include medium and heavy-duty trucks and* *buses*. This would be especially beneficial for commercial trucking applications where any increase in capital costs must meet stringent criteria for payback periods.

Congress should build upon the success of these programs to expand their efforts in response to the President's call for increased investment in U.S. infrastructure. It bears repeating: estimates suggest that using the currently available authority, the LPO could leverage up to $100 billion of investments to support innovation and infrastructure modernization across the entire energy sector.

16. The U.S. Nuclear Energy Enterprise: A Key National Security Enabler



ENERGY FUTURES INITIATIVE

ENERGY FUTURES INITIATIVE

POLICY PAPER

The U.S. Nuclear Energy Enterprise: A Key National Security Enabler

AUGUST 2017

900 17TH ST. NW, SUITE 1100, WASHINGTON, D.C. 20006

Many states recognize the climate change benefits of existing nuclear power plants, although most states have renewable portfolio standards that credit the zero emissions characteristics of renewables only. There is considerable regulatory activity in developing rate structures that value grid services (e.g., capacity, storage), but little activity for valuing fuel diversity and "baseload" services. The national security imperatives of nuclear energy, however, are not addressed in state ratemaking. As such, the fundamental role of a robust nuclear energy sector in meeting national security imperatives must be addressed by the Federal government.

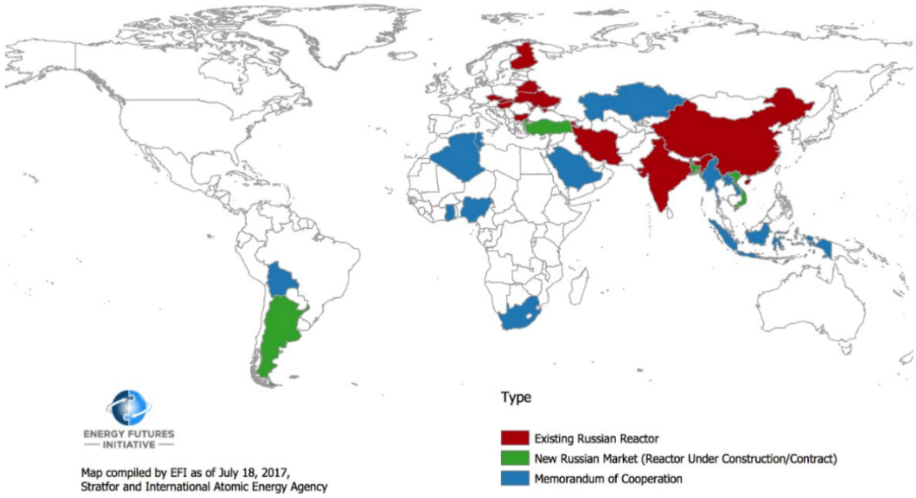
This report discusses the underpinnings for policies that would internalize the national security benefits of a robust nuclear enterprise, both generation from existing and new nuclear power plants and the associated and extensive supply chain.

Meeting National Security Priorities Requires a Robust Nuclear Energy Industry. This sector helps the U.S military meet specific defense priorities, supports the implementation of U.S. nonproliferation policy, and is essential to the global projection of U.S. military capability. The flip side is that an eroding nuclear enterprise will compromise important nuclear security capabilities or make them more costly.

The Role of Nuclear Fuel Cycle Development Standards in Nuclear Nonproliferation. The U.S. initiated the era of nuclear energy. A pillar for this leadership role has been the Atomic Energy Act Section 123 requirements for bilateral agreements with countries that receive nuclear technology, services and/or know-how, supplemented by export licensing programs at the Nuclear Regulatory Commission (Part 110) and at the Department of Energy (Part 810) that regulate individual transactions within the 123 frameworks. While this supply chain remains strong, other countries with less stringent requirements have advanced their capabilities dramatically and are capturing significant global market share for new reactor construction.

The most obvious case in point is in the Middle East, where recent U.S. 123 negotiations with Egypt, Jordan and Saudi Arabia have been unsuccessful; all three countries have signed agreements with Russia for reactor construction and fuel supply. In addition, Russia has finished construction of Iran's operating reactor, is committed to additional reactor construction, and supplies Iran with nuclear fuel. Russia also has an agreement with Turkey.

Figure 46
Foreign Markets for Russian Nuclear Technology and Services



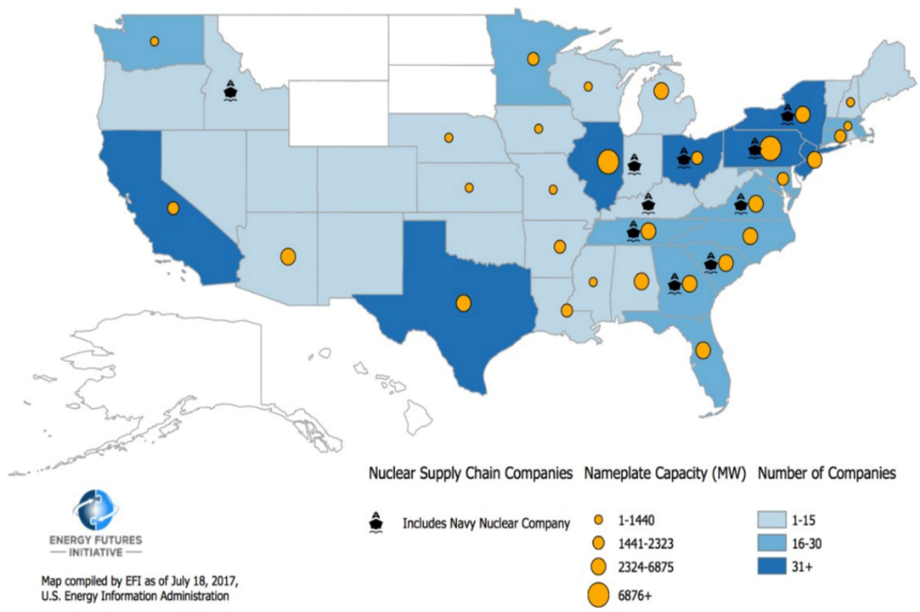
The dominant Russian presence in the Mideast nuclear power market does not augur well for U.S. national security objectives in the long term. A strong domestic nuclear enterprise will be necessary, perhaps not sufficient, to protect and advance U.S. national security equities as nuclear fuel cycles develop internationally in regions that historically have had little or no nuclear energy.

The U.S. Nuclear Navy Relies on a Robust Domestic Nuclear Energy Supply Chain. The Naval Nuclear Propulsion Program is comprised of military and civilian personnel who design, build, operate, maintain and manage the nearly one hundred reactors that power U.S. aircraft carriers and submarines and provide training and research services. The program is operated jointly by the Department of Energy and the U.S. Navy.

Two important points must be made in this context. First, a strong domestic supply chain is needed to provide for nuclear Navy requirements. This supply chain has an inherent and very strong overlap with the commercial nuclear energy sector and has a strong presence in states with commercial nuclear power plants.

Figure 47

Commercial and U.S. Navy Supply Chain Companies by State



Second, the Navy will eventually need additional highly enriched uranium (HEU) to fuel its reactors for long intervals between refueling. Because of the national security use and the sensitivity of HEU production, the entire supply chain from uranium feed to the enrichment technology must be U.S. origin. There is currently no such domestic capability in the supply chain. The relatively lengthy time period required to stand up such a capability raises serious, near-term concerns about the U.S. capacity to meet this critical national security need.

Supporting the Global Strategic Stability and Deterrence Value of Nuclear Weapons. Even as we aspire to the eventual elimination of nuclear weapons, they are and will remain at the core of the United States' defense posture for the foreseeable future as a deterrent to the use of nuclear weapons against the U.S. and its allies. The nuclear weapons stockpile requires a constant source of tritium (half-life about 12.5 years), provided by irradiating special fuel rods in one or two commercial power reactors. Once again, we do not have the long- term capability to meet this need because of the absence of an enrichment facility using U.S.-origin technology. This is a glaring hole in the domestic nuclear supply chain as the only enrichment facility in the United States today uses Urenco (European) technology to supply power reactor fuel.

The U.S. Nuclear Energy Supply Chain. The United States has been a leader in "all things nuclear" – nuclear energy, nuclear technology for medical and industrial uses, and nuclear security. However, the reality is that the supply chain, while extensive, has been sustained by the large, deployed fleet (still by far the world's largest). Furthermore, the early retirement of existing plants will also impact the supply chain, which already has significant gaps. Without a strong nuclear energy program, which is by far the largest nuclear activity in the United States, sustaining the supply chain for both civilian and national security objectives will be challenging.

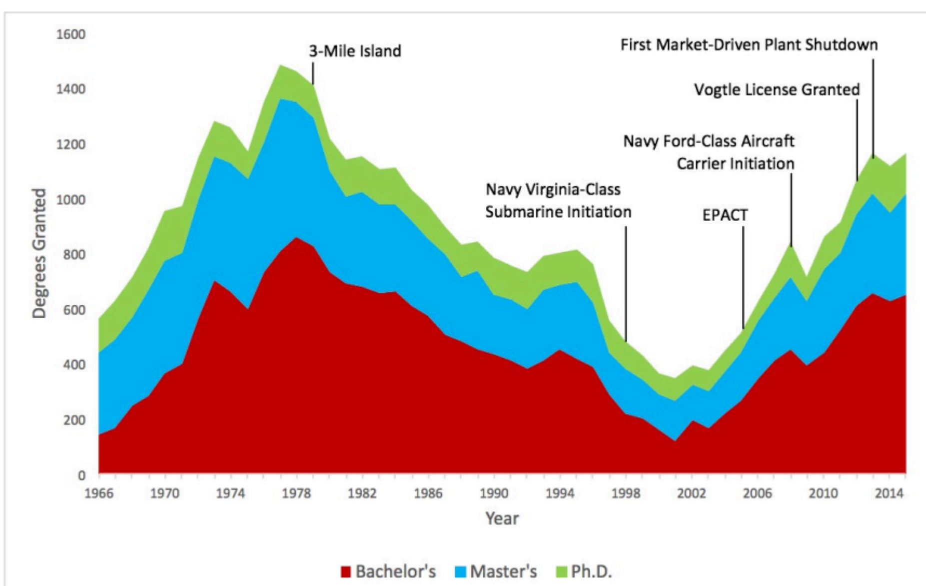
Discussions with several U.S. companies point to the eroding supply chain, since many key components are no longer supplied domestically or have limited domestic fabrication capability; among them are reactor pressure vessels; steam generators; pressurizers; main condensers and turbine generators; specialized valves; and passive residual heat removal. Beyond these commercial supply chain gaps is another concern: the specialized national security requirements, such as domestic origin enrichment capability, that cannot be met with today's supply chain.

The picture is clear: a stabilized existing reactor fleet and new builds, perhaps incentivized by the favorable emissions characteristics of nuclear power, will be needed to rebuild a supply chain that will underpin both clean energy and national security success.

Nuclear Engineering Human Resource Pipeline. Early in this century, the promise of a "nuclear renaissance" was embodied in the Energy Policy Act of 2005 that included the authorization of loan guarantees and of nuclear energy research and education program expansion, standby insurance and production tax credits for new plant construction. Several universities reestablished nuclear engineering educational programs and total enrollments and graduates steadily increased over the decade. These actions demonstrated that colleges and universities and students are quite responsive (with relatively short time delays) to changes in the nuclear energy marketplace. This progress is now at risk.

Figure 48

History of U.S. Nuclear Engineering Graduates, 1966-2015



At a minimum, high quality university programs are likely to tip more towards international students coming from countries with expanding nuclear prospects, which will further dilute the pool of American nationals who can fill national security roles. Retirements are also a significant concern. The Nuclear Energy Institute reports that the nuclear power sector will soon lose 25,000 skilled workers to retirement. Clearly, without a vibrant nuclear enterprise, it will be difficult to attract the talented scientists and engineers needed to support both commercial and national security needs for decades to come.

It is essential that policymakers recognize that a robust nuclear energy enterprise is a key enabler of the Nation's nonproliferation goals, and that it supports both the fleet modernization plans of the U.S. Navy, as well as the global strategic stability and deterrence value of nuclear weapons. To ensure that these issues and concerns are addressed going forward, the Federal government could:

- Make maximum flexible use of its existing resources and capabilities, including credit support, tax incentives and federal siting and/or purchase power agreements, to bolster support for current new builds and to encourage additional new builds. This could include legislative action where necessary, to extend the availability of the current PTC and the DOE Title XVII loan guarantee program.
- Work with states to harmonize federal and state policies affecting the design of organized electricity markets to appropriately value attributes of nuclear electricity including supply diversity.
- Direct FERC to place greater emphasis on the national security importance of nuclear power and its associated supply chain.
- Foster the organization of a broad-based consortium of nuclear supply chain companies, power generation companies, financing institutions and other appropriate entities to share the risk and benefits of additional new builds domestically, and a competitive offering internationally of new commercial nuclear power plants. The federal government should make maximum flexible use of existing resources and capabilities, including export financing assistance, as an inducement for formation of the consortium.
- Expand and accelerate support for RD&D for a new generation of advanced nuclear reactor technologies. The program should be fully competitive, stage-gated and cost-shared. The 2016 SEAB Task Force report provides a good template. The initial phase of technology development, engineering and systems analysis and conceptual design should be funded at a level of about $2 billion over the next 5 years.
- Maintain and expand current programs to provide support for nuclear engineering education, including fellowships as well as training grants targeted to key occupational needs.
- Regain U.S. leverage in using 123 Agreements to advance nuclear nonproliferation objectives by developing more flexible approaches for negotiating future agreements.