Breakthrough Energy

US FEDERAL

Climate Policy Playbook

February 2021

Contents

Overview

To avoid the most calamitous impacts of climate change, the world needs to reach net-zero greenhouse gas (GHG) emissions by 2050. To get there, both federal and state governments and leaders in the private sector will need to enact smart, targeted policies that accelerate innovation and encourage the widespread adoption of clean technologies across the five major economic sectors where emissions are currently coming from. (We call these the "Five Grand Challenges.")

At Breakthrough Energy, we have enlisted some of the world's top scientists, entrepreneurs, environmentalists, and experts to map out the most practical paths to reaching net-zero emissions. From these discussions, we have created comprehensive Policy Playbooks for lawmakers and decision-makers who want to reduce carbon emissions, speed the deployment of new technologies from idea to market, and create a world where everyone has access to clean, affordable, and reliable energy.

Our policy recommendations cover each of the Five Grand Challenges in turn and are designed to reduce the green premium for clean technologies, expand R&D infrastructure, support the demonstration and early adoption of game-changing innovations, and encourage market signals, consumer choices, and positive feedback loops that accelerate the decarbonization of the entire global economy. Certain key policies—such as investing in R&D, incentivizing innovation and entrepreneurship, and putting a price on carbon—can spur transformational change across multiple economic sectors. These cross-cutting Priority Innovation Policies are covered in their own section after the Grand Challenges.

Policy, of course, happens in the context of politics. It is not realistic to expect all of this to be adopted in one legislative effort. It is, however, quite important for the world to establish concrete plans for how to use policy to drive adoption of the critical technologies that will help avoid a climate disaster. Our hope is the playbooks provide multiple ways for policymakers to make the right decisions to lead to the future we hope is possible.

Breakthrough Energy recognizes and appreciates the individuals and organizations that contributed to this work.

Achieving an Equitable Net-Zero Future

While critically important for the future of the planet, achieving net-zero emissions should not be our only goal. The policies we outline throughout this playbook are designed to be implemented so that they provide direct benefit to all communities. That includes addressing the historic environmental injustices that have disproportionately impacted low-income groups and communities of color, including Black, Latino, and Indigenous communities, resulting in severe economic and public health disparities.

We believe it is imperative that lawmakers and decision-makers work to achieve net-zero emissions through equitable climate action as well as clean technologies that help transform rural, urban, and tribal communities by providing economic opportunities, building resilient green infrastructure, and improving public health. Across the Five Grand Challenges, climate policy should both be comprehensive and prioritize frontline and fenceline communities that disproportionately bear the burden of climate damages, while holding polluters accountable through strong enforcement.

Breakthrough Energy supports an inclusive policy process. Equitable climate policy should be developed with low-income communities and communities of color to ensure that they are designed to serve the needs of historically impacted communities. Active participation in climate policy by minority groups (i.e. Black, Latino, and Indigenous communities) can also help ensure that clean technologies are strategically deployed in communities that face the most severe economic and environmental disparities.

Our Equity Principles

Improve public health through equitable climate action

Sources of GHG emissions are often sources of other pollutants as well, such as sulfur dioxide and particulate matter. Communities of color and low-income communities disproportionately bear the brunt of health impacts caused by climate change and environmental hazards. Where possible, policies aimed at reducing GHG emissions should also be designed to reduce co-pollutants and mitigate health inequalities in disproportionately impacted communities.

Ensure clean energy and technologies are affordable for all

Climate policy should be designed to ensure that everyone has access to clean, reliable, and affordable energy. Successful climate policy will reduce the green premium of clean energy and technologies for low-income households and communities of color. Policy design should include safeguards to ensure that energy and fuel prices are not regressive and will not disproportionately impact communities of color and those that cannot directly access green technology.

Invest in high road jobs and disproportionally impacted communities

Direct investments in communities revitalize and stimulate local economies. Climate policies should ensure that investment and job creation are occurring in historically impacted communities. Investments should prioritize a just transition for fossil-based economies and provide resilient infrastructure and economic mobility options for rural and urban communities.

GRAND CHALLENGE

Electricity

How We Plug In

ELECTRICITY

Overview

Electricity is essential to modern life: it powers our homes, schools, stores, offices, hospitals, and factories. Electricity generation is also the second-largest source of greenhouse gas (GHG) emissions in the United States. In 2018, it accounted for 30 percent of emissions.

For decades, coal generated roughly half of our electricity, with oil, gas, nuclear, and hydro generating the other half. But this power mix has begun to shift. The recent shale boom has doubled natural gas's share of power generation in the U.S. Wind and solar generation routinely make up more than half of new capacity added to the grid. And improvements in energy efficiency are helping to flatten demand for electricity.

These changes have reduced GHGs, but continued progress is not guaranteed. To reach net-zero emissions, we need to first decarbonize electricity generation, then adopt carbon-free electrification across all sectors of the economy.

ELECTRICITY SOLUTION

Clean Dispatchable Power

Overview

Advanced nuclear power, geothermal energy, and thermal generation with carbon capture can all help the U.S. reach net-zero emissions. These technologies are dispatchable, which means they are useful complements to wind and solar resources, which have limited ability to be dispatched and are sometimes not available when needed. As a result, clean dispatchable power sources help maintain the stability and reliability of the power grid.

While these technologies are at various stages of commercial development, new policies are required to deploy them at scale. Additionally, while all these technologies significantly reduce CO_2 emissions, they vary in their performance on other environmental metrics like air pollution and waste management. Policies that seek to deploy these technologies should address these concomitant environmental risks, particularly those that disproportionately impact low-income communities and communities of color.

Market Challenges

High Capital Costs and Access to Capital

Dispatchable low-carbon power sources carry higher capital costs than conventional fossil fuels, onshore wind, and solar technologies—especially at commercial scale. Because of these challenges, developers usually face limited access to private-sector financing. As a result, they often struggle to compete with incumbent technologies.

Regulatory Uncertainty

Developers face licensing, permitting, and other regulatory hurdles when designing, constructing, and operating power plants and associated infrastructure like CO_2 pipelines. These processes are important for protecting safety, health, and the environment, and regulation on CO_2 storage is an essential complement to increased geologic injection. However, each new plant may face multiple rounds of review, leading to longer project timelines and increasing risk.

Public Perception

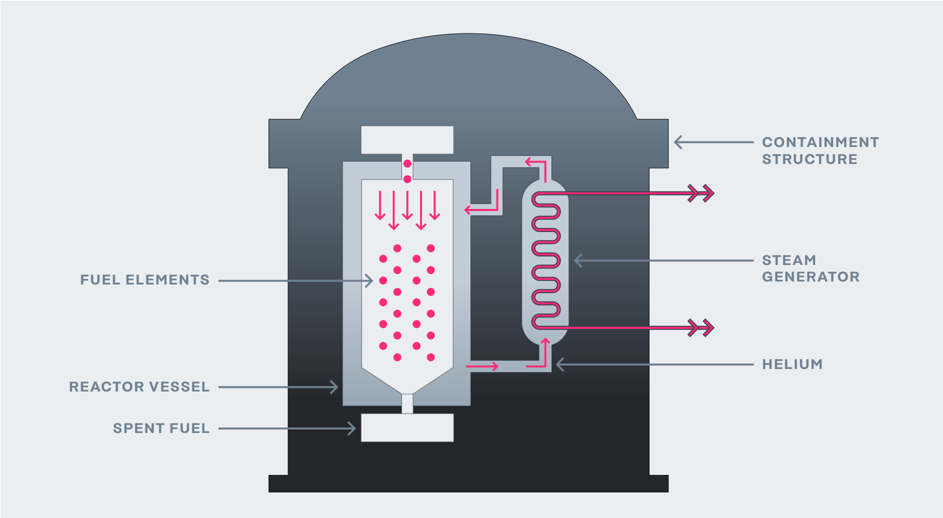
Some clean dispatchable technologies face high levels of public scrutiny. Alongside significant local issues like waste management, the public places greater weight on risks that are perceived to be potentially catastrophic, such as a nuclear meltdown or a geological leakage. Both policy and technology have a role to play in addressing these concerns. For example, many new nuclear technologies have been designed with passive safety features that dramatically reduce the risk of nuclear accidents.

Technologies

Advanced Nuclear (Next-Generation Fission)

R&D VALIDATION SCALE

Researchers are exploring a wide range of next-generation fission technologies—like the helium-based reactor shown here—that improve on today's Generation III+ reactors.



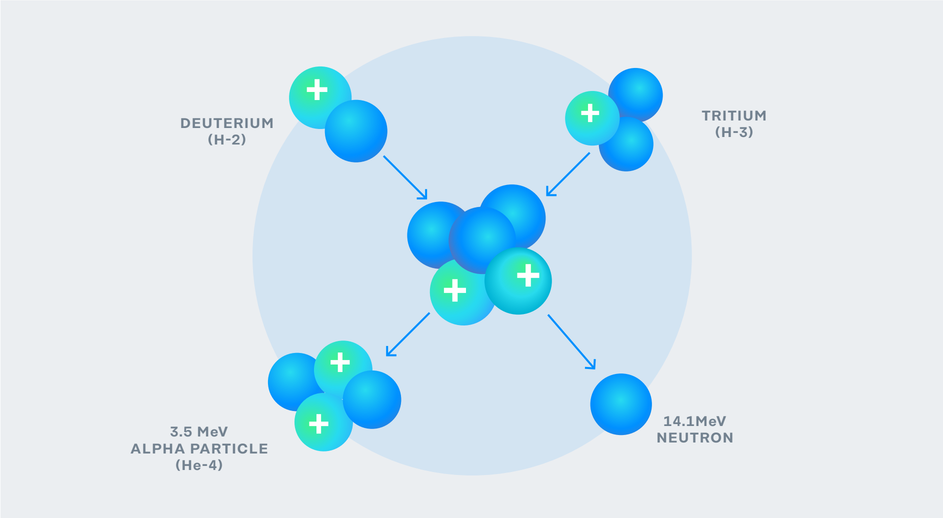
Nuclear power already provides about 10 percent of the world's electricity, and this figure could rise as nuclear technologies that are safer (including having a lower risk of proliferation), cheaper, faster to build, and produce less nuclear waste are developed.

Researchers are currently investigating a wide range of next-generation fission technologies that improve on today's Generation III+ reactors. These advanced reactors are characterized by the coolant they use—such as gases (like helium), liquid metals, and molten salt—and offer varying trade-offs between size, safety, cost, and complexity. They can also be built to prioritize resiliency from extreme weather events and the health and safety of nearby communities. Policies to deploy advanced nuclear power must ensure adequate safeguards for low-income communities and communities of color.

Fusion

R&D VALIDATION SCALE

In a nuclear fusion reaction, hydrogen isotopes deuterium and tritium fuse and recombine into a helium atom and a neutron, releasing energy in the process.



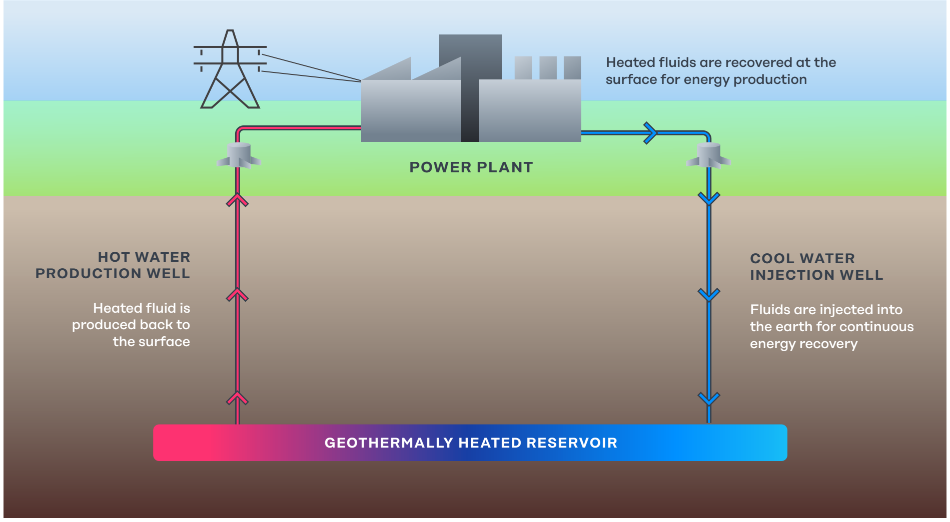
Creating energy from controlled nuclear fusion—the fusing of two atomic nuclei—has long been considered a key priority of clean energy R&D. If we can accomplish this feat, we can generate substantial amounts of zero-carbon energy while alleviating some of the challenges around safety, waste, and weapons proliferation associated with nuclear fission.

But despite more than 60 years of research, we have yet to achieve controlled fusion for energy production. Even when we do, making fusion cost-effective will remain a significant challenge. That said, innovative new approaches in recent years have given rise to a fusion technology renaissance that may still open the way to cheap, reliable, emissions-free fusion energy for the world.

Geothermal Systems

R&D VALIDATION SCALE

A conceptualization of an enhanced geothermal system, with a man-made geothermal reservoir, is shown here.



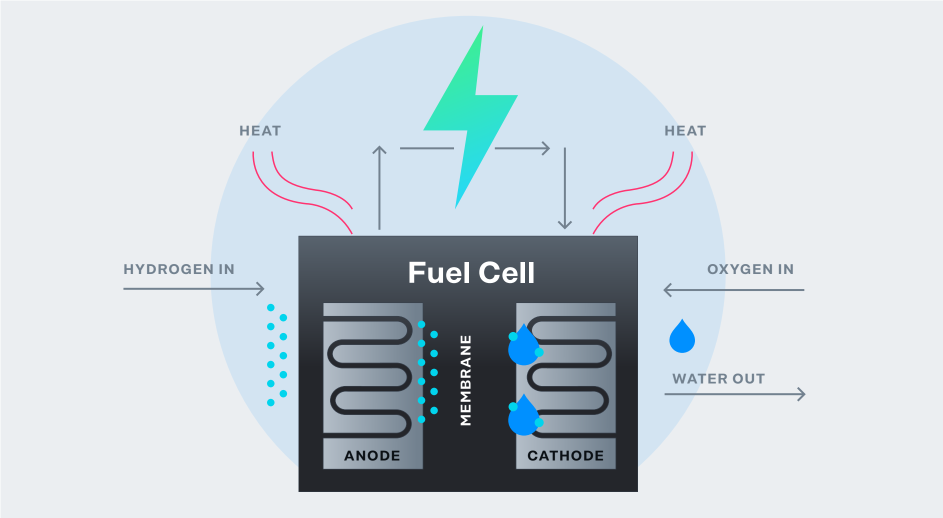
Geothermal electricity is generated by using an underground geothermal resource to heat water or another fluid, which then turns the turbine of a generator. If we can find a cost-effective way to tap into it, Earth's vast reserves of deep geothermal heat present a huge opportunity to provide large amounts of zero-carbon power: experts estimate more than 1,000 GW are readily available in the U.S. alone.

Enhanced geothermal systems (EGS), which provide access to a wider range of temperatures and rock formations than conventional resources through new drilling and fracturing techniques, can open more parts of the U.S. to geothermal development. Advances in EGS will bring down costs and improve performance. New technologies for extracting heat at higher efficiencies from lower temperature resources can also expand the use of this vast, safe, and underutilized energy resource.

Fuel Cells

R&D **VALIDATION** SCALE

A fuel cell utilizes a fuel—most commonly hydrogen—and oxygen to generate electricity through a chemical conversion process, with heat and water as the only byproducts of hydrogen fuel cells.



In a fuel cell, electrons are split from fuel and pass through an external circuit, creating a flow of electricity. A variety of fuels can be used: hydrogen is the most common, and its only byproduct is water. Fuel cell technologies can help offset the inherent variability of wind and solar power.

When coupled with a hydrogen electrolyzer with hydrogen storage, this system could act as energy storage for the electric grid. For fuel cells to truly provide cost-effective flexibility on the distribution grid, we need transformational advances that make them significantly more affordable. The production of hydrogen for these fuel cells also needs to be decarbonized for the technology to become a viable alternative to fossil fuel-based incumbents.

Power Generation with Carbon Capture

R&D **VALIDATION** SCALE

Operational since 1996, the Sleipner CCS facility in Norway is one of the world's longest-running large-scale CCS projects, capturing and storing approximately 1 million tons of CO_2 per year deep under the North Sea.

Source: Equinor.

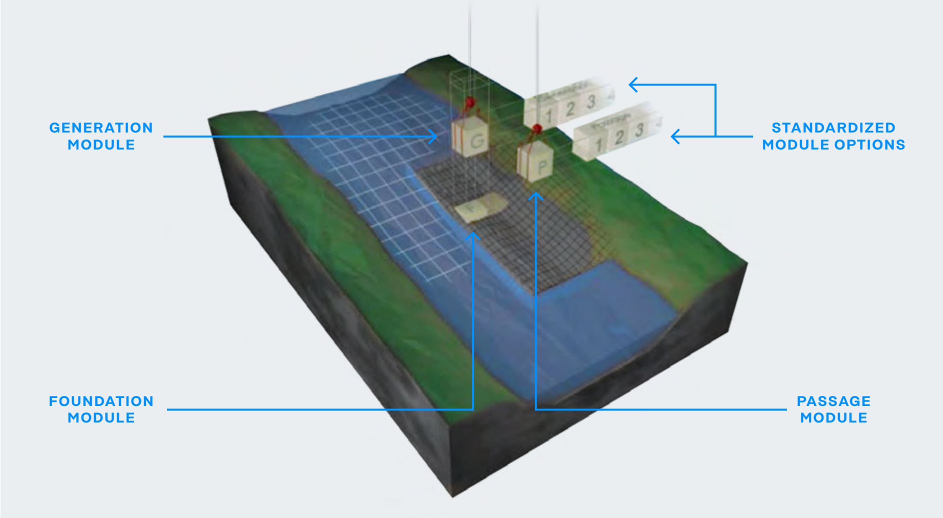
One of the most promising solutions for dramatically reducing CO_2 emissions from large-scale fossil fuel power plants lies in carbon capture technologies. CO_2 can be captured from the fuel before combustion via gasification or reforming, for example. It can also be captured from the exhaust gas of the plant, typically using a thermally regenerated amine-based process. The fuel can also be combusted in pure oxygen, resulting in a purer and easier to capture CO_2 stream. The captured CO_2 can then be put to a productive use or stored securely underground.

Further development of low-cost, highly efficient CO_2-capture technologies can make this potentially powerful emissions reduction solution a widespread commercial reality, provided it is paired with policies and technologies that address other pollutants from fossil fuel production and combustion. Carbon capture technologies have faced some criticism from environmental justice and other groups concerned with local air quality and land use impacts. Durable policy support for these technologies should include consideration of all air quality and economic impacts, especially those affecting low-income and historically disadvantaged communities.

Next-Generation Hydropower

R&D **VALIDATION** SCALE

A modular hydropower approach, conceptualized here, could help new hydropower facilities meet site-specific parameters, as well as power generation and environmental goals.



Hydropower provided 6.5 percent of total electricity and 40 percent of renewable electricity in the U.S. in 2018. While this is a carbon-free electricity source, constructing new dams often generates resistance, large hydropower projects are subject to cost and schedule overruns, and many old dams are nearing the end of their current permits and face challenges in re-permitting.

Distributed, low-head hydropower could resolve many of these challenges, but costs remain prohibitive. At the same time, existing technologies do not mitigate many of the environmental concerns associated with large dams, such as fish passage and ecological disruption. New kinds of turbines could help mitigate these concerns and enable more hydropower development, while streamlined permitting can accelerate existing timelines.

Additional Resources

- U.S. Department of Energy, GeoVision
- MIT, Future of Nuclear Energy in a Carbon-Constrained World
- Third Way, Advanced Nuclear 101
- C2ES, Carbon Capture
- NETL, Compendium of Carbon Capture Technology
- U.S. Department of Energy, Siting and Regulating Carbon Capture, Utilization and Storage Infrastructure

ELECTRICITY SOLUTION

Renewable Energy

Overview

Thanks to technological advances and policy incentives, the costs of onshore wind and solar photovoltaic (PV) energy have declined by 75 percent and 74 percent respectively since 2008, making wind and solar the cheapest sources of new generation in many parts of the country.

Over the same period, wind grew from 0.4 percent to 6.6 percent of U.S. power generation. Likewise, solar grew from 2 million megawatt hours (MWh) in 2008 to 96 million MWh in 2018 and now accounts for 2.3 percent of total electricity generation in the U.S. Continuing these trends will require further innovation in the design, production, siting, and operation of these renewable energy sources.

Market Challenges

Market Rules

Today, wind and solar are the cheapest sources of new electricity generation in many parts of the U.S., but fundamental changes to power markets are necessary to further expand the deployment of renewable energy nationwide. Currently, operators meet demand for electricity on the grid largely by turning fossil-fueled generating plants on and off—a process called dispatching. As more electricity comes from renewables, there will be fewer of these dispatchable plants available to adjust for demand.

To accommodate increasing shares of renewable energy, markets will need to incentivize flexibility in demand for electricity. In addition, current grid operations, market rules, and environmental policies don't fully value the services that new technologies and system-management practices can provide to reduce GHG emissions. Until these evolutions occur, renewable energy growth across the country will be constrained.

High Capital Costs and Access to Capital

The capital costs of large-scale, land-based wind and solar technologies have declined impressively over the past decade, but we will need a broader suite of renewable technologies to decarbonize the power sector in a cost-effective way. Other renewable technologies, such as offshore wind and concentrating solar power, still face high capital costs relative to incumbent fossil generators.

Because these technologies are earlier in their deployment, financial institutions also tend to perceive them as riskier investments, leading to higher financing costs. These costs often trickle down to the consumers, disproportionately affecting low-income and marginalized communities.

Siting Renewable Generation

Wind and solar are land-intensive generation sources compared with fossil generation and need to be built in areas with plenty of sun or wind. If renewable energy is going to continue to play a large role in the U.S. energy system, it will need better access to optimal locations. Federal lands and waters are home to some of the best renewable resources in America, but some current permitting rules can slow or prevent developers from accessing them.

Technologies

Onshore Wind

R&D VALIDATION **SCALE**

Advances in taller wind turbines with larger blades can help onshore wind power provide an increasing share of U.S. electricity

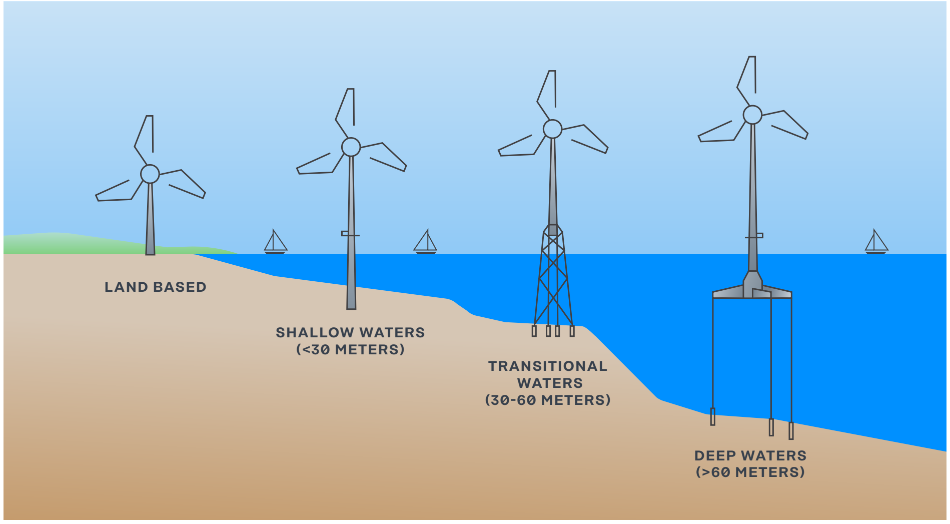
The fundamentals of generating power from wind have not changed much over time: large blades rotate in the wind, spinning a rotor that drives a turbine and generates electricity. What has changed are the cost and performance of wind-generation technologies. Technological innovation and growing markets have enabled the successful large-scale use of wind power around the world. Since 2008, the price of wind energy has dropped by 75 percent, while installed wind capacity has more than tripled. Wind power now provides more than 6 percent of U.S. electricity.

Taller wind turbines and larger blades can improve performance and open more areas of the U.S. to wind development. These trends, along with further performance and cost improvements, can drive further deployment of onshore wind technologies.

Offshore Wind

R&D VALIDATION SCALE

While fixed foundations are a proven technology, demonstrations of floating foundations are needed to enable offshore wind deployment in deeper waters.



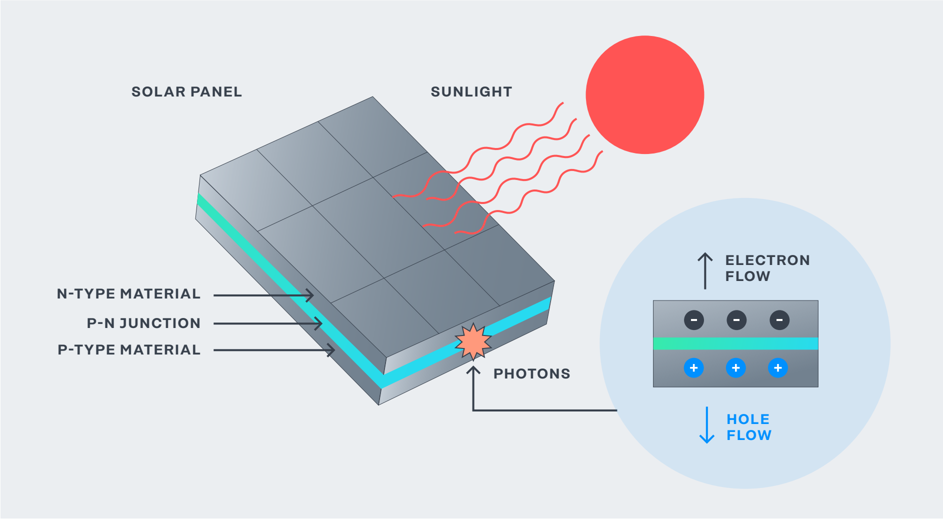
Offshore wind technology works much like onshore wind, except the turbines are in bodies of water—generally oceans or lakes. This brings both advantages and challenges. High-quality offshore wind resources tend to be located closer to major coastal population centers compared with their onshore counterparts. This reduces the need for substantial transmission buildout, and capacity factors are generally higher offshore as well. Maintaining offshore turbines is also more difficult, though lessons can be drawn from decades of experience maintaining offshore oil rigs.

Since turbines can be placed in water with varying depths and sea-floor composition, different types of turbine foundation are needed. Though most commercial offshore turbines today use fixed foundations, floating foundations allow turbines to be deployed in deeper water where wind may be stronger.

Solar Photovoltaics

R&D VALIDATION SCALE

A solar cell is composed of p-type and n-type semiconductors, which form an electric field at the p-n junction. When sunlight hits the solar cell, energy from photons transfer to electrons, creating electron-hole pairs that flow in opposite directions to create an electric current.



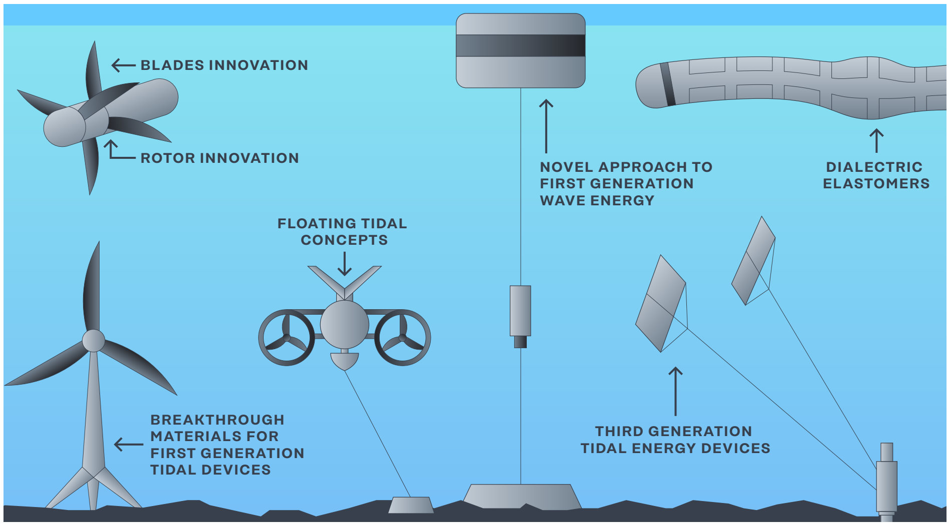
The amount of solar energy that hits Earth every day is enough to power the world many times over with carbon-free electricity. Solar panels convert solar energy into usable power by using the photovoltaic effect to generate direct-current electricity. Continued innovation and increasing scale have made solar power directly competitive with incumbent fossil generation in many regions.

Continued cost reductions can further drive the use of solar power on the grid and make it possible for solar to decarbonize other economic sectors—through the production of low-carbon transportation fuels and industrial materials, for example. While most solar cells today are made of silicon, a new generation of technologies made of new materials, such as perovskites, could bring down costs even further. Tandem solar cells incorporating multiple materials could also improve efficiency and further reduce overall system cost.

Ocean Energy

R&D VALIDATION SCALE

Research in a variety of technologies is needed to reduce costs and increase reliability of ocean energy.



The world's oceans are a vast source of renewable energy that is typically more predictable than wind and solar power. Promising ocean energy resources that could provide significant amounts of carbon-free power include wave energy, ocean-current energy, and in some regions, tidal energy.

Of these technologies, wave and tidal power have made the most progress to date. However, due in large part to ocean conditions, today's technologies are not yet cost competitive with other sources of electricity. A new generation of transformational ocean energy technologies can unlock the carbon-free energy resources that exist in oceans all around the world.

Additional Resources

- **U.S. Department of Energy, Wind Vision**
- **U.S. Department of Energy, On the Path to SunShot**
- **U.S. Department of Energy, Powering the Blue Economy**
- **NREL, Renewable Electricity Futures Study**
- **NREL, Eastern Renewable Generation Integration Study** and **Western Wind and Solar Integration Study**
- **NREL, Annual Technology Baseline** and **Standard Scenarios**

ELECTRICITY SOLUTION

Transmission and Markets

Overview

We usually build power plants near large concentrations of power users. But wind and solar must be generated where those resources are readily available. As such, high-voltage transmission infrastructure to move power efficiently from where it's generated to where it's used is critical to ensuring that grid operators can provide reliable service while reducing overall carbon emissions.

Market Challenges

Inadequate Planning

The current electric grid in the U.S. is a balkanized system with limited regional capacity. The regional transmission planning that does occur usually focuses on ensuring reliability and replacing aging assets within a utility's service area. While these are important considerations, large-scale transmission planning should expand to account for other key criteria, including: 1) economic efficiency (for example, reduced congestion and curtailment), and 2) climate and other policy benefits. Current planning practices do not prioritize clean energy or effectively allow for higher penetration of renewable energy sources like wind and solar.

Permitting Obstacles

States have always had authority over the permitting of transmission lines, and interstate transmission projects are still subject to permitting and zoning approval by local and state government entities. In some instances, one local government has blocked the development of a multi-state transmission project that would bring renewable energy to a major population center. While the federal government has backstop siting authority that could address these barriers to transmission permitting, it has never been used.

Disagreement on Fair Cost Allocation

Transmission lines require significant capital and will only be developed if project costs can be recovered in a reasonable timeframe. Most lines follow the regulated cost-recovery model, whereby utilities and developers get state or Federal Energy Regulatory Commission (FERC) approval to charge a certain rate to customers based on their costs. But it can be difficult for stakeholders to agree on these costs, especially in the case of multi-state lines. Not everyone may agree on the net benefit of reducing emissions and share costs accordingly.

Technologies

Low-Cost, Long-Distance Transmission

R&D VALIDATION SCALE

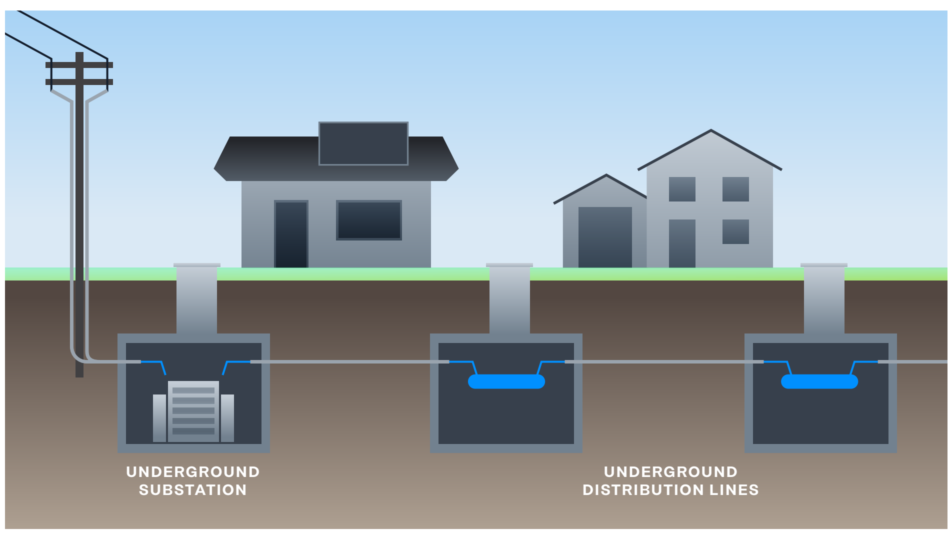
Today, most high-voltage lines are alternating current (AC), but innovations in direct current (DC) lines and superconducting materials can achieve lower-cost transmission over longer distances.

Technological advances in high-voltage DC (HVDC) and superconducting materials provide opportunities to build low-cost, long-distance transmission lines, including underground lines. HVDC and superconducting lines have lower losses and lower heat production than AC lines. As a result, they can achieve higher current over long distances at a lower cost, both above ground and underground.

Underground Transmission Lines

R&D VALIDATION SCALE

Advances in HVDC technology and superconducting materials provide opportunities to build low-cost, long-distance underground transmission lines that can dissipate or withstand the heat generated by resistive losses.



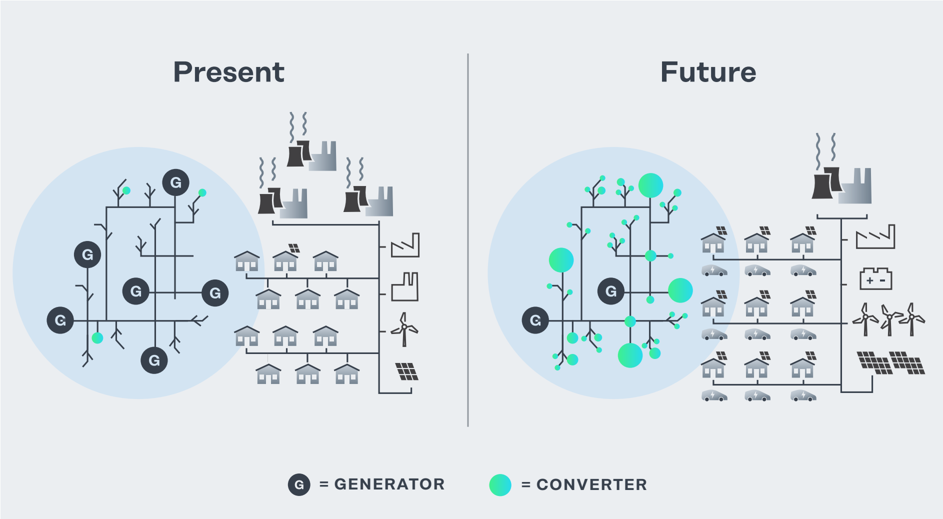
While ambient air cools above-ground transmission lines, underground power lines can overheat if they are not designed to dissipate or withstand the heat generated by resistive losses. This limits the current they can carry.

Some companies are working on next-generation technologies using high-voltage DC (HVDC) technology to dissipate heat and reduce the cost of underground lines significantly. The conductor and insulation for underground cables can be optimized for the thermal characteristics of the soil they are passing through. (525-kiloVolt cross-linked polyethylene insulated cables enable much higher line ratings, for instance, which means a single cable can deliver many more GW.)

Enhanced Converter Technology

R&D VALIDATION **SCALE**

Existing power systems are dominated by conventional AC power plants and contain a small amount of inverter-based DC generation. Next-generation controllers will enable architectures with much more inverter-based generation and enhanced grid control.

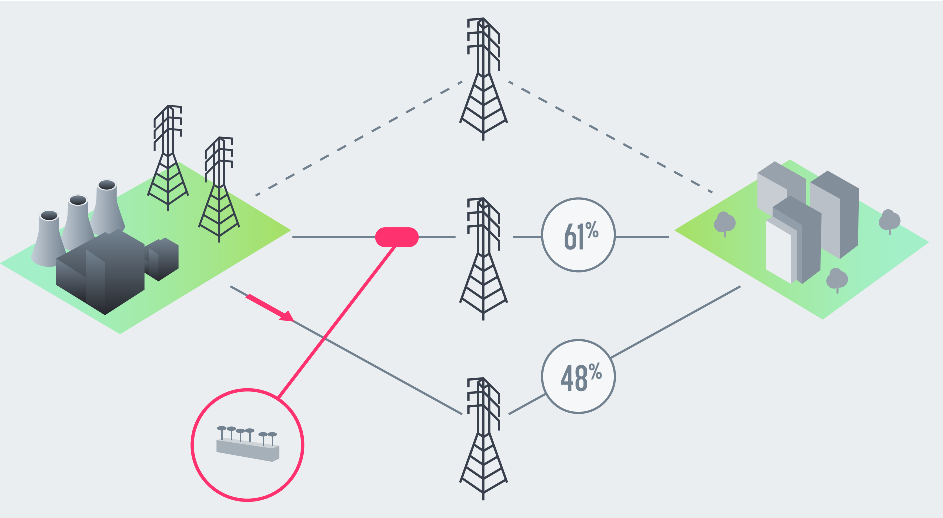


Solar, batteries, and some types of wind generators produce DC power that is converted to AC. The growth of these resources increases the need for new mechanisms for maintaining grid stability. Enhanced power converters will play an important role. Today's converters follow frequency and voltage signals on the grid that are set by conventional AC power plants. Parts of the grid using large amounts of renewable energy sources and few conventional power plants are reaching reliability constraints that limit the addition of new wind and solar generators. Advanced converters can overcome these limits by contributing to grid control.

Grid Control Technologies

R&D VALIDATION **SCALE**

A schematic of how grid control technologies can optimize energy transmission from generator to load is shown here.



Grid control technologies, such as dynamic line ratings and power flow control, can deliver more energy over existing lines with speedy, low-cost installations. Dynamic line ratings use real-time temperature measurements to keep lines from overheating and causing long-term damage. Power-flow control technologies can also optimize transmission by increasing flow over less used lines. Deploying these technologies can result in significant cost savings and increased energy delivery.

Additional Resources

Infrastructure:

- → **NREL, Renewable Energy Futures Study, 2012**
- → **NREL, Eastern Renewable Generation Integration Study, 2016**
- → **Pfeifenberger, J. & Chang, J. "Well-Planned Electric Transmission Saves Customer Costs," June 2016, Brattle Group**
- → **NREL, Interconnections Seams Study**
- → **American Wind Energy Association, Grid Vision: The Electric Highway to a 20th Century Economy, May 2019**

Market rules and system operation:

- → **"Customer-Focused and Clean: Power Markets for the Future," November 2018**
- → **NREL, "Operational Analysis of the Eastern Interconnection at Very High Renewable Penetrations," September 2018**
- → **CAISO, First Solar, NREL, "Using Renewables to Operate a Low-Carbon Grid"**
- → **"Secrets of Successful Integration: Operating Experience with High Levels of Inverter-Based Generation," IEEE PES Power and Energy Magazine, November/December 2019**
- → **"Future Electricity Markets: Designing for Massive Amounts of Zero-Variable Cost Renewable Resources," IEEE Power and Energy Magazine, November/December 2019**

ELECTRICITY SOLUTION

Energy Storage

Overview

Another critical tool that can expand the use of renewable energy sources like wind and solar power is technology that can store electricity and dispatch power at times, such as nighttime or windless days, when these resources are less available.

A range of long-duration storage options already exist. Traditional pumped hydroelectric storage—which stores energy in the form of water in an upper reservoir, pumped from another reservoir at a lower elevation—has been in use since the 1920s. It provides over 95 percent of the United States' energy storage capacity today. The next generation of energy storage technologies include flow batteries, underground pumped hydro (which does not require elevation), and molten salt storage. Deploying this next generation of technologies at scale will require policy innovations and market rule reform.

Market Challenges

Cost Barriers

Several cost-effective grid-scale energy storage options are already available on the market today, but each has its own challenges. Pumped-storage hydroelectricity faces land-use and other environmental constraints, and these projects are only viable in areas with favorable geography for them. Lithium-ion battery prices are dropping rapidly, but current models can only store several hours' worth of energy.

Other storage technologies like flow batteries, thermal storage, and subsurface pumped hydro address these barriers. However, they are still progressing through various stages of research, design, and development. The higher costs for variable renewables combined with longer-duration storage are especially stark when compared to combustion turbines fueled by natural gas—the dominant technology providing peaking capacity to the grid. Like earlier-stage innovations discussed elsewhere in the power sector, newer technologies also tend to face higher capital costs that do not take into account the negative externalities of fossil fuel sources.

Market Rules

The ability of energy storage to participate in wholesale markets is determined by regional grid operators, as overseen by federal regulators. Though recent federal orders have begun to open these markets more broadly, regulators still need to make major changes to market rules before energy storage can be fully integrated with power generation resources.

Land Use and Permitting

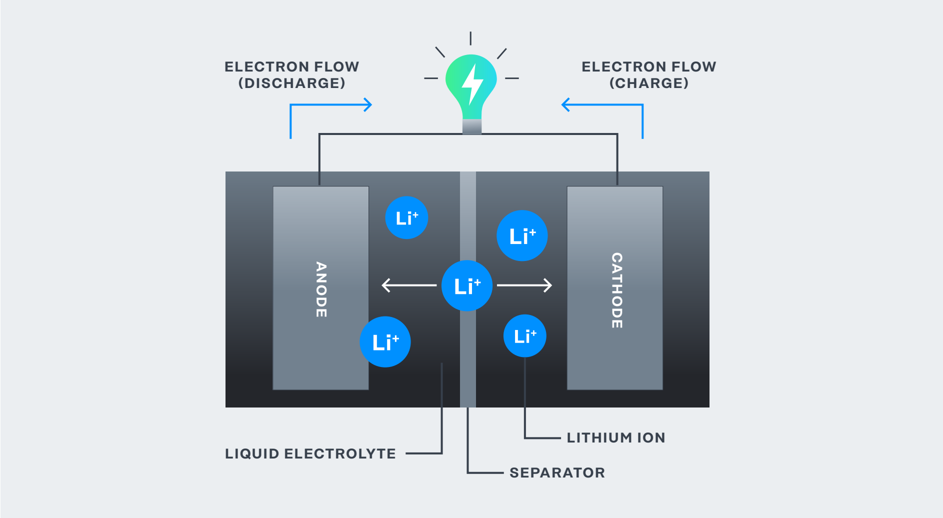
Some forms of energy storage, like pumped-storage hydroelectricity, are land-use intensive, and as a result, may face public opposition. Underground pumped hydro can help mitigate some of these concerns but triggers additional permitting requirements for its subsurface injection process.

Technologies

Lithium-Ion Batteries

R&D VALIDATION **SCALE**

A lithium-ion battery consists of an anode, cathode, separator, electrolyte, and positive and negative current collectors. The lithium ions flow from the anode to the cathode and vice versa, depending on whether the battery is discharging or charging, respectively.



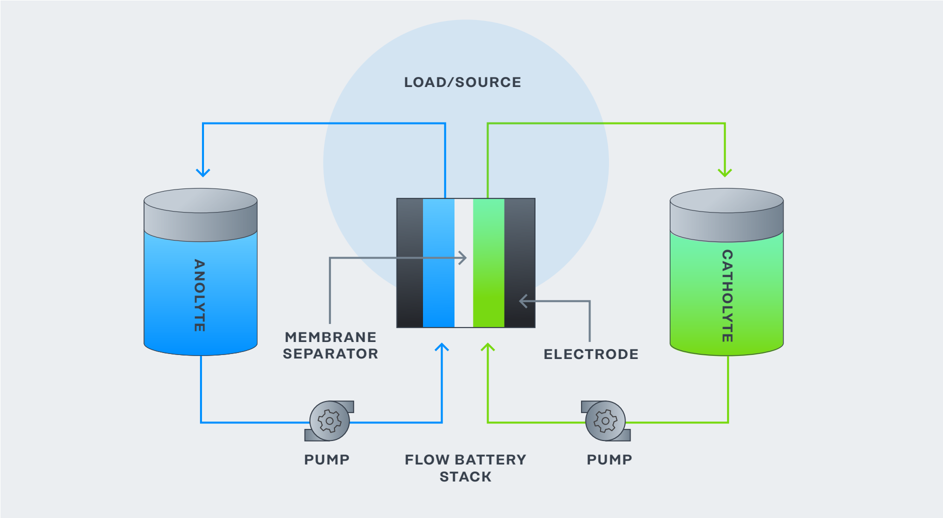
As an increasing share of variable renewable energy is brought onto the power grid, it becomes more and more important to have resources that can mitigate that variability. Lithium-ion batteries (LIBs) are increasingly being deployed as a potentially low-carbon solution to fill in the gaps of variable generation. These batteries work by passing lithium ions through an electrolyte from negative to positive electrodes, thus generating electric current. (The ions flow in the opposite direction when the battery is charging.)

LIBs are increasingly cost competitive with other, more fossil fuel-intensive forms of responding to variability (like natural gas-fired combustion turbines), and they are scalable from house-sized batteries to utility-scale deployments. But today's batteries have limited discharge periods and degrade in performance over their lifetime. Continued R&D to address these challenges can enable LIBs to contribute further value to the power grid.

Flow Batteries

R&D **VALIDATION** SCALE

A redox flow battery, shown here, uses chemical reduction and oxidation reactions in the anolyte and catholyte solutions that flow through a battery stack to transfer energy during charge and discharge.



Flow batteries are a promising class of long-duration energy storage technology. A flow battery generates electricity by flowing stores of liquid electrolytes through an electrode stack. It can be recharged by reversing the direction of ion exchange or (more rapidly) by replacing the discharged electrolytes with new liquid. Compared with LIBs, flow batteries can discharge over longer durations, scale more easily, and suffer less performance degradation over time.

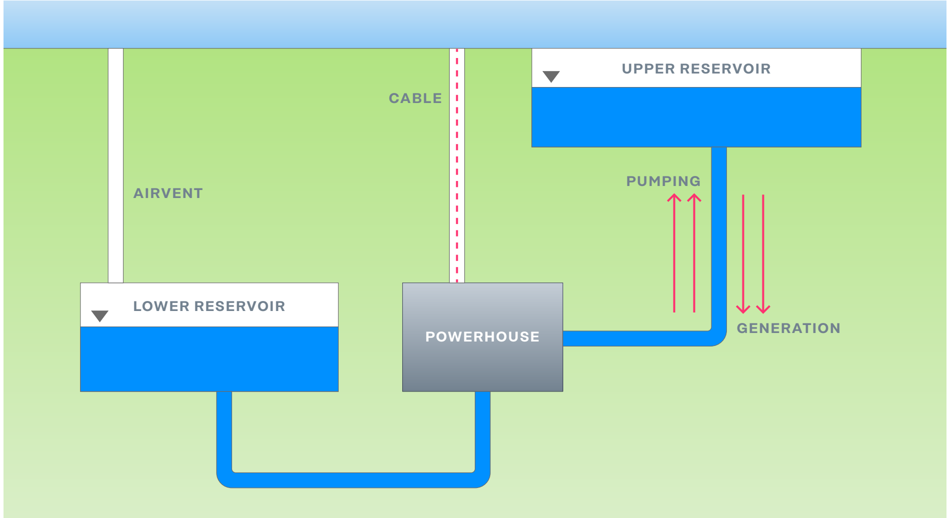
The most common battery chemistry today is based on vanadium, which is relatively expensive. Though the cost of conventional flow batteries is still higher than LIBs, this gap is projected to shrink in the coming years, particularly as R&D continues on new battery chemistries, such as those based on iron.

Next Generation Pumped Hydro Storage

R&D **VALIDATION** SCALE

One type of next generation PSH is subsurface PSH, conceptualized here, which involves locating one or both reservoirs below ground and therefore, has the potential to reduce site footprint and environmental impact.

Source: Based on original by University of Colorado at Boulder.



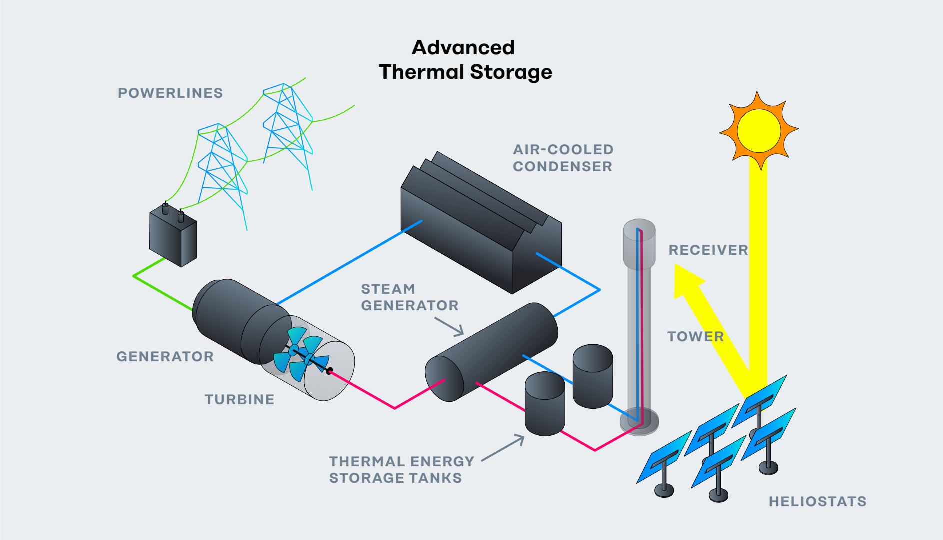
Pumped storage hydropower (PSH) provides 95 percent of utility-scale energy storage on the U.S. grid today. During periods of low electricity demand and/or inexpensive power, a PSH facility pumps water into an upper reservoir. When the energy is needed, gravity draws the water back downhill, through a typical water-driven turbine and generator. Despite its large market share, very little PSH is being built today, as such facilities have a large site footprint and specialized site requirements.

Researchers are pursuing several options for overcoming these challenges. Among these options is subsurface PSH, which pumps water into underground water wells, creating a large amount of pressure. To generate electricity, the pressure is released, pushing the water up the well and through a turbine. This approach can make use of existing “brownfield” sites like abandoned mines or caverns.

Advanced Thermal Storage

R&D VALIDATION SCALE

Advanced thermal storage systems, such as the CSP system shown here, store energy by heating a medium such as molten salt and converting that heat into electricity when it’s needed.



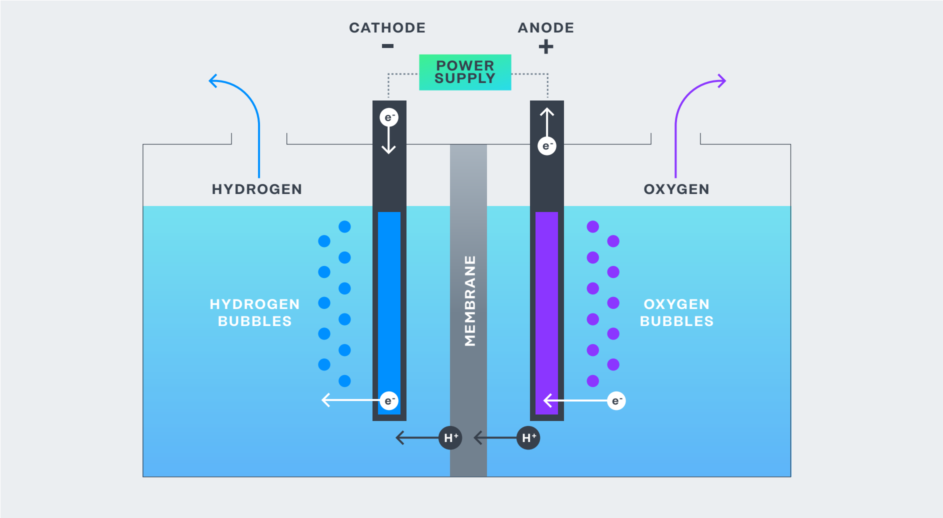
Though most people think of batteries when they think of energy storage technologies, there are other ways to store energy as well. For instance, energy can be stored thermally by heating a medium and converting that heat into electricity when it’s needed.

The most common medium for thermal storage today is molten salt, which can be heated to more than 1000 degrees Fahrenheit using the thermal output of a fossil plant or a concentrating solar power (CSP) facility and then stored in an insulated tank. This molten salt can then be run through a heat exchanger to generate steam to drive a turbine, generating electricity when needed. Molten salt can also be used to store electricity as heat by using either resistive heating or a heat pump cycle and heat engine cycle. Researchers are also looking at new forms of thermal storage such as phase-change materials and a variety of options for both hot and cold storage.

Low-GHG Hydrogen

R&D **VALIDATION** SCALE

In a polymer electrolyte membrane electrolyzer, shown here, water reacts at the anode to form oxygen gas and positively charged hydrogen ions, and the hydrogen ions move selectively across the membrane to combine with electrons at the anode to form hydrogen gas.



Hydrogen can be used in stationary fuel cells that help stabilize the grid under increasing penetrations of variable renewable energy, in fuel cell vehicles, and as a fuel or feedstock in industrial processes. Most hydrogen today is produced through a carbon-intensive process called steam methane reforming (SMR), which derives hydrogen from natural gas through an industrial process. An alternative approach is electrolysis, which uses electricity to split water molecules (H_2O) into hydrogen (H_2) and oxygen (O_2). Depending on how the electricity used for electrolysis is generated, this approach can be much less carbon-intensive than SMR.

As the grid relies more heavily on wind and solar energy, hydrogen production is one way that excess generation from these variable sources can be stored. The hydrogen made is subsequently used in a fuel cell to generate electricity during periods when wind and solar aren't fully meeting energy demand. To achieve this goal, electrolysis costs will have to decline substantially.

Additional Resources

- → **U.S. Department of Energy, Potential Benefits of High-Power, High-Capacity Batteries**
- → **NREL, The Potential for Battery Energy Storage to Provide Peaking Capacity in the United States**
- → **RMI, Breakthrough Batteries**
- → **IRENA, Electricity Storage and Renewables: Costs and Markets to 2030**
- → **NREL, Renewable Electricity Futures Study**

ELECTRICITY POLICIES

Policy Overview

Permitting and Licensing Reform

Leveling the playing field for clean and renewable electricity technologies requires regulatory clarity and efficiency. For example, licensing for nuclear-power technologies should be modernized to focus on the most crucial issues, including safety, performance, and environmental protection. Getting to net-zero emissions across the economy will also require a rapid and substantial expansion of our capacity to generate wind and solar power. To enable this expansion, policymakers need to reform federal permitting requirements for new wind and solar plants. Expedited permitting and leasing, especially on low-impact federal lands, will also facilitate increased renewable energy development.

Early Deployment of Grid Enhancing Technologies

Transfers of energy across long distances can be expanded by what the Federal Energy Regulatory Commission (FERC) has termed "Grid-Enhancing Technologies" (GETs). These include power-flow control, transmission-switching equipment, and advanced line-rating management technologies.

Right now, the principal barrier to deploying GETs is a lack of incentives for regulated transmission owners. Modernized regulation should offer these owners better incentives to make low-cost operational improvements that will enable them to deliver more energy over existing lines.

Government Procurement

Government procurement policy plays a critical role in accelerating the deployment of new technologies in other sectors, and it can do the same for clean electricity and energy storage. Using their procurement power, the Department of Energy (DOE), the Department of Defense (DOD), Power Market Administrations, and other government agencies can drive new power generation and storage technologies onto the market at relatively low cost to taxpayers.

For more, see the deep dive on

→ **Electricity and Storage Procurement**

Clean Electricity Standard

A power sector-specific policy option is a technology-neutral clean electricity standard (CES). A CES requires electric utilities to generate or procure some portion of their total electricity sales from qualifying clean energy sources. Under this market-based approach, the government sets a target for the share of clean electricity sold, and utilities are free to choose how they meet that target.

A CES offers an alternative or complementary approach to a carbon price for the power sector.

For more, see the deep dive on

→ **Clean Electricity Standard**

Technology-Neutral Deployment Tax Credit

Tax credits have already enabled the successful deployment of clean energy technologies—especially wind and solar power. A technology-neutral tax credit for clean and renewable power generation and energy storage can accelerate the development of new technologies further, bringing the electricity sector closer to net-zero emissions.

Technology-neutral deployment tax credits offer an alternative to a CES or carbon pricing. This mechanism is less economically efficient than a carbon price or a CES and would be most effective if paired with carbon pollution standards.

Carbon Pollution Standards

Another alternative to carbon pricing or a CES is to regulate carbon pollution from fossil-fired generators more directly. Policymakers could design such regulations to ensure that new generation would have emissions limits and ensure that historically disadvantaged communities see direct emission reductions and economic benefits.

Building the Macro Grid

To transition from today's balkanized energy grid to a more seamless system, federal policy should expand transmission infrastructure within and among the three North American grids (Eastern, Western, and Texas). Smart policies can remedy flaws in the current regulatory environment—particularly those involving planning, permitting, and paying for transmission assets—and help ensure that long-term benefits and costs are properly allocated.

For more, see the deep dive on

→ **Building the Macro Grid**

Power Market Design and Structure

Wholesale power markets in the U.S. were designed for incumbent sources of electricity, where fuel and operating costs comprise a meaningful share of the total cost of generation. These markets need to be redesigned to make better use of wind and solar, whose operating and fuel costs are minimal, and reward energy storage technologies for returning value to the grid. Expanding trading platforms such as Regional Transmission Organization (RTO) spot energy markets will improve the seamless exchange of power and level the playing field for clean energy technologies. The federal government and federally regulated operators of independent systems play a critical role in facilitating this transition and can encourage a higher penetration of renewable and energy storage resources.

For more, see the deep dive on

→ **Power Market Structure and Design**

Cross-Sectoral Policies

Additional cross-sectoral policies would also help develop and deploy clean electricity technologies and solve the Electricity Grand Challenge.

For more, see the deep dives on

→ **Public Sector R&D**
→ **National Laboratory Reform**
→ **Stimulating Clean Energy Entrepreneurship**
→ **Demonstrating and Validating New Technologies**
→ **R&D Tax Credit**
→ **Technology-Neutral Innovation Tax Credit**
→ **Project Financing**
→ **Carbon Pricing**

ELECTRICITY

Electricity Deep Dives

ELECTRICITY DEEP DIVES

Clean Electricity Standard

Overview

Under a clean electricity standard (CES), the federal government sets increasing annual targets for shares of clean power sold by each electric utility or retail electricity seller and gives these entities flexibility in how they choose to meet these targets. Utilities must then generate or procure this portion of their total electricity sales from qualifying clean sources.

To demonstrate compliance with the CES, utilities must hold "clean electricity credits" (CECs) equivalent to their target requirement each year. CECs, which are created when a unit of electricity is generated by a qualifying clean technology, can be earned in several ways. In states with regulated electric markets, utilities can generate their own clean power and directly retire the credits that result. Alternatively, or in deregulated electricity markets where utilities cannot own generation facilities, they can agree to long-term procurement contracts with a separate generator, paying them for both power and credits.

Some utilities may be able to generate excess CECs. Since these CECs can be severed from the physical units of electricity that produced them, they can be sold to other utilities that haven't met their target. Allowing CEC trading within a CES framework creates a powerful and efficient market-based system that 1) provides financial incentives to clean electricity adopters, 2) minimizes the total system cost of clean electricity generation, and 3) helps drive higher levels of clean electricity deployment.

Principles

Covered Entities: This policy should apply to all electric utilities and entities that sell retail electricity to customers in the U.S.

Targets/Ambition: A CES should target 100 percent clean power generation by no later than 2050, with interim milestones that accelerate on a five-year schedule. To ensure regulatory certainty, the federal government must establish annual CES targets that are ambitious and achievable. These targets should be periodically reviewed in light of utility progress and continued technology cost evolution. Setting targets at the utility level provides a granular way to measure progress towards full decarbonization. These targets will also need to account for interactions with existing state clean and renewable electricity portfolio standards.

Qualifying Technologies: All net-zero technologies should be eligible to generate CECs. Both new and existing generators should be eligible to generate CECs.

Compliance Flexibility: To enhance the economic efficiency of a CES, CECs should be fully tradable. Utilities should also be allowed to bank certain excess credits for future compliance. The federal government should also establish a trading platform (like PJM's Generation Attribute Tracking System) to help facilitate these trades.

Ratepayer Impacts: A CES policy should be designed to shield ratepayers from excessive costs while encouraging utilities to aggressively deploy clean electricity and provide equitable access to clean electricity specifically in communities that are disproportionately impacted by the effects of climate change and air pollution.

Equity Impacts: A CES should include design elements to prioritize decarbonization and improvements in local air quality in and near low-income communities and historically disadvantaged communities, while promoting a wide portfolio of clean energy deployment across the U.S. A CES should conform to equity principles and address direct environmental and economic benefits in historically disadvantaged communities.

ELECTRICITY DEEP DIVES

Building the Macro Grid

Overview

We need to bolster the reliability and resilience of the current U.S. power system, enable the use of more renewable energy sources such as wind and solar, and help provide the necessary infrastructure for wide-area power exchange across the country. As such, the federal government should support the development and deployment of a national macro grid that can expand transmission infrastructure within and among the three major North American grids (Eastern, Western, and Texas).

While building a robust interstate transmission network is clearly in the national interest, most transmission permitting is currently handled by state and local authorities. In addition, the federal government's limited backstop siting authority (authorized by the Energy Policy Act of 2005) is not being successfully utilized. As part of a 21st century macro grid policy, Congress should fix flaws in the current permitting regime, grant federal oversight authority comparable to its oversight of interstate pipelines, and permit new rights of way. Congress should also continue to include critical environmental considerations in transmission planning and development.

Under a comprehensive macro grid policy, the federal government can seek to use existing rights of way for transmission use and proactively facilitate permitting for energy transmission on federal lands where it is appropriate. In addition, the Department of Energy's (DOE's) Power Marketing Administrations (PMAs) (BPA, WAPA, SWPA, SEPA) can plan, build, own, and operate significant parts of the macro grid. These PMAs already own tens of thousands of miles of high-voltage transmission lines, have already been granted financing and development authority by Congress, and have considerable experience developing, owning, and operating transmission lines in the public interest.

Federal agencies can also assist states in the development of mutually acceptable routes for multi-state lines and provide technical assistance grants to accelerate the planning and rollout of the macro grid.

Principles

Strengthening Federal Planning Authority: Congress should clarify and strengthen the authority of the Federal Energy Regulatory Commission (FERC) to require regional, inter-regional, and interconnection transmission planning. For its part, FERC should plan for the development and rollout of a seamless national grid. These plans should account for state energy policies, including clean energy requirements, as well as utility resource plans and the preferences and locations of retail energy users. In addition, Congress should direct federal PMAs to take the lead in planning parts of the macro grid and authorize technical assistance grants so that states can improve their transmission capacity and coordination. Congress should also expand the goals of DOE's National Interest Electric Transmission Corridors program to include reducing greenhouse gas (GHG) emissions.

Accelerating Permitting: Building on the Energy Policy Act of 2005, Congress should enhance FERC's authority to quickly approve projects and permitting in electric-transmission corridors deemed in the national interest. While primary jurisdiction should continue to rest with state and local authorities, FERC will be able to resolve disputes and mitigate unreasonable delays. Congress should also direct the Federal Highway Administration (FHA) and other relevant agencies to include high-voltage AC/DC transmission rights-of-way in their transportation permits and streamline environmental reviews of transmission projects. Finally, Congress should require states to consider public benefits of transmission lines in their planning processes and provide financial support to states hosting interstate lines.

Regulatory Cost Allocation: A macro grid policy should use both regulated and market-based "merchant" transmission business models. Since transmission remains both a natural monopoly and public good, regulated transmission is needed to build an efficient, reliable macro grid at scale. At the same time, encouraging merchant transmission will help offset regulatory costs through voluntary capacity reservations by market participants. FERC's planning and cost allocation rulemaking should replace the "participant funding" approach used in many Regional Transmission Organizations (RTOs), whereby the transmission needed to serve large renewable resource areas gets assigned to individual generators seeking to interconnect. This approach is flawed because, when a lot of transmission is needed, the cost of the network upgrades can be prohibitively expensive for the individual generators at the front of the interconnection queue. This "participant funding" approach should be replaced by one that allows for proactive transmission construction that is financed in part by load beneficiaries around the system rather than individual generators alone.

Federal Incentives: To ease barriers to transmission development and spread the costs of infrastructure in the national interest, the federal government should 1) contribute to the upfront financing of regionally beneficial lines, and 2) provide financial incentives to encourage the development and deployment of a macro grid. These incentives could include investment tax credits for developers of new high-voltage inter-regional lines, loans akin to those administered by the Transportation Infrastructure Finance and Innovation Act (TIFIA), or bonds similar to the Competitive Renewable Energy Bonds (CREBs) that helped finance renewable energy and transmission development. Other financing options include authorizing master limited partnerships, a tax vehicle widely used in oil and gas pipelines, for transmission projects, or directing FERC to implement a “wires charge” across users to fund transmission.

AC/DC Interoperability: Alternating current (AC) lines allow local communities and networks to enjoy reliable energy, while direct current (DC) lines enable greater efficiency over long distances. Macro-grid policy should work to advance both AC and DC lines, using each and/or both where appropriate. DC lines are particularly important at the “seams” between interconnections and can enable substantial GHG reductions and customer savings.

Supporting Local Reliability: Hospitals, research facilities, military, law enforcement, and other social services require local power that is not subject to grid vulnerabilities and is more reliable than any current distribution system can provide. While facilitating wide-area power exchange, a comprehensive macro-grid policy should also support backup generation and expand options for distributed resources and micro-grids so that fully reliable power is available wherever and whenever it is needed.

ELECTRICITY DEEP DIVES

Power Market Design and Structure

Overview

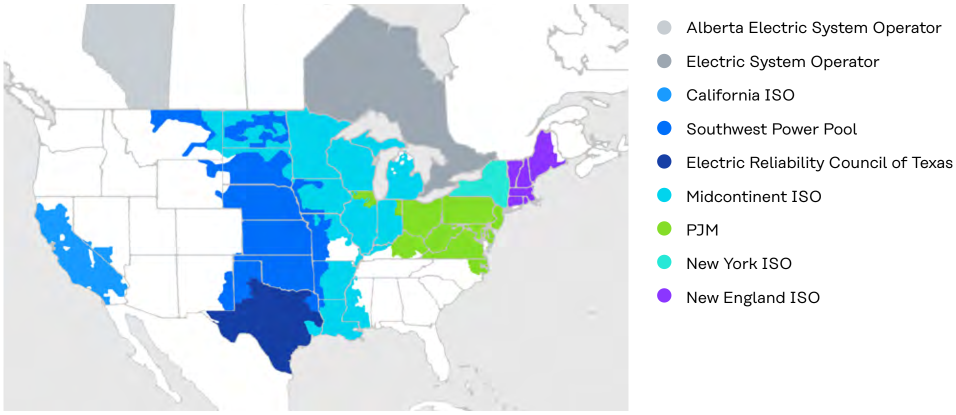
For power systems to provide electricity to all while relying mainly on renewable energy sources, they must be able to transfer large amounts of energy across wide geographic areas. They also need to rapidly redispatch supply and demand resources to respond to changing renewable energy output over the course of the day.

Two distinct characteristics of renewable energy require wide-area power exchange. First, most high-quality wind and solar resources are located far away from population centers. Second, fluctuations in output from individual plants can provide electricity service when it is needed, but only aggregated across areas with different wind regimes, local weather, and load patterns.

In other words, large regional trading platforms are required to enable wide-area power exchange. These platforms take the form of Regional Transmission Organization (RTO) and Independent System Operator (ISO) wholesale energy markets where wholesale buyers and sellers of energy trade in a way that is integrated with the reliable operation of the transmission network. ISOs and RTOs (generally used interchangeably) currently cover two-thirds of the U.S.

FIG. 01

Regional Transmission Organizations



Source: Modified from a map created using Energy Velocity, November 2015.

Since they are currently based on legacy market rules used to dispatch traditional power plants, RTO market designs must be updated to ensure effective use of renewables while improving customer affordability and access to high quality services in rural areas and in aging city infrastructure.

For example, instead of focusing on meeting summer peak load as the main planning objective, power system operators need to focus on the daily "net load." Dispatch protocols also must work for the different cost and operating constraints of renewable resources compared to traditional power plants. Traditional plants have significant fuel and operating costs and day-to-day "startup" and "shut down" costs, none of which are shared by renewable sources. Storage resources are energy-limited, requiring different methodologies to optimize their charging and discharging.

Principles

Expanded RTO Membership: Congress should encourage public and private utilities to join an RTO that meets the minimum characteristics and functions of FERC Order No. 2000 issued in 1999. RTOs allow entities, all of whom have occasional need for regional power exchange, to schedule their owned or contracted generation to serve their own load. RTOs are also sensitive to regional differences that may affect fast dispatch and reliable operation. For example, each region has a different resource mix and will likely make choices for their power needs based on resource availability, politics, and culture. RTOs should allow for multiple types of corporate structure including vertically integrated utilities, restructured companies, municipal and cooperatively owned utilities, and independent third parties.

Best-Practice Market Design: Power market design should efficiently dispatch all supply and demand resources on the system, while respecting physical constraints and reliability criteria. Among the design factors that are desirable to achieve the most efficient market are:

- **A large regional scope** to capture efficiencies of resources operating at different times and to access a wide range of dispatchable resources to maintain supply and system balance.
- **Seamlessness between RTOs** to enable energy transactions that support efficiency and reliability.
- **A fast, dynamic, and responsive market** that allows for locational marginal prices (LMP) to signal efficient production and consumption by grid location, fast rebalancing to adjust to changing system conditions, competitive procurement of operating reserves, co-optimization of energy and reserves to ensure their most efficient assignment, and a "multi-settlement" system that allows for operators to lock in supply in advance of when its needed while still allowing for re-balancing in real time.
- **Non-discriminatory rulemaking:** Along with allowing for the full value of resources to receive compensation as they provide it, ISOs and RTOs should assign capacity values for renewables and short- and long-duration storage resources based on their system value. They should also allow storage resource owners to bid in their markets and to operate their storage and

hybrid units autonomously, since owners are often better able to optimize their resource output than central grid operators. ISOs, RTOs, market monitors, and the Federal Energy Regulatory Commission (FERC) should review market power mitigation rules and bidding requirements that were originally designed for fuel-based resources to avoid constraining the efficient operation of energy-limited resources or limiting the fair bidding price of storage resources in the market. Finally, ISOs and RTOs should commit storage and demand-side resources in advance to allow for planning and scheduling operations through multi-day markets.

- **Price flexibility:** For operators to ensure reliable service, supply must always equal demand. Prices are the signal for resources to operate where and when needed. As such, prices should be allowed to rise to the level that reflects the value of the product. "Scarcity pricing" and "Operating Reserves Demand Curves" (ORDC) have become a best practice in ISO/RTO operation that allow for more accurate short-term price signals to encourage operation of flexible resources such as storage and demand response where and when they are needed, as well as long-term price signals to encourage their development.

  FERC, ISOs, and RTOs should also set prices according to value of lost load as represented by demand side bids prices. This level is likely well above the operating cost of the last supply source dispatched, and prices set at that level provide a strong incentive for resources to operate when they are needed. Such prices compensate resources accurately for the value of their output. In lieu of actual demand side bids, ISOs and RTOs can use an administrative proxy scarcity price such as the $9000/MWh used in Texas and an administrative Operating Reserve Demand Curve (ORDC).

- **Incorporate probabilities:** RTOs and ISOs should replace the past practice of deterministic commitment of generating units with a probabilistic unit commitment approach. This method would reflect the probability distributions of renewable energy output that are known and can be utilized.

- **Frequency response:** FERC, RTOs and ISOs should develop interconnection-wide markets for frequency response to offset regional scarcity. Renewable energy sources can provide operating headroom as one efficient source of frequency response, but they would need to be compensated to provide this headroom without foregoing too much energy revenue. An efficient market should allow for efficient pricing and compensation for frequency response.

- **Contingency reserves:** FERC, RTOs, and ISOs should make "contingency reserves" available to provide for system balancing when renewable energy output changes abruptly. Right now, the product is only used for conventional generation outages, when the system need is almost identical. Allowing contingency reserves to be used for renewable output changes reduces the current over-procurement of other reserves.

- **More finely grained markets:** FERC, RTOs, and ISOs should refine the capacity markets to price and compensate more finely grained services based on the product needed at the exact time and place. Since supply and demand resource quantities vary by season, a good first step would be towards seasonal markets.

- **Consumer protections:** Market power mitigation provisions should prevent dominant suppliers from raising prices above competitive levels. Transmission rights that can be purchased by transmission customers should also provide a way to lock-in transmission delivery costs.

Facilitating Long-Term Contracts: FERC, RTOs, and ISOs should ensure that markets participants have free unfettered parties to contract on a bilateral long-term basis. Long-term contracts enable lower cost financing of power generation and provide a more assured means of cost recovery than relying on spot markets, where every market participant can sell any excess or buy power on a day-to-day basis. In a well-functioning market, wholesale electricity buyers (utilities, competitive retail suppliers, or end-users) procure energy for their needs on a long-term basis to reduce their own price risk and allow for lower costs of capital for new supply. While most of the demand in a region is pre-arranged through long-term contracts, parties frequently have some excess or shortfall to cover, which the spot market addresses.

Respect for State Policies: Congress should affirm that the RTO's role is to operate the wholesale market without interfering with state clean energy policies. Specifically, legislation should clarify that FERC is not authorized to discriminate based on the receipt of state incentives or to interfere with state clean energy policies through "mitigation" schemes. FERC should reject tariff provisions that force state-supported resources to bid higher than their costs going forward, regardless of whether they received state incentives.

RTO Carbon Pricing: FERC should allow RTOs to incorporate carbon pricing into their tariffs and bidding rules, and Congress should affirm FERC's authority in this domain via legislation. Pricing carbon at the RTO level should not preempt state-level carbon pricing or other climate policies, and should include equity and public health considerations.

Reasonable Interconnection Costs: Interconnection rules should provide reasonable assessments of the network transmission upgrades required to interconnect storage, renewable, and hybrid resources. These resources operate differently than traditional ones and the operational assumptions (time of day or season of operation) make a significant difference in the costs they are assessed. FERC, RTOs, and ISOs should also work to abandon "participant funding" based interconnection cost assignment, which leads to a constant churn of projects coming in and out of the queue. A well-planned transmission grid should replace the need for generators to pay for network upgrades.

Balanced Governance: Congress should direct FERC to regularly review the governance of RTOs to ensure adequate representation from all customer classes, states, and environmental and new technology interests relative to incumbent resource interests. The regional trading platform should have an independent board, per the guidelines of FERC's Order No. 2000, and ensure that consumers have as much voice as suppliers.

Distributed Resource Integration: Since an increasing quantity of resources are "behind the meter" and there are opportunities for efficient trading between end-users, FERC, RTOs, and ISOs should allow full access to wholesale markets for distributed resources. States and utilities can offer trading platforms for these resources that are connected to lower voltage distribution systems overseen by state and local authorities.

ELECTRICITY DEEP DIVES

Electricity and Storage Procurement

Overview

The U.S. government is the world's largest consumer, procuring $550 billion in goods and services each year. This gives the federal government substantial heft in a wide range of markets, including energy technologies. As such, early federal investment can provide a stable source of demand for critical emerging clean technologies, and help manufacturers and developers grow their operations to commercial scale.

Congress could enact a government-wide procurement target that establishes, in megawatts (MW) and megawatt hours (MWh), specific levels of electricity and energy storage technologies for applicable federal facilities. Policymakers should scale and tailor this target to the size and needs of each agency. For example, the Department of Defense (DOD) could have a target that reflects its large size and supports the unique reliability and resilience needs of military installations and operating bases. Congress could also authorize federal agencies to launch demonstration projects for earlier-stage clean technologies to meet their unique electricity and storage needs, especially for long-duration storage (i.e., an energy storage system that can continuously provide energy at capacity for at least eight hours).

Principles

Technology Neutrality: To encourage flexibility and innovation, agencies should solicit electricity and storage solutions in terms of specific needs (reliability, capacity, duration, or size, for example) rather than mandating specific technology categories.

Target Level: To establish an appropriate target, the Department of Energy's (DOE's) Federal Energy Management Program should conduct a baseline assessment of electricity and storage needs and cost-effective deployment potential on a facility-by-facility basis across the government, in coordination with facilities and sustainability experts within each agency. DOE and the Council for Environmental Quality should then establish aggressive but achievable increasing annual targets for each agency to meet to scale federal procurement to these levels by 2030.

Emissions Optimized Procurement: Agencies should assess projects on their emissions reduction potential rather than on a kilowatt hour basis. They should prioritize clean electricity and storage procurements that will displace the greatest emissions. When possible, agencies should work to shift electricity demand out of high emissions periods and into the cleanest periods.

24/7 Zero-Carbon Electricity Procurement: Agencies should shift their approach to encompass 24/7 net-zero emissions electricity at all points of load. In addition to variable renewable resources like wind and solar, agencies should look toward sources of clean, firm, and dispatchable generation—like geothermal, nuclear, and fossil with carbon capture—that will be critical to supporting 24/7 zero-carbon power.

Broad Storage Procurement Application: Policymakers should set storage targets to encourage the deployment of a wide array of storage applications, including diurnal and long-duration storage, in bulk power and distribution systems as well as energy systems at federal facilities.

Longer Contracts: The federal government is the largest consumer of electricity in the country, giving it substantial power in power purchase markets. However, existing law generally limits long-term power purchase agreements (PPAs) to just ten years, while commercial PPAs tend to range from 15 to 25 years. Allowing the federal government to enter into long-term PPAs can result in lower unit costs for electricity, benefiting the federal government, and greater revenue certainty, benefiting developers.

Demonstration Projects: Current commercial technologies will not meet all the federal government's wide-ranging electricity and energy storage needs. As such, Congress should fund a limited number of early-stage technology demonstration projects for federal operation. For instance, in cases where battery storage duration is too short (or where achieving appropriate duration would make batteries too bulky), Congress can help create early markets for long-duration storage and "power-to-x" technologies. To support further development of these technologies, DOE and the General Services Administration (GSA) should collaborate to define diurnal and long-duration storage performance characteristics.

Accountability: Agencies should report on progress toward their targets to the Office of Management and Budget (OMB) each year as part of OMB's annual Sustainability Scorecard.

Applicable Agencies: The procurement targets and demonstration projects should apply to all agencies, including energy-generation and transmission sites such as Power Marketing Authorities (PMAs) and the Tennessee Valley Authority. While limited exemptions could potentially be granted for national security purposes, Congress should highlight that electricity and storage often enhance our national security objectives (for example, distributed, portable storage at forward operating bases, or microgrids supported by long-duration storage for critical defense infrastructure).

GSA Schedule: GSA should be flexible in accommodating new procurement pathways for electricity and storage, particularly through modifications to existing procurement schedules (as has previously been done for the Energy Savings Performance Contract ENABLE project). Procurement should adhere to existing principles of competitive solicitation.

Additional Electricity Policies

Clean Energy Bonds

States and municipalities typically sell bonds to finance capital-intensive public projects and certain "qualified" private projects. In some cases, the federal government works to make these bonds more attractive to potential investors by exempting their interest from investors' federal income tax liability or providing a tax credit in lieu of interest payments. These concessionary bond mechanisms encourage investors to accept a lower interest rate (since the foregone earnings are offset by lower tax payments) and reduce the cost of capital for project developers. These bonds can buy down the green premium specifically in low-income and historically disadvantaged communities.

Similarly, Congress should expand access to concessionary bond financing for all clean energy technologies in two ways:

- **Tax-exempt private activity bonds:** Though tax-exempt bonds are usually used to finance public projects, in limited circumstances states and municipalities can also issue them for "qualified private activities." Today, those activities include some electricity distribution infrastructure and combined heat and power (CHP) facilities. Congress should expand this list to include a full suite of the clean energy technologies necessary to accelerate deep decarbonization. Given the scale of deployment needed, Congress should also increase the state-level caps on this type of bond financing.
- **Tax credit bonds:** While tax-exempt bonds lower an investor's tax liability, tax credit bonds (TCB) give investors a tax credit. The Secretary of Treasury sets a national credit rate, and investors receive some or all that credit rate (depending on the type of TCB) on the face value of their bond on an annual basis. As with tax-exempt bonds, this federal subsidy provides cheaper access to capital for the bond issuer since bondholders do not receive interest payments. Congress previously authorized this type of bond structure in the form of clean renewable energy bonds as part of energy legislation in 2005, but this program was cut as part of the 2018 tax bill. Congress should enact a new clean energy tax credit bond that is available to all clean energy technologies.

Master Limited Partnerships (MLPs)

Master limited partnerships (MLPs) are a type of corporate structure that are taxed like a business partnership but whose shares are traded in a market, like stocks. One key benefit of this structure is avoiding double taxation: MLP income is distributed as dividends to shareholders and then taxed as personal income. Lower taxes reduce the cost of developing energy projects funded through MLPs. At the same time, MLP dividends—distributed on a quarterly basis and determined contractually—provide a steady return to investors.

By statute and IRS interpretation, MLPs are not currently available to most industries, including clean energy developers. But MLPs are broadly available to the oil and gas industry and are widely used by midstream companies such as pipeline developers. About two-thirds of MLPs are midstream oil and gas companies, which collectively had a market capitalization of nearly $300 billion in mid-2019.

Congress can drive investment toward, and accelerate the widespread adoption of, net-zero technologies by passing a bill that explicitly makes this corporate structure available to a broader range of clean energy technologies.

Technology-Neutral Refundable Tax Credits

Renewable energy production and investment tax credits (PTC and ITC) have been the most important federal policies driving the substantial growth in wind and solar deployment over the past decade. These credits lower the cost of renewable energy deployment by reducing the tax burden of developers (or the tax equity investors involved in transactions). The PTC provides a per-kilowatt-hour credit for each unit of electricity generated by qualifying facilities, while the ITC provides a percentage credit based on qualifying construction costs.

Though both credits have been extremely effective, their impact has been limited by the list of technology types that qualify for them. To address this, Congress should consider a tax credit available to any generator that emits low or zero greenhouse gases (GHGs). This approach levels the playing field and allows all clean electricity technologies to compete for market share. If adopted in conjunction with carbon pollution standards for fossil-fired generators, a technology-neutral tax credit can hasten the deployment of clean technologies and decarbonize the electric grid.

Several policy design choices can maximize the impact of this tax credit. Developers should be able to choose between a production or investment credit, depending on which one best suits their project's financial needs. Either way, the incentive should come in the form of a refundable tax credit, allowing even small developers with minimal tax burdens to receive the incentive without needing to partner with a tax-equity investor through complex financing arrangements. Some approaches allow low-GHG emitting technologies to receive a portion of the credit commensurate with that technology's ability to mitigate carbon emissions. Finally, the credit could be made available to existing clean generators that haven't previously received the PTC or ITC, such as existing nuclear plants, if the incentive would prevent premature retirement.

Carbon Pollution Standards for Fossil-Fired Generators

The Clean Air Act mandates that the Environmental Protection Agency (EPA) regulate air pollution from new stationary sources, including fossil-fired electricity generators. EPA is also required to set guidelines for states to cut emissions from power plants already in operation. Past administrations have adopted regulations limiting the amount of carbon dioxide that most new and existing fossil-fired generators can emit. Particularly as carbon capture and other low-GHG technologies continue to develop and decline in cost, EPA should reexamine the current determinations of emission limits for fossil-fired generators and establish standards that require new generators to be as clean as possible. Updated guidelines to states should set clear requirements that accelerate the decarbonization of the power sector and prioritize cleaner generators in proximity to low-income and historically disadvantaged communities that have experienced a disproportionate share of air pollution.

Under the Clean Air Act, the EPA sets an emissions limit based on the “best system of emission reduction” (BSER), factoring in appropriate costs and benefits. Since declining technology costs for carbon capture and other low-GHG options for generators change the appropriate BSER regularly, the EPA should continually reassess these determinations.

Transmission Grid Enhancing Technology Deployment

Grid enhancing technologies (GETs) such as power-flow control and advanced line-rating management can deliver more energy over existing lines with faster and less expensive installations. The principal barrier to GETs today are economic disincentives arising from current policy. Transmission owners earn greater returns on large capital investments because they are regulated under the standard approach called “cost-of-service,” which compensates for capital investments plus a return on equity.

Regulators should counteract these disincentives inherent in cost-of-service regulation to ensure that owners can also pursue low-cost operational improvements. Under one such approach, “shared savings,” the utility earns a share of the savings created by deploying advanced transmission technologies. Other forms of performance-based regulation can likewise modify or replace the current standard.

In addition, the Federal Energy Regulatory Commission (FERC) should require the inclusion of GETs in transmission planning processes and mandate deployment of these technologies where benefits exceed costs. To accomplish this, FERC should undertake a rulemaking process to better implement the incentives provision of the Federal Power Act, Section 219(b)3, included in the Energy Policy Act of 2005. An approach based on “benefits” could take account of the consumer savings from reducing costly congestion, as well as the reliability and resilience benefits of these technologies.

FERC should also integrate GETs into regional planning processes to ensure these cost-effective improvements are explored before undertaking expansion or seeking new rights of way. Finally, DOE should evaluate the benefits, opportunities, and barriers to wide deployment of GETs and provide technical assistance to transmission system operators interested in using them.

GRAND CHALLENGE

Transportation

How We Get Around

TRANSPORTATION

Overview

The internal combustion engine revolutionized transportation, increased human mobility, opened new educational and economic opportunities, and facilitated the movement of goods around the world.

But these benefits have come at a steep cost to the climate. Fossil fuel combustion in cars, trucks, trains, planes, and ships represents the leading source (32 percent in 2018) of greenhouse gas (GHG) emissions in the U.S. While cars are the largest source of transportation GHGs today, emissions from trucks, planes, and ships are growing at an even faster rate.

Mitigating the most catastrophic impacts of climate change will necessarily involve decarbonizing transportation. And that will require a complete transformation of the way goods and people move from place to place. Smart, well-designed policies can shape the technology and investment decisions that put the entire U.S. transportation sector on a path to net-zero emissions.

The key components of this transportation revolution are electrification, low-GHG liquid fuels, and more efficient mobility. Electrification (plus a decarbonized grid) is one of the most promising solutions for vehicles that travel shorter distances between refueling. For longer-distance and off-road applications, low-GHG liquid fuels are critical.

More efficient vehicles and increased access to transit are also essential components of a comprehensive decarbonization strategy for transportation. Pushing the transportation sector toward net-zero emissions can also help address historic disparities in access to affordable, clean mobility options for historically disadvantaged communities. Similarly, investments in clean vehicle infrastructure can reduce emissions while addressing transit deserts and providing more access to zero- and low-carbon transportation options in all U.S. communities.

TRANSPORTATION SOLUTION

Electrification

Overview

The cost of lithium-ion batteries has declined by 87 percent since 2010, making electric vehicles (EVs) increasingly competitive with their gas-powered counterparts. Over the same period, annual sales of electric passenger vehicles in the U.S. have grown from under 10,000 a year to more than 360,000. Electric buses and electric trucks are also beginning to hit the streets and the market.

Nonetheless, if EVs are going to change the overall trajectory of U.S. emissions, they must be supported by key technological innovations. These include batteries with ranges competitive with internal combustion engines; market reforms, such as well-designed market-based standards to accelerate vehicle deployment; and smart public policies, such as greater investment in public, private, and fleet charging infrastructure, specifically in marginalized communities.

Market Challenges

Public Perception

As a transportation fuel, electricity still faces high levels of public uncertainty. Consumers tend to resist new technologies that can be considered unproven, and they often express anxiety over electric vehicles' range and charging. While long-range EVs currently meet the average workweek mileage of Americans and battery costs are steadily decreasing, public perception continues to limit EV market penetration. In addition, traditional vehicle dealerships are often unequipped to provide consumers with information about the benefits of EVs, further hampering adoption. Additional outreach on the benefits and remaining utility of used EVs should also be prioritized to encourage widespread EV adoption in low-income communities and expand equitable access to clean transportation technology.

Charging Infrastructure

As home charging is not feasible for many drivers and vehicle owners, a robust network of public charging infrastructure is required to expand equitable access to EVs. One recent survey found that grocery stores, restaurants, and shopping malls are the most convenient public charging locations. Yet to date, the build-out of chargers at these and other public sites has not overcome this anxiety over the vehicles' range. Access to public charging infrastructure lowers the barriers to adoption for EVs, since low-income communities often include more renters who cannot make structural changes to their homes. Public charging infrastructure also provides an avenue for those residing in apartment complexes to access this service, which in turn could lead to greater EV adoption.

Cost Barriers

Price and availability of electric vehicles are major barriers to widespread adoption. From 2010 to 2019, the cost of lithium-ion batteries has dropped by 87 percent and current projections show that costs will reach the $100/kWh mark by 2023. Nonetheless, batteries are currently the most expensive component of an EV. Despite these falling costs and fuel savings, high EV purchase price continues to be a barrier to wide-spread adoption, specifically for low-income drivers. In addition, the costs of building EV infrastructure can delay public charging options that would mitigate public perceptions of range anxiety.

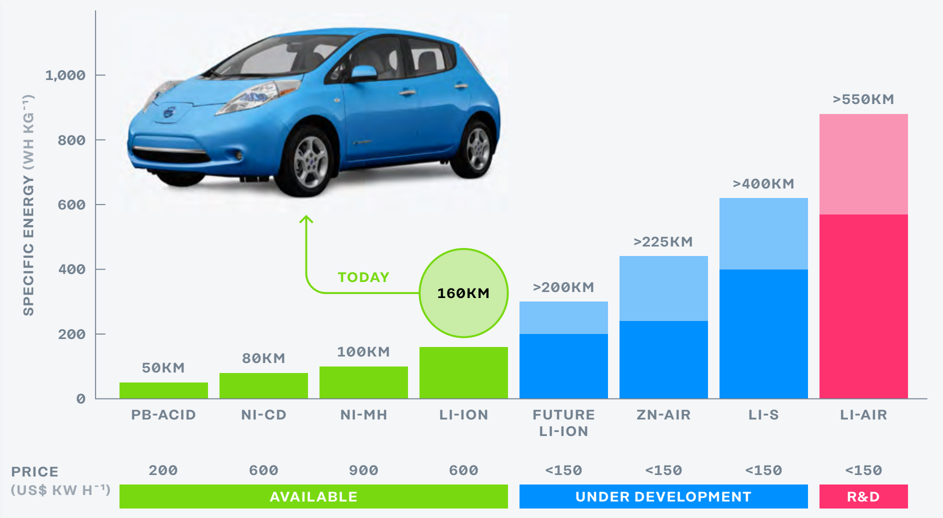
Technologies

Long Range Batteries

R&D | VALIDATION | SCALE

New battery chemistries under development have the potential to unlock cheaper, longer-range batteries compared to today's technology.

Source: Based on original from Nature Materials.



One of the most promising opportunities to reduce emissions in transportation lies in electrifying cars and trucks. But to make plug-in vehicles ubiquitous, they will need to approach the performance, cost, range, and fueling time of today's gasoline and diesel-powered vehicles—which will in turn require continued dramatic improvements in battery and battery-charging technologies.

The development of a new generation of extremely inexpensive, energy-dense, and quick-charging batteries would allow electric cars and trucks to replace traditional vehicles much more rapidly. Examples of long-range battery technologies include all-solid-state lithium-metal batteries (which use lithium metal as the anode and a solid electrolyte) and comparatively lightweight lithium-sulfur batteries. Commercialized versions of these could result in smaller batteries that are cheaper on a dollars per kilowatt-hour basis.

Battery Materials

R&D **VALIDATION** SCALE

An aerial view of the brine pools and processing areas of the Soquimich lithium mine on the Atacama salt flat. Lithium is a key material in batteries, and directly extracting lithium from brines could reduce the costs of both lithium production and battery storage.

As demand for electric vehicles grows, demand for battery materials—particularly cobalt, nickel, and lithium—and the need for battery disposal will grow. New approaches to digitizing and leveraging geological data could identify and open new supplies of cobalt, although human rights concerns have promoted a move away from cobalt towards other materials. Lithium, meanwhile, is found in brine and hard-rock deposits and is extracted via evaporation ponds or hard-rock mining respectively. Evaporation ponds, however, are land-use intensive and difficult to develop, while hard-rock mining has high environmental impact and higher costs.

Directly extracting lithium from brines could enable lithium production at a lower cost. In addition, battery recycling can serve as an important source of materials for new batteries and enable responsible end-of-life treatment for used ones. To enable widescale battery recycling, collection systems must be improved and recycling technology and capacity must be developed.

Charging Infrastructure

R&D **VALIDATION** SCALE

Technologies such as increased deployment of DC fast chargers, advancements in vehicle-to-grid (V2G) connectivity, and inductive charging can reduce electric vehicle charging time, optimize the use of renewable electricity, and improve transit efficiency.

Technologies that expand and expedite electric and hydrogen vehicle charging are also needed to achieve deep decarbonization in the transportation sector. Innovations that advance hydrogen storage and transport, including cold or cryo-compressed hydrogen storage and cryogenic liquid tanker trucks or gaseous tube trailers, are required for large-scale deployment of fuel cell vehicles.

Technology advancements for electric vehicle and equipment charging include increased deployment of DC fast chargers, advancements in vehicle-to-grid (V2G) connectivity, and inductive charging. These can reduce charging time, optimize the use of renewable electricity, and improve transit efficiency.

Additional Resources

→ **ICCT: Funding the Transition to All Zero-Emission Vehicles**
→ **BNEF: Electric Vehicle Outlook 2019**
→ **IEA: Global EV Outlook 2019**

TRANSPORTATION SOLUTION

Low-Carbon Fuels

Overview

In long-haul transportation sectors such as aviation and maritime travel, the distance between refueling opportunities makes today's batteries impractical. In these cases, low-carbon liquid fuels such as advanced biofuels and electrofuels created with clean-power generation are essential.

Fuels whose lifecycle GHG emissions, including land use and feedstock impacts, are lower than the fossil fuels they displace can help decarbonize sectors in transportation where the green premium of electrification is very high. Electrofuels can also complement renewable energy sources, such as solar and wind power, whose availability fluctuates over the course of the day. (This is known as "load balancing.") Finally, the combustion of low-carbon fuels can improve air quality relative to the fossil fuels they replace, meaning their rollout should be prioritized in communities that are disproportionately impacted by poor air quality and adverse health outcomes from fossil fuel combustion today.

New policies to drive innovation and investment will further reduce costs and accelerate widespread deployment of these necessary transportation technologies.

Market Challenges

Supply of Feedstocks

Deep decarbonization analyses suggest there may not be sufficient feedstock to produce enough biofuels to displace today's petroleum-based transportation fuels. By one estimate, converting all the world's grassland to energy would replace only 15 percent of world energy requirements by 2050. Land use, water quality, and biodiversity concerns may limit the feedstock for biofuel production, while technological limitations and costs may prevent increased use of advanced, low-carbon biofuels.

While consistent supplies of dedicated energy crops present the best opportunity for the supply of low-GHG liquid fuels, significant market barriers and sustainability concerns still pose challenges to the deployment of dedicated energy crops at scale. Increasing the total supply of sustainable biomass would require an expansion of dedicated cellulosic energy crops such as switchgrass, miscanthus, and short-rotation poplar. Consistent supply of renewable energy can also be a barrier to the economic viability of synthetic hydrocarbon fuel production.

Regulatory Uncertainty

Uncertainty in regulatory policies related to biofuel requirements can hamper investment in low-carbon fuel technology. Current federal fuels policies, including the Renewable Fuel Standard and production and investment incentives, do not provide a long-term price signal that would help drive deeper investment in advanced biofuel technology. At the local level, permitting and siting related to land use and production facilities can also present a barrier to biofuel production.

Policies that encourage long-term regulatory certainty and support project efficiency can work to remove these market barriers while also providing important health, safety, and environmental benefits. Permitting and land use policies should also promote equity and ensure that communities in need are prioritized for low-carbon investments that do not increase local air pollution levels. These investments are vital to reduce the amount of income spent on meeting energy needs and to offset energy poverty.

Cost Barriers

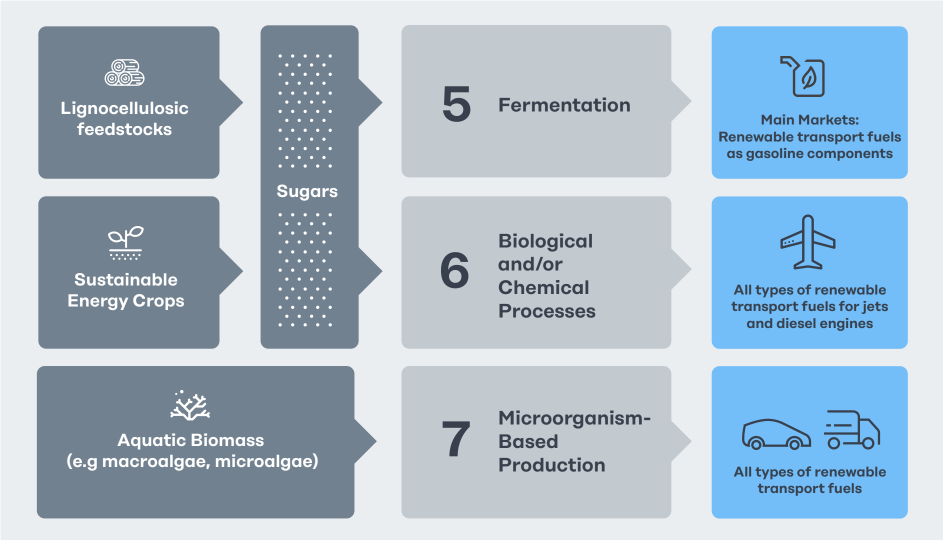
High feedstock and production costs are significant market barriers to advanced biofuels. Feedstock price is often seen as the single most important influence on advanced biofuel production overall. For electrofuels, the high cost of renewable hydrogen and challenging production processes also limit adoption. Costs are also a factor in market penetration of hydrogen as well as synthetic hydrocarbon fuels where infrastructure and energy requirements are high-cost relative to fossil fuels. Policies that bridge the financial gap between advanced technology fuels and conventional fossil-based fuels can spur additional demand and work to eliminate these market barriers.

Technologies

Advanced Biofuels

R&D | VALIDATION | SCALE

A variety of sustainably-sourced non-food biomass can be transformed into all types of renewable transport fuels through fermentation, biological and/or chemical processes, and microorganism-based production.



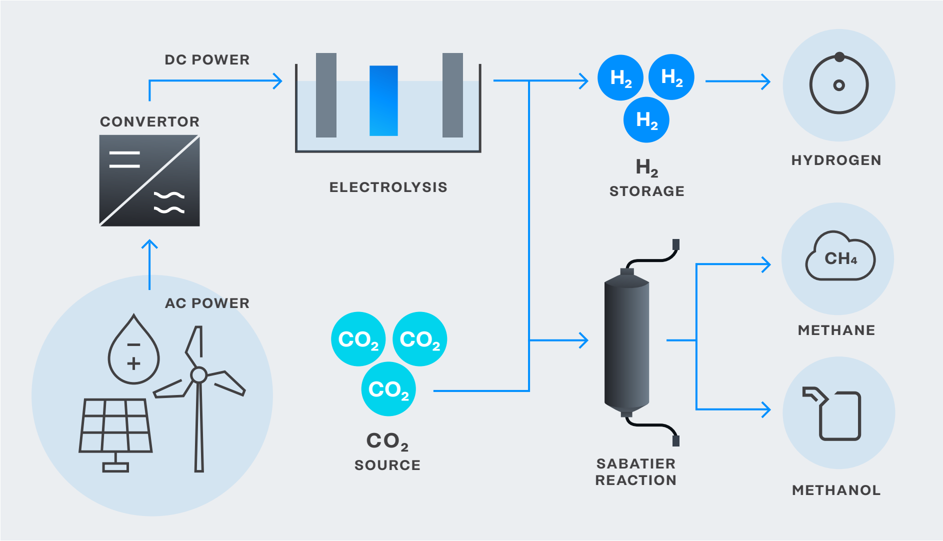
Low-carbon biofuels made from sustainably produced non-food biomass can dramatically reduce CO_2 emissions from the transportation sector while providing the high energy density and easy storage of a liquid transportation fuel. In the U.S. alone, even before considering the potential for algae as a biofuel feedstock, more than 1 billion tons per year of biomass could sustainably be converted to biofuels, replacing up to one-third of the petroleum the U.S. transportation sector uses today.

To produce biofuels cost-effectively at global scale, we must develop transformational innovations that reduce the costs of energy crop production, harvesting, and transportation and develop new higher yield, low-cost technologies for biofuels conversion.

Electrofuels

R&D | VALIDATION | SCALE

A variety of electrofuels can be produced by reacting hydrogen (produced from the electrolysis of water) and CO_2. For example, methane and methanol can be produced through the Sabatier reaction.



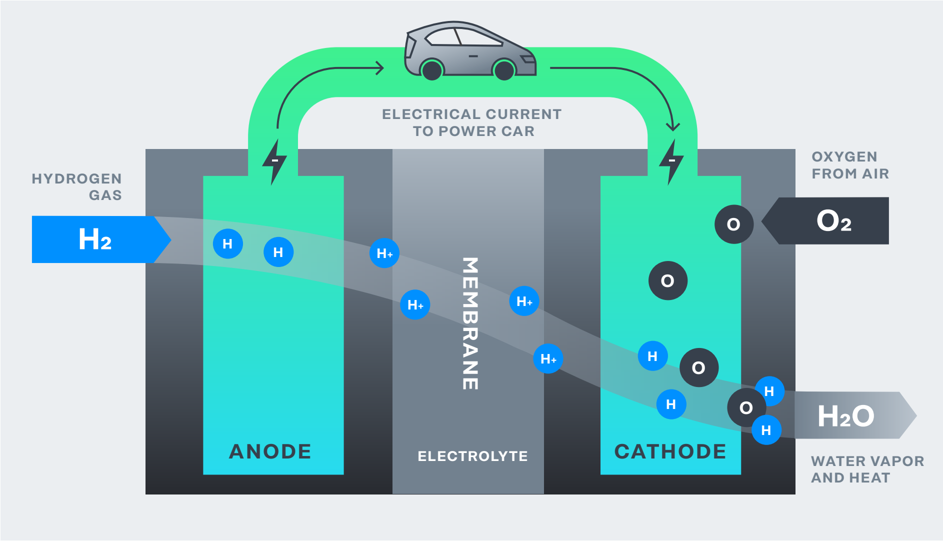
Electrofuels (also called power-to-gas or synthetic fuels) are fuels produced from electricity, CO_2, and water. Electrofuels are produced by mixing hydrogen and CO_2 in a synthesis reactor, resulting in a range of liquid and gaseous fuels including gasoline and diesel. The production process also generates marketable byproducts: high-purity oxygen and heat.

Electrofuels can help manage variations in electricity production, reduce the need for biofuels, and aid in decarbonizing transportation sectors where fuel switching is difficult, such as shipping. If electrofuels are produced from renewable electricity and CO_2 from either sustainable bioenergy or air capture, they could also be a carbon-neutral alternative that enables the continued use of existing investments in vehicles and fuel infrastructure.

Fuel Cells

R&D VALIDATION SCALE

A hydrogen fuel cell utilizes hydrogen and oxygen to power a vehicle through a chemical conversion process, with heat and water as the only byproducts.



At present, electrochemical conversion technologies such as fuel cells can convert hydrogen into automotive power with almost 60 percent efficiency, and are theoretically capable of exceeding 80 percent. In addition to solving other challenges, such as the development of high-density onboard hydrogen storage technologies and low-cost hydrogen production and distribution, the cost of fuel-cell technology must be significantly reduced for the widespread deployment of fuel-cell–powered vehicles.

Key challenges for fuel-cell cost reduction include reducing the use of precious-metal catalysts, improving the performance of potentially cheaper anion-exchange–based fuel cells, and finding transformational new fuel-cell technologies that can efficiently convert easily distributed and storable liquid fuels (like alcohols or hydrocarbon) into low-carbon automotive power. In addition, additional hydrogen infrastructure is needed to support hydrogen fueling for transportation and could help in expanding clean public transit options in historically marginalized communities.

Additional Resources

- DOE: 2016 Billion-Ton Report
- Congressional Research Service: The Renewable Fuel Standard (RFS): An Overview
- NREL: Bioenergy Market Report
- UCS: California's Clean Fuel Standard Boosts the Electric Vehicle Market

TRANSPORTATION SOLUTION

Efficient Mobility

Overview

To make transportation more efficient, we need to move more goods and passengers while emitting fewer harmful GHGs. Some efficiency improvements, such as reducing vehicle miles traveled (VMT) and the carbon footprint of freight and cargo handling, can create economic benefits across the transportation sector.

While expediting near-term decarbonization, increasing mobility and transit options can also provide important health and community benefits. Prioritizing clean and affordable transportation options is a common tenet of national environmental justice efforts. Scaling up investments in efficient mobility, zero-carbon public transit, affordable access to zero- and low-carbon vehicles, and planning for communities to promote safe walking and biking can reduce carbon emissions, improve air quality, and result in better health and more low-carbon public transit options in disadvantaged communities.

In addition, technologies that increase fuel economy, reduce the weight of vehicles and equipment, and provide equitable transportation options across all communities will further amplify the carbon reductions achieved through electrification and the use of low-GHG liquid fuels.

Market Challenges

Land Use and Permitting

Local policymakers must develop transportation systems that balance the needs of all users: freight carriers, motorists, transit riders, bicyclists, and pedestrians. But land use and permitting can be a significant barrier to the development of efficient, balanced, multimodal transportation networks. Planners must consider existing housing and development policies and zoning requirements when considering major investments in transit or improvements to freight facilities. Policies should link housing, land use, and mobility and work to streamline the permitting processes for projects that show net benefits in housing and environmental attributes, including air quality improvements and employment opportunities. They should also prioritize investments that provide direct benefit to underserved and historically disadvantaged populations.

Public Perception

In the U.S., transit ridership has grown by more than 20 percent in the last decade. However, public perception of transit as unreliable, inefficient, and inconvenient has slowed its rate of market adoption. Transit investment has lagged in low-income and historically disadvantaged communities, resulting in transit deserts in areas with limited economic opportunity and poor air quality. Transit demand has also been hampered by low gas prices that do not reflect the fuel's green premium, as well as by the rise of transportation network companies (TNCs) like Uber and Lyft. Policies that increase investment in public transit and result in more reliability and lower costs can work to reduce these market barriers.

Shifting public expectations of freight delivery systems also impede the development of more efficient mobility. The race towards ever-faster shipping is driving companies like Amazon, UPS, and FedEx to increase delivery trips. Instant (and often free) shipping encourages consumers to make multiple small purchases which can increase vehicle miles traveled (VMT) and reduce efficiency. Policies that encourage reductions in freight VMT and require adoption of zero-emission freight equipment can work to reduce the carbon footprint of this new reality of instant delivery.

Cost Barriers

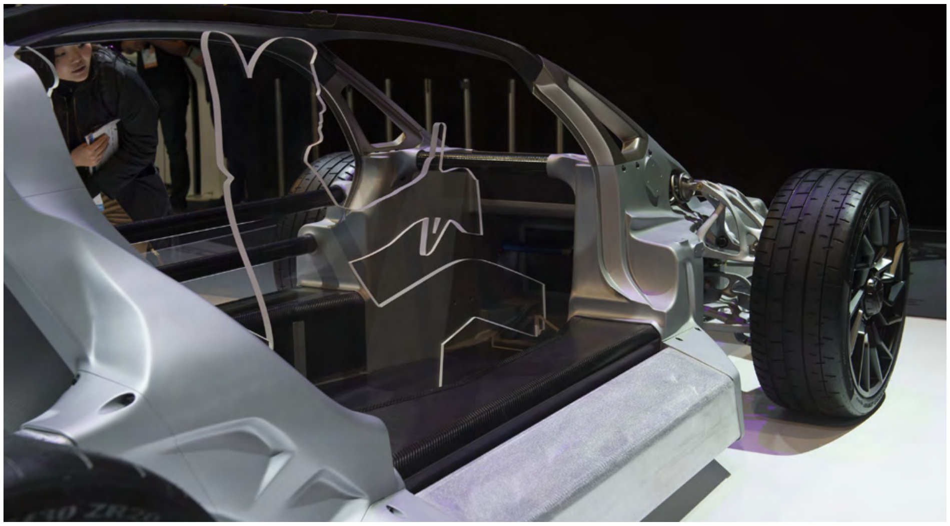
Large upfront capital costs are a huge market barrier to the purchase of zero-emission freight equipment at transportation hubs such as ports, distribution centers, airports, and rail yards. Despite potential long-term savings due to reduced operating and maintenance costs, zero-emission equipment remains out of reach for most transit and freight operators. Procurement policies that require federal and state purchases of advanced technology equipment can drive down production costs through economies of scale. Fiscal incentives can further reduce the green premium of zero-emission equipment and help encourage market penetration.

Technologies

Lightweight Materials

R&D **VALIDATION** SCALE

Manufacturing vehicles with advanced lightweight materials can significantly improve their efficiency, thereby reducing emissions.



One of the best ways to reduce carbon emissions from transportation is to make all vehicles—cars, trucks, planes, trains, and ships—lighter. In a typical light-duty car, every 10 percent reduction in weight increases fuel efficiency by 6-8 percent, and a 30 percent weight reduction improves efficiency by up to 20-25 percent.

The use of strong, lightweight materials like carbon-fiber–reinforced plastics and metals such as aluminum or magnesium present tremendous opportunities for vehicle-weight reduction. However, these materials are currently too expensive to manufacture, and cost-effective technologies for joining them together into lightweight structures do not yet exist in many cases. To see dramatic reductions in GHG emissions, we need to develop transformational new lightweight materials, inexpensive manufacturing processes, and new material-joining processes.

Additional Resources

- → **OneNYC: 2050**
- → **EPA: Managing Supply Chain GHG Emissions**
- → **CAP: Reducing Carbon Footprint Through Infrastructure**
- → **California Sustainable Freight Action Plan**

TRANSPORTATION POLICIES

Policy Overview

Procurement

Federal procurement policies can reduce costs and drive private sector demand for the next generation of EVs and EV equipment, low-carbon fuels, and efficient, low-GHG transportation products and equipment.

Procurement policies that focus on categories with little electric-technology penetration—including heavy-duty vehicles and equipment and marine vessels—can spur market adoption and encourage long-term deep decarbonization. The infrastructure required to support federal EV procurement can also increase public access to EV charging and support equitable access to vehicle charging in historically disadvantaged communities.

Procurement targets based on a fuel's relative carbon intensity can remain technology neutral, while incentivizing both advanced biofuels and continued innovation. In addition, long-term federal contracts for low-GHG fuel procurement can create consistent revenue streams for producers. This, in turn, can finance further capital expenditures in the development and deployment of advanced biofuels.

Federal procurement policies that base purchases on GHG emissions can motivate deployment of more efficient, low-GHG products and equipment. Federal "Buy Clean" standards support products with lower lifecycle emissions and motivate efficiency in supply chains. Prioritizing low-emission products and equipment for public transit can also speed the deployment of early-stage technologies.

For more, see the deep dive on

→ **Transportation Procurement**

Driving Market Penetration

Despite decreasing green premiums in electric vehicles and equipment, factors such as cost, vehicle range, customer education, and the phase-out of federal tax credits continue to slow the pace of EV market penetration. Lack of equitable public charging infrastructure has also prevented EV adoption, specifically in rural and historically marginalized communities. Consumer hesitation about relatively new technologies also poses a major barrier to the widespread deployment of low-GHG fuels.

Federal funding focused on increasing consumer awareness and providing equitable access to charging/fueling infrastructure can maximize the impact of federally supported investments and help mitigate these market barriers to EV and low-carbon fuel adoption.

Land Use Permitting Reform

Transportation networks shape and are shaped by development and land-use patterns that can either support or hinder a more sustainable and multimodal future. Along with infrastructure and technology, strategies to reduce emissions in transportation must actively encourage development, conservation, and land-use patterns that promote deep decarbonization. Modifying permitting and planning rules to expedite clean mobility and infrastructure can support long-term investment in, and the deployment of, more efficient mobility options.

Clean Fuel Standard

A clean fuel standard can offer an alternative or complementary approach to a carbon price for the transportation sector. As the power sector becomes cleaner, electricity has the potential to be a zero-emission fuel that can displace gasoline and diesel. Electrofuels (synthetic liquid or gaseous fuels made using electricity) also show great promise in medium- and heavy-duty applications by providing alternatives to fossil fuels for vehicles and other equipment that have been difficult to decarbonize.

A technology-neutral clean fuel standard that incentivizes fuel-use based on its carbon intensity can propel the large-scale deployment of electricity and low-carbon fuels, as well as the infrastructure required to support electric vehicle and equipment fleets. This deployment of clean alternatives can in turn improve air quality and provide direct economic benefits to historically disadvantaged communities.

For more, see the deep dive on

→ **Clean Fuel Standard**

ZEV Mandate

Zero-Emission Vehicle (ZEV) mandates can achieve long-term emission reductions by requiring manufacturers to offer specific numbers of the cleanest vehicles and equipment available. These clean technologies include full battery-electric, hydrogen fuel cell, and plug-in hybrid-electric equipment. ZEV mandates can reach beyond cars to include trucks and buses, off-road equipment, and even marine and rail applications. They help ensure the supply of clean technology is ready and available to meet consumer demand.

Efficiency Standards

Thanks in part to efficiency standards, carbon emissions from light-duty vehicles have decreased 23 percent and fuel economy has increased 29 percent since 2004. But these tremendous gains have yet to be realized in other transport modes—including medium- and heavy-duty vehicles, rail, marine vessels, and off-road equipment.

Efficiency standards that encourage further innovation will lead to consumer cost savings. They will also spur long-term investments in technology and infrastructure by providing regulatory certainty for expected future vehicle performance improvements. Efficiency standards should also increase options to procure affordable and efficient vehicles.

Investment in Infrastructure

Significant federal resources are needed to shore up aging roads and bridges, provide resilience against natural disasters, promote efficient mobility, and encourage deep decarbonization in transportation, especially in low-income and historically marginalized communities. For example, robust EV charging infrastructure is critical to widescale and equitable adoption of electric vehicles. As such, the federal government should ensure investments in EV charging infrastructure are appropriately prioritized in any major federal infrastructure investment package. Several federal funding mechanisms exist to support this critical clean infrastructure, including increasing investment in existing competitive and formula clean energy grant programs.

Federal infrastructure bills should also provide flexibility for states to shift federal funds toward transit projects, promote the efficient movement of goods, empower local metropolitan planning organizations, and link air quality and climate impact directly to transportation project selection and funding. To reduce social inequities, infrastructure investments should be prioritized in low-income and historically disadvantaged communities to provide direct air quality benefits in areas that have been disproportionately burdened by emissions to date.

Cross-Sectoral Policies

Additional cross-sectoral policies would also help develop and deploy clean transportation technologies and solve the Transportation Grand Challenge.

For more, see the deep dives on

- → **Public Sector R&D**
- → **National Laboratory Reform**
- → **Stimulating Clean Energy Entrepreneurship**
- → **Demonstrating and Validating New Technologies**
- → **R&D Tax Credit**
- → **Technology-Neutral Innovation Tax Credit**
- → **Project Financing**
- → **Carbon Pricing**

TRANSPORTATION

Transportation Deep Dives

TRANSPORTATION DEEP DIVES

Clean Fuel Standard

Overview

A clean fuel standard (CFS) requires the producers and importers of fuels used in transportation to reduce their greenhouse gas (GHG) emissions over time. As a performance-based standard, a CFS encourages the use of low-carbon transportation fuels based on their carbon intensity (CI), or their lifecycle GHG emissions per unit of energy.

Under a CFS, the federal government sets decreasing annual CI targets but does not mandate how fuel providers meet them. Fuels whose CI does not exceed the benchmark generate credits, while fuels whose GHG emissions are too high generate deficits. Producers and importers comply with the CFS by providing a mix of fuels that generates more credits than deficits.

Producers of low-carbon fuels can use them to offset their own deficits or sell them to other fuel providers. Credits can be bundled and sold with low-carbon fuels. They can also be traded separately, generating revenue for the fuel producer and minimizing the total cost of achieving the CI reductions.

Policy Principles

Generating Credits: In a CFS, there are three ways to generate credits:

1. Providers of low-carbon fuels generate credits by attaining a certified CI. Credits are calculated relative to the annual CI benchmark and are verified by a third party.
2. Project-based credits are generated through actions that reduce GHG emissions in the petroleum supply chain, including carbon capture using direct air capture (DAC). Crediting for projects is based on lifecycle emission reductions and verified by a state-approved verifier.
3. Deployment of Zero-Emission Vehicle (ZEV) infrastructure generates credits based on the capacity of the hydrogen station or EV charging site, minus the emissions of the fuel dispensed.

Covered Entities: Every provider of transportation fuel in the U.S. should be required to comply with the CFS. Providers include electric utilities, natural gas utilities, and suppliers of liquid and gaseous fuels used in aviation, marine, on-road, and off-road applications. Petroleum importers, refiners, and whole-salers are also required to participate. Zero- and low-carbon fuel providers can opt in if they wish.

Targets/Ambition: A CFS should aim to decarbonize U.S. transportation fuels completely by 2050. To provide regulatory certainty, a CFS policy should establish a schedule for CI benchmarks that outlines the average CI that fuels replacing gasoline and diesel must meet at any given time.

Qualifying Technologies: Technologies available that already comply with the CFS include ethanol from grains and sugars, biodiesel and renewable diesel, biogas, compressed natural gas (CNG), liquid natural gas (LNG), electricity, hydrogen, lignocellulosics, and classic Fischer-Tropsch fuels.

Tech Neutrality: A CFS is technology neutral: it provides a strong price signal for the development and deployment of the lowest-carbon fuels without choosing winners or losers. The scope of the standard should capture the diverse fuel portfolio available both today and in the near future.

CI Determination: The CFS asks fuel providers to determine the CI of the fuels they sell and report that information to EPA for review and approval.

Trading: Credit trading is a central tenet of a CFS. It promotes economic efficiency and provides a revenue stream for low-carbon fuel providers. Trading also provides flexibility by making it possible for fuel providers to bank credits for future compliance. The federal government should establish a trading platform to facilitate and verify these trades and monitor the market.

Price Collar: Providing a stable, long-term price signal is key to achieving deep decarbonization under a CFS. A carefully designed price collar can promote stability in the credit market and make clear the total cost of compliance. In some applications, a price collar can also provide access to additional pools of credits, providing compliance flexibility when short-term imbalances exist in credit supply and demand.

A CFS policy should establish a credit-price ceiling that increases through 2050, along with a mechanism that ensures no credits are sold above that ceiling. By providing certainty as to the highest potential credit price, fuel providers can make cost-effective investment decisions related to the generation and sale of credits. Similarly, A CFS policy should also establish a credit-price floor and a mechanism that guarantees no credits are sold below that price. This also provides certainty about the lowest potential cost of credits, which fuel providers can use to obtain long-term contracts and bank financing for capital projects.

Emissions Accounting and Verification: The federal government must estimate the lifecycle GHG emissions of all transportation fuels in the U.S. Third-party experts should verify these estimates to make sure the CFS is successfully reducing CI and emissions.

Driver Impacts: A CFS should be designed to protect drivers from excessive fuel costs and provide equitable access to clean fuels, specifically in communities that are disproportionately impacted by the effects of climate change and air pollution. At the same time, revenues generated from the sale of zero- and low-carbon fuels should provide benefits to all Americans, including reducing co-pollutants and mitigating health inequalities in historically marginalized communities.

Air Quality Impacts: A CFS should include provisions that incentivize air quality improvements in communities with poor air quality. The standard can include design elements to prioritize electrification in and near low-income and historically disadvantaged communities while promoting a wide portfolio of clean fuels across the U.S. A CFS must conform to equity principles and prioritize direct environmental and economic benefits in disadvantaged communities.

TRANSPORTATION DEEP DIVES

Procurement

Overview

Federal procurement policies can require federal agencies and federally funded state and local agencies to purchase zero- and low-carbon transportation equipment and fuels. These policies can reduce costs and drive market adoption of emerging technologies, provide a pathway to gradually transition to zero- and low-carbon transportation, and spur infrastructure investments that can benefit the private sector.

Principles

Covered Entities: The federal government should establish transportation procurement requirements for federal agencies and federally funded state and local agencies. The federal government should prioritize procurement policies focused on fleet electrification (including the U.S. Postal Service) which can lead to increased access to public charging, specifically in low-income and historically marginalized communities. It should also establish timelines to transition to zero- and low-carbon vehicles, fuels, and equipment through 2050 for technologies that are not yet commercially viable. Finally, the federal government should establish Zero Emission Vehicle (ZEV) mandates for transit agencies, military bases, and vehicle fleets by scheduling increasing ZEV purchase requirements through 2050.

For applications where electrification is not yet feasible, the federal government should mandate purchase requirements for low-carbon fuels and equipment based on their relative efficiency and carbon intensity (CI), defined as their greenhouse gas (GHG) emissions per unit of energy. The federal government should also require that all federal fleets and federally funded transportation and transit projects include electric charging and low-carbon fuel infrastructure.

Targets/Ambition: Federal transportation procurement policies should align with Buy Clean policies that incorporate emissions information into federal purchasing decisions. In general, they should aim to decarbonize federally funded transportation fleets by 2050. To provide certainty, the federal government should establish annual procurement requirements for vehicles, equipment, and fuels.

Qualifying Technologies: Federal procurement policies should be technology-neutral: they should promote the lowest-carbon technologies and fuels for every application, prioritizing deployment in low-income and historically disadvantaged communities. All zero-emitting GHG vehicles and fuels should receive prioritization, as should opportunities to offset combustion emissions through carbon removal and carbon sinks.

Compliance Flexibility: Establishing annual ZEV and fuel procurement requirements provide a clear market signal for investments in emerging technologies. However, compliance flexibility is important since products may become commercially viable sooner or later than anticipated. Periodic technology assessments should be scheduled to ensure that needed technologies are advancing to market.

TRANSPORTATION DEEP DIVES

Additional Transportation Policies

Driving Market Penetration for Electrification

Despite decreasing green premiums in electric vehicles and equipment, some key market barriers continue to prevent widescale adoption, especially in low-income and historically disadvantaged communities. Policymakers often lack data on the economic and environmental benefits of long-term investments in electric vehicles (EVs), equipment, and infrastructure. Consumer hesitation about relatively new technologies and concerns about cost are also significant barriers to widespread deployment.

The federal government can address these challenges and help drive the market adoption of electric vehicles and equipment through three avenues:

- **Consumer Awareness and Deployment of Charging Infrastructure:** Research shows that consumers cite EV infrastructure location and availability as barriers to purchasing EVs and electric equipment. As such, the federal government should commit funds to improve the Alternative Fuels Data Center (AFDC), which provides a map of public charging infrastructure for a variety of alternative fuel types across the U.S. and Canada. Improving the AFDC and promoting its use online will help consumers gain awareness of charging options and locations and lead to increased demand for EVs. Potentially expanding the AFDC to include collection of limited driver and charger usage can also provide information on where infrastructure expansion is needed. Prioritizing outreach in low-income and disadvantaged communities can also expand the deployment of both new and used EVs and promote equitable penetration.
- **Manufacturer and Transit Outreach Requirements:** The impact of federal fiscal incentives can be amplified by requiring funding recipients like transit agencies and related organizations to promote electrification, low-carbon fuels, and efficient mobility. The federal government should tie technical assistance requirements to fiscal incentives targeting outreach to small businesses and low-income communities. It should also establish best practices in consumer awareness and education, infrastructure operation and maintenance, and transit mobility options and require participation by agencies and manufacturers receiving federal monies. Additionally, the federal government should require recipients to track their own outreach and outcomes. Best practices established at the state level for EV charging and infrastructure development should be expanded at the federal level as well.

- **Metric Tracking for Federally Supported Transportation Programs:** Tying the impact of federal fiscal incentives to their outcomes can help identify the most cost-effective interventions. As such, the federal government should establish reporting and tracking requirements for incentive recipients to better inform future disbursement for electrification, low-carbon fuels, and efficient mobility. Fiscal incentive recipients should be required to track metrics related to changes in energy and fuel consumption, maintenance and reliability, safety, employment, and other environmental impacts. The federal government should use this collected data to perform retrospective analyses that identify the most effective fiscal incentive programs and encourage more efficient design of future programs.

ZEV Mandates

Zero-Emission Vehicle (ZEV) mandates can achieve long-term emission reductions by requiring manufacturers to offer for sale specified numbers of the cleanest vehicles and equipment available. These technologies can include full battery-electric, hydrogen fuel cell, and plug-in hybrid-electric equipment. ZEV mandates can also go beyond light-duty vehicles to heavy-duty vehicles, off-road equipment, and even marine and rail application. ZEV mandates ensure that the supply of clean technology is ready and available to meet consumer demand.

Federal ZEV Mandate: To achieve deep decarbonization, the U.S. must dramatically increase the market penetration of ZEVs across the spectrum of vehicles and equipment. The federal government could implement ZEV mandates for light-duty vehicles, medium- and heavy-duty vehicles and equipment, and marine and aviation vessels. Each ZEV mandate should require manufacturers to meet increasing credit-based ZEV requirements over time.

For each specific class of vehicle or equipment, the federal ZEV mandate should be tied to manufacturer volume, with exemptions and modified requirements for small- and medium-volume manufacturers (the definition is dependent on vehicle or equipment classification). The ZEV mandate should credit battery electric vehicles and fuel cell electric vehicles based on all-electric range (AER), with plug-in hybrid vehicles (PHEV) credited at a lower value based on their equivalent all-electric range (EAER). The federal ZEV mandate should also allow for a credit market, through which manufacturers that over-comply can generate revenue by selling credits to other manufacturers so they too can reach compliance.

California has implemented a ZEV mandate for light-duty vehicles which is projected to result in ZEV market share of about 8 percent in 2025. In 2017, China also finalized a modified version of California's program, the New-Energy Vehicle (NEV) mandate. The federal government should adopt a light-duty vehicle ZEV mandate at least as stringent as the California policy. In medium- and heavy-duty vehicles, California has an open regulatory procedure, the Advanced Clean Trucks (ACT) regulation, that would require manufacturers to increase the sale of ZEV class 4-8 trucks to 50 percent of total sales by 2030. Similarly, the federal government could expand the Phase 2 greenhouse gas (GHG) regulation devised by the Environmental Protection Agency (EPA) and

National Highway Traffic Safety Administration (NHTSA) to include a ZEV mandate and a ZEV credit market to facilitate compliance.

ZEV mandates are also needed for hard-to-decarbonize off-road equipment, locomotives, and airplanes. The federal government could promulgate new emissions standards for these vessels that require some zero-emission capacity, which would result in both air quality improvements and reductions in GHGs.

- The federal government should create Tier 5 locomotive emission standards requiring locomotives to have the capacity for zero-emission operation. Estimates show that this could reduce GHG emissions by up to 25 percent over existing locomotive standards.
- The Federal Aviation Administration (FAA) should update its guidelines to include zero-emission aircraft and, as outlined in the Clean Air Act, work with EPA to issue efficiency standards that include requirements for zero-emission operation among small aircraft. The efficiency standards should also include a reduction in fuel consumption in line with International Civil Aviation Organization (ICAO) performance standards requiring carbon intensity reductions in the aviation sector starting in 2028.
- In addition, the federal government should participate in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) which will require measurement, verification, and reporting of GHG emissions to ICAO. The federal government should also support the Electric and Hybrid Aircraft Platform for Innovation (E-HAPI) which is piloting efforts for zero-emission aviation across vessel types around the world.

Driving Market Penetration for Low-GHG Fuels

Despite decreasing green premiums in low-GHG fuels, some key market barriers continue to slow widescale adoption. Consumer hesitation about relatively new technologies is a major barrier to widespread deployment. In addition, corporations and policymakers often lack information on the performance and air quality impacts of low-GHG fuels as well as the economic benefits of expanding markets for advanced biofuels.

- **Alternative Fuel GHG Labeling Requirements:** The federal government should expand the alternative fuel labeling requirements to include information related to the economic and environmental benefits of alternative fuels. Currently, fuel dispensers are required to identify the components of alternative fuels to help consumers make informed decisions about fueling their vehicles. Electric Vehicle Supply Equipment (EVSE) manufacturers are required to disclose information regarding the kilowatt capacity and voltage of charging equipment.

  In addition to the current requirements, the federal government should require EVSE and fuel dispensers to include information regarding the economic and environmental attributes of fuel, including costs and cost savings relative to conventional fossil fuels, fuel source and transportation costs, and potential air quality and GHG impacts. It should also establish guidelines for required metrics and presentation as well as a schedule of when to update the fuel information.

- **Outreach Requirements for Biofuel Producers Receiving Federal Fiscal Incentives:** The impact of federal fiscal incentives can be amplified by requiring funding recipients to promote electrification, low-carbon fuels, and efficient mobility. The federal government should tie technical assistance requirements to federal fiscal incentives targeting outreach to small businesses and low-income communities. It should also establish best practices in consumer awareness and education, infrastructure operation and maintenance, and transit mobility options. Additionally, the federal government should require recipients to track their own outreach and outcomes. Best practices established for EV charging and infrastructure development at the state level should be expanded at the federal level.
- **Cost-Benefit Analyses of Federally Supported Investments in Low-GHG Fuels, Equipment, and Infrastructure:** Tying the impact of federal fiscal incentives to outcomes can help identify the most cost-effective interventions. As such, the federal government should establish reporting and tracking requirements for recipients of federal fiscal incentives to better inform future incentive disbursement for electrification, low-carbon fuels, and efficient mobility. Fiscal incentive recipients should be required to track metrics related to changes in energy and fuel consumption, maintenance and reliability, safety, employment, and other environmental impacts. The federal government should use the collected data to perform retrospective analyses that identify the most effective fiscal incentive programs and encourage more efficient design of future fiscal programs.

Efficiency Standards

Moving more people and goods with fewer emissions is key to achieving long-term GHG and air quality reductions. Since 2004, carbon emissions from light-duty vehicles have decreased 23 percent and fuel economy has increased 29 percent. Unfortunately, these tremendous gains have yet to be realized in other transport modes, including medium- and heavy-duty vehicles, rail, marine vessels, and off-road equipment. Further efficiency gains will result in cost savings to consumers and corporations, improvements in air quality, and can drive long-term investments in technology and infrastructure.

- **Adopt Stringent Federal Efficiency Standards for Aviation:** GHG emissions from aviation continue to rise, accounting for 2.5 percent of global energy-related emissions in 2018. Energy efficiency in aviation has also been slowing, from 3.2 percent from 2000 through 2014 to less than 1 percent from 2014 to 2016. In addition, and notwithstanding the system-wide disruption caused by the COVID-19 pandemic, passenger activity in aviation is generally increasing. To address these trends, the federal government should implement more stringent aviation efficiency standards that go beyond the ICAO 2028 standards.

- **Increase Stringency of 2021–2026 GHG Emissions Standards for Light-, Medium-, and Heavy-Duty Vehicles:** EPA and NHTSA should increase the stringency of the Corporate Average Fuel Economy (CAFE) and GHG emissions standards for model 2021–2026 passenger cars and light trucks. These federal standards should match or exceed standards set in California, including ZEV requirements. EPA should also increase the stringency of Phase 2 GHG regulations for medium- and heavy-duty trucks to improve fuel efficiency, reduce emissions and air pollution, and bolster energy security. These standards will both reduce GHG emissions and result in significant air quality improvements.
- **Mandate Federal Efficiency Standards for Marine Vessels:** The federal government should strengthen existing oceangoing vessel efficiency standards and establish Tier 5 marine diesel engines standards in the Emissions Control Area (ECA) for North America and the U.S. Caribbean that include zero-emission operation.

Low-Carbon Transportation Infrastructure

Significant federal resources are needed to shore up aging roads and bridges, provide resilience against natural disasters, and promote efficient, low-emissions mobility across the transportation sector. Federal infrastructure bills should prioritize investments in low-carbon transportation infrastructure, provide flexibility for states to shift federal funds toward transit projects, promote efficient goods movement and logistics systems, empower local metropolitan planning organizations, and link air quality and climate impact directly as criteria for transportation project selection and funding.

- **Link Federal Transportation Infrastructure Funding to Air Quality and Reductions in GHGs:** The federal government can ensure that any federal transportation infrastructure funding supports resilience and results in measurable GHG reductions. All federal transportation bills should include emissions reduction targets and reporting requirements to track the impact of direct federal spending on GHG emissions and air quality impacts.
- **Prioritize Federal Investment in EV and Low-Carbon Fuel Infrastructure:** When considering major federal infrastructure investment packages, Congress should ensure investments in EV charging infrastructure, as well as low-carbon fuel distribution and dispensing infrastructure, are prioritized appropriately. Congress should consider a wide range of funding mechanisms to fund much-needed decarbonization infrastructure, including increasing funding for existing competitive and formula clean energy grant programs and prioritizing deployment in low-income and historically disadvantaged communities.

GRAND CHALLENGE

Manufacturing

How We Make Things

MANUFACTURING

Overview

Manufacturing—the cement in our buildings and bridges, the steel in our cars and appliances, the clothes we wear, the books we read, the plastic toys and containers we buy, refining the gas we put in our cars—directly accounted for nearly 26 percent of greenhouse gas (GHG) emissions in the U.S. in 2018, making it the nation's third largest source after transportation and power generation.

(That number includes emissions from the production, transportation, and transformation of oil and gas, but not from the combustion of those fuels in buildings, power plants, and vehicles. It also excludes emissions associated with the generation of electricity used in industrial processes.)

Adding the emissions associated with electricity use in the manufacturing sector increases its emissions share to 29 percent of the U.S. total, essentially tied with transportation as the largest-emitting sector in the economy. These emissions come from using energy to generate heat, electricity, and steam, drive machines, and from chemical reactions that are the basis for how we manufacture goods today.

To get our industrial sector to net-zero emissions, policy action needs to encourage the development and deployment of new technologies. Currently, low-GHG technological options in this sector are lagging in deployment compared to electricity, buildings, or transportation, and there are fewer existing policy levers. Fortunately, more opportunities are emerging to decarbonize manufacturing—including electrifying industrial processes that currently use fossil fuels, developing low-GHG alternatives to fuels where electrification isn't cost-effective, increasing energy and material efficiency, deploying carbon capture technologies, and reducing methane emissions from the production and transportation of oil and gas.

MANUFACTURING SOLUTION

Electrification

Overview

A primary source of manufacturing-sector emissions is the fossil fuel combustion used to create the heat many industrial processes require. New heat pumps, boilers, and furnaces powered by clean electricity can provide a low- or zero-emissions alternative to these existing fossil-fueled heat sources. They can also improve local air quality, which is especially important given that many manufacturing facilities are located in, and have created adverse health impacts for, low-income communities.

Electrification is particularly promising for manufacturing processes that require relatively low-temperature heat, which comprise 30 percent of industrial heat requirements. Other production processes, like drying and curing, can also use electricity in place of fossil fuels.

Market Challenges

Economic Structure

The economic structure of the manufacturing sector presents a barrier to deeper decarbonization. Manufacturing firms make investment decisions on long timeframes, and the equipment they purchase can last for 50 years or more. There is currently very little economic incentive to electrify still-functioning equipment within its useful operational life. Moreover, the largest industrial GHG emitters tend to produce materials that are highly commoditized. In a competitive global market, there are few opportunities to receive a premium for low-carbon products. In addition, the fragmentation of product value chains means the necessary capital for decarbonization investments may not be at the firms that need to make those investments.

Technology Limitations

Many manufacturing processes require very high temperature heat: above 700 degrees Fahrenheit. Currently, there are few options available, other than fossil fuel-fired technologies like boilers and furnaces, to reach these temperatures. Innovations such as high temperature heat pumps powered by electricity are not yet capable of providing high enough temperatures.

Access to Capital

The upfront capital costs associated with replacing existing equipment with new electrification technologies is high, especially if the equipment is still within its estimated useful life. Industrial producers tend to operate with tight profit margins and can get higher investment returns on new production or product development rather than from energy upgrades or retooling at existing facilities. Even if the expenditures are justified based on operational savings, securing enough capital to make these incremental infrastructure investments remains a barrier to electrifying the manufacturing sector.

Technologies

Electrification Technology

R&D VALIDATION SCALE

Electrifying technologies—such as new high-temperature heat pumps, boilers, and furnaces powered by carbon-free electricity—provide a critical opportunity to reduce greenhouse gas emissions across the manufacturing sector.

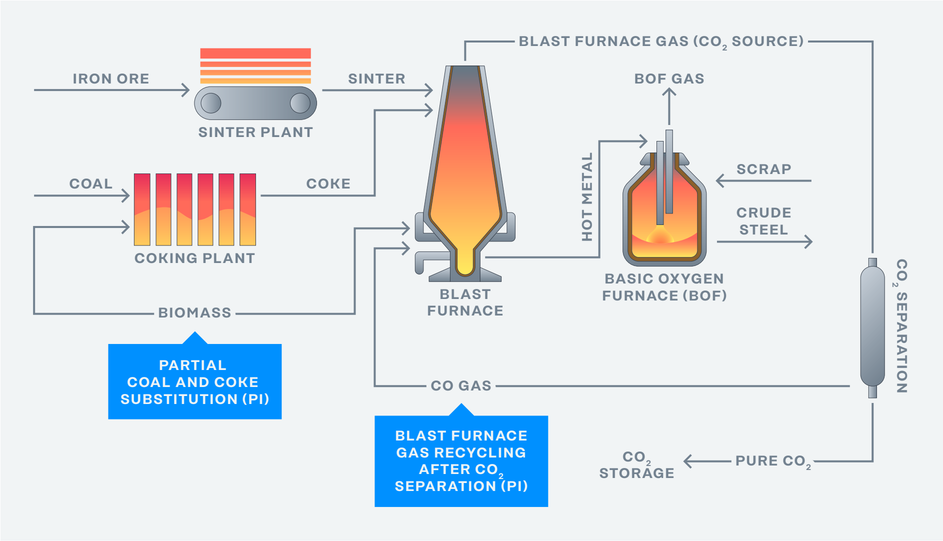
The electrification of technologies across the manufacturing sector provides an opportunity to replace current carbon-intensive systems with low-carbon alternatives. For instance, a large fraction of the energy used by manufacturing is for process heating, which is almost entirely powered by fossil fuels. The development of new high-temperature heat pumps, boilers, and furnaces powered by carbon-free electricity has the potential to shift manufacturing away from non-electric sources of energy and significantly reduce GHG emissions and improve air quality.

Other potential manufacturing processes that are candidates for electrification include machine drives and facility HVAC. Depending on the application, certain electrification technologies are commercial while others are still early-stage.

Low-GHG Steel

R&D VALIDATION SCALE

Two process integration (PI) pathways for reducing emissions from existing steelmaking processes are shown: biomass substitution for coal and CO_2 capture and recycling.



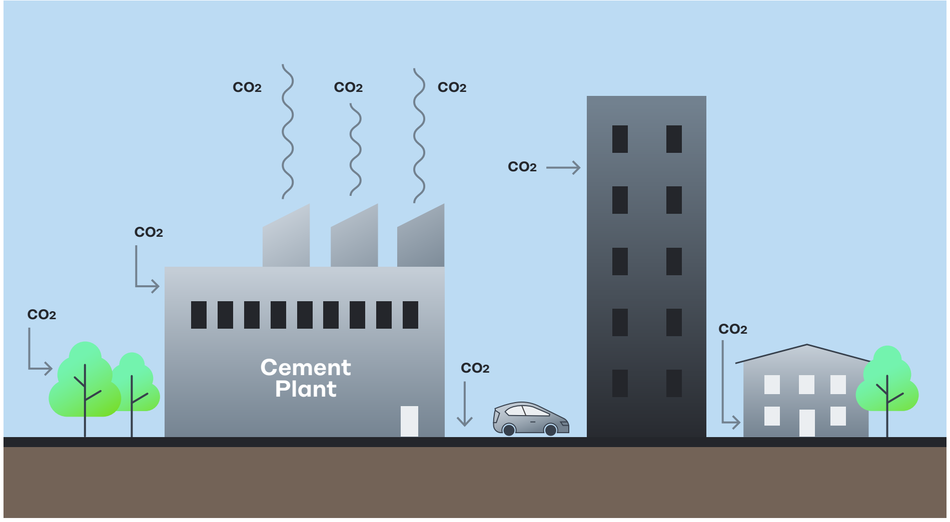
Iron and steel production are responsible for about 5 percent of global greenhouse gas emissions. Most of these emissions come from the fossil fuels used to convert iron ore into steel through carbothermic reduction, particularly in the blast furnace. Existing cleaner production technologies include direct reduction of iron oxide to steel using natural gas, molten oxide electrolysis, CO_2 capture and storage, steel recycling using electric arc furnaces for some steelmaking applications, and the replacement of coal in the steelmaking process with lower-GHG feedstocks.

At present, many of these technologies are not cost competitive with the incumbent processes for primary steel production. The slow stock turnover of industrial facilities also presents a challenge to the rapid diffusion of lower-carbon production approaches. Reducing iron oxide to iron and steel using low-carbon electricity or low-GHG hydrogen (rather than natural gas) is a potentially transformative technology that could substantially reduce steel sector emissions even further.

Low/Negative-GHG Cement

R&D VALIDATION SCALE

Cement production releases a significant amount of CO_2 emissions, but new processes and materials are under development that could consume more CO_2 than was generated over the cement's life cycle.



The production of cement is responsible for about 7 percent of global GHG emissions—roughly 40 percent of which is from the energy used and 60 percent from the CO_2 released chemically by the heating of limestone.

Opportunities for significant emissions reductions in cement and concrete include CO_2 capture and storage, the development of low-emission material substitutes for cement/concrete, recycling end-of-life concrete for reuse, and the development of processes and materials that consume CO_2 (as opposed to generating it) in cement or cement-replacement production—thereby enabling emissions-negative cement production.

Additional Resources

- → Berkeley Lab: Electrification of Buildings and Industry in the United States
- → EPA: Renewable Industrial Process Heat
- → NREL: Electrification of Industry
- → RMI: The Next Industrial Revolution
- → RMI: The Disruptive Potential of Green Steel
- → Rhodium Group: Clean Product Standards

MANUFACTURING SOLUTION

Low-Carbon Fuels

Overview

Biofuels, hydrogen, and other electrofuels derived from clean electricity can provide heat for manufacturing processes and replace conventional fossil-derived fuels. These low-GHG fuels are important in applications for which electrification is too costly or which require very high temperatures.

While many alternative fuels exist today, they are not yet commercially competitive at scale. We need policies that can drive investment in the production of low-GHG fuels, improve air quality, reduce costs, and accelerate the rollout of new technologies.

Market Challenges

Technological Limitations

Though pathways to produce synthetic liquid fuels and biofuels exist today, technologies to produce low-GHG liquid fuels are still in development and not yet to scale. These technologies rely on processes still in their early stages such as producing low-GHG hydrogen and high-temperature heat as well as synthesizing advanced biofuels. All these technologies require more research and development before becoming commercially available at scale.

Supply of Feedstocks

Increasing the total supply of sustainable biomass will require a large-scale expansion of dedicated cellulosic energy crops such as switchgrass, miscanthus, and short-rotation poplar. By one estimate, even if all the world's grassland was converted to energy cropping, only around 15 percent of world energy requirements in 2050 could be replaced with biomass. Expanding the supply of waste feedstocks is not viable either because the supply of used cooking oil, animal fats, tall oil, and palm fatty acid distillate (PFAD) is relatively fixed and limited. The use of forest residues or forest woody biomass is another option, especially in North America and in parts of Europe, though there is significant regional variability in the timing and availability of wood waste.

Low-carbon synthetic fuels rely on a different type of "feedstock": low-cost, zero-carbon electricity. As such, the current lack of consistent and sufficient supply of renewable energy is also a barrier to economically viable synthetic hydrocarbon fuel production. For now, production costs remain significantly higher than fossil fuels.

Cost Barriers

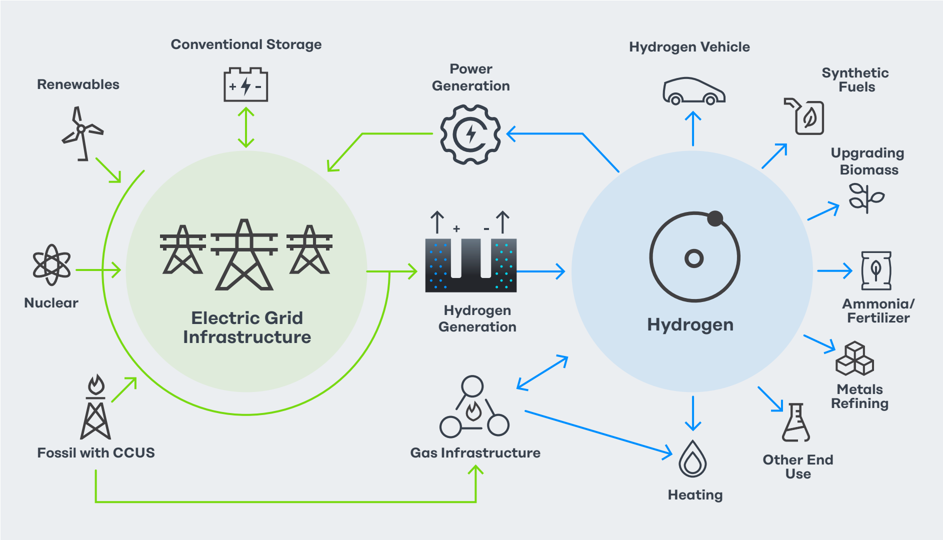
Advanced biofuels remain considerably more expensive than fossil and food-based biofuels. This is especially true for aviation and marine fuels, two of the most important markets to crack. Low-GHG synthetic fuels are also early in their deployment, making their costs much higher than conventional liquid fuels as well.

Technologies

Low-GHG Hydrogen

R&D VALIDATION SCALE

Low-GHG hydrogen has the potential to drastically reduce emissions from a variety of industries as a fuel or feedstock, as well as from the transportation and power sectors.



Low-GHG hydrogen is an alternative fuel or feedstock that can be attractive for a wide range of applications. Produced cheaply and without the co-production of CO_2, hydrogen has the potential to revolutionize almost every emissions-intensive industry on earth, from fuels to fertilizers and steel to cement. Hydrogen also offers energy-storage capabilities, which can help variable renewable sources (such as wind and solar) capture a larger share of the electricity market.

Recent technical breakthroughs and the changing nature of zero-carbon electricity production offer a plethora of new approaches to the production of "green" hydrogen, including thermochemical, electrochemical, and geologic (mined) hydrogen-generation technologies. Low-GHG hydrogen can also be produced via traditional natural gas steam methane reforming if the resulting CO_2 is captured, a process referred to as "blue" hydrogen.

Additional Resources

- → DOE: Fuel Cells Technologies Office
- → IRENA: Innovation Outlook: Advanced Liquid Biofuels
- → DOE Alternative Fuels Data Center: Hydrogen

MANUFACTURING SOLUTION

Energy and Material Efficiency

Overview

Efficient manufacturing means it takes less energy to make the same product, reducing GHG emissions on a per-unit basis. Strategies for increasing efficiency vary across manufacturing sectors but include replacing old equipment with newer, energy-saving models and using intelligent energy management systems to turn equipment down or off when it isn't needed. A more efficient manufacturing sector will reduce overall costs of decarbonization by requiring less low-GHG fuel or carbon capture deployment.

Market Challenges

Economic Structure

The economic structure of the manufacturing sector presents a barrier to deeper decarbonization. Manufacturing firms make investment decisions on long timeframes, and the equipment they purchase can last for 50 years or more. There is currently very little economic incentive to replace still-functioning equipment within its useful operational life with a more efficient alternative. Even given this long-term investment thinking, manufacturing facilities in the U.S. tend to overlook efficiency improvements with all but the shortest payback periods. Moreover, the largest industrial GHG emitters tend to produce materials that are highly commoditized. In a competitive global market, there are few opportunities to receive a premium for low-carbon products. Fragmentation of product value chains also means the necessary capital for decarbonization investments may not reside at the firms that need to make them.

Access to Capital

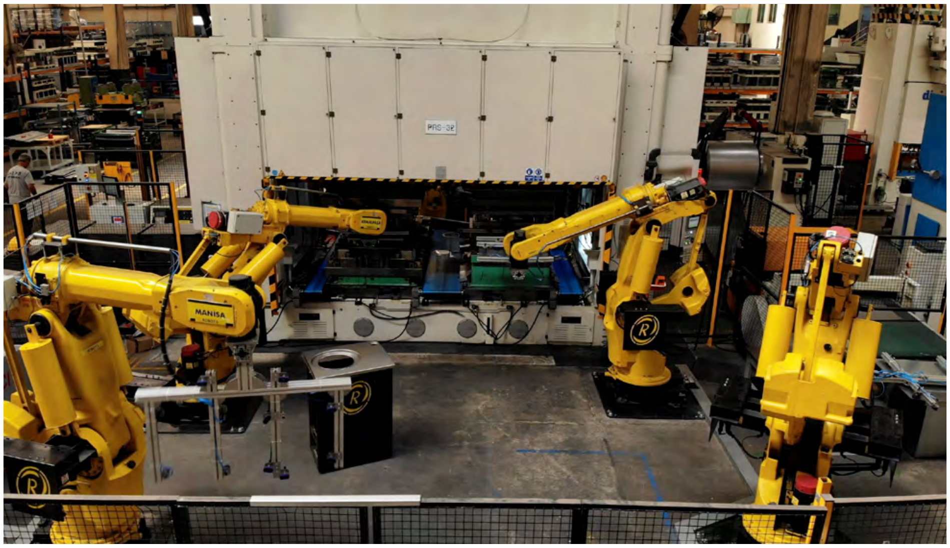
The upfront capital costs associated with replacing existing equipment with new efficient technologies is high, especially if the equipment is still within its useful life. Industrial manufacturers tend to operate with tight profit margins and can get higher investment returns on new production or product development rather than from energy upgrades at existing facilities. Even if the economics are justified over the equipment's lifetime, securing sufficient capital to make these investments in facility-level retrofits presents a barrier to increasing efficiency in the manufacturing sector.

Technologies

Industrial Energy Efficiency

R&D VALIDATION SCALE

Smart manufacturing can increase energy efficiency and reduce emissions by optimizing industrial processes through the use of sensors and data processing.



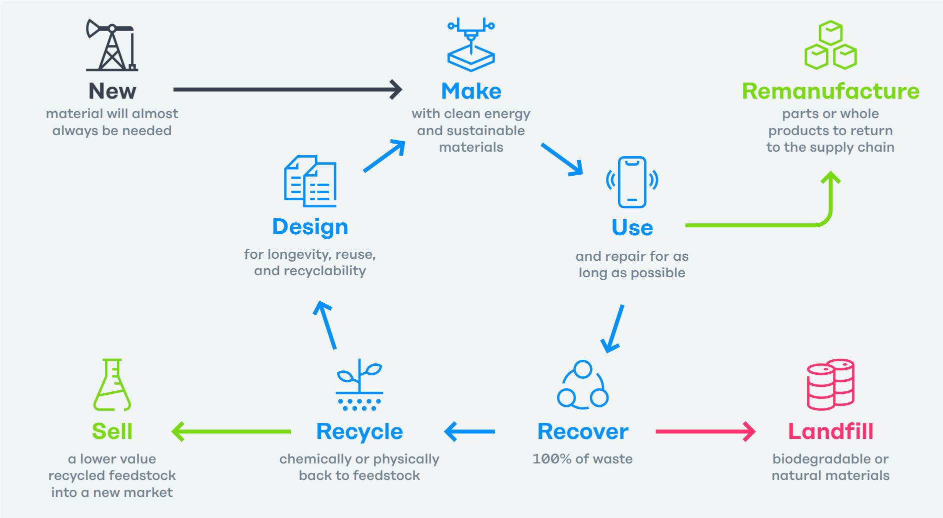
The manufacturing sector has a long track record of adopting energy efficiency measures that have helped contribute to the declining carbon intensity of manufacturing over time. As RD&D continues, more energy-efficient technologies and practices can further reduce industrial carbon emissions.

One particularly promising area of research is smart manufacturing: using sensing and data-processing capabilities to optimize industrial processes and reduce energy consumption. In smart manufacturing, advanced sensors are placed at key points through an industrial process, collecting data on production conditions, inputs, and outputs. This data is then processed using advanced computer models and algorithms and applied to the improvement of manufacturing processes. These changes can be made at many stages: in-situ via real-time controls, via changes to human-technology interfaces, or in complete overhauls of existing processes.

Circular Economy

R&D VALIDATION SCALE

A circular economy model, shown here, reduces energy intensity and emissions by retaining the value of goods and materials for as long as possible through improved design, reuse, repair, remanufacture, recovery, and recycling.



A circular economy is a more sustainable alternative to the linear "take-make-dispose" model of consumption. As the world's population increases, urbanizes, and becomes more affluent, consumption and material intensity will rise accordingly. This will drive up input costs and increase price volatility at a time when access to new resource reserves is becoming more challenging and expensive.

The circular economy—reusing, recovering, and recycling—is less energy-intensive than producing goods from virgin materials. Key materials that can contribute to emissions reductions through recycling are aluminium, steel, plastics, paper, cement, and food. New business models, practices, and technology solutions are in various stages of development and deployment for the way goods are designed, made, and used and for how recyclables are collected, sorted, and recovered.

Additional Resources

- → **ENERGY STAR: Industrial Energy Management**
- → **ACEEE: Industrial Energy Efficiency Program**
- → **GreenBiz: How to Boost Heavy Industry's Energy Efficiency**
- → **American Institute of Chemical Engineers: The Four Pillars of Industrial Energy Efficiency**
- → **Appliance Standards Awareness Project (ASAP)**

MANUFACTURING SOLUTION

Carbon Capture

Overview

To limit emissions, manufacturing facilities can install technology that captures CO_2 before it is released into the atmosphere. Carbon capture technologies allow captured carbon to be stored underground or used to produce carbon-based products such as electrofuels, concrete, and chemicals. Direct air capture (DAC) is a related technology that pulls CO_2 out of the air for use or storage.

Carbon capture and DAC technologies can be important tools in reaching net-zero emissions across the economy, but they cannot scale up to the level they are needed without durable policy support to accelerate investment and deployment. Carbon capture and DAC technologies have faced some criticism from environmental justice and other groups concerned with local air quality and land use impacts and enhanced oil recovery (EOR)—policy must also ensure that deployment results in net-zero/negative emissions overall. Durable policy support for these technologies should include consideration of all air quality and economic impacts, especially those affecting low-income and historically disadvantaged communities.

Market Challenges

Insufficient Existing Carbon Markets

Existing policies that create markets for using or storing CO_2, such as California's Low Carbon Fuel Standard (LCFS) and the federal 45Q tax credit, represent positive initial opportunities for deployment. However, they have not yet achieved scale. Markets for CO_2 as a product, such as the food and beverage and EOR industries, have long-established incumbent supply chains for CO_2 which comes mostly from cheaper natural sources than captured CO_2. Further policy interventions are needed to create large markets for new sources of captured CO_2 to serve.

Regulatory Uncertainty

Regulatory uncertainty currently surrounds carbon capture and sequestration permitting. CO_2 injection permitting is currently a 5-to-6 year process. These long timelines present myriad challenges for project financing. Without clear, practical rules, investors may avoid pursuing carbon capture and DAC projects.

High Cost Compared to Alternative

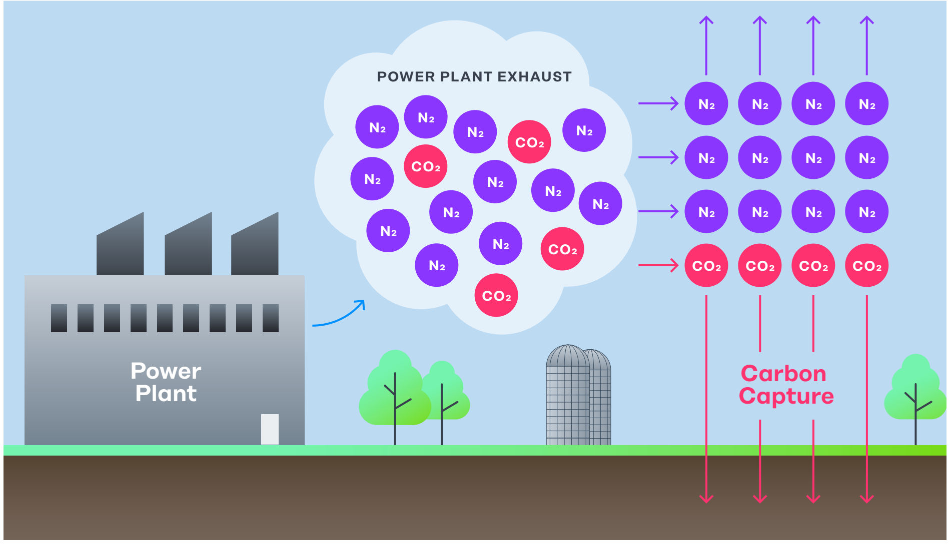
Today, CO_2 from natural or "terrestrial" sources tends to be cheaper than CO_2 captured from manufacturing facilities or via DAC. Though policies like the LCFS and the 45Q tax credit create an incentive for storing CO_2, this incentive is not currently enough to overcome the high initial costs of DAC and carbon capture technology. Without a comprehensive framework that values captured carbon and carbon removal, such as a carbon price or other incentives, these technologies will not deploy at the scale required to reach net-zero emissions.

Technologies

Industrial Carbon Capture

R&D **VALIDATION** SCALE

Carbon capture can be used to remove the CO_2 from waste streams of industrial facilities or power plants to be stored safely underground or used in products.



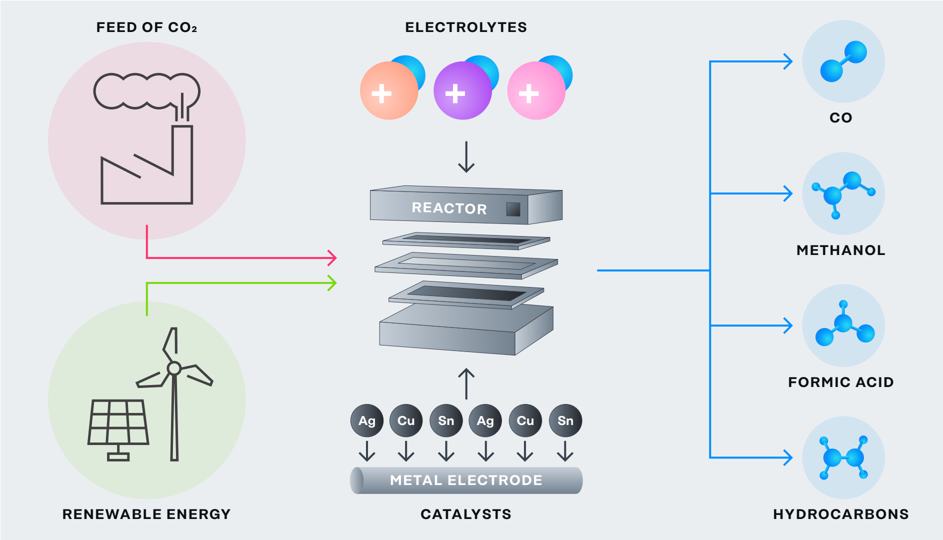
Carbon capture, utilization, and storage (CCUS) is already a cost-effective means of cutting emissions in some parts of the manufacturing sector and has the potential to be so in others. Carbon capture technology removes CO_2 from the exhaust that manufacturing processes and power plants create. Instead of being released into the atmosphere, the captured CO_2 can either be used in products or safely stored deep underground.

CO_2 can be captured from the fuel prior to its combustion through gasification or reforming, or from the gas the plant exhausts, typically using a thermally regenerated amine-based process. The fuel can also be combusted in pure oxygen, resulting in a purer CO_2 stream that is more easily captured and purified. Using carbon capture in industrial plants can cut the emissions from carbon-intensive processes such as steel and cement production. Further development of transformational new low-cost, high efficiency CO_2-capture technologies can bring this potentially powerful solution into widespread commercial use.

CO_2 to "X"

R&D **VALIDATION** SCALE

Electrochemical reduction of CO_2, conceptualized here, is one method to convert captured CO_2 into value-added small molecules and chemicals using renewable energy.



Coupled with either industrial CO_2 capture or direct air capture (DAC) capabilities, captured CO_2 can be used for both existing manufacturing processes and emerging technology approaches. Both carbon-neutral fuels and carbon-negative materials offer significant GHG offset impact potential. Syntheses of small molecules from CO_2 enable the production of additional chemicals, fuels, and materials.

The technologies to convert these versatile building blocks into other molecules include both thermochemical and electrochemical approaches. They also incorporate an increased deployment of renewable electricity, allowing renewables to further decarbonize more manufacturing processes

Additional Resources

- → **C2ES: Carbon Capture**
- → **NETL: Carbon Capture Program**
- → **Carbon Capture Coalition: Federal Policy Blueprint**
- → **Center for Carbon Removal: Carbon Removal Policy: Opportunities for Federal Action**
- → **Rhodium Group: Capturing Leadership**

MANUFACTURING SOLUTION

Oil and Gas Methane

Overview

The oil and gas industry emits methane, a potent GHG, throughout the oil and gas supply chain, including during production, refining, processing, and transportation of fuels. In 2018, the oil and gas sector was the largest single source of methane in the manufacturing sector and represents more than 15 percent of total manufacturing emissions. The bulk of these emissions come from leaks and venting, also called fugitive emissions, from production wells and associated equipment and processes, as well as transmission and distribution pipelines.

Many low-income and historically disadvantaged communities are directly impacted by oil and gas methane—both in terms of exposure to methane and health-impacting co-pollutants and relying on the industry for employment. If natural gas is going to play a role in a decarbonized future, curbing oil and gas methane emissions across the nation—and especially in disadvantaged communities—is imperative. Technologies to detect and prevent leaks are readily available and can dramatically reduce emissions when combined with the use of best practices and high-performance equipment.

However, complementary policy is needed to achieve widescale adoption of these solutions. Policies that create setbacks or buffer zones around oil and gas facilities have gained traction with environmental justice groups concerned with the adverse health, air quality, and land use impacts associated with them.

Additional Resources

- International Energy Agency, Global Methane Emissions from Oil and Gas
- ICF International for the Environmental Defense Fund, Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries
- RMI, The Role of Gas in the Energy Transition
- Resources for the Future, Differentiation of Natural Gas Markets by Climate Performance
- Methane Guiding Principles
- United Nations Economic Commission for Europe and the Global Methane Insitute, Best Practice Guidance for Effective Methane Management in the Oil and Gas Sector

MANUFACTURING POLICIES

Policy Overview

Buy Clean

Buy Clean procurement aims to reduce carbon emissions by focusing on incentives and requirements for lower-carbon infrastructure and building materials. This policy approach uses the carbon intensity of materials, or the lifecycle GHG emissions involved in their production or use, as a key criterion for procurement decisions for publicly funded projects. Buy Clean can set allowable carbon-intensity performance thresholds that decrease over time. This encourages the disclosure of emissions data via environmental product declarations (EPDs), creates a market for low-GHG materials, often lowers financing costs, and reduces harmful emissions from manufacturing.

For more, see the deep dives on

→ **Buy Clean**

Risk-Based Safety Standards

Getting to net-zero emissions will require a substantial and rapid expansion of carbon capture for manufacturing applications in the near-term, as well as negative emissions options such as direct air capture (DAC) by mid-century. For this to occur, federal requirements for siting and monitoring carbon capture need to be developed and reformed. Regulatory clarity and environmental protection are crucial as carbon capture and sequestration technologies progress toward full-scale commercial deployment. Safety standards must be equitable and ensure that low-income and historically disadvantaged communities directly benefit from investments, cleaner air, and emissions reductions associated with DAC technology adoption.

For more, see the deep dive on

→ **Risk-Based Safety Standards**

Clean Product Standard

A clean product standard (CPS) is a technology-neutral approach to reducing emissions from the manufacturing of industrial products. In this approach, the government sets a target for the GHG intensity of a set of basic manufactured products and allows flexibility in how to meet that target—including the potential to trade with other producers. A CPS would facilitate a cost-effective, market-based system to drive down the average GHG intensity of key manufactured goods like steel or cement.

A CPS offers an alternative or complementary approach to a carbon price for the industrial sector.

For more, see the deep dive on

→ **Clean Product Standard**

Technology-Neutral Deployment Tax Credit

Tax credits have already successfully enabled the deployment of clean energy technologies—especially wind and solar. A technology-neutral refundable tax credit for the electrification and increased efficiency of manufacturing activities, low-carbon industrial fuels, and industrial carbon capture can spur more open-ended innovation across this suite of technologies.

Technology-neutral deployment tax credits offer an alternative to a CPS or carbon pricing. This mechanism is less economically efficient than a carbon price or a CPS and would be more effective if paired with regulatory carbon pollution standards to ensure emissions reductions.

Carbon Pollution Controls

An alternative to carbon pricing or a CPS is the establishment of controls on carbon pollution from fossil-fueled manufacturing facilities. Such regulations could be applied to both new and existing facilities through authority granted by the Clean Air Act. The efficacy of this policy approach could be further enhanced by pairing it with a technology-neutral tax credit.

Minimum Efficiency Standards

The federal government can establish minimum energy performance standards for industrial equipment like motors, lighting, and other types of small industrial equipment. Though these technologies account for a relatively small share of overall energy use in manufacturing, efficiency standards have a successful track record of delivering energy savings and emissions reductions and should not be overlooked. The Environmental Protection Agency (EPA) and Department of Energy (DOE) play critical leadership roles in advancing complementary policies for manufacturing efficiency.

Federal Infrastructure Spending for CO_2 Pipelines

Scaling carbon capture technology deployment will require a commensurate scaling of CO_2 pipelines to transport captured CO_2 to sites for utilization or storage. Congress can support this need by ensuring that investment in CO_2 pipelines is part of any major federal infrastructure package it advances. Congress could consider federal investment in CO_2 pipelines through a range of programs and funding mechanisms, including making federal loans or loan guarantees available to pipeline developers. It could also consider direct investments or grants to supplement existing private investments in pipeline development, particularly for the most critical trunk pipelines that could enable high CO_2 throughput.

Performance Standards for Oil and Gas Facilities

EPA regulates methane from oil and gas facilities as an air pollutant under Section 111 of the Clean Air Act, which requires the Agency to establish a “best system of emissions reductions” for new and existing facilities. The Bureau of Land Management (BLM) also regulates methane from oil and gas production on federal lands. EPA and BLM should use their authorities to strengthen performance standards for reducing methane emissions from the oil and gas sector.

Cross-Sectoral Policies

Additional cross-sectoral policies would also help develop and deploy manufacturing technologies and solve the Manufacturing Grand Challenge.

For more, see the deep dives on

- → **Public Sector R&D**
- → **National Laboratory Reform**
- → **Stimulating Clean Energy Entrepreneurship**
- → **Demonstrating and Validating New Technologies**
- → **R&D Tax Credit**
- → **Technology-Neutral Innovation Tax Credit**
- → **Carbon Sequestration Tax Credit**
- → **Project Financing**
- → **Carbon Pricing**
- → **Clean Fuel Standard**

MANUFACTURING

Manufacturing Deep Dives

MANUFACTURING DEEP DIVES

Buy Clean

Overview

Buy Clean is a set of public procurement policy instruments aimed at infrastructure and building materials to rapidly reduce greenhouse gas (GHG) emissions from government entities. It is also a powerful tool to incentivize the purchase of low-carbon materials from manufacturing suppliers. The proposed policy framework below sets a performance standard based on carbon intensity (CI), which includes direct emissions from a product's production, transportation, and use.

Procurement policies help support the transition to zero- and low-carbon products and create a competitive advantage for clean manufacturing in the U.S. The federal government is a major purchaser of cement and steel, but the costs of those materials are a relatively small share of the roughly $300 billion spent annually on public construction projects. As a result, a Buy Clean policy can meaningfully contribute to decarbonization of these industries at a fairly small cost to taxpayers. Under Buy Clean, the federal government could direct federal agencies to purchase low-carbon materials and products (e.g., concrete, steel, timber). The policy could set CI performance thresholds for covered products that decrease over time.

Buy Clean would help incentivize disclosure of environmental impact data across a range of industrial products, create a market for low-GHG infrastructure and building materials, and significantly reduce emissions associated with publicly financed projects.

Principles

Ambition: Federal Buy Clean policies should incorporate emissions information into federal purchasing decisions based on CI and should aim to decarbonize federally funded infrastructure and building projects by 2050. To provide certainty, Buy Clean policies should establish annual procurement targets across a range of covered products.

Eligibility: Eligible materials should include concrete, steel, aluminum, wood, glass, insulation, ceiling tile, gypsum board, flooring materials, and asphalt. Federal transportation projects, construction projects, and building renovation projects above a certain size should adhere to Buy Clean requirements.

Targets: The policy should set the maximum CI for each eligible material based on available data (e.g., environmental product declarations, (EPDs)). These CI targets should decrease over time, in line with targets for net-zero emissions by 2050.

Incentives for Performance: Buy Clean should incentivize use of the lowest emissions products. This could be done through financial incentives (e.g., rebates based on CI), explicit evaluation preference (e.g., additional 'points' awarded during competitive bidding), or through carbon shadow pricing to incorporate climate externalities directly into procurement decisions.

Qualifying Technologies: Procurement should be technology neutral and promote the lowest-carbon technologies in appropriate applications.

Flexibility: Periodic technology assessments should be scheduled to ensure that technologies are continuing to advance and will be available when required across the U.S., and that they are providing direct benefits to low-income and historically disadvantaged communities where appropriate.

Disclosure: Buy Clean policy relies on tracking and disclosure of embodied carbon by government agencies and suppliers. Buy Clean should require the disclosure of facility-specific EPDs to determine the CI of products eligible for procurement. EPDs usually capture the embodied impact of materials and products by reporting "cradle-to-gate" emissions: those generated during life cycle stages A1 (raw material extraction), A2 (transportation of materials to manufacturing facilities), and A3 (processing and manufacturing). Alternatively, for building construction, governments can consider whole building footprint disclosure using life cycle assessment (LCA) methods. The federal government could provide technical assistance and/or fiscal incentives to help facilities develop and defray the cost of these disclosures.

Permitting: When applicable, the government should fast-track permitting for projects using lower-carbon technologies, designs, or materials.

MANUFACTURING DEEP DIVES

Clean Product Standard

Overview

A clean product standard (CPS) is a novel proposal to create a technology-neutral, market-based policy for cost-effective decarbonization of the production of basic manufactured materials. A CPS establishes the maximum amount of greenhouse gases (GHGs) that can be emitted while creating manufacturing products sold in the U.S.

Manufacturers can employ any technological solutions that allow them to achieve the emissions limit, including the use of low-carbon electricity, liquid fuels, and feedstocks, as well as process and efficiency improvements and deployment of carbon capture systems. The stringency of the standard for each product category tightens over time, creating regulatory certainty for an ambitious, but achievable path toward deep decarbonization.

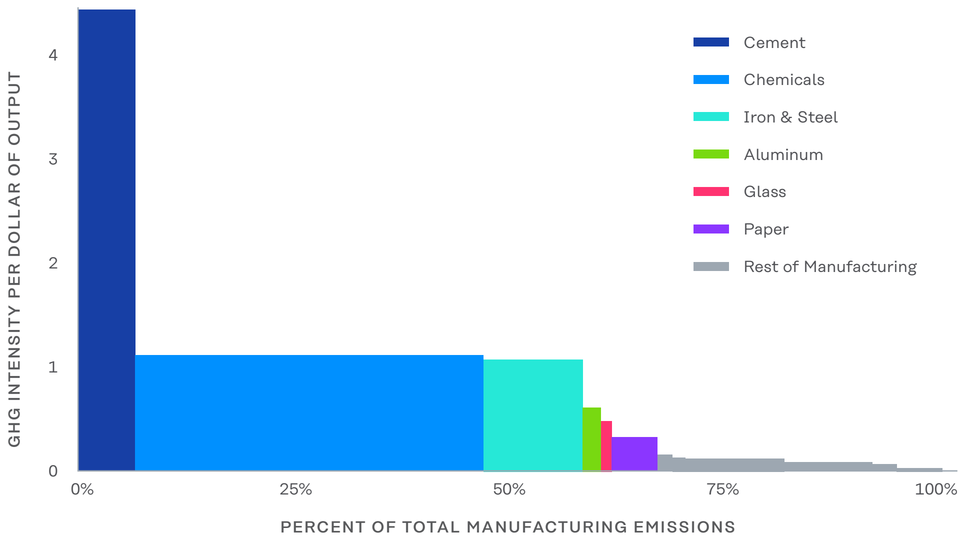
Obligated parties demonstrate compliance with the standard by reporting GHG emissions to a designated federal agency. The reporting structure builds on voluntary reporting and product labeling under other policies (e.g., government "Buy Clean" procurement policies). A CPS also leverages existing corporate voluntary tracking and goals for GHG emissions, including emissions directly tied to the manufacturing of a company's products as well as upstream supply chain emissions from the production of intermediate inputs.

To avoid the potential for adverse competitiveness effects and emissions leakage, a CPS applies to all designated products sold—not just produced—in the U.S. A CPS could also be expanded to encompass final consumer products that rely heavily on CPS-regulated inputs. A CPS allows for trading of compliance credits, similar to other market-based policies like cap-and-trade or a clean electricity standard.

Principles

Scope of Coverage: Deciding which products to cover is a balance between the scope of coverage (i.e., percent of emissions covered) versus administrative complexity (e.g., number of firms, how much of economic output, diversity of subsector's output). The designated federal agency reviews GHG emissions intensity on a disaggregated level (as defined by North American Industry Classification System (NAICS) code or a similar classification scheme) and determines which specific industries are subject to the CPS. Applying a CPS to six major product classes with the highest GHG intensity—cement, chemicals, iron and steel, aluminum, glass, and paper—would cover more than 60 percent of manufacturing emissions and roughly 40 percent of industrial emissions overall.

GHG Emissions and GHG Intensity of Manufacturing, 2018



Source: Rhodium Group analysis

Point of Obligation: A CPS applies at the point of first domestic sale of a covered product. Generally, this first sale is either from the producing facility or importer to an early step in a longer product supply chain. By setting the point of obligation at this level, a CPS minimizes the number of obligated entities, thus reducing administrative complexity. An obligated entity reports the total GHGs emitted during the production of a covered product. They also demonstrate compliance with the product's emissions limit, either directly or through trading. These reports are subject to periodic audit.

Standard: The designated federal agency determines aggressive but achievable trajectories for emissions standards that reach net-zero GHGs for covered products by 2050. In the meantime, the agency should set appropriate targets so that industries can show incremental progress and meet compliance thresholds, accounting for the GHG intensity of a given set of products. The designated federal agency reviews these targets regularly and increases the stringency of emissions standards if they are being substantially exceeded.

Reporting Metrics: The appropriate compliance metric under a CPS is total GHG emitted per unit produced. The designated federal agency calculates this metric for each obligated entity, based on that entity's annual reporting of three main pieces of data for each product class:

- Direct facility emissions from the combustion of fossil fuels and from industrial processes that result in GHG emissions (i.e., Scope 1 emissions)
- A facility's use of purchased electricity, which the designated federal agency will use to calculate indirect emissions (i.e., Scope 2 emissions) based on an appropriate regional electric sector emissions rate. For example, this may be based on EPA's Emissions and Generation Resource Integrated Database (eGRID).
- The total quantity of product produced each year. Depending on the product, this may be reported in terms of weight or volume of output, total number of discrete items produced, or another appropriate output measure.

Tradability: CPS compliance credits are tradeable in a limited but expanding fashion. Early in policy implementation, a CPS allows for averaging one producer's output across multiple facilities. Tradability could be expanded to allow for trading between any producer of a specific product as the standard's stringency increases, minimizing sector-wide compliance costs while providing a financial incentive for early aggressive decarbonization.

Innovation Credits: To incentivize early deployment of clean manufacturing technologies, the CPS could include a voluntary compliance period before mandatory targets are implemented. In this period, obligated entities could generate innovation compliance credits which can be banked and used to demonstrate compliance once targets become binding. The designated federal agency should account for these innovation credits in their periodic target reviews.

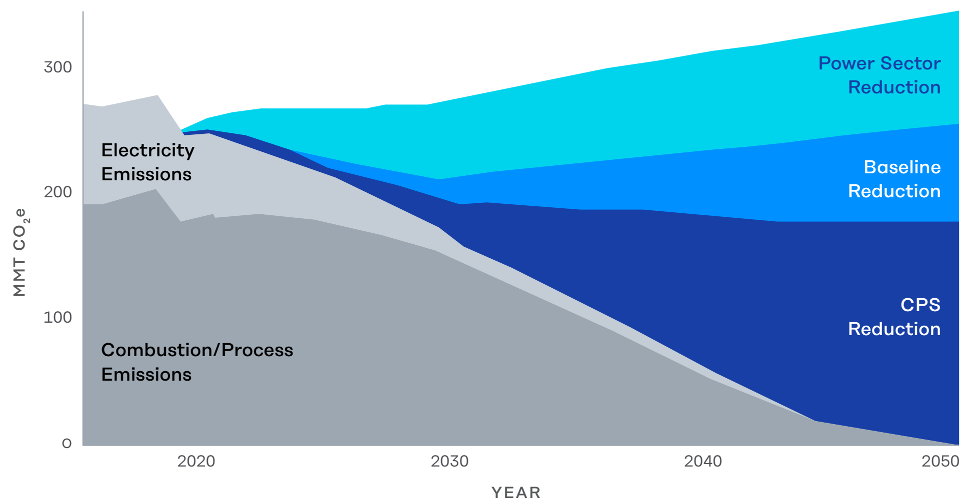
International Trade: Any entity that imports regulated products is subject to the same requirements as domestic producers. Domestic producers could be exempted from these standards on products that are exported for sale outside the U.S. Such a move may assist in maintaining U.S. competitiveness in these industries but would weaken the overall emissions impact of the policy and may run afoul of World Trade Organization (WTO) rules.

Downstream Products: Regulating the GHG intensity of basic products that are embedded in further downstream products (either intermediates or final products) presents greater administrative complexity. As with other aspects of the CPS, policymakers must balance ambition with complexity, but preventing emissions leakage is critical to maintaining the integrity of the CPS and protecting U.S. competitiveness. Policymakers could require manufacturers and assemblers of final products to demonstrate compliance with CPS requirements for any basic materials used throughout their supply chain, but this should only be done for products that incorporate material amount of CPS-covered basic materials and that are at their last point of sale to a final consumer.

Impact

The overall impact of a CPS is a function of the design choices outlined above. Any actual reduction pathway would be set on a product-by-product basis, based on rigorous analysis of available compliance options and scaled to policymakers' level of ambition. Decisions about which product classes are obligated to comply and the treatment of internationally traded materials will also affect the emission outcomes of a CPS.

U.S. Manufacturing Emissions in Key Industries Under a CPS



U.S. Manufacturing Emissions (Direct Combustion, Process, and Power Sector) in Key Industries under a Clean Product Standard.

Source: Rhodium Group analysis

As an illustrative example, this figure demonstrates the impact of a CPS that achieves net-zero emissions in the production of the six categories of GHG-intensive materials discussed above, consistent with an economy-wide path to zero. The power sector reducing its GHG intensity to zero contributes to the overall emissions reduction from production of these materials (as seen in the lightest blue wedge of the chart).

Once a cleaner grid is accounted for, obligated parties would be expected to achieve 1–4 percent annual reductions in non-power emission intensity in the 2020s, up to about 23 percent annual reductions in the 2040s. A portion of these reductions are already anticipated in the modeling baseline and come in the form of cost-effective efficiency improvements and other changes to the makeup of these industries (the middle blue wedge). The remainder of the reductions on the path to zero are achieved by the CPS (the dark blue wedge). These reductions could be achieved through a variety of decarbonization approaches, as described above, including switching to lower-carbon fuels, electrification of fossil processes, and the use of carbon capture technologies, among others.

MANUFACTURING DEEP DIVES

Risk-Based Safety Standards

Overview

Achieving net-zero emissions by 2050 will require capturing carbon dioxide (CO_2) from factories and power plants and safely storing it underground. Federal requirements for siting, operating, monitoring, and closing sequestration sites have already been established. However, they are largely untested at scale and may need to be revised based on real-world experience.

While there is considerable industry experience injecting CO_2 for enhanced oil recovery (EOR), legal and regulatory standards can be improved to take direct climate benefits into account. Clear, practical rules can accelerate carbon capture and direct air capture (DAC) project deployment, strengthen public trust in these clean technologies, and ensure low-income and historically marginalized communities receive direct benefits from their rollout, such as cleaner air and more job opportunities.

Principles

Permitting for CO_2 Pipelines: Scaling carbon capture and storage projects will require a significant expansion of existing pipelines that can transport CO_2 from industrial sites to storage locations. On average, it takes large-scale pipelines over two years from when the permit application is submitted for installation to be completed. To meet future CO_2 pipeline demands, the federal government should invest resources in expediting the permitting process and creating clear and consistent rules and standards for CO_2 pipelines, while maintaining strict environmental and safety standards and ensuring ample community and landowner input.

Geological Storage Site Selection: Expanding geological storage will require comprehensive site mapping, robust risk assessments, and well-established safeguards. These efforts will require the federal government to continue supporting existing programs, while increasing focus on certain key issues. For example, safe site selection means increased research and field testing to identify injection locations and techniques with the lowest risk of induced seismic activity and water contamination. The federal government should take on this work to increase project safety and improve the information available to the carbon capture industry. Additionally, improved monitoring of carbon storage sites—technologies to identify leakage and seismicity, for instance—is critical, as is working to accelerate the carbon uptake of secondary trappings to provide additional storage over time.

Federal agencies including the Environmental Protection Agency (EPA), the Department of Energy, and the Department of the Interior will need to work together to improve geological storage site selection.

Permitting for CO_2 Injection: With enough policy support, sequestering carbon directly underground will become increasingly viable for carbon capture projects. EPA's Underground Injection Control (UIC) program for Carbon Dioxide Geological Sequestration Wells, known as Class VI rules, were established in 2010 to protect the safety of drinking water sources from carbon capture projects. Today, they regulate sites used for CO_2 injection into geological formations, but the approval process has been slow. Individual states can apply to the EPA to regulate Class VI projects themselves, but so far North Dakota and Wyoming are the only states to have done so.

EPA's Class VI permit approval process must become more efficient to maintain water safety and allow for the growth of carbon capture projects. Increasing the professional staff and resources assigned to the Class VI well program will allow permits and state primacy requests to be processed more quickly and efficiently.

Many early carbon capture projects are likely to use CO_2 for EOR. Such projects are classified by EPA as Class II Oil and Gas Related Injection Wells. Eventually, these wells will no longer produce oil; at that point, operators may choose to permanently sequester additional CO_2 at these sites. Yet UIC's regulations remain ambiguous as to when sites must transition from Class II to Class VI rules. UIC should address this regulatory uncertainty and offer a clear roadmap for sites to follow.

MANUFACTURING DEEP DIVES

Carbon Sequestration Tax Credit

Overview

Section 45Q is a federal tax credit that helps advance the market for carbon capture and technological carbon removal in the United States. The 2018 budget deal increased the financial incentives for carbon removal projects via 45Q: the updated tax credit provides $50/metric ton of CO_2 captured for geological storage and $35/metric ton of CO_2 captured for enhanced oil recovery or other uses. Despite this boost, the policy as it exists today is still not enough to incentivize the large-scale deployment of clean technologies such as carbon capture and direct air capture (DAC).

Principles

Credit Reform: It is common for early-stage deployment projects to have little to no tax liability because they are not yet profitable. The 2018 changes to 45Q made the credit transferable, allowing developers to use tax equity partnerships to take advantage of the economic incentive. Since the developer pays a high premium in this structure, however, they lose a large portion of the incentive. Making the credit refundable would allow developers to monetize the credit directly, avoiding costly tax equity and complicated project finance structures.

Deadline Extension: Deadlines to begin construction with short time horizons discourage investors from pursuing carbon capture projects because of their long lead times. Extending the commence-construction deadline will dramatically increase the number of carbon capture projects incentivized by 45Q.

Additional Support for New Technologies: The deployment of carbon capture technologies for high, low, and atmospheric concentration levels of CO_2 is critical for economy-wide decarbonization. Lower concentration streams of carbon dioxide are more costly to capture. Therefore, the 45Q credit should be increased for certain emerging technologies.

No Minimum Threshold: 45Q currently has minimum capture thresholds for carbon capture projects: 500,000 tons a year in the power sector, 100,000 tons in the manufacturing sector, and 25,000 for carbon utilization projects. This limits the number of carbon capture projects that can take advantage of the tax credit and has the potential to stifle early-stage deployment efforts for smaller-scale projects.

Clarify Guidance for LCA Requirements: The current 45Q statute states that the amount of carbon dioxide removal a project qualifies for will be based upon a life cycle analysis (LCA) of greenhouse gas emissions. However, guidance on how the LCA will be determined remains unclear. Because the goal of an expanded 45Q credit at this stage is technology deployment, it is important to ensure that LCA guidance is clear and verifies that projects have climate benefits, but is not overly burdensome in a way that will stifle early projects.

MANUFACTURING DEEP DIVES

Additional Manufacturing Policies

Clean Energy Bonds

States and municipalities typically sell bonds to finance capital-intensive public projects and certain "qualified" private projects. In some cases, the federal government helps to make these bonds more attractive by exempting their interest from investors' federal income-tax liability or by providing a tax credit in lieu of interest payments. These concessionary bond mechanisms encourage investors to accept a lower interest rate, with the foregone earnings offset by lower tax payments, and reduce the cost of capital for project developers.

Congress should enact provisions expanding access to concessionary bond financing for all clean energy technologies in two ways:

- Tax-exempt private activity bonds: Though tax-exempt bonds are usually used to finance public projects, in limited circumstances states and municipalities can issue tax-exempt private activity bonds for "qualified private activities." Currently, these activities include some electricity distribution infrastructure and combined heat and power (CHP) facilities. Congress should expand this list to include the full suite of clean energy technologies necessary to accelerate deep decarbonization. Given the scale of deployment necessary and public benefit of such deployment, Congress should also increase the state-level caps on this type of bond financing.
- Tax-credit bonds (TCB): Whereas tax-exempt bonds lower an investor's tax liability, tax-credit bonds provide a tax credit directly to them. The Secretary of Treasury sets a national credit rate, and investors receive some or all that credit rate (depending on the type of TCB) on the face value of their bond each year. As with tax-exempt bonds, this federal subsidy provides cheaper access to capital for the bond issuer since they do not make interest payments to bondholders. Congress previously authorized the use of this type of bond structure for clean renewable energy bonds in 2005, but this program was cut as part of the 2018 tax bill. Congress should enact a new clean energy tax credit bond that is available to all clean energy technologies.

Master Limited Partnerships (MLPs)

Master limited partnerships (MLPs) are a type of corporate structure that are taxed like a business partnership but trade their shares in a market (like stocks). One key benefit of this structure is the avoidance of double taxation: MLP income is untaxed and distributed as dividends to shareholders, after which it is taxed as personal income. Lower taxation reduces the cost of developing energy projects funded through MLPs. At the same time, MLP dividends provide a steady return to investors.

MLPs are broadly available to the oil and gas industry and are widely used by midstream companies such as pipeline developers. About two-thirds of MLPs are midstream oil and gas companies, which collectively had a market capitalization of nearly $300 billion in mid-2019. By statute and IRS interpretation, MLPs are not currently available to most industries, including clean energy developers.

Opening MLPs to all clean energy technologies can drive substantial levels of investment in these technologies. Congress can enable this by passing a bill that explicitly makes this corporate structure available to a broader range of clean energy technologies.

Wholesale Power Market Reforms

Increasing the share of electricity in the overall energy use of manufacturers enhances the ability to provide flexibility back to the power grid. This participation in capacity, energy, and ancillary services markets can provide additional revenue to electrified industrial facilities, which helps improve the economic case for electrification.

Grid flexibility makes it possible for the system to incorporate increasing amounts of variable renewable energy such as wind and solar power. Many manufacturing facilities can turn production down or off for periods of time, but they rarely do so unless it makes economic sense. Organized wholesale markets create this economic incentive by allowing participants to bid to provide grid services. For instance, in capacity auctions, participants bid to be available to respond to shorter-term market signals. In energy auctions, which happen both in real time and a day or so ahead of time, participants are paid to provide a set amount of generation or demand reduction for a specific time window. Finally, some grid operators also run auctions for participants to provide additional services to the grid.

Organized wholesale markets fall under the jurisdiction of the Federal Energy Regulatory Commission (FERC), which has typically allowed industrial facilities and other providers of demand-side flexibility to participate in these auctions either directly or through demand-side aggregators. FERC should continue to review grid operator tariffs, so they are consistent with the principles of fair and open competition on a technology-neutral basis. FERC should also support the creation of new products that reward the unique capabilities of demand-side flexibility.

Energy Productivity Standard

Energy productivity is a measurement of how much energy is used in the production of a certain amount of economic output. Boosting energy productivity means achieving higher levels of economic output while using an equivalent or smaller amount of energy—helping to achieve both economic and decarbonization goals.

In 2015, the U.S. Department of Energy (DOE) and private sector partners announced an initiative aimed at doubling energy productivity across the economy by 2030. The federal government should now adapt this approach to establish ambitious, binding, and sector-specific energy productivity standards (EPS) for the manufacturing sector. These standards should account for both current baseline levels of energy productivity and the potential for productivity gains in each subsector.

As with other market-based policies, an industrial EPS should allow for flexible compliance with targets and give participants the option to trade the credits they earn. To the extent possible, the industrial EPS should be administered through agencies that have experience collecting energy and environmental data from large industrial facilities, such as the Environmental Protection Agency's Greenhouse Gas Reporting Program.

Minimum Energy Performance Standards for Industrial Equipment

Minimum energy performance standards (MEPS) establish a minimum efficiency level, or maximum limit on the amount of energy that a specific piece of equipment can use. Manufacturers must then design and build equipment that meets these standards and demonstrate compliance through a standardized set of independent tests. If these tests find that a piece of equipment is out of compliance with the relevant standard, its manufacturer is subject to fines.

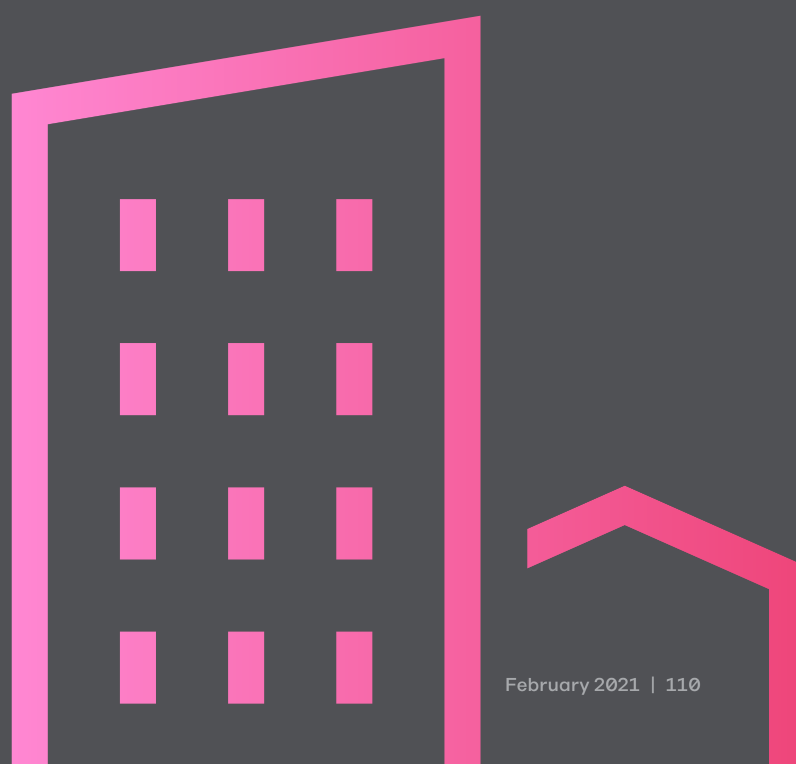
Congress has identified a set of industrial equipment subject to MEPS, including electric motors and industrial pumps, and established a way for DOE to add more equipment to this list as it deems appropriate. Still, only 30 percent of today's industrial energy consumption is used in products covered by these MEPS. This leaves a substantial share of manufacturers' energy use uncovered by mandatory standards.

Congress should direct DOE and the Energy Information Administration to study ways to expand the use of MEPS in the manufacturing sector, particularly with regard to process heat. On the basis of these findings, Congress should direct DOE to develop standards for more equipment and provide for periodic review of adopted standards.

GRAND CHALLENGE

Buildings

How We Live



BUILDINGS

Overview

Buildings emit carbon in two ways: through daily use (known as operational carbon emissions) and via the manufactured cement, steel, and iron used to make them (known as embodied carbon emissions).

Operational carbon emissions can be reduced over time by taking steps like installing a more energy-efficient HVAC system or swapping out a gas furnace for one that runs on electricity from a decarbonized power grid. Today, these operational emissions comprise about 10 percent of total greenhouse gas (GHG) emissions. Embodied carbon emissions, by contrast, are locked in place as soon as a building is built. That means, ultimately, we can't decarbonize the buildings sector without getting the manufacturing sector to net-zero at the same time.

To reduce building emissions, we need policies that drive deployment of new technologies, such as low-GHG building materials and ultra-efficient heat pumps, and that create incentives for the electrification and improved efficiency of clean technologies that already exist. These policies should also seek to incentivize emission reductions in low-income and historically disadvantaged communities where maintenance issues and split incentives between tenants and landlords have hampered efficiency gains.

BUILDINGS SOLUTION

Electrification

Overview

A primary source of building sector emissions is the combustion of fossil fuels to create heat and to fuel appliances like stoves. Roughly 50 percent of households in the United States are heated using natural gas and propane, a significant portion of which relies on aging infrastructure.

Air-source heat pumps offer an alternative to existing fossil sources for space and water heating and cooling. Likewise, electrified appliances like induction cooktops offer alternatives to fossil-fired stoves. When powered by clean electricity, building electrification will further accelerate the path to net-zero emissions.

Market Challenges

Consumer Inertia and Capital Constraints

Much of America's consumer base has grown accustomed to using natural gas or other fossil fuel-based appliances. Limited awareness of the health and safety risks of gas, the methane leakage and carbon impacts of natural gas, electric alternatives, misperceptions of electrification, consumer preferences, and product experiences all serve to slow the necessary shift away from fossil fuels. Furthermore, the economic benefits of building electrification are not immediate. Building electrification is usually cost-effective over an asset's lifetime, but high upfront capital costs and split incentives between tenants and building owners often prevent heat pump deployment. Even if electrifying makes economic sense, consumers can face long payback periods for these devices while gas remains cheap, significantly impacting adoption, especially in low-income areas.

Supply-Side Limitations

Electrification efforts can be thwarted by the respective interests of incumbent utilities, contractors, vendors and other supply-side actors. Even without technical challenges or performance issues, contractors at the back end of the technology adoption curve are often less equipped to sell electrification effectively and tend not to promote it. Utilities that supply natural gas often oppose electrification because it can negatively impact their business models. There is a limited number of contractors offering, servicing, or interested in new electric equipment and those who do often advise customers to implement incumbent, fossil-reliant options.

Existing Infrastructure and Stock Turnover

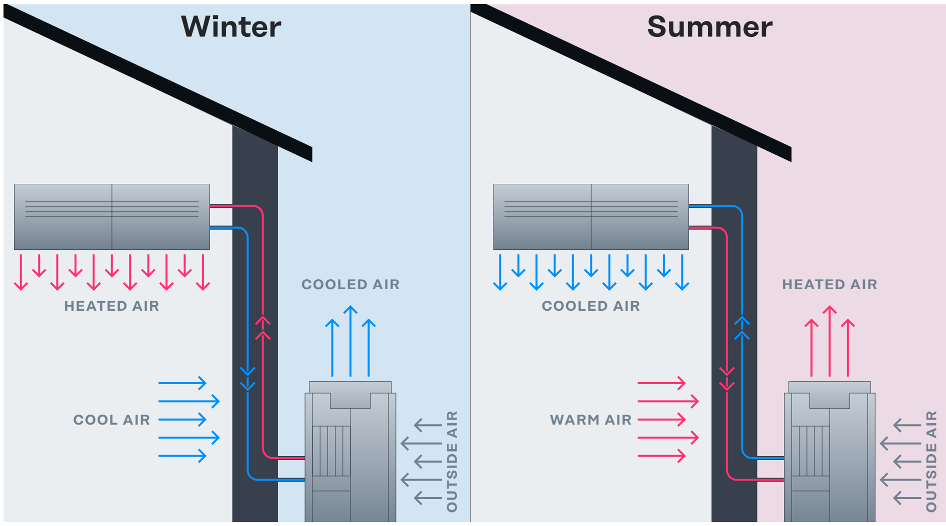
Most of the existing building stock and electric distribution infrastructure was not built with the intention of complete electrification, presenting a critical barrier to faster progress. Increases in peak demand and insufficient demand-side management could require costly upgrades to our power system on a local and regional scale. In addition, gas appliances and distribution infrastructure are already in place and provide easy and cheap access to gas for many customers. At the building level, architectural challenges can hinder fuel-switching retrofits (e.g., buildings may lack appropriately sized and ventilated space for heat pump water heaters) and the replacement rate of combustion devices is slow (with 15-20 years of useful life).

Technologies

Electrified Space/Water Heating

R&D VALIDATION SCALE

Air-source heat pumps use electricity to provide space heating and cooling by using the outside air as a heat source or sink, respectively.



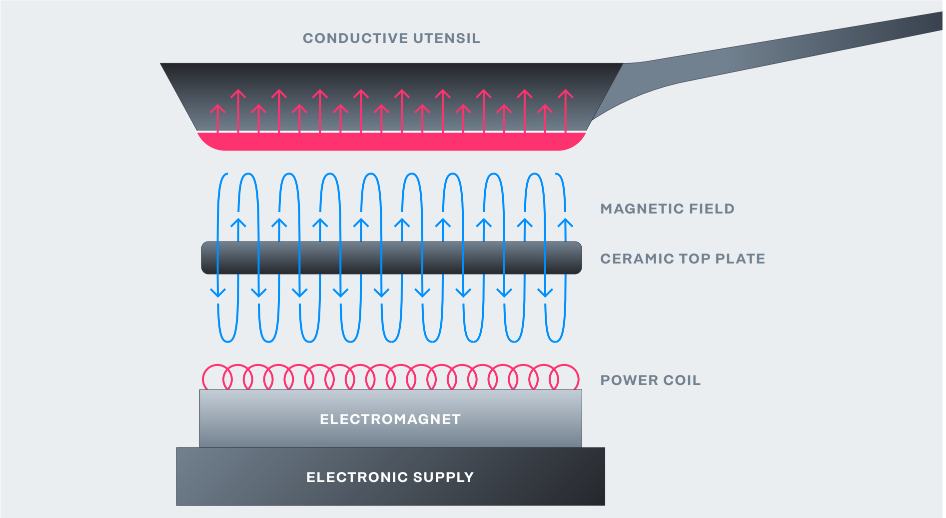
Heat pumps use electricity and have various applications including space heating and cooling, water heating, and clothes dryers. The broad categories of heat pumps—air-source, water-source, and ground-source—each use these respective materials as a heat source or sink. Grid-interactive heat pumps can shift the timing of demand based on grid signals (pricing, carbon, etc.)

Due to significant technological advances over the last decade and contrary to popular belief, many heat pumps today can function cost-effectively even in the coldest climates. Heat pumps are also reversible: one piece of equipment can provide both heating and cooling services. These systems can be designed for all building types, from single family homes to large commercial buildings. Barriers to further adoption include awareness, relatively higher up-front capital costs (which could be mitigated by new financing approaches), and, for geothermal heat pumps, wider availability of drilling.

Electrified Appliances

R&D VALIDATION **SCALE**

Induction stoves use electricity to generate a magnetic field, inducing many smaller currents in iron and stainless steel cookware and converting the energy from those currents into heat.



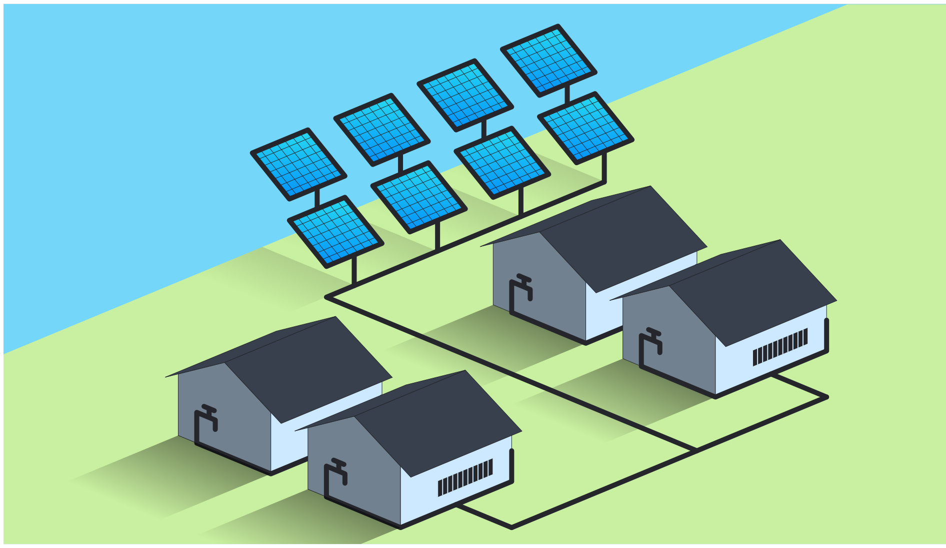
Nearly all U.S. cooktops are traditional natural-gas or electric models. A growing alternative technology, the induction stove, presents opportunities for electrification and efficiency improvements. Induction stoves use electricity to generate a magnetic field. Once a pot or pan is set on the burner, the magnetic field induces many smaller currents in the cookware's metal. Cast iron and stainless steel are poor conductors of electricity; as a result, much of the energy from the current running through them is converted into heat.

The heat coming from the pan itself rather than the burner makes for a more efficient cooking process. Induction stoves can offer a cooking experience that rivals gas cooking, including faster times and a high degree of control and simmering. Two principal barriers to the wider adoption of induction stoves in the U.S. are their high upfront cost and the perception among many consumers that gas stoves provide the best cooking experience. Broader deployment of induction stoves will therefore rely on cost reductions to make them more competitive and awareness efforts to drive greater adoption.

District-Scale Heating and Cooling

R&D **VALIDATION** SCALE

District heating and cooling, such as the solar district heating system depicted here, provides an efficient method to heat/cool multiple buildings by distributing hot/cool water or steam through a connected system of pipes.



District heating and cooling involves distributing hot and cool water or steam through a system of pipes to provide space heating, space cooling, and domestic hot water to multiple buildings. A district-scale system allows for heat recovery, which means that heat is let into, and extracted from, the system in different places. Moving heat around to where it is needed, rather than wasting it at different points, makes these systems highly efficient.

The U.S. market has two major needs for ready-to-deploy district solutions: 1) converting existing district systems (typically steam-based) to zero emissions and 2) building new district systems with greater efficiency than single-user systems. Retrofitting existing systems is particularly important: they are often over 50 years old, powered by coal or natural gas, and generally provide only heating, not cooling. Many are now being updated, creating a significant opportunity for innovative retrofits that use renewable energy and improve efficiency.

Generally, individual district-scale applications require a great deal of engineering customization. Easier-to-deploy, integrated solutions are needed to standardize district-scale configurations of commercially available clean technologies (e.g., geothermal heat pumps, solar thermal). Improving legal structures and access to capital are also critical to that end.

Additional Resources

→ **R&D to Market Success: BTO-Supported Technologies Commercialized from 2010–2015**

→ **The Impact of Fossil Fuels in Buildings**

→ **The Economics of Electrifying Buildings**

→ **Reinventing Fire**

→ **Value Potential for Grid-Interactive Efficient Buildings in the GSA Portfolio: a Cost-Benefit Analysis**

→ **Making the Transition from Zero Energy to Zero-Carbon Building Policies**

BUILDINGS SOLUTION

Energy Efficiency

Overview

When buildings operate more efficiently, they consume less energy, reducing GHG emissions on a per unit basis. Strategies for increasing efficiency include replacing old equipment and using sensors and energy management software to optimize a building's emissions and energy use. More efficient buildings reduce energy demand, lowering the overall costs of decarbonization.

Market Challenges

Information Gaps

Energy waste and carbon emissions are easy to overlook. Making good investment decisions regarding efficiency requires both an understanding of a building's relative performance and an awareness of cost-effective improvement opportunities. The disclosure of building energy performance information (energy use, costs, and related emissions) is not required in most jurisdictions—particularly in the residential sector, where energy information has historically not been accounted for in standard mortgage underwriting and appraisal processes. In addition, consumers are often unaware of the economic, health, safety, and comfort-related benefits of implementing efficiency upgrades.

Capital Constraints and Split Incentives

Efficiency improvements can require considerable upfront capital expenditures. Many building owners—particularly lower income homeowners and small- to medium-sized commercial building owners—face capital constraints and limited project financing options. Many commercial owners invest with short-term (<5–7 year) hold periods and thus are generally unwilling to put their own capital into deeper retrofit projects with longer than 3- to-5-year payback periods. Furthermore, those who pay for efficiency upgrades are not always the same people who reap the savings, and the resulting misalignment of incentives can further hamper implementation in rental buildings, especially in low-income and historically disadvantaged communities.

Supply-Side Limitations

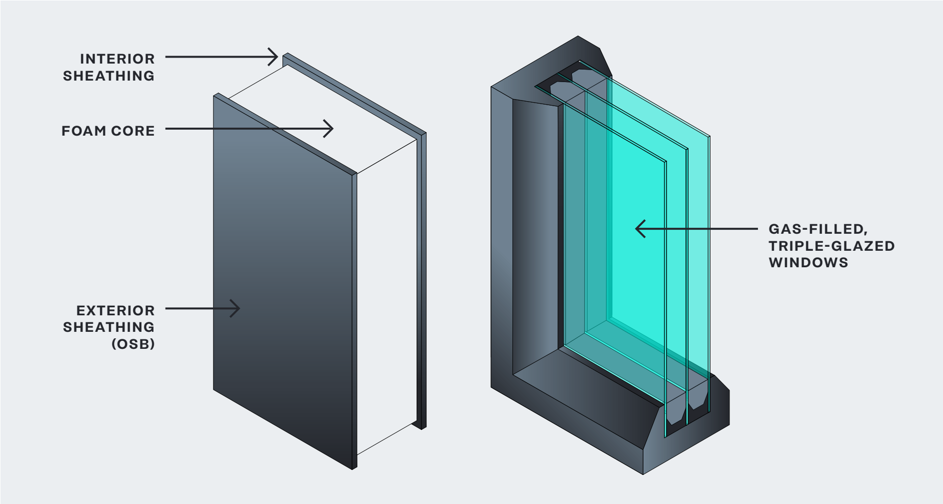
The massive increase in building improvements needed to reduce emissions across the U.S. will strain the existing labor force and supply chains. When it comes to the construction process itself, the design and development of most buildings typically happens through a fragmented, linear process involving many different stakeholders (including owners, architects, engineers, consultants, contractors, and subcontractors). With competing agendas, limited budgets and resources, and unequal access to information, buildings are often not designed to optimize systems and equipment. There is no single point of access to energy upgrades given the range of available measures and technologies (like heat pumps, insulation, and lighting) which makes implementation more difficult for both consumers and contractors. Many contractors and appliance vendors are less familiar with key efficiency technologies and have little incentive to learn about, procure, stock, and install them properly – preferring instead to keep selling what they know. Contractors and vendors may also prefer not to sell more efficient products, given they require less frequent replacement and therefore decrease sales. Finally, most building designers are not sufficiently experienced in zero-emission design strategies beyond current code requirements, and they typically do not have the budget or the time to learn and innovate.

Technologies

Advanced Envelope Solutions

R&D **VALIDATION** SCALE

Advanced building-envelope solutions such as structural insulated panels (SIPs) and thin-center glass triple-pane windows can make heating and cooling more efficient.



More than one-third of building energy consumption in the U.S. goes to heating and cooling, making advanced building envelopes one of the biggest opportunities for savings. Advanced envelope solutions encompass a variety of technologies and strategies, some established and others emerging, that help prevent the loss or gain of heat in and out of a building via heat transfer and air leakage.

Super high-efficiency envelope solutions—such as modified atmospheric insulation panels, polymeric vacuum insulation spheres, and ceramic aerogels—require more R&D to bring down costs. More established envelope solutions that can benefit from deployment-focused efforts include structural insulated panels

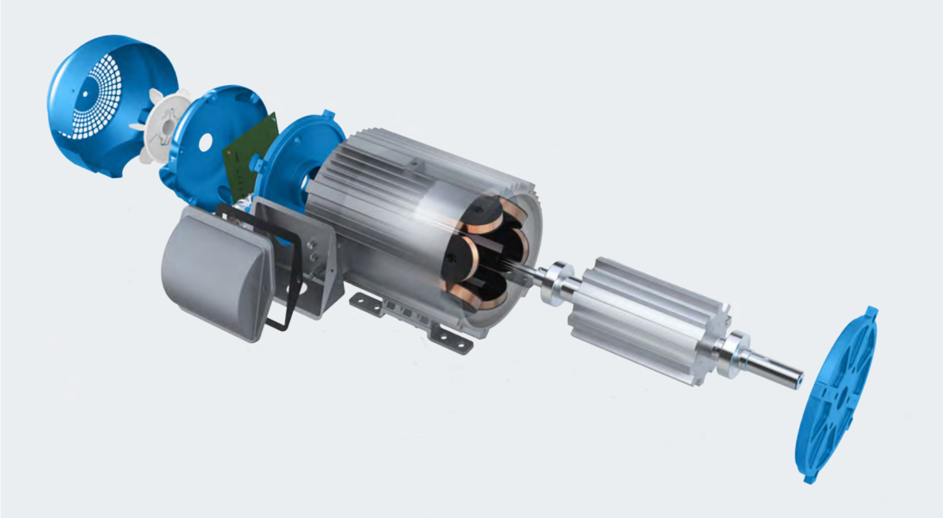
(SIPs) and thin-center glass triple-pane windows. Other options include external window shades, which can block the sun's heat before it passes through the window, and green walls, which take advantage of plants' ability to absorb the sun's energy.

Advanced Motors for Pumps, Compressors & Fans

R&D **VALIDATION** SCALE

This pump, designed by Turntide Technologies, combines two proven technologies: the switched-reluctance motor and the computing technology used in smart phones and cars. The result is a motor system that consumes energy only when needed.

Source: Image courtesy of Turntide Technologies.



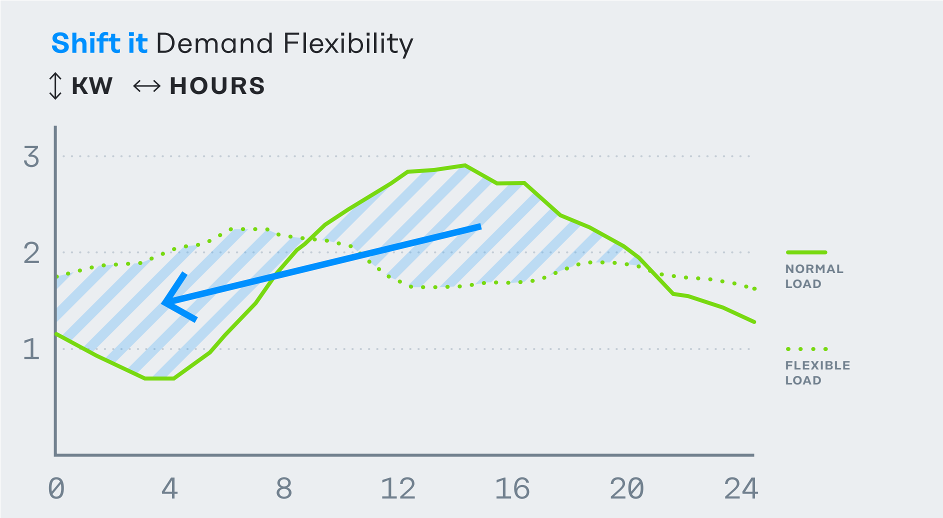
Electric motors consume approximately 45 percent of global electricity production and represent a $100B+ annual market. Advanced high-efficiency motors and motor-control technologies (such as variable frequency drives (VFDs)) are critical to enabling drastic building-efficiency improvements via higher-efficiency HVAC systems, fans, and refrigerators.

Significant advances in power electronics, control algorithms, machine learning, and novel fabrication techniques are enabling new generations of motors (such as switch reluctance and axial flux) that can improve system level power consumption for HVAC, fans, and refrigerators by 10 to 50 percent.

Grid Interactivity

R&D **VALIDATION** SCALE

Demand flexibility allows buildings to act like batteries, shifting the timing of their energy consumption to optimize for saving energy or money and/or reducing emissions.

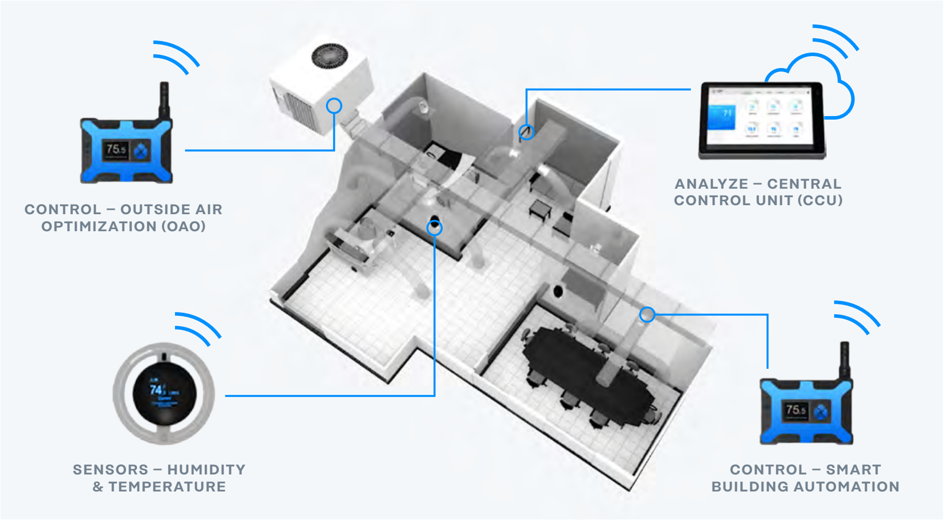


Advances in networking and sensors have it made it possible for building equipment to be connected to cloud-based software systems that can be used 24/7 to reduce energy. Certain systems and equipment can automatically respond to signals from the electric grid and shift the timing of their consumption to optimize for saving energy, money, and/or emissions. (Shifting timing is called demand management or flexibility.) Demand flexibility solutions include hardware (e.g., connected thermostats, timed or remotely controlled EV chargers) and software controls and algorithms that manage a building's response to a signal to use less energy for a short period of time. This capability allows the building to act like a battery, making it easier for grid operators to use more renewable power.

Next-Gen Building Management

R&D VALIDATION SCALE

Advanced building management systems reduce energy consumption by using connected sensors, wireless controls, and big data to optimize building performance.

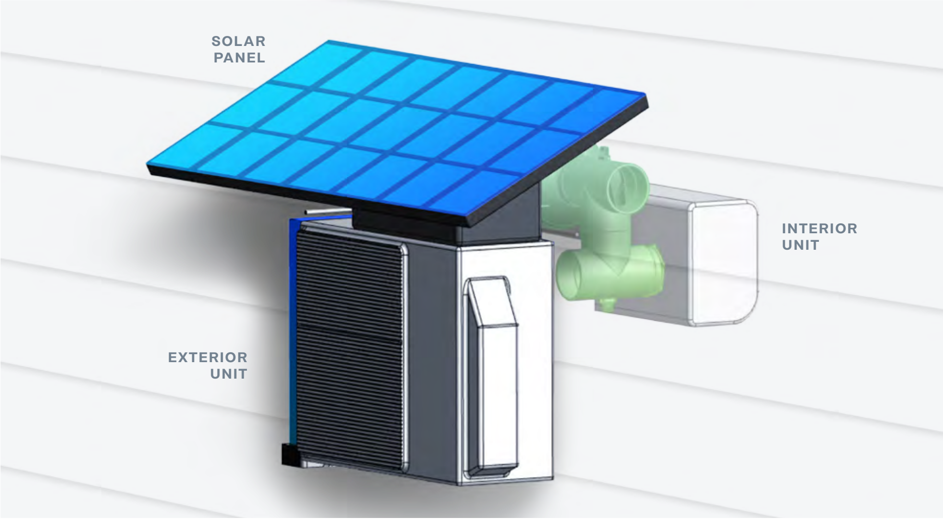


Next-gen systems that manage building HVAC and lighting have been proven to improve comfort, enhance air quality, and reduce energy consumption by 20 percent to 30 percent with relatively low cost and fast installation. These systems include intelligent data dashboards, fault detection and diagnostics, and AI-drive optimization of building systems. The systems generate savings by using wireless controls, big data, and connected sensors to implement strategies such as optimizing trade-offs between compressors, chillers, and fans and reducing simultaneous heating and cooling. These systems also typically reduce operations expenses and improve comfort by controlling temperature more tightly.

Super-Efficient Cooling Technology

R&D VALIDATION SCALE

Cooling technologies that use no or low-GWP refrigerants can reduce emissions significantly compared to conventional AC technologies. Pictured here, the Global Cooling Prize Finalist Technology Schematic: Vapor compression with desiccant dehumidification.



Air conditioning uses a significant amount of energy, contributing to higher emissions and rising temperatures. This creates a dangerous feedback loop—more warming leads to more air conditioning, and so on. Also, most air conditioners (ACs) use high-global warming potential (GWP) refrigerants that often leak during equipment operation, maintenance, or end of life.

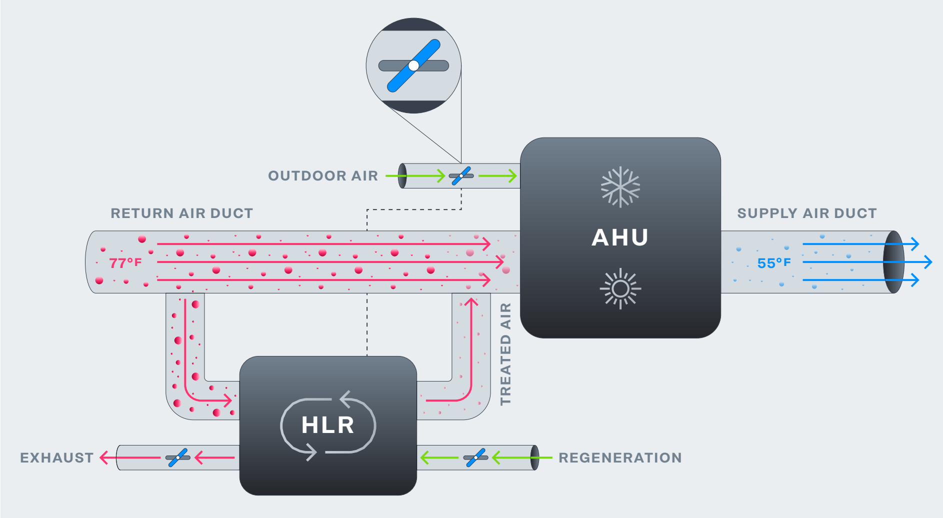
Considering the rapid increase in AC use due to rising global temperatures, incomes, and urbanization, developing cooling technologies that use no or low-GWP refrigerants and have a multifold improvement in efficiency is critical. Promising solutions are being developed, ranging from novel membrane materials to vapor compression control technologies to unique dehumidification methods. Some approaches also take a "systems engineering" approach to build better systems without major tech development. These technologies can all achieve significant emissions reductions relative to conventional AC technologies.

Ventilation Technology: CO_2/Contaminant Filtering & Outside Air Reduction

R&D **VALIDATION** SCALE

enVerid's HLR® (HVAC Load Reduction) system is an example of an advanced ventilation technology that can provide energy and cost savings for buildings. By scrubbing return air for indoor air contaminants, the HLR module minimizes the need for outdoor air, thereby reducing the amount of heating or cooling required by the air handler unit (AHU).

Source: enVerid.



From a list of over 300 technology solutions, DOE's Office of Energy Efficiency & Renewable Energy selected a final set of high priority technology options that could provide significant HVAC savings for commercial buildings. Ventilation Reduction through Advanced Filtration was ranked third overall.

Reducing the amount of outside air introduced to commercial buildings minimizes the need to constantly heat, cool, or manage the humidity of that air to match indoor conditions. This reduction in outside air enables the use of smaller HVAC systems (CAPEX reduction) and improves operational efficiency of the HVAC equipment for the life of the system (OPEX reduction).

Technologies that enable a reduction in outside air not only improve building operations efficiency, but also address the new ASHRAE 62.1 Indoor Air Quality standards that require the management of seventeen contaminants, including CO_2, formaldehyde, and a full range of VOCs in commercial and multi-unit residential buildings. Researchers at Harvard University published a study correlating cognitive ability with lower CO_2 levels in commercial buildings, finding ample evidence that cleaner indoor air leads to greater human health and higher cognitive performance.

Additional Resources

- → **The Economics of Zero-Energy Homes**
- → **The Economics of Demand Flexibility**
- → **Value Potential for Grid-Interactive Efficient Buildings in the GSA Portfolio: A Cost-Benefit Analysis**
- → **Insight Brief: Demand Flexibility**
- → **Grid-interactive Efficient Buildings**
- → **Advanced Metering Infrastructure and Customer Systems**
- → **Energy Saver Technology Resources**
- → **New Buildings Institute: The GridOptimal Building Initiative**

BUILDINGS SOLUTION

Low-Carbon Building Materials

Overview

Embodied-carbon emissions originate from activities at the top of the construction supply chain, like the mining and transportation of raw materials and the operation of manufacturing facilities. Nonetheless, opportunities to reduce these emissions are available throughout the design and construction process.

Since the impact of embodied carbon is realized at the beginning of the building life cycle, it is critical to develop low-carbon materials for building construction. The effect of these low-carbon materials can be further amplified when paired with low-carbon building design strategies like materials optimization engineering and building and materials salvage and reuse.

Market Challenges

Actionable Data

The data currently available for assessments of embodied carbon are of varying quality. These data are typically sourced from national life cycle assessment (LCA) databases, which tend to be generic (with average values for the country) and are rarely updated in the U.S. Environmental data can also be sourced from environmental product declarations (EPDs), which can be reported by manufacturers in either product-specific or industry average reports. In some product categories, suppliers have reported product data, while in other sectors only industry-average data exists. Without standardized metrics to assess embodied carbon, decision-makers have difficulty setting appropriate limits or targets. Alignment on metrics and assessment methods requires often-challenging collaboration across a range of industry organizations including green building programs, government, and industry. In short, embodied carbon data for the building industry must improve in coverage and quality to become more actionable.

Prescriptive Standards

Highly codified to protect life and safety, the building industry can be slow to change, making innovation and new approaches difficult. Building codes tend to be prescriptive instead of performance based. This means that the codes often limit the introduction of new technologies that could support embodied carbon reductions. For example, cross-laminated timber (CLT) is a promising low-carbon wood alternative to concrete and steel, but building codes often limit how tall a CLT building can be, which restricts how and where it can be used.

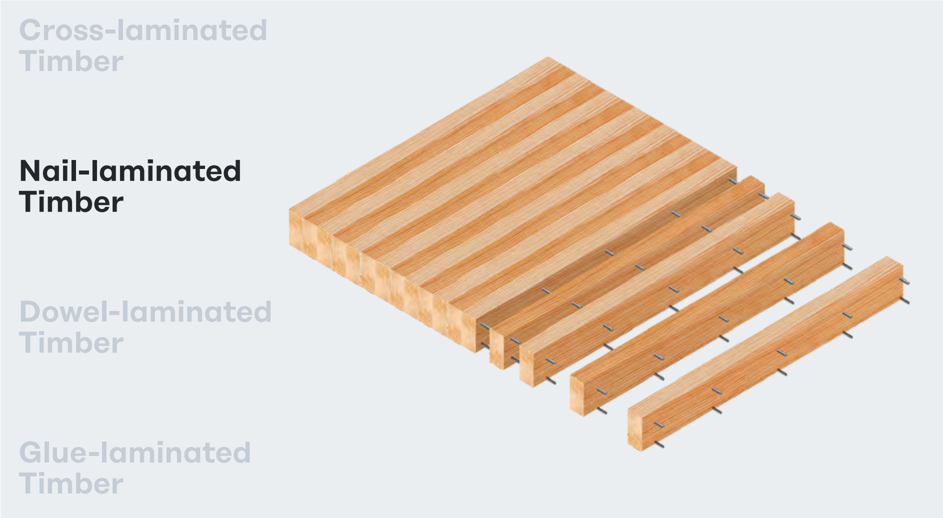
Technologies

Bio-Based Materials

R&D | **VALIDATION** | SCALE

Nail-laminated timber is a type of engineered wood product, a bio-based material that can significantly lower the embodied carbon of buildings.

Source: Thinkwood.com.



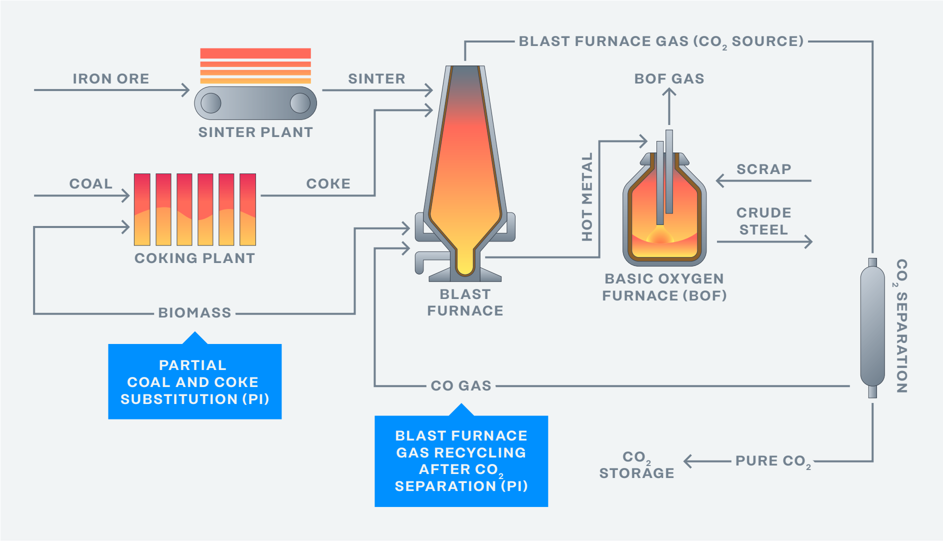
Bio-based or biogenic materials are derived from plant or animal sources and have a long history of use in buildings. Among them are engineered wood products, engineered bamboo, hempcrete blocks, and other plant-derived materials. These materials typically require only moderate amounts of processing energy to create effective building materials. As a result, they tend to have very low embodied carbon—often an order of magnitude lower than more highly processed materials such as steel and cement.

Bio-based materials also grow by absorbing CO_2 from the atmosphere and using the carbon to build cellulose, with half the weight of most biogenic materials composed of atmospheric carbon. This embodied carbon, when stored within a building for its 50+ year lifetime, remains out of the atmosphere for that duration, enabling these buildings to often have a net carbon benefit.

Low-GHG Steel

R&D **VALIDATION** SCALE

Two process integration (PI) pathways for reducing emissions from existing steelmaking processes are shown: biomass substitution for coal and CO_2 capture and recycling.



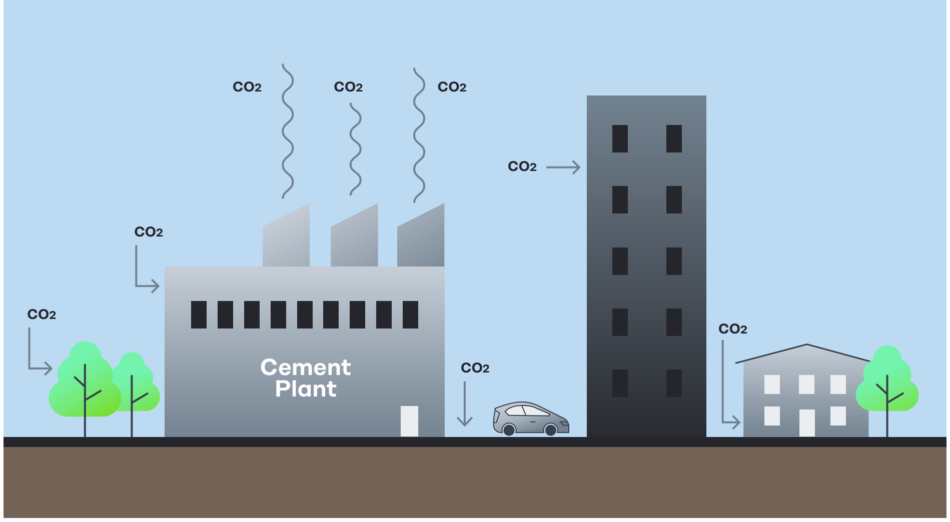
Iron and steel production are responsible for about 5 percent of global greenhouse gas emissions. Most of these emissions come from the fossil fuels used to convert iron ore into steel through carbothermic reduction, particularly in the blast furnace. Existing cleaner production technologies include direct reduction of iron oxide to steel using natural gas, molten oxide electrolysis, CO_2 capture and storage, steel recycling using electric arc furnaces for some steelmaking applications, and the replacement of coal in the steelmaking process with lower-GHG feedstocks.

At present, many of these technologies are not cost competitive with the incumbent processes for primary steel production. The slow stock turnover of industrial facilities also presents a challenge to the rapid diffusion of lower-carbon production approaches. Reducing iron oxide to iron and steel using low-carbon electricity or low-GHG hydrogen (rather than natural gas) is a potentially transformative technology that could substantially reduce steel sector emissions even further.

Low/Negative-GHG Cement

R&D **VALIDATION** SCALE

Cement production releases a significant amount of CO_2 emissions, but new processes and materials are under development that could consume more CO_2 than was generated over the cement's life cycle.



The production of cement is responsible for about 7 percent of global GHG emissions—roughly 40 percent of which is from the energy used and 60 percent from the CO_2 released chemically by the heating of limestone.

Opportunities for significant emissions reductions in cement and concrete include CO_2 capture and storage, the development of low-emission material substitutes for cement/concrete, recycling end-of-life concrete for reuse, and the development of processes and materials that consume CO_2 (as opposed to generating it) in cement or cement-replacement production—thereby enabling emissions-negative cement production.

Modular/Off-Site Construction

R&D VALIDATION **SCALE**

Container City II was constructed in east London in 2002 from standard shipping containers to produce flexible accommodation and workspaces at low cost. The installation took only 8 days.

Modular or off-site construction is the process of designing, engineering, and producing components for buildings away from the construction site. For example, panelized or modularized components can be used in structural, enclosure, or interior partition applications. This type of construction can have significant benefits over conventional on-site construction, including: 1) significantly more rapid build times on site; 2) higher-performance, tighter tolerance structures; 3) lower overall cost; and 4) reduced job-site and overall waste. While these types of buildings represent only a small share of total new construction today (<5 percent), we expect that fraction will grow as technologies improve and as builders are able to realize the cost benefits associated with modern industrial practices and supply-chain improvements.

Additional Resources

- World Green Building Council (World GBC): Bringing Embodied Carbon Upfront
- C40 Cities: Building and Infrastructure Consumption Emissions
- International Energy Agency (IEA): 2019 Global Status Report for Buildings and Construction Sector
- Zizzo Strategy: Embodied Carbon of Buildings and Infrastructure: International Policy Review
- Bionova / OneClickLCA: The Embodied Carbon Review—Embodied Carbon Reduction in 100+ Regulations and Rating Systems Globally
- Carbon Leadership Forum: Buy Clean Washington
- Zera Solutions: Policy Research on Reducing the Embodied Emissions of New Buildings in Vancouver

BUILDINGS POLICIES

Policy Overview

Building Performance Disclosure

Information about a building's emissions and energy use is largely invisible to its owners, occupants, and the market at large. Likewise, it's not always easy to identify cost-effective upgrades when there is no clear data or metric for performance. Improved disclosure of building-level energy consumption, costs, and emissions will increase awareness, fill information gaps, inform retrofit strategies, incentivize competition between owners, protect consumers, and facilitate standards for efficiency.

Data and Disclosure

Measuring embodied carbon emissions requires a standardized, transparent, and reputable source of life cycle assessment (LCA) data. DOE can improve the consistency and quality of LCA data by keeping its national life cycle inventory databases up to date and encouraging LCA data reporting. The Department of Energy (DOE) should update the U.S. Life Cycle Inventory database managed by the National Renewable Energy Laboratory (NREL) and include all major materials used in construction.

Consumer Awareness

To overcome consumer hesitance to building electrification, federal agencies like the Environmental Protection Agency (EPA), the Department of Housing and Urban Development (HUD), and the Consumer Product Safety Commission (CPSC) can raise awareness of the environmental risks of fossil fuel combustion in buildings and encourage consumers to replace combustion appliances with electric alternatives.

Building Codes and Standards

Federal policymakers have a critical role to play in support of state-level building efficiency and electrification policies. For instance, they can develop model standards and approaches to facilitate faster and broader adoption of smart policy. DOE should also provide resources to encourage the adoption of key state policies, including existing building emissions standards and new building codes.

For more, see the deep dive on

→ **Building Codes and Standards**

Access to Finance

Capital constraints, in the form of limited access to capital or financing and/or unwillingness to pay high upfront project costs, keep many building owners from implementing energy upgrades. The federal government can unlock access to more capital for efficiency and electrification upgrades through loans, loan guarantees, and other fiscal incentives. These financing options spread project costs over time. They can also overcome split incentives between building owners and tenants. (For example, owners can be discouraged from investing in upgrades when savings would accrue to their tenants, not them.)

Direct Deployment

Given their number and size, federally owned and assisted buildings can lead by example to accelerate the decarbonization of the buildings sector. For example, the General Services Administration (GSA), the largest commercial landlord in the U.S., controls some 377 million square feet of real estate. HUD spends over $5 billion on energy for housing programs each year. Though there is a wide variety of federal avenues where energy efficiency and electrification interventions could be implemented, funding for building retrofits and new construction should focus specifically on the GSA and three key affordable housing programs: the Low-Income Housing Tax Credit, Community Development Block Grants, and HUD rental programs.

For more, see the deep dive on

→ **Direct Deployment**

Appliance Standards

Currently, federal regulations do not treat GHG emissions as an equivalent priority to energy usage, which implicitly hinders electrification and efficiency over the long term. Correcting these practices will send important market signals and can reduce the green premium for low-GHG alternatives. DOE and EPA should prioritize GHG emissions and energy use in regulations and standards for appliances and equipment, as well as in voluntary programs such as EnergyStar ratings.

Reduce Emissions from Refrigerants

Hydrofluorocarbons, or HFCs, are industrial coolants used for air-conditioning and refrigeration. Per unit of mass, they are more destructive than carbon emissions. As a result, eliminating these super pollutants is among the most cost-effective opportunities for GHG mitigation in the short term.

Alternative refrigerants exist and are widely used outside of the U.S. As such, the federal government should adopt Significant New Alternatives Policy (SNAP) standards banning the use of super-polluting HFCs in end-use appliances. DOE should also develop and improve programs to manage leakage and end-of-life recovery for appliances.

Cross-Sectoral Policies

Additional cross-sectoral policies would also help develop and deploy building technologies and solve the Buildings Grand Challenge.

For more, see the deep dives on

→ **Public Sector R&D**
→ **National Laboratory Reform**
→ **Stimulating Clean Energy Entrepreneurship**
→ **Demonstrating and Validating New Technologies**
→ **R&D Tax Credit**
→ **Technology-Neutral Innovation Tax Credit**
→ **Project Financing**
→ **Carbon Pricing**
→ **Buy Clean**
→ **Clean Product Standard**

BUILDINGS

Buildings Deep Dives

BUILDINGS DEEP DIVES

Building Codes and Standards

Overview

Federal policymakers have a critical role to play in support of individual states' building policies. In particular, the Department of Energy (DOE) and other federal agencies should develop standards and approaches that can drive new construction to zero emissions as quickly as possible. They should also provide technical guidance and funding support to states as they implement performance standards for existing buildings.

Policy Principles

Model Building Codes: New residential and commercial buildings must be built to zero-emissions standards as soon as possible, so that we don't lock in inefficient operations for decades. Zero-emission buildings (also called net-zero-carbon buildings) are high-performance structures that use integrated energy-saving solutions and produce or procure at least as much renewable energy as they consume from emissions-producing sources every year. While the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the International Codes Council have typically developed model building codes, DOE should advance model codes as well and standardize technical guidance to facilitate their adoption by states and localities.

Along with prioritizing deployment in low-income and historically disadvantaged communities, a national zero-emissions model code for new residential and non-residential buildings (differentiated by building type and climate zone) should incorporate the following key elements:

- Prescriptive and performance pathways that require sufficient levels of energy efficiency to achieve zero emissions, after the inclusion of renewable energy and other measures. Prescriptive standards set forth specific requirements for building envelopes, HVAC systems, water heating, power, lighting, energy storage, and other equipment. Performance standards should be based on federally developed carbon intensity (CI) targets by building type and climate zone in lieu of traditional energy-use intensity (EUI) targets. This could be facilitated by the creation of a "CarbonStar" program and rating system akin to EnergyStar, based on life cycle assessment data.

- Electrification criteria for new construction, with technical guidance on climate-specific electric systems and appliances for all end uses, including heating and cooling, hot water, clothes drying, and cooking. Guidelines should prohibit on-site combustion of fossil fuels in buildings as well as associated hookups.
- Renewable-energy requirements, which can be differentiated for states that have 100 percent clean electricity targets and states that do not. For the former, all-electric requirements will eventually be enough for new buildings to achieve net-zero emissions, but model codes can incentivize building-level renewable energy in the interim. For the latter, model codes should include requirements for on-site renewable energy generation and off-site renewable energy procurement sufficient to meet or exceed the emissions-producing energy the building consumes. Off-site procurement requirements should support local demand for clean energy (via green tariffs or community solar, for instance).
- Electric vehicle (EV) charging infrastructure requirements for single-family residential (e.g., one EV-ready parking space), with standardized EV requirements and ratios differentiated for other building types (e.g., multifamily, hotel, commercial) to support current and future EV adoption at scale.
- Demand-side flexibility standards for certain appliances (such as heat pumps or EV chargers) that automatically shift loads to times of renewable generation and/or other grid signals. These standards would help align the supply and demand of renewable energy and improve grid stability.
- Low embodied carbon materials requirements that seek to reduce emissions from the supply chain of building materials: mining, manufacturing, and transport, for example. These requirements should include caps on allowable embodied carbon for different materials or building types.
- Support for code compliance at all levels via expanded training, educational platforms, and credentials for design and construction professionals, and/or funding support to states for such purposes.

Existing Building Emissions Standards: Because on-site building energy use and building electricity consumption are responsible for 31 percent of all emissions in the U.S., and because an estimated two-thirds of today's buildings will still be standing by mid-century, we must increase the pace and scale of retrofits for efficiency and electrification, specifically in low-income and historically disadvantaged communities. Existing building emissions standards establish decreasing limits for annual operational emissions from larger commercial and multifamily buildings. Using emissions-based rather than energy-based standards can further accelerate electrification as the power supply becomes cleaner.

The DOE can standardize technical guidance and federal policymakers can allocate funding to support policy implementation at the state or local level by:

- Directing DOE to develop carbon emissions intensity targets (kgCO_2e/sf/yr) by building-use type and climate zone for commercial and multifamily buildings through 2050 to facilitate state-level policy development.

- Directing DOE to develop technical guides to support implementation and achieve emissions targets, including prioritized climate-specific efficiency and electrification retrofit strategies by building-use type.
- Directing EPA to develop functionality within its EnergyStar Portfolio Manager software to automate the conversion of energy-consumption data (by fuel type) into emissions, accounting for local or regional electricity mix emissions factors as well as time-of-use emissions where possible, to streamline and standardize reporting processes.
- Providing funding support to states implementing emissions standards, including early adoption incentives and funds to help building owners pay for retrofits.

BUILDINGS DEEP DIVES

Direct Deployment

Overview

Given the size of their collective footprint, federally owned and assisted buildings can lead by example to accelerate the decarbonization of the buildings sector. This includes the 377-million square-foot portfolio of the General Services Administration (GSA), the largest commercial landlord in the U.S., as well as housing programs supported by the Department of Housing and Urban Development (HUD).

Though there is a wide variety of federal avenues where energy efficiency and electrification interventions could be implemented, proposed actions focus specifically on the GSA and key affordable housing programs.

Policy Principles

The federal government should leverage existing programs to advance direct deployment of electrification and efficiency technologies, including:

- **GSA:** Maintain 100 percent zero-emission policy targets for all federal buildings by 2030 and upgrade all federal buildings to zero emissions accordingly, leading by example for the broader marketplace. Leverage GSA's portfolio to kickstart the market for demand flexibility and grid-interactive technologies and drive cost reductions, as well as mainstream best practices.
- **LIHTC:** The IRS implements the Low-Income Housing Tax Credit (LIHTC) program, which provides tax credits to homebuilders through state housing finance agencies (HFAs) to allow property rents to be set at affordable levels. Reform the LIHTC program to support energy retrofits as part of the capital cycle and require highly efficient new construction. The IRS, for example, could mandate that HFAs must distribute tax credits only to developers that meet certain efficiency standards, both for new construction and rehabilitation projects.
- **CDBG:** HUD allocates community development block grants (CDBG) to state and local governments, which use the funding for a wide variety of community improvement projects. With new funding, direct a certain portion to building improvement projects and establish related energy efficiency standards.

- **HUD Housing Programs:** HUD provides rent subsidies to tenants through three main channels: Section 8 housing vouchers, privately-owned subsidized housing, and public housing. Each can incorporate incentives or requirements for efficiency:
    - **Section 8 Vouchers:** As the largest HUD subsidy program by number of households (2.3 million), Section 8 housing-choice vouchers assist tenants in renting homes on the private market. The government could provide access to an efficiency upgrade fund or other incentives to landlords who accept Section 8 vouchers.
    - **Privately-Owned Subsidized Housing:** Project-based Section 8 rental assistance provides affordable rental units through long-term contracts between HUD and property owners, assisting roughly 1.4 million households. Grants or subsidies for efficiency improvements should be tied into the renewal of contracts.
    - **Public Housing:** Properties owned by local public housing authorities (PHAs) but subsidized by the federal government assist over one million households. PHAs receive operating funds that often support modernizations and can apply for competitive grants to renovate public housing. These funds should carry a requirement that certain efficiency standards be met.
- Invest in a nationwide retrofit program for public and affordable housing, using a centralized platform to lower costs and increase contractor capacity to drive broader market adoption.

BUILDINGS DEEP DIVES

Additional Buildings Policies

Access to Finance

Capital constraints such as limited access to capital and high upfront project costs represent a major market barrier keeping many building owners from implementing energy upgrades. The federal government can unlock access to more capital for efficiency and electrification upgrades in ways that spread upfront project costs and overcome split incentives between building owners and tenants (encouraging owners to invest in upgrades even when savings would accrue to their tenants). The federal government should also prioritize capital availability in low-income and historically disadvantaged communities.

To reduce these capital constraints, the federal government can:

- Establish a Clean Energy Deployment Administration (CEDA) and/or National Climate Bank/Clean Energy and Sustainability Accelerator that can leverage public funds to stimulate private investment at high ratios (through loan loss reserves, credit enhancements, or other guarantees) and provide broader access to capital to scale a range of building-level efficiency and electrification projects. The bank or fund should support a diversity of proven financial instruments and channels designed for a variety of building types and owner/tenant relationships, including energy savings performance contracts, as-a-service or pay-for-performance offerings, and on-bill financing.
- Enable on-bill financing (OBF) and commercial property assessed clean energy (C-PACE) financing nationwide through federal legislation.
- Establish clearer links in the single-family residential sector between home energy ratings and green mortgage products. For instance, homeowners/buyers should be allowed to finance energy improvements as part of their mortgages, particularly through government-sponsored enterprises such as Fannie Mae and Freddie Mac. In addition, residential appraisal and mortgage underwriting processes should explicitly account for home energy information (especially costs), correcting a historic market failure.
- Provide financial resources and incentives to states to support commercial and multifamily building owners who are required to upgrade to comply with emissions standards.
- Renew the Energy Efficiency and Conservation Block Grant to fund state and local high efficiency, all-electric construction projects.
- Budget federal funds to stimulate more investment into building decarbonization at a scale beyond the billions of ARRA dollars allocated to improve the performance of public housing, government buildings, and energy infrastructure.

Building Performance Disclosure

Building energy and emissions information is largely invisible to building owners, occupants, and the market at large. Opportunities for cost-effective upgrades are likewise invisible. Transparent disclosure of building-level energy consumption, in terms of both costs and emissions, increases mainstream awareness, fills information gaps, informs retrofit strategies, encourages competition between owners, and protects consumers.

To facilitate transparent disclosure of this information, federal policymakers can:

- Require commercial and multifamily energy and emissions benchmarking and disclosure (to occupants, prospective buyers, and local governments) annually nationwide using the Environmental Protection Agency's (EPA's) EnergyStar Portfolio Manager software.
- Direct EPA to develop functionality within Portfolio Manager to automate the conversion of energy consumption data by fuel type into emissions, accounting for local or regional electricity mixes and emissions factors.
- Require single-family home energy ratings based on on-site assessments—using nationally standardized programs like RESNET's Home Energy Rating System (HERS) for new construction and the Department of Energy's (DOE's) Home Energy Score for existing homes—to be disclosed to prospective buyers/occupants and local governments when a property is listed or rented.
    - These ratings should include energy consumption, costs, emissions, and cost-effective improvement recommendations and should be made public so service providers and other market actors can use them.
    - Disclosure of these ratings at the time of listing will allow new homebuyers to integrate energy improvements into their mortgage financing at the lowest cost of capital (e.g., Fannie Mae's and Freddie Mac's green mortgage products) and encourage broader market valuation of energy performance.
    - Leveraging third-party rating programs (e.g., HERS or Home Energy Score) with built-in quality control can be an effective way to address widespread code compliance and enforcement challenges for new construction.

Appliance Standards

Currently, federal regulations do not treat greenhouse gas (GHG) emissions as an equivalent priority to energy use, which discourages electrification over the long term and limits consumer awareness around emissions.

To send important market signals and improve the economics of electrification and broader adoption of emissions-reducing technologies, federal policymakers could:

- Direct DOE and EPA to make GHG emissions an equivalent priority to energy use in all regulation development, including appliance and equipment standards, and in voluntary programs.
- Direct EPA to develop an emissions rating system equivalent to EnergyStar (i.e., CarbonStar) that explicitly considers electrification and grid-interactivity in its ratings. EPA should also establish EnergyStar designations for electric cooktops.
- Ramp up GHG standards for manufacturers' product portfolios over time (as with CAFE standards), prioritizing more aggressive standards for select high-impact end uses.
- Improve and expand access to appliance performance and emissions data through user-friendly, consumer-facing labels or apps.

Hydrofluorocarbons (HFCs)

HFCs are climate super-pollutants and eliminating them is among the most cost-effective near-term mitigation opportunities. Alternative refrigerants exist and are widely used outside of the U.S. As such, the federal government should ratify the Kigali Amendment to the Montreal Protocol and promulgate regulations to phase down production of high global warming potential (GWP) HFCs.

Policymakers can go further by:

- Addressing existing stocks of HFCs, encouraging the recovery and destruction of HFCs at appliance end-of-life.
- Employing federal purchasing power to promote a shift to low-GWP alternatives in appliances.
- Ensuring that federal codes and standards facilitate a rapid transition to low-GWP coolants.
- Enhancing leak management programs for large appliances used in retail buildings such as grocery stores.

GRAND CHALLENGE

Agriculture

How We Grow Things

AGRICULTURE

Overview

The U.S. is one of the world's largest agricultural producers and largest exporter of food. American farms are some of the most efficient and productive in the world, but direct emissions from agriculture comprise more than 8 percent of total U.S. emissions.

Soil management practices that release nitrous oxides (N_2O) into the atmosphere are the largest single source of these agricultural greenhouse gas (GHG) emissions (49 percent). The second largest (44 percent) is the methane produced by livestock raised for meat and dairy production.

Slowing agricultural emissions while still meeting growing global demand for food will require significant innovations in agricultural practices. On the supply side, new technologies, practices, and policies will need to increase productivity, reduce the use of fertilizers, increase carbon sequestration through soil management, and cut methane emissions from livestock. At the same time, demand-side measures can minimize the consumption and waste of GHG-intensive foods.

AGRICULTURE SOLUTION

Soil and Nutrient Management

Overview

Roughly half of all agricultural GHG emissions in the U.S. come from soil-management practices such as tillage, fertilization, and irrigation. However, numerous scientific studies show that management systems designed to improve soil health can also aid carbon sequestration and reduce GHG emissions.

At the same time, they provide important environmental co-benefits: they can improve water quality, suppress pathogens, and support safer pollinator habitats and biodiversity in general. They can also benefit farmers and ranchers by increasing a soil's available water-holding capacity and nutrient availability, improving drought resilience, reducing input costs, and mitigating erosion.

Scaling up these practices can increase carbon sequestration and reduce GHG emissions across the agricultural sector and result in significant air and water quality improvements that can directly benefit agricultural workers.

Market Challenges

Knowledge Gaps

Soils have different carbon-sequestration potential. Calculating the actual sequestration potential for different practices in each soil or group of similar soils will help provide farmers and ranchers with accurate carbon management recommendations. This will require integrating new and affordable soil carbon measurement technologies with digital soil mapping and simulation modeling.

At the same time, in order to improve nitrogen use efficiency (NUE) and therefore reduce losses from sources of essential agronomic nitrogen such as fertilizers, soil organic matter, crop residues, cover crops, and animal manures, we need a better understanding of how soil nitrogen availability and plant nitrogen demand change over time and space. Foundational research that integrates the dynamics of nitrogen availability (regulated by soil processes, weather, and other variables) with the dynamics of plants' nitrogen demand would enable better nitrogen management and recovery.

High Costs for Measurement Technologies

We need credible and transparent mechanisms for verifying the quantity of carbon sequestered in soil to confirm that practices are successful in capturing and storing atmospheric CO_2. Current technologies that calculate carbon stocks by measuring soil carbon and soil bulk density are time consuming and expensive. Consequently, developing soil-carbon testing technology that is economical, accurate, and standardized is fundamental to scaling soil-carbon sequestration. Further modeling is also needed fornitrogen management and systems level assessment at watershed-to-regional scale so that conservation practices can be quantitatively evaluated. Without low-cost methods of estimating sequestration potential on individual farms, many researchers and policymakers continue to rely on average sequestration estimates.

Economic Incentives and Market Demand

The costs and benefits of adopting carbon reduction practices are often unclear to farmers and agricultural producers. Many of these uncertainties are due to a lack of standardized scientific measurement of sequestration and understanding of carbon saturation, the heterogeneity in soil sequestration levels, and the variability in implementation across farms. Even if better estimates existed, potentially high upfront costs also limit adoption rates.

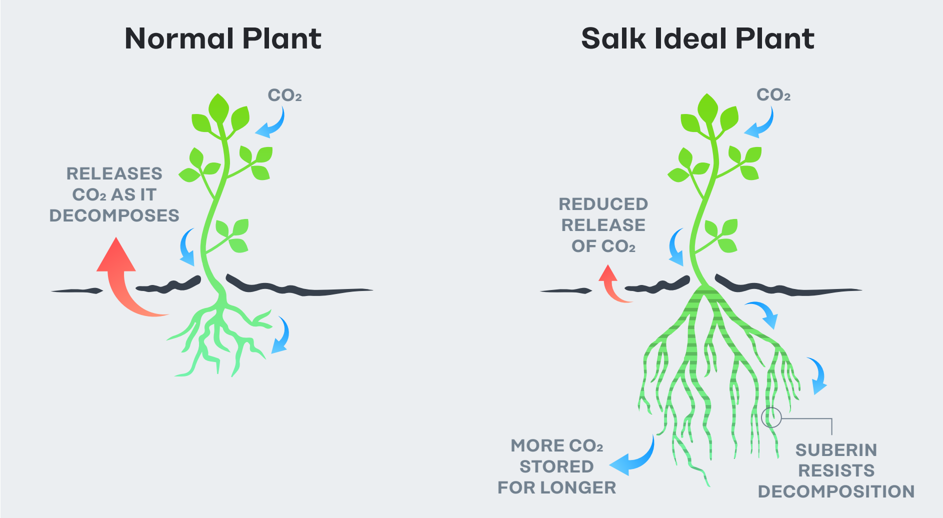
Reducing GHG from the agriculture sector is further complicated by the current nature of commodity cropping systems, which are dominated by monocrops and rely on commercial inputs. For example, the livestock industry has consolidated to put downward pressure on production costs and the fertilizer industry is increasingly concentrated in order to maximize profits through market scale. If these consolidated producers do not see the business case for soil management practices and technologies, GHG reductions may not occur at scale.

Technologies

High Sequestration Crops and Soil

R&D | VALIDATION | SCALE

Because of the suberin (a natural carbon polymer) in their roots, Salk Ideal Plants release significantly less CO_2 when they decompose than their normal counterparts.



Crops and soil can sequester larger amounts of carbon. High carbon-input crop phenotyping, for example, can be achieved by genetically modifying crops or by perennializing grain, seed, and other crops to keep their root residues in the soil. Another approach is to apply biochar (plant matter turned to charcoal) or compost to cropland, which can improve soil health.

Crop Productivity

R&D VALIDATION SCALE

Used largely as animal feed, soy (shown here) is a critical piece of the global food system. Demand for soy is projected to increase significantly over the coming decades. Innovations in crop productivity can help meet this demand without extensive land use changes.

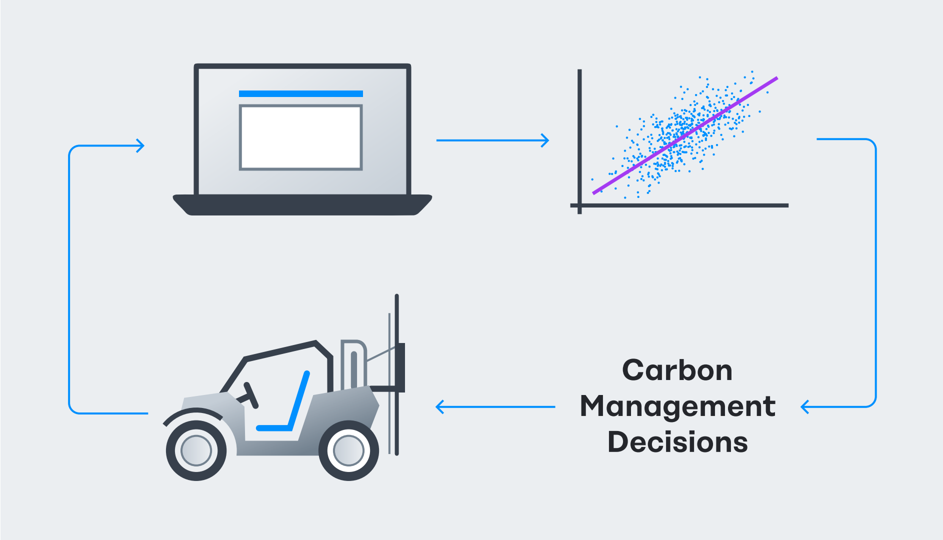
Feeding a growing and increasingly affluent global population without extensive changes in land use will require dramatic growth in agronomic yields. These yields must rise despite growing pressure from climate-change–induced variability, reduced soil quality, and pests.

To make this happen, we need technological solutions to rapidly transform crops, improve climate resiliency, and use new modes of production. For the greatest impact, producers should apply these innovations to the large-acreage crops, including wheat, soy, rice, and maize, that underpin the global food system.

Measurement Technologies

R&D **VALIDATION** SCALE

Developing accurate, low-cost, and efficient technologies for measuring soil carbon and nitrogen stocks in the field will be critical for scaling soil carbon sequestration and reducing nitrogen losses to the environment, respectively.



We need accurate, low-cost, and efficient technologies to quantify soil carbon and nitrogen stocks in the field. Current technologies to measure soil carbon and bulk density are time-consuming and expensive. Developing remote-sensing soil-carbon technology that is economical, accurate, and standardized is fundamental to quantifying and scaling soil carbon sequestration.

Nitrogen measurement technologies also have the potential to significantly improve nitrogen use efficiency, thereby reducing nitrogen losses to the atmosphere (as nitrous oxide) and to water (as nitrate).

Low-GHG Fertilizer

R&D **VALIDATION** SCALE

Microbial fertilizers could help reduce N_2O emissions. Step 1: Identify millions of isolated microbes in diverse soils, creating a sophisticated map of the soil microbiome. Step 2: Characterize key microbes' genetic potential to fix atmospheric nitrogen and live in a symbiotic relationship with cereal crop. Step 3: Fine-tune these microbes so they release nitrogen through the roots to meet the growing crop's nutritional needs.

While nitrous oxide (N_2O) emissions tied to nitrogen fixation and decomposition of crop residues are particularly challenging to mitigate, there is substantial potential to reduce emissions arising from fertilizer application and manufacture. Development and adoption of technologies such as enhanced efficiency fertilizers and microbial fertilizers could reduce the need for synthetic or organic fertilizer and reduce N_2O emissions. Developing ammonia for use in fertilizer is also highly emissions-intensive and can be made cleaner through direct electrochemical and solar conversion processes, in addition to processes that could provide low-cost green hydrogen to traditional ammonia production.

Additional Resources

- → **Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies**
- → **Paustian, K., Larson, E., Kent, J., Marx, E., and Swan, A. 2019. Soil C Sequestration as a Biological Negative Emission Strategy. Frontiers in Climate 1:1 11**
- → **Soil Health Institute White Paper on Addressing Climate Change Through Soil Health**
- → **NRDC, Covering Crops: How Federal Crop Insurance Program Reforms Can Reduce Costs, Empower Farmers, and Protect Natural Resources**

Chambers, A., Lal, R., and Paustian, K. 2016. "Soil carbon sequestration potential of U.S. Croplands and Grasslands: Implementing the 4 per Thousand Initiative." *Journal of Soil and Water Conservation 71*:68-74. doi:10.2489/jswc.71.3.68A

AGRICULTURE SOLUTION

Agricultural Methane Abatement

Overview

Several biological processes important to our agriculture and food systems emit methane, a greenhouse gas that is as much as thirty times more harmful to the environment than carbon dioxide. The most significant source of methane is livestock—especially cattle, swine, and sheep. Adjusted feeding practices and other technical interventions can lower these enteric emissions, and controlling the way manure decomposes can reduce emissions of both methane and nitrous oxide.

Another important source of agricultural methane is decaying plant and food matter, particularly in landfills. The adoption of methane-recovery technologies by most U.S. landfills, as well as increasing rates of recycling and composting, has kept these emissions on a downward trend over the past two decades, but more can still be done to accelerate these reductions. Polices to reduce agricultural methane should include provisions to ensure direct benefits to low-income and historically disadvantaged communities centered around agricultural industries.

Market Challenges

High Capital Costs

Since methane abatement from livestock waste and food waste is capital intensive, access to financing is key to the widespread adoption of new technology. Anerobic digestion facilities and methane control systems at landfills require large upfront capital investments that may be hard to finance through traditional loans due to uncertain future revenue streams. Reducing enteric fermentation through livestock feed additives also requires capital investments in research and development (R&D) of advanced feed technologies. But as many of these technologies are in the early development stages, traditional financing is often not available.

Land Use and Permitting

Methane abatement from livestock waste and food waste can require large-scale facilities to contain and digest methane emissions. These facilities must meet air, water, health and safety, and land-use requirements, and zoning ordinances and permitting requirements can delay or even prevent their construction. Despite advancing technologies that reduce the impacts of handling livestock and food waste, as well as strict requirements to meet local and national codes for safety, permitting and zoning remain barriers to the widespread adoption of methane-reduction mechanisms. Land use and permitting must ensure that reductions in methane emissions do not increase local air pollution and that they maintain soil and water quality.

Public Perception

Many consumers are wary of the potential health impacts of some methane-abatement strategies, such as feed additives that may reduce enteric fermentation. Public sentiment can also prevent installation of methane capture facilities for livestock and food waste. Policies that support advanced technologies that limit the impact of waste-to-energy facilities on the local community, as well as neighborhood outreach, can help limit the negative public perception of critical methane-abatement technologies.

Technologies

Cattle Productivity & Enteric Emissions

R&D VALIDATION SCALE

Project "Clean Cow" aims to reduce methane emission by 25 percent. An enzyme inhibitor added to the feed helps reduce the amount of methane produced in the rumen.

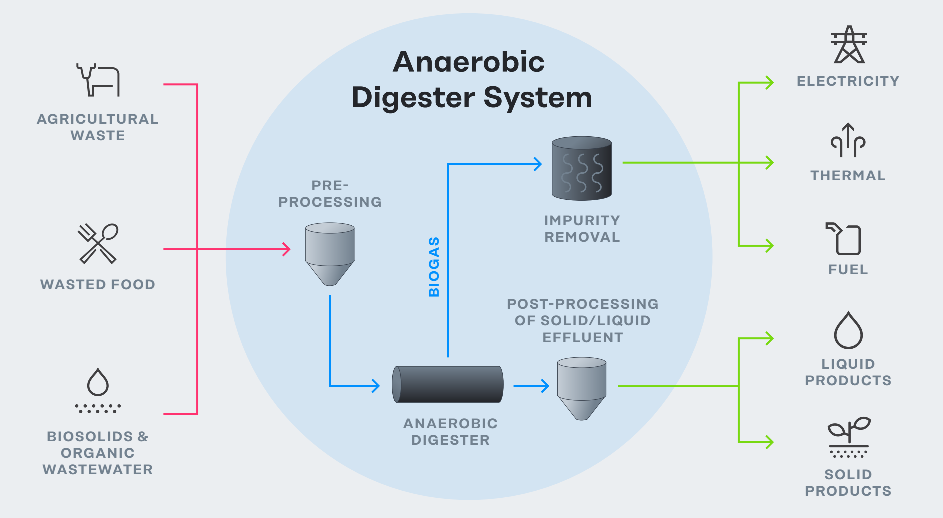
Cattle account for approximately 10 percent of total global greenhouse gas emissions, including about 60 percent of global N_2O and 50 percent of methane. (Livestock produce significant amounts of methane as part of their normal digestive processes.) Simply making cattle production more efficient, by increasing cattle productivity while decreasing enteric emissions, is in the interests of both farmers and the environment.

Technological opportunities to achieve this include tools to increase livestock productivity and the development of advanced ruminant dietary additives that reduce enteric methane emissions. Some feed additives can inhibit the microorganisms that produce methane in the rumen and subsequently reduce emissions. These methane-reducing feed additives and supplements can be synthetic chemicals, natural compounds (such as tannins and seaweed), or fats and oils.

Methane Digesters

R&D VALIDATION **SCALE**

Advanced anaerobic-digester technologies can reduce manure emissions while producing biogas and other useful nutrients.



Greenhouse gas emissions from animal manure represent about 2 percent of global emissions. The breakdown of manure applied to soils and pasture results in significant emissions of N_2O, while manure management in low-oxygen environments such as open lagoons results in significant methane emissions globally.

Opportunities to reduce manure emissions include the development of advanced anaerobic digester technologies. Anaerobic digestion is a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. One of the end products is biogas, which can be combusted to generate electricity and heat or processed into renewable natural gas and transportation fuels. Separated digested solids can be composted, utilized for dairy bedding, directly applied to cropland, or converted into other products. Nutrients in the liquid stream can be used as fertilizer. Environmental justice organizations have opposed methane digesters due to their potential impacts on local air, water, and soil quality. Policies supporting methane digesters must ensure that rural communities benefit environmentally and economically. They may also require provisions limiting the on-site combustion and flaring of methane.

Additional Resources

- → **FAO: Livestock Solutions for Climate Change**
- → **EPA: Landfill Methane Outreach Program**
- → **Climate and Clean Air Coalition: Reducing Enteric Methane for Improving Food Security and Livelihoods**

AGRICULTURE SOLUTION

Alternative Proteins

Overview

Even with significant improvements in livestock production, meat and dairy will likely remain the most greenhouse gas (GHG) intensive foods on our plates. Yet the plant-based meat and dairy market is taking off in the U.S., driven by a spate of innovation in new food products that increasingly resemble conventional meat and dairy in terms of taste, texture, and price.

If products on the market today are any indication, plant-based pork and chicken could reduce emissions by 30–36 percent compared to their meat counterparts, and plant-based burgers could reduce emissions by 80–90 percent compared to conventional beef patties. At the same time, emerging technologies to produce cell-based or cultivated meat in the lab are advancing rapidly, and their products could be on consumers' plates in the next 3–5 years. Initial studies suggest that cell-based beef could reduce the impact of livestock on land use by more than 95 percent and bring down GHG emissions by some 80 percent compared to conventional beef.

Market Challenges

Supply Chain Constraints

A transition from animal agriculture toward alternative proteins will have massive supply chain implications for global commodity markets. Among them is expanding or retrofitting ingredient processing capacity to create suitable inputs for plant-based products, fermentation, and cultivated meat. Currently, agricultural supply chains are heavily optimized around commoditized feedstocks for animal agriculture, whereas alternative proteins will require novel crop development, clean regulatory pathways, and new processing methods. The variability and inconsistency of raw materials can cause supplier lock-in and increase the technical risk associated with reformulation or process alterations, which can result in resistance from buyers to modify their supply chain.

Production Capacity and Cost

Production capacity is one of the most significant constraints facing the alternative protein industry. Producers do not have the types and quantities of ingredients and other inputs they need, and production equipment is highly specialized. As a result, demand for high-quality alternative protein foods—especially for products like plant-based burgers that require specialized equipment and processes like high-moisture extrusion—has far outpaced supply, and even well-capitalized alternative protein manufacturers have struggled to keep up with sales growth. Shortages aren't the only problem; higher production costs and prices are one of the most significant barriers to industry and consumer adoption of alternative protein foods. That said, economies of scale from higher production volumes will make high-quality alternative-protein foods and ingredient inputs more affordable. This, in turn, will unleash demand and expand consumer access.

Information Gaps and Consumer Awareness

Because the alternative protein sector is still nascent, gaps in fundamental research areas can lead to redundant efforts. More informational resources would address these knowledge gaps, catalyzing greater participation and minimizing market inefficiencies. Research tools and comprehensive public databases are required to address critical technical challenges such as full genome sequencing for food-relevant species.

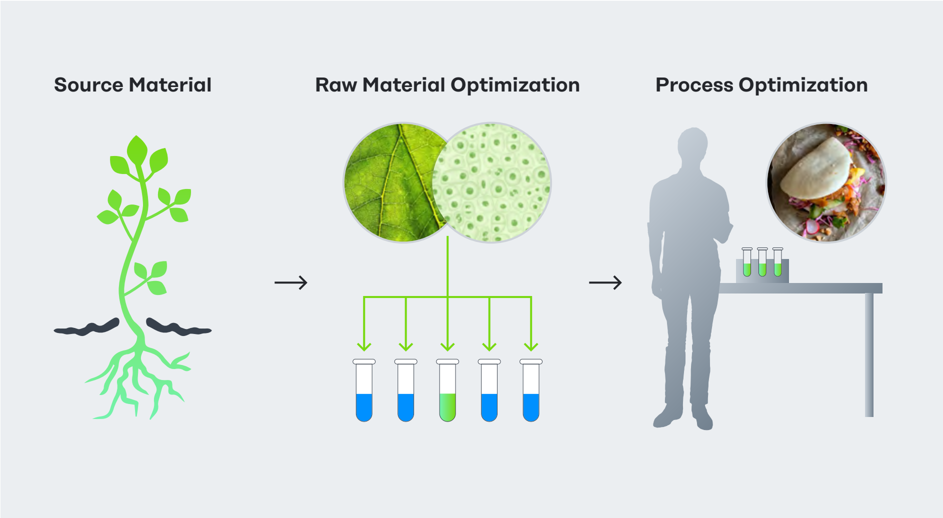
In addition, consumers lack awareness of key aspects of alternative proteins, including the nutritional and health impacts of these foods. At the same time, stringent labeling regulations often prevent plant-based products from using meat- and dairy-related terms in their packaging, further confusing consumers.

Technologies

Plant-Based Proteins

R&D **VALIDATION** SCALE

Food scientists produce plant-based meat through a series of optimization steps from source material to end product.

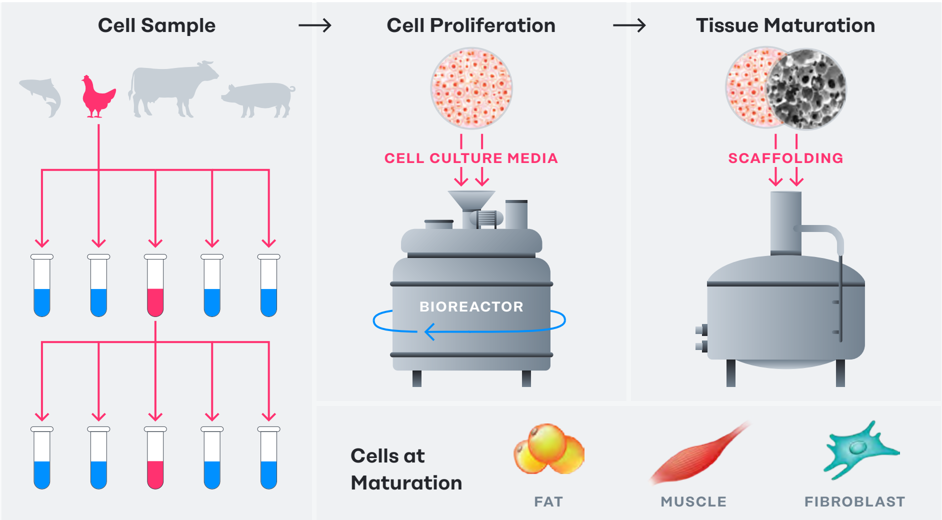


Producing plant-based meat is a four-step process. First, food scientists select the best source material for the product: today this is often wheat or soy, but it could also be a novel plant source or fungi, algae, or bacteria. Next, they optimize that source, giving it the attributes the final product needs, such as higher protein content or reduced off-flavors. Then they isolate the desired raw materials from the source materials, which undergo mechanical and/or chemical processes to create optimal ingredients for the final product. Finally, art and science combine these ingredients to create the desired taste, texture, smell, and appearance.

Cultivated Meat Production

R&D **VALIDATION** SCALE

In the production of cultivated meat, a small sample of animal cells proliferates in a cultivator (bioreactor) and then differentiates into muscle, fat, and connective tissue.



The production of cultivated meat borrows technology from the cell-therapy industry. First, a small biopsy of cells is obtained from an animal. These cells are placed in a tank (called a bioreactor or cultivator) and "fed" with nutrients that allow the cells to divide and multiply exponentially. Once they have increased to a sufficient quantity, the conditions in the cultivator are changed, and the cells differentiate to the cells that make up meat—muscle, fat, and connective tissue. This process takes around 6–8 weeks, far faster than the time required to raise an animal for slaughter (and, of course, the animal in question never needs to be killed).

Additional Resources

- State of the Industry Report: Cell-based Meat, The Good Food Institute
- State of the Industry Report: Plant-based Meat, Eggs and Dairy, The Good Food Institute
- "Food Label Censorship: Anti-Market and Anti-Speech," The Good Food Institute
- "Meat by the Molecule: Cultivated Meat 101," The Good Food Institute
- Meat Re-imagined: The Global Emergence of Alternative Proteins, Food Frontier
- Creating a Sustainable Food Future, A Menu of Solutions to Feed Nearly 10 Billion People by 2050 (Synthesis Report), World Resources Institute
- Meat: The Future Series, Alternative Proteins, World Economic Forum
- The Plant Milk Report, ProVeg International

FAIRR (A Global Network of Investors Addressing ESG Issues in Protein Supply Chains)

- Appetite for Disruption: How Leading Food Companies are Responding to the Alternative Protein Boom
- Protein Producer Index

AGRICULTURE SOLUTION

Food Waste

Overview

In the U.S., about 40 percent of all food goes uneaten. That's enough food to fill a semi-truck every 20 seconds, and almost all of it ends up in landfills. In fact, food makes up the largest share of landfill waste today, and it generates extremely potent methane emissions as it decays. (Just one-third of all that wasted food each year could feed all food-insecure Americans.)

Given the complex nature of food systems and variety of food products in the U.S., a suite of solutions will be required to address this waste issue. These include improving the efficiency of operations and supply chains and finding productive uses for edible byproducts.

Market Challenges

Lack of Visibility and Measurement

Since most businesses and households do not track or measure their food waste, it is essentially invisible—and so are its costs. Businesses that don't track food waste in detail cannot systematically reduce it nor evaluate the cost-benefit of solutions. Local governments too lack the level of information that could help design programs, incentivize leaders and identify laggards, or evaluate progress. Individuals, too, are ignorant of their waste, with 75 percent of Americans reporting they waste less than the average American.

Misaligned Incentives

Both food and waste disposal cost relatively little, especially when compared with labor, real estate, or the potential loss of customers. Food businesses may prioritize hiring fewer workers or providing customers more options, even if it means more food is thrown out. Additionally, many food businesses drive profits through high volume sales, leading to large portions and promotions that encourage overbuying—which in turn leads to waste at the consumer level. Finally, farmers will choose to leave entire fields or types of products unharvested if market prices do not warrant the costs of harvesting and transporting the product.

Food Safety Requirements

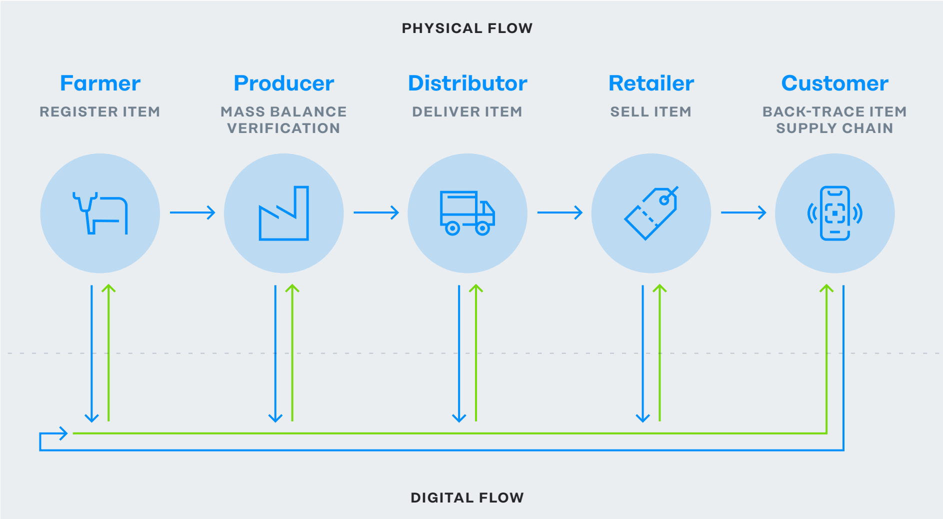
Food safety is of paramount importance to both the food industry and regulators. A single lapse can have a dangerous and long-lasting impact. Companies and regulations therefore give a wide berth to anything that would incur increased food safety risk, leading to huge amounts of food being discarded as a precautionary measure. Furthermore, rules and enforcement can vary from one jurisdiction to another, causing confusion and lowest-common-denominator policies for businesses operating facilities across multiple regions. Policies also vary from one jurisdiction to another on, for instance, whether food from a salad bar can be donated or how it must be cooled. Despite a federal law providing liability protections, some businesses remain reluctant to donate food for fear of a food safety issue.

Technologies

In-Field Loss and Supply Chain Waste

R&D VALIDATION SCALE

Digitally sharing information and data across food supply chains can help optimize the food system and reduce waste.



In developed economies, as much as 20 percent of agricultural production can be lost to agronomic pests and pathogens. In large part, this is a result of herbicide resistance and emerging pests pushed into new geographies by climate change. Technologies that include early detection of threats and precision application of responses are needed.

Approximately one-third of the food we produce today is lost or wasted. For consumers and retail, action is needed to address this waste. Because food is lost to different causes across the supply chain, a variety of technologies are emerging to help. These include everything from hyperspectral imaging that evaluates produce quality and shelf-life to machine learning-assisted forecasting for grocery stores and temperature sensors in trucks.

Additional Resources

- → Rethink Food Waste Through Economics and Data
- → Natural Resources Defense Council, Wasted: How America Is Losing up to 40 Percent of its Food from Farm to Fork to Landfill
- → Champions 12.3, reports on U.S. Sustainable Development Goal 12.3
- → World Resources Institute, Reducing Food Loss and Waste: Setting a Global Action Agenda

AGRICULTURE POLICIES

Policy Overview

Procurement

The federal government's food programs directly fund billions of meals for millions of Americans every year through the Supplemental Nutrition Assistance Program (SNAP), the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), school meals, and the Child and Adult Care Food Program (CACFP). Policies and guidelines for these programs, as well as General Services Administration (GSA) contracting guidelines, also indirectly impact billions of dollars in purchasing decisions for retailers, vendors, and consumers. Requiring federal agencies and federally funded programs to promote best practices and technologies in sourcing goods and handling waste can validate and accelerate their adoption. Likewise, federal procurement requirements can offer incentives to farms, facilities, retailers, and workers who implement emissions-reducing practices and technologies.

For more, see the deep dive on

→ **Alternative Protein Procurement**

Federal Regulatory Approvals for Cultivated Meat

Regulatory schemes for this emerging method of food production must ensure public safety while offering producers a clear and efficient path to market and a level playing field with conventionally produced meat and seafood. In the United States, the U.S. Department of Agriculture (USDA) and the Food and Drug Administration (FDA) will jointly regulate the production of cultivated meat and its entry into the marketplace. They are still working to refine the technical details of this framework, but the process they settle on should keep labeling regulations on cultivated meat, poultry and seafood from posing a barrier to market entry.

For more, see the deep dive on

→ **Alternative Protein Labeling**

Reporting and Regulations

Under both the Obama and Trump administrations, the FDA, USDA, and Environmental Protection Agency (EPA) established a joint goal to reduce food waste by 50 percent by 2030. To help achieve this goal, these agencies should adopt some of the key recommendations made by the Government Accountability Office, such as developing mechanisms to monitor, evaluate, and report on results. In addition, these agencies should lead by example, with top food-procurement agencies such as the USDA Food and Nutrition Service, Department of Defense, and Department of Veterans' Affairs measuring and reporting the quantity of edible food they discard and create plans for reducing waste.

The FDA and USDA can further reduce food waste by modernizing relevant regulations. For example, now that we can use technology to evaluate the risk of pathogen exposure more precisely, these agencies should adjust their regulations accordingly—which will lead to lower rates of discarded food that is safe to eat.

Federal Crop Insurance Reform

The Federal Crop Insurance Program (FCIP) could be a powerful lever for improving soil management practices and deploying methane-reducing technologies. Offering a discount on federal premiums in exchange for producer risk management strategies, such as conservation practices that reduce erosion, build soil carbon, and increase nitrogen-use efficiency, could increase soil carbon sequestration and GHG reduction significantly. Linking funding and crop insurance to lower-methane practices could accelerate their use across the agricultural sector.

For more, see the deep dive on

→ **Federal Crop Insurance Reform**

Reform Conservation Programs

The USDA is the largest provider of financial assistance to farmers and ranchers who seek to improve environmental outcomes on their land. These programs also provide important technical assistance to farmers and ranchers. Funds such as the Environmental Quality Incentives Program and the Conservation Stewardship Program have improved environmental outcomes, water quality, and soil health on agricultural lands. Funding conservation programs to achieve ongoing performance improvement linked to climate benefits would meet these important goals and strengthen existing land conservation policy. Eligibility could also be expanded to more types of land and a wider swath of participants.

Strengthen Soil Erosion Standards

Conservation compliance has two parts: soil conservation and wetlands protection. While conservation compliance has been highly successful in reducing soil erosion, croplands still lose over a billion tons of topsoil every year. Strengthening the soil erosion standard, applying soil erosion reduction requirements to all soils (not just Highly-Erodible Land (HEL)), and more robustly enforcing the adoption of conservation-compliance policies could reduce erosion and improve soil health.

Federal Mandates

Federal mandates requiring methane reductions from large-scale agricultural and waste-handling facilities can drive deep decarbonization across the sector. For instance, regulating methane emissions from new and existing concentrated animal feeding operations (CAFOs) under the Clean Air Act could dramatically reduce methane emissions, reduce air pollution, and improve water quality. Federal mandates targeting waste and the removal of organic materials from the waste stream can also result in deep reductions in methane emissions and improvements in air quality.

Food Waste Federal Resources for States

Food waste often falls under the purview of state and local governments, but federal funding can provide the resources needed to adopt infrastructure-intensive waste-reducing and composting policies and make it economically viable to expand implementation of best practices at schools and farms. Grant programs and technical assistance can support state-level implementation of best practices like food-conservation laws, landfill bans, reporting requirements, full utilization on farms, and waste reduction in K–12 Child Nutrition Programs.

For more, see the deep dive on

→ **Food Waste Federal Resources for States**

Sensible Food Labeling Standards

Food labels must make sense to consumers. Lawmakers and regulators should resist efforts to prohibit the use of common terms that consumers understand (like "milk" or "cheese") on food labels that compete with conventional meat and dairy. New restrictive legislation, regulation, or interpretation cannot be justified on the grounds of protecting consumers from misleading labels when consumers clearly have no difficulty understanding plant-based food labels.

For more, see the deep dive on

→ **Alternative Protein Labeling**

Date Label Standardization

Confusion over the meaning of date labels (and thus over when food is no longer safe to eat) is one significant cause of wasted food from home kitchens. There is currently no federal regulation of date labels, and state laws are dizzyingly inconsistent. Combined with consumer education, standardizing these labels could save an estimated 800 million pounds of food per year.

Cross-Sectoral Policies

Additional cross-sectoral policies would also help develop and deploy agriculture technologies and solve the Agriculture Grand Challenge.

For more, see the deep dives on

→ **Public Sector R&D**
→ **National Laboratory Reform**
→ **Stimulating Clean Energy Entrepreneurship**
→ **Demonstrating and Validating New Technologies**
→ **R&D Tax Credit**
→ **Technology-Neutral Innovation Tax Credit**
→ **Project Financing**
→ **Carbon Pricing**
→ **Clean Fuel Standard**

AGRICULTURE

Agriculture Deep Dives

AGRICULTURE DEEP DIVES

Federal Crop Insurance

Overview

The Federal Crop Insurance Program (FCIP) is a powerful policy lever that can accelerate the adoption of conservation practices that reduce greenhouse gas (GHG) emissions and sequester soil carbon. Crop insurance is also the foundation of the farm safety net, which helps producers manage the risks associated with crop yield and revenue loss. Under the FCIP, the federal government pays more than 60 percent of a producer's insurance premium, with the largest 10 percent of farms receiving 68 percent of the federal subsidy. The vast majority of cropland is planted in corn and soybean acres, of which FCIP insures about 88 percent.

Common-sense reforms could improve FCIP's efficacy and cost effectiveness. They could also drive GHG reductions by linking the producer's actual risk, as predicted by field-level planting and conservation practices, to their insurance premiums and federal subsidies. States like Iowa and Illinois are already piloting approaches that reduce premiums for farmers who plant cover crops.

Such reforms could garner broad-based support and improve FCIP's overall risk-management performance by reducing long-term risk and taxpayer cost; lowering GHG emissions, increasing carbon sequestration, reducing erosion, and increasing the efficiency of nitrogen use; aligning with corporate and philanthropic sustainable supply-chain efforts; facilitating the growth of the carbon market; and enhancing long-term agricultural productivity.

Principles

Strengthened FCIP Eligibility Requirements: Currently, to maintain eligibility for Farm Bill benefits like subsidized crop insurance, producers must comply with a minimum set of conservation requirements aimed at conservation and wetlands protection. For example, producers who farm on highly erodible land (HEL) must have a conservation plan that, in general, reduces soil erosion to no greater than "2T" (or approximately twice the rate that soil is formed) via practices such as cover cropping, no-till, reduced-till, and contour farming.

Conservation compliance has been highly successful in reducing soil erosion, but over a billion tons of topsoil are still lost on croplands every year. Strengthening science-based standards and expanding coverage beyond HEL could reduce soil erosion even further. According to the U.S Department of Agriculture (USDA)

Economic Research Service, approximately 35 percent of farms implement a full nitrogen-management plan designed to optimize plant uptake and reduce nitrogen losses to air (GHG emissions) and water (nitrate pollution). Commodity-crop producers could improve the efficiency of their nitrogen use even further if policymakers required nutrient-management plans as a condition of eligibility for FCIP subsidies and provided needed technical assistance in their development and implementation.

More Accurate Premium Rate Calculations: The Risk Management Agency (RMA), the USDA agency that implements FCIP, should link FCIP insurance premiums and federal subsidies to actual crop-yield risk by accounting for field-specific conservation practices. For example, there is evidence that FCIP insurance premiums do not adequately account for soil type, which predicts yield risk. As a result, producers with riskier practices, like farming on HEL, may receive a disproportionate share of the premium subsidy compared to those who do not plant on highly erodible land. By better predicting risk based on field-level conditions such as soil type, soil health, and conservation practices, FCIP could encourage climate-smart agricultural practices and discourage riskier ones.

Expanded Conservation Incentives: In the 2018 Farm Bill, Congress incrementally improved FCIP policy by reducing barriers to and encouraging adoption of conservation practices. It clarified that producers retain federal crop-insurance eligibility when they plant a cover crop by deeming it a good conservation practice as long as termination guidelines are followed. Congress could authorize RMA to provide an additional premium benefit for producers who use good soil-stewardship practices such as improved fertilizer management, cover cropping, and reduced tillage. Combining premium incentives designed to encourage the adoption of practices that build long-term resilience and reduce GHGs with more accurate risk assessments would drive landscape-level change.

Science and Data Driven Policy: Significant knowledge gaps still exist regarding the ways in which some farming and conservation practices may impact risk, yield, and productivity. The 2018 Farm Bill began to close this gap by requiring the Secretary of Agriculture to identify data sets that quantify the use and effect of conservation practices on crop yield, soil health, and other risk factors. In addition, the Secretary of Agriculture is required to report to Congress on how these data sets may be made available to researchers, maximizing their benefits. Congress could build on this foundation by mandating and funding a transparent, science-based approach to federal crop-insurance rates that more accurately assess risk in order to reduce cost and boost more resilient agricultural production. Given their role, Congress could direct RMA to begin such data collection.

Technical and Financial Assistance: For improved soil management to reduce GHG emissions and increase soil-carbon sequestration, additional funding is needed to help producers select and implement conservation practices. Producers need increased technical agronomic information on when, where, and how to implement soil-health–management systems. Existing Farm Bill conservation programs and technical assistance mechanisms can deliver this increased capacity. At the same time, Congress should boost conservation funding, including rebuilding the capacity of the National Resources Conservation Service (NRCS) and the Cooperative Extension System (CES) to provide producers with the independent, science-based technical assistance necessary to implement best conservation practices and verify their performance. Congress should also increase support for agricultural extension offices.

AGRICULTURE DEEP DIVES

Food Waste Federal Resources for States

Overview

State-level food-waste diversion laws are currently the strongest policies driving millions of tons of food waste away from landfills towards better use. Still, federal funding can support the infrastructure necessary to accommodate these food-waste diversion policies. Funding infrastructure for food donation, composting, and anaerobic digestion enables states to have solutions in place when they choose to adopt low-waste policies.

Principles

Evaluation Criteria: In evaluating state applications for federal resources, policymakers should prioritize several key criteria:

- Type of policy: Priority should be given to entities with existing policies in place, including those that ban food from landfills, create a mandatory diversion percentage requirement, require a portion of edible food to be recovered for human consumption, reward prevention of food waste, require food waste reduction plans, or require food waste measurement and reporting requirements for food business and/or waste haulers.
- Existence of policy: Priority should be given to those with existing policies, but remaining funds may be distributed to those without relevant policies because policies are often phased in or only apply once infrastructure is built. This allows jurisdictions to build out food waste reduction programs even without official policy.
- Inclusion of prevention and food rescue: Extra priority should be given to entities with policies that move up the Environmental Protection Agency's Food Recovery Hierarchy, encouraging food waste prevention and rescue as well as recycling. Prevention and food rescue have significantly higher greenhouse gas reductions than composting or anaerobic digestion.

Recipient Agencies: Funds for composting, anaerobic digestion, and waste collection (e.g., scales for haulers) should be distributed to the state or local agency with jurisdiction over waste, which often is the Department of Environmental Quality. Funds for food rescue infrastructure may be distributed to the Department of Health, as they are typically in contact with food rescue networks in their jurisdiction, though in some cases it may also make sense to dispense funds to the agency with waste jurisdiction.

Infrastructure Types: Funds should be divided by infrastructure type to support different aspects of food waste reduction. A certain portion should support prevention through measurement or other technologies, another via food rescue infrastructure, and another to anaerobic digestion or composting infrastructure.

- Funds to support prevention can go to emerging measurement technologies, such as scales on waste hauling trucks.
- The primary infrastructure needed for food rescue is refrigeration, including refrigerated trucks, large cold storage for food banks, and smaller cold storage for end recipient agencies.
- Infrastructure support for composting should go to commercial scale, aerobic composting and enabling technologies such as de-packaging machines. Anaerobic digestion may be independent, on farms, or at water treatment facilities, but in all cases should ensure that food waste makes up at least 20 percent of processed materials. Funding should also support community-scale composting, which supports job creation, community empowerment, and other social benefits along with the ecological benefits of increasing composting infrastructure.

AGRICULTURE DEEP DIVES

Alternative Protein Labeling

Overview

Restrictive labeling laws and regulations pose a major potential barrier to consumer acceptance of alternative proteins. By banning the use of words like "meat" and "milk" to refer to alternative proteins, and sometimes by requiring other language intended to turn off consumers, these rules limit the market growth of plant-based products and create barriers to entry for cultivated meat when it reaches the market.

Advocates of these restrictions typically frame them in terms of prohibiting "misleading" labels but explicitly target the use of specific words even in contexts that are not misleading, and with no evidence of consumer confusion.

Principles

Sensible Labeling: Food labels must make sense to consumers. Lawmakers and regulators should resist efforts to prohibit the use of common terms that consumers understand (like "milk" or "cheese") on food labels that compete with conventional meat and dairy. New restrictive legislation, regulation, or interpretation cannot be justified on the grounds of protecting consumers from misleading labels when consumers clearly have no difficulty understanding plant-based food labels.

Adherence to Existing Law: Misleading labels are already prohibited by federal law. New legislation cannot be justified on the grounds of protecting consumers from misleading labels when these are already prohibited.

Protections for Existing Alternatives: These terms have a long history of use in the context of plant-based foods, and consumers understand how they are used in those contexts ("veggie burger," for example). Terms like "almond milk" and "soy milk" have been used for centuries and should not be modified.

Agency Guidance: The Food and Drug Administration (FDA) has jurisdiction over labeling of plant-based dairy and plant-based meat products as well as cultivated seafood and non-meat products of cellular agriculture. The U.S. Department of Agriculture (USDA) has jurisdiction over labeling of cultivated beef, pork, and poultry. The FDA should issue formal guidance allowing the use of compound or modified food names incorporating appropriate meat or dairy terminology in contexts where a reasonable consumer would understand that the modified food name denotes a distinct plant-based product, and both should work together to ensure consistent, accurate labeling regimes for cultivated meat.

AGRICULTURE DEEP DIVES

Alternative Protein Procurement

Overview

The federal government's food programs directly fund billions of meals for millions of Americans every year through the Supplemental Nutrition Assistance Program (SNAP), the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), school meals, and the Child and Adult Care Food Program (CACFP). Policies and guidelines for these programs, as well as General Services Administration (GSA) contracting guidelines, also indirectly impact billions of dollars in purchasing decisions for retailers, vendors, and consumers. Adjustments in federal policy can result in more plant-based options in stores and on menus, allowing consumers to choose more sustainable options.

In each case, current guidelines sometimes encourage the inclusion of healthy and sustainable options, including plant-based options. Still, there are many opportunities to expand access and improve the sustainability of the food options available through these federal programs. For example, outdated guidelines treat protein—with an emphasis on animal protein—as if it were a nutrient of public health concern. Updated guidelines would focus on true nutrients of concern like calcium, potassium, and vitamin D and would account for the health benefits of plant-based foods. Improved guidance and incentives for retailers and contractors can also encourage greater availability of plant-based options.

Principles

Modified Nutrient Requirements: Policymakers should modify the protein requirements of food programs like school meals, CACFP, and WIC that can exclude foods like dairy alternatives and focusing instead on nutrients of public health concern like calcium, vitamin D, and potassium.

Proactive Procurement: Federal agencies, including GSA, should give explicit preference in award decisions to vendors who commit to offering plant-based options daily. They should also assist alternative-protein and plant-based companies in becoming U.S. Department of Agriculture (USDA) food processors for the National School Lunch Program (NSLP).

Incentives and Awareness: Policymakers should increase awareness among school-lunch coordinators of plant-based options that can meet healthy meal plan guidelines in the NSLP and the School Breakfast Program (SBP), and provide financial incentives for weekly or daily inclusion of these plant-based meal options.

SNAP Modifications: The federal government should allow more plant-based products to count as multiple distinct varieties within a staple food category in SNAP retailer requirements, including the protein category. This would allow smaller SNAP retailers to stock more plant-based products. In addition, policymakers should ensure that SNAP guidance to retailers clearly describes how plant-based options can satisfy SNAP retailer requirements. For example, a recent SNAP Staple Foods overview does not list nuts, nut butters, soy products, beans, or peas as permissible protein-rich substitutes in the “Meat, Poultry, or Fish” group, and does not list soy-based milks, yogurts, and cheeses in the dairy group.

POLICY SOLUTIONS

Carbon Removal

Negative Emissions Solutions

CARBON REMOVAL

Overview

Carbon removal includes the natural and technological processes that remove excess carbon dioxide (CO_2) from the atmosphere and store it permanently underground, in plants and soils, or in durable products, reducing net emissions into the atmosphere. (For instance, natural, ecological processes such as photosynthesis enable CO_2 storage in trees, native grasslands, and soils. On the other hand, when forests are degraded and lands are poorly managed, net global carbon emissions increase.)

Since 2005, the amount of natural carbon removed in the U.S. has remained relatively constant: enough to offset about 12 percent of the country's carbon dioxide emissions.

In addition to natural processes, technological strategies for carbon removal and storage do exist—though they have not been deployed at scale. Direct air capture (DAC) uses machines to pull CO_2 out of the atmosphere and store it safely underground. Bioenergy with carbon capture and sequestration (BECCS) involves using carbon removal technologies to capture and store CO_2 from biomass use or combustion.

Along with deep decarbonization across all sectors of the economy, carbon removal is essential to getting to net-zero emissions by mid-century. This will require both natural and technological means of removal, such as enhanced carbon uptake from forests, adjusted agricultural practices, and large-scale deployment of DAC with sequestration.

CARBON REMOVAL

Natural Solutions

Overview

Natural ecosystems like forests, mangroves, peatlands, and tidal marshes have an exceptional capacity to remove carbon from the atmosphere and oceans. Plants and soils absorb carbon dioxide through the process of photosynthesis and store it in biomass and sediment. Conversely, when forests are cut down or coastal ecosystems and soils degraded, net CO_2 emissions increase.

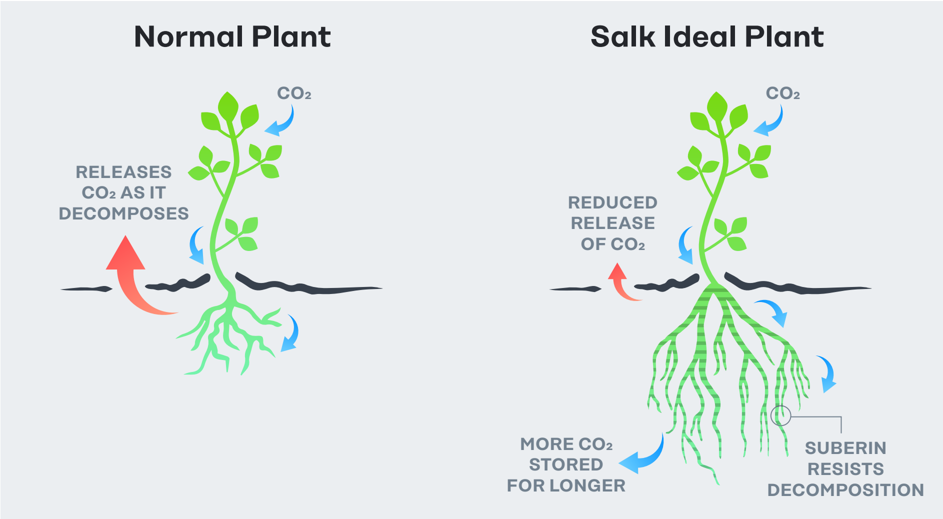
To bolster the carbon uptake of these systems, it is important to manage them properly. Countries can take a variety of actions to preserve forest health, including reforestation (reestablishing tree cover in destroyed or degraded forests), extended timber rotations (allowing trees to grow older and larger before harvest), and fire management (restoring forests through activities like thinning and prescribed burning to prevent catastrophic wildfires). Agricultural practices that disturb the soil and release carbon—such as tilling, overgrazing, and excessive use of fertilizers and pesticides—can be mitigated through farmer education and policies encouraging agriculture and land-management practices that increase soil carbon. Nature-based solutions have the added benefit of building resilience to climate impacts and improving biodiversity. These solutions can also directly benefit the low-income and historically marginalized communities that have not had access to carbon management practices.

Technologies

High Sequestration Crops and Soil

R&D VALIDATION SCALE

Because of the suberin (a natural carbon polymer) in their roots, Salk Ideal Plants release significantly less CO_2 when they decompose than their normal counterparts.

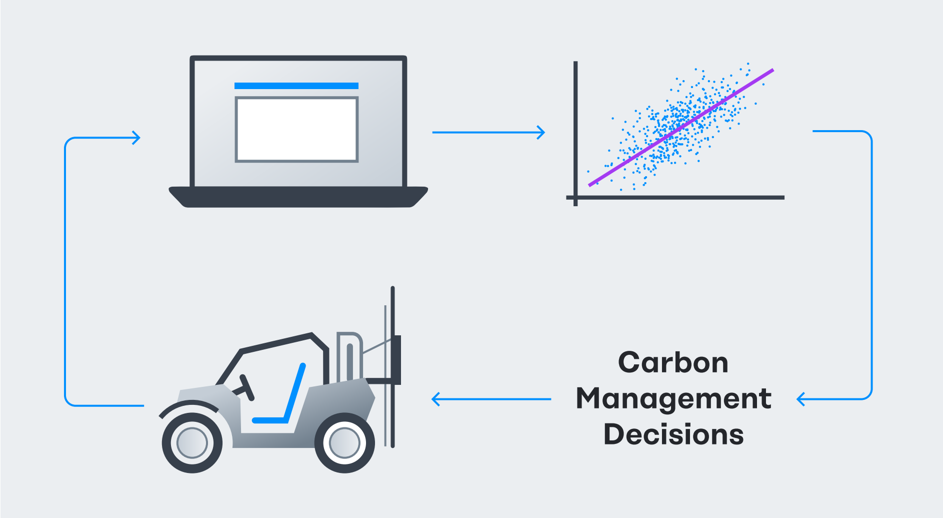


Crops and soil can sequester larger amounts of carbon. High carbon-input crop phenotyping, for example, can be achieved by genetically modifying crops or by perennializing grain, seed, and other crops to keep their root residues in the soil. Another approach is to apply biochar (plant matter turned to charcoal) or compost to cropland, which can improve soil health.

Measurement Technologies

R&D VALIDATION SCALE

Developing accurate, low-cost, and efficient technologies for measuring soil carbon and nitrogen stocks in the field will be critical for scaling soil carbon sequestration and reducing nitrogen losses to the environment, respectively.



Accurate, low-cost, and efficient technologies are needed for quantifying soil carbon and nitrogen stocks in the field. While technologies exist to measure soil carbon and bulk density, they are currently time-consuming and expensive. Developing remote-sensing soil-carbon technology that is economical, accurate, and standardized is fundamental to quantifying and scaling soil carbon sequestration.

Nitrogen measurement technologies also have the potential to significantly improve nitrogen use efficiency, thereby reducing nitrogen losses to the atmosphere as nitrous oxide and to water as nitrate.

Policies

Phase: Research and Development

RESEARCH & DEVELOPMENT | VALIDATION & EARLY DEPLOYMENT | LARGE SCALE DEPLOYMENT

Federal investment in research and development (R&D) supports economic growth, drives down costs for key technologies, and promotes U.S. leadership on clean energy and climate. Investment in R&D for nature-based sequestration is driven primarily by the Agricultural Research Service (ARS), the National Institute of Food and Agriculture (NIFA), and the U.S. Forest Service (USFS). Further R&D for nature-based sequestration comes from the Department of Energy's (DOE's) National Labs and the Advanced Research Projects Area-Energy's (ARPA-E's) ROOTS program.

Federal policymakers should increase investment and enact programmatic reforms to ensure federal agencies focus on advancing R&D for:

- Soil carbon measurement technologies;
- Remote sensing and inventories to support improved carbon data for forest management, blue carbon, and peatlands;
- Next-generation nitrogen management in crop production;
- High-carbon-sequestration and resilient soils, plants, trees, and crops;
- Capture and isolation of CO_2 in coastal and deep ocean waters; and
- Carbon mineralization in surface and subsurface rock formations.

For more, see deep dives on

→ **Public Sector R&D**
→ **DOE National Lab Reform**
→ **Stimulating Clean Energy Entrepreneurship**

Phase: Validation and Early Deployment

R&D | **VALIDATION** | SCALE

Before we can deploy natural carbon removal technologies at scale, we must demonstrate and validate their cost and performance in real-world conditions. Demonstration projects reduce the economic and institutional risks of new technologies. As such, the federal government should develop a robust portfolio of demonstration projects for soil management and carbon sequestration best practices that can illustrate their benefits.

For more, see the deep dive on

→ **Demonstrating and Validating New Technologies**

Phase: Rapid, Large Scale Deployment

R&D | VALIDATION | **SCALE**

Conservation Program and Incentives (learn more)

Strengthening conservation programs administered by the U.S. Department of Agriculture (USDA) will improve environmental outcomes on farm and ranch land. For example, tying federal financial assistance and crop insurance to conservation practices will reduce erosion, build soil carbon, and increase nitrogen-use efficiency. USDA and Department of Interior conservation programs for forests, grasslands, and wetlands should also be strengthened. These programs will increase carbon sequestration and reduce greenhouse gas emissions.

Management

Forest-management objectives include maintaining ecological diversity and health, restoring degraded ecosystems, and reducing fire hazards. To coordinate these efforts, regions should share best practices for forestry management and conservation. This type of information sharing occurs at the federal level through the USFS' network of research stations, which operate under the USDA. The robust research system provides an effective framework for sharing forestry knowledge across the nation, and can be further improved by collecting and sharing data on incentives to increase private landowner engagement with forest management efforts.

Fiscal Incentives

The USFS has programs to assist private forest owners who aim to protect their lands (the Forest Stewardship Plan, for example). The federal government can expand these fiscal incentives, through tax credits and payouts, to encourage landowners to employ best practices in forest stewardship. Such programs also increase the long-term economic viability of forest-land ownership.

Ecosystem Restoration

The federal government can expand programs whose mission is restoring federal forests and coastal wetlands. For instance, the Collaborative Forest Landscape Restoration Fund is now limited to 10 projects per year across the country. Expanding this and other programs can accelerate the restoration of federal forest and wetlands and increase the nation's natural carbon-removal capacity.

Additional Resources

- → **USDA: Forest Management for Carbon Benefits**
- → **Forest Climate Action Team: California Forest Carbon Plan**
- → **USDA Forest Service: Forest Inventory and Analysis National Program**
- → **Berkeley Forests: Carbon Calculator**
- → **International Union for the Conservation of Nature: Blue Carbon Issue Brief**
- → **US EPA: Cap and Trade Funded Coastal Wetland Restoration-Carbon Sequestration Projects**

CARBON REMOVAL

Technological Solutions

Overview

IPCC modeling of global emissions pathways that limit warming to 1.5° C includes large-scale deployment of commercial technologies that can remove carbon dioxide (CO_2) from the atmosphere, offsetting current or past greenhouse gas emissions. For example, direct air capture (DAC) pulls excess carbon dioxide directly from the ambient air. Bioenergy with carbon capture and sequestration (BECCS) uses biomass as a feedstock to produce electricity or fuels and captures the resulting CO_2 emissions. The captured CO_2 from both processes is used either as a feedstock in durable, long-lived products (such as concrete or carbon fiber) or safely stored deep underground, where it is naturally absorbed over time.

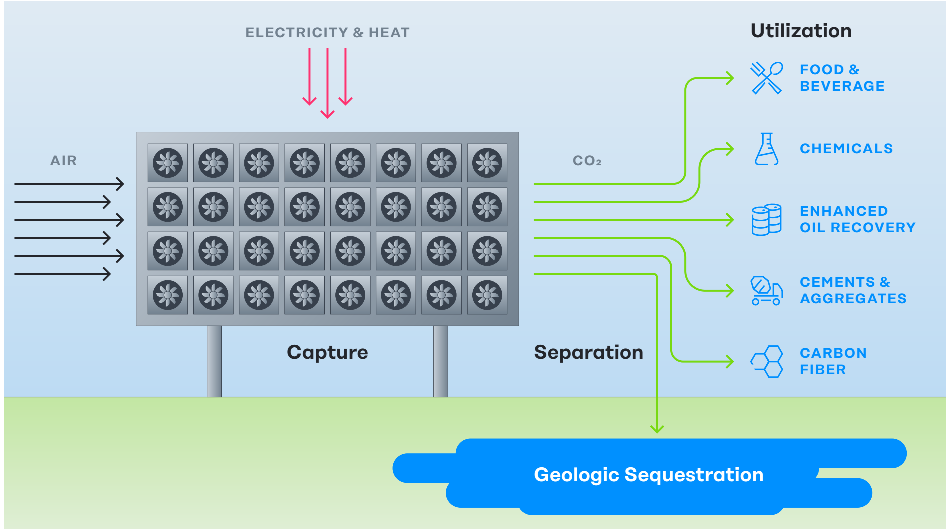
DAC combined with sequestration can achieve net-carbon removal when powered with clean energy and is easier to broadly scale up than other carbon-removal options. (For instance, BECCS' scalability is limited by the availability of sustainable biomass.) Currently, the primary limiting factor to DAC is its high cost, which will decrease as it is deployed.

Technologies

Direct Air Capture

R&D VALIDATION SCALE

DAC uses electricity, heat, and a filtering technology to remove CO_2 from ambient air. The CO_2 can then be utilized in a variety of products or stored safely underground.



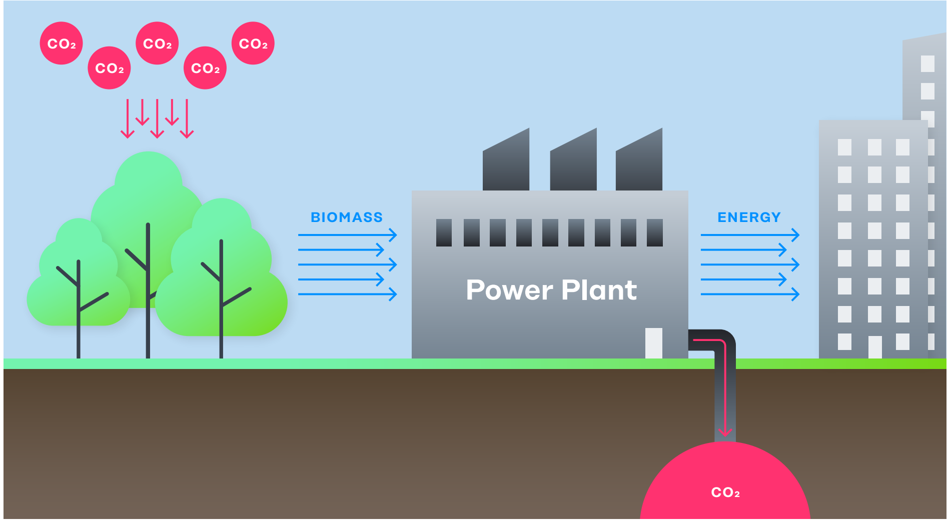
DAC is an early-stage technology that pulls ambient air into a filter and uses chemical processes to remove CO_2. The CO_2-free air is released back into the atmosphere, while the captured CO_2 can either be used in products or safely stored deep underground. There are two primary approaches to DAC: one uses a liquid-solvent technology and the other a solid-sorbent technology.

DAC can play a particularly key role in decarbonization because it is able to offset emissions from harder-to-abate sectors like energy-intensive manufacturing processes, heavy-duty transportation, and aviation.

Bioenergy with Carbon Capture and Storage

R&D VALIDATION SCALE

BECCS is a technology that enables negative-emissions energy and fuel production. Energy crops, which absorb CO_2 during growth, are burned for electricity generation, heat, and biofuel production. The CO_2 emitted during the burning process is captured and stored safely in geological formations.



BECCS involves capturing CO_2 from biomass-fired electric power plants and biofuel production and safely storing it underground. BECCS can be a negative-emission technology if the stored CO_2 is greater than the CO_2 emitted during biomass production, transportation, and use. BECCS can be applied across several sectors of the economy, including electricity generation, biofuel production, and manufacturing products like steel and cement. For now, however, land-use competition between energy crops and food production represents a key barrier to the full deployment of this promising technology.

Policies

Phase: Research and Development

RESEARCH & DEVELOPMENT | VALIDATION & EARLY DEPLOYMENT | LARGE SCALE DEPLOYMENT

Federal investment in research and development (R&D) supports economic growth, drives down costs for key technologies, and promotes U.S. leadership on clean energy and climate. Investment in R&D for carbon removal technologies comes primarily from the U.S. Department of Energy's (DOE's) Office of Fossil Energy (FE). Further R&D for carbon removal comes from DOE's Advanced Manufacturing Office, Bioenergy Technologies Office, Advanced Research Projects Area-Energy (ARPA-E), and its National Labs. However, current efforts have been limited in size and scope and are far from sufficient.

The federal government should establish a cross-cutting interagency effort that draws on the expertise of multiple federal agencies. Federal policymakers should also increase investment and enact programmatic reforms to ensure this effort focuses on advancing R&D for:

- Direct air capture (DAC); and
- Bioenergy with carbon capture and sequestration (BECCS).

For more, see deep dives on

→ **Public Sector R&D**
→ **DOE National Lab Reform**
→ **Stimulating Clean Energy Entrepreneurship**

Validation and Early Deployment

R&D VALIDATION SCALE

Demonstration

Before we can deploy promising clean energy technologies at scale, we must demonstrate and validate their cost and performance in real-world conditions. Demonstration projects reduce the economic and institutional risks of new technologies. As such, DOE should develop a robust portfolio of demonstration projects for technological carbon removal, including a near-term focus on DAC. To ease initial deployment, demonstration DAC plants should be co-located at sites that are suitable for underground carbon storage or have a demand for carbon utilization.

For more, see the deep dive on

→ **Demonstrating and Validating New Technologies**

Fiscal Incentives

Federal tax credits, loan guarantees, and other fiscal incentives can help support the early deployment of DAC technologies by reducing the cost of DAC plants and driving private sector investment. Extending and expanding the existing 45Q tax credit, alongside other fiscal incentives such as loan guarantees, master limited partnerships, and private activity bonds, will accelerate the deployment of DAC.

For more, see the deep dive on

→ **Carbon Sequestration Tax Credits**

Government Procurement

Government purchasing power could make a substantial difference for DAC technologies that are near commercialization. Current procurement practices generally require cost-competitiveness with conventional fossil fuels, but a commitment from federal agencies—including the Department of Defense and Department of the Interior—would reduce the green premium associated with DAC-based fuels and give them a much-needed boost.

Risk-Based Safety Standards

Since DAC with geologic storage is still an emerging technology for carbon removal, the federal government's permitting process for saline storage remains slow and costly. The Environmental Protection Agency (EPA) must establish an efficient permitting process that effectively upholds local environmental safeguards. Until EPA can demonstrate that the regulatory path is efficient and predictable, investors may avoid these projects.

Permitting improvements will bring down project costs, reduce investment risks, and bolster DAC deployment. To further support carbon removal technologies, the federal government can assess geologic formations for storage suitability.

For more, see the deep dive on

→ **Risk-Based Safety Standards**

Rapid, Large Scale Deployment

R&D VALIDATION **SCALE**

Carbon Pricing

Federal carbon prices should include a credit for carbon that is removed from the atmosphere using DAC and geologically stored. This can be accomplished through a carbon tax or a cap-and-trade system.

For more, see the deep dive on

→ **Carbon Pricing**

Clean Fuel Standard

A technology-neutral clean fuel standard that incentivizes the use of low-GHG fuels can propel their deployment on a large scale. Likewise, the standard should be expanded to include fuels developed using carbon captured from DAC facilities. Such policies can establish an important market for DAC while reducing emissions across several sectors of the economy.

For more, see the deep dive on

→ **Clean Fuel Standard**

Additional Resources

- **Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies**
- **C2ES: Carbon Capture**
- **NETL: Carbon Capture Program**
- **Rhodium Group: Capturing Leadership**

POLICY SOLUTIONS

Priority Innovation Policies

Cross-Cutting Solutions

PRIORITY INNOVATION POLICIES

Overview

The Priority Innovation Policies cut across economic sectors. Without them, we cannot address the Five Grand Challenges, get emissions to net-zero, or create a world where everyone has access to clean, affordable, and reliable energy.

PRIORITY INNOVATION POLICIES

Public Sector R&D

Overview

Today's technologies have the potential to bend the carbon-emissions curve—but new, better, and cheaper innovations are a key component of any achievable plan for reaching a net-zero emissions economy by 2050. In other words, accelerated clean energy innovation is essential to halting climate change and limiting the rise of global temperatures.

Government investment in clean energy research, development, and demonstration (RD&D) can accelerate this necessary innovation and catalyze greater private sector investment. But current levels of public sector RD&D funding are not large enough to put the United States and the world on a path to net-zero emissions. As such, the federal government should both increase funding to its energy-RD&D agencies and reorganize them to address the climate crisis more effectively.

The federal government should be set up to make the best use of its resources, with a centralized office that is responsible for inventing, piloting, and commercializing clean energy technologies. To reduce duplication, focus the government's efforts, and get the most innovation out of every dollar of funding, the federal government should establish a National Institutes of Energy Innovation (NIEI) modeled on the National Institutes of Health (NIH).

An NIEI would have a clear mission to support the world's best scientists and entrepreneurs as they develop the critical technologies and solutions needed to address the climate crisis. The institutes would focus on advancements in cross-cutting technologies, end-use sectors, and clean electricity and fuel sources, reducing costs and spurring large-scale deployment. They would closely integrate breakthroughs in fundamental science with subsequent stages of product development, production, and deployment to achieve successful commercialization pathways for technologies.

In the near term, there are other important actions the federal government can take to improve the focus of its R&D efforts. The recommendations below focus on these actions.

Policy interventions include:

1. **Increasing federal funding for clean energy–innovation investments** at the Department of Energy (DOE) and other federal agencies by a factor of five over the next ten years.
2. **Updating DOE's mission and goals** to meet the critical challenges facing the nation's energy systems.
3. **Balancing the federal government's innovation portfolio** so that it covers all sources of emissions and all sectors of the economy.
4. **Performing agency-wide, multi-year innovation-portfolio planning** that connects RD&D needs and funding to national energy and climate goals.
5. **Transforming DOE's organizational structure** to better connect basic and applied energy research, rebalance the innovation portfolio, and depoliticize research programs.
6. **Stabilizing funding** for federal innovation programs.

Legislative Principles and Policy Recommendations

1. Increase federal funding for clean energy innovation.

Current levels of funding for clean energy innovation in the public and private sectors do not match the urgency and scale of investment needed to put the United States and the world on a path to net-zero emissions by mid-century. Congress should make clean energy innovation a national priority by providing funding stability for energy-innovation programs and ramping up funding for clean energy RD&D to $35 billion annually within 10 years.

Clean energy RD&D can lead to technological advances that reduce the cost of, and accelerate the transition to, a clean energy economy. In fact, federal support for clean energy innovation has already yielded tremendous public benefits. For instance, decades of federal investment in solar and wind power, lithium-ion batteries, and efficient LED lightbulbs have helped reduce their cost by 75 to 95 percent. At the same time, these investments have generated huge benefits for taxpayers.[1] A review of federal renewable energy and energy-efficiency research programs between 1976 and 2015 found that an investment of $12 billion yielded $388 billion in net economic benefits from lower energy costs and avoided pollution.[2] Similarly, federal investment in pollution-control technologies in the 1980s helped keep energy costs low while generating $50 billion in savings from public health benefits. These investments also helped make the U.S. a global leader in environmental technologies.[3]

Nonetheless, the current pace of innovation is too slow to lead the nation and the world to net-zero emissions by 2050.[4] Growth in energy demand is outpacing the clean energy transition: while global energy demand grew by 2.3 percent in 2018, carbon-free energy from renewables and nuclear power met just under a third of this new demand. In most cases, energy from unabated fossil fuels remains cheaper than clean alternatives.[5] (However, the costs of new renewable

1. Natural Resources Defense Council (NRDC), "Revolution Now," April 10, 2018, https://www.nrdc.org/revolution-now

2. U.S. Department of Energy (DOE), "Aggregate Economic Return on Investment in the U.S. DOE Office of Energy Efficiency and Renewable Energy" (DOE, October 2017), https://www.energy.gov/sites/prod/files/2017/11/f46/Aggregate%20ROI%20impact%20for%20EERE%20RD%20-%2010-31-17%20%28002%29%20-%2011-17%20%28optimized%29.pdf

3. R.H. Bezdek and R.M. Wendling, "The return on investment of the clean coal technology program in the USA," Energy Policy 54 (2013) 104–112. http://dx.doi.org/10.1016/j.enpol.2012.10.076; Department of Energy, "Clean Coal Technology: From Research to Reality," accessed March 10, 2019, http://energy.gov/fe/downloads/clean-coal-technology-research-reality

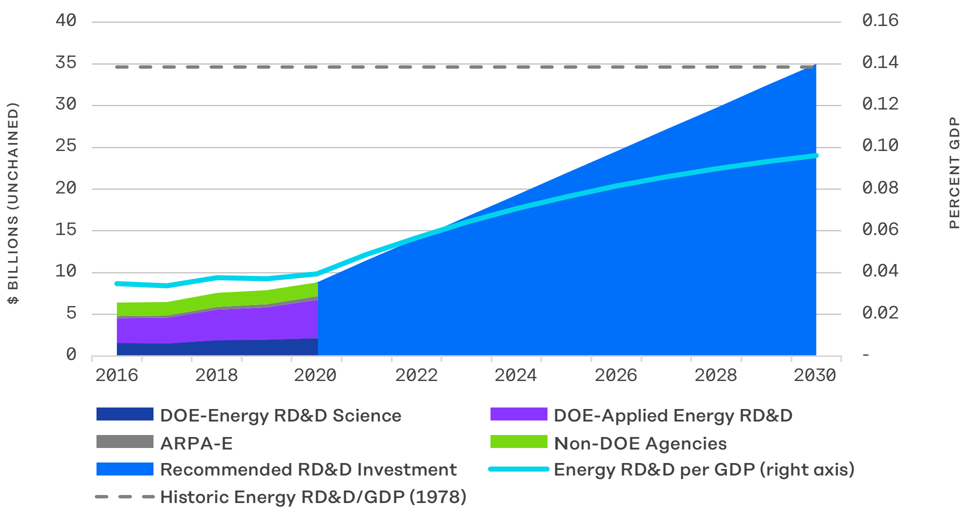
4. International Energy Agency (IEA), "Clean Energy Innovation," July 2020, https://www.iea.org/reports/clean-energy-innovation

projects are increasingly lower than those of new and existing coal-fired plants.) As a result, in the U.S. and around the world, carbon dioxide emissions increased in 2018 and 2019.[6] At the same time, patent applications in clean energy have declined in recent years, indicating that the pace of innovation is slowing down.[7]

Globally, only $22 billion in public funds are spent on clean energy research and development (R&D) each year. In the United States, investment in energy RD&D as a portion of GDP has declined over the past four decades—from 0.14 percent of GDP in 1978 to 0.04 percent of GDP in 2019.[8] The United States currently spends about $7 billion per year on clean energy innovation, about 75 percent of which is funneled through the DOE.

This budget should be quintupled over ten years to at least $35 billion by 2030. This increase would bring climate- and energy-related research to 0.1 percent of GDP—in line with other national priorities. Rapid increases in federal RD&D investment have been enacted in the past: Congress doubled investment in biomedical research at the NIH over a five-year span from 1998-2003. As of fiscal year (FY) 2019, the budget of NIH is $37.9 billion per year.

Historic and Recommended Investment in Clean Energy Research, Development, and Demonstration



2. Update the Department of Energy's mission and goals.

Congress prescribes the goals of DOE's energy research portfolio—in fact, all DOE grant announcements identify the specific goal the grant seeks to meet—yet it has not updated these goals since 2005.[9] In the fifteen years since, our energy system has undergone a rapid transformation—and over the next fifteen, this transformation will need to accelerate at a pace and scale never before seen in human history.

5. International Energy Agency (IEA), "Global Energy & CO2 Status Report 2018," March 2019, https://webstore.iea.org/global-energy-co2-status-report-2018

6. Global Carbon Project, "Global Carbon Budget 2019" Earth System Science Data, 11, 1783-1838, DOI: 10.5194/eesd-11-1783-2019, https://www.globalcarbonproject.org/carbonbudget/index.htm

7. Colin Cunliff, "Omission Innovation 2.0: Diagnosing the Global Clean Energy Innovation System," September 2019, https://itif.org/publications/2019/09/23/omission-innovation-20-diagnosing-global-clean-energy-innovation-system

8. Colin Cunliff, "FY 2020 Energy Innovation Funding: Congress Should Push the Pedal to the Metal," April 2019, https://itif.org/energy-budget

9. Energy Policy Act of 2005, 42 U.S.C § 16181 (2005): DOE shall conduct a balanced set of programs of energy research, development, demonstration, and commercial application with the general goals of (1) increasing the efficiency of all energy intensive sectors through conservation and improved technologies; (2) promoting diversity of energy supply; (3) decreasing the dependence of the United States on foreign energy supplies; (4) improving the energy security of the United States; and (5) decreasing the environmental impact of energy-related activities.

In order to encourage the development and deployment of innovative carbon-free energy technologies and help the nation meet its energy objectives, Congress needs to update DOE's goals. These updates should fall into five main categories: climate change, manufacturing competitiveness, technology demonstrations, energy equity and environmental justice, and technology-specific program missions.

Climate Change

Current law only requires DOE perform energy esearch, development, demonstration, and deployment (RDD&D) to "decreas[e] the environmental impact of energy-related activities." This broad mandate leaves much to interpretation and creates uncertainty that hinders the work of DOE scientists.[10]

Congress should update DOE's goals to make clear that addressing climate change is a fundamental part of the Department's mission. This will give its scientists a stronger mandate to pursue decarbonization solutions like low-carbon liquid fuels, dispatchable zero-carbon power, carbon capture, and carbon dioxide removal technologies. At the same time, making this focus explicit will eliminate the rationale for DOE's few remaining research efforts aimed at extending the life of fossil-energy resources without carbon capture (like small modular coal plant designs, for example). Congress should clearly state that federal RDD&D funding should wholly prioritize development of low-carbon solutions.

Manufacturing Competitiveness

Addressing climate change is a huge global economic opportunity. For example, the International Energy Agency estimates that nearly $60 trillion will be invested in global energy markets over the next twenty years.[11] Much of the opportunity in this space lies in manufacturing: building tomorrow's energy technologies like solar, wind, batteries, efficient appliances, and carbon capture technologies, and reducing the energy demand and greenhouse gas (GHG) emissions associated with all manufacturing, particularly in energy-intensive industries like petroleum refining, chemicals, iron and steel, and cement.

The federal government can do much more to support clean energy manufacturing and catalyze this enormous economic opportunity. First, Congress should make increased U.S. manufacturing competitiveness a key goal for federal energy research. This shift will give DOE permission to develop new programs to support American workers.

At the same time, Congress should ask DOE to identify opportunities across the RDD&D pipeline to support U.S. industries. For example, in the growing offshore wind market, Congress could enact programs to support domestic wind turbine manufacturing, fund workforce training programs, improve permitting processes for offshore cables, and develop tax policies to speed offshore wind deployment.

10. Ibid.

11. "World Energy Outlook 2018," International Energy Agency (November 2018). https://www.iea.org/topics/world-energy-outlook

Technology Demonstrations

DOE's current authorization calls for it to build a "balanced" portfolio of RDD&D, yet the agency's attention to critical later-stage research that reduces the time to market for clean energy technologies has fluctuated according to each administration's ideological leanings. Meanwhile, the private sector is often reluctant to take expensive risks in this area, which is why it is essential that the government support technology demonstration and commercial application. Congress can boost DOE efforts in this space by establishing, for instance, an office dedicated to managing DOE demonstration projects.

Energy Equity and Environmental Justice

The negative effects of climate change and pollution fall most heavily on low-income and historically marginalized communities that the clean energy transition has been slow to reach. Congress should specify that equity, energy access, and environmental justice are critical objectives of DOE research, and it should authorize and fund specific programs to address the energy needs and pollution burden of low-income and historically disadvantaged communities.

Technology-Specific Missions

Along with agency-wide goals, Congress mandates technology-specific research-area missions for each program office—missions that have, until Congress recently passed the Energy Act of 2020, not been updated since the Energy Policy Act of 2005. The lack of updated, specific authorizing language has often led to limited and inconsistent interpretation of research funding areas by DOE program managers. Moving forward, more regular comprehensive updates will be needed to reflect contemporary research challenges and opportunities in energy technology.

3. Balance the federal government's innovation portfolio.

Right now, DOE's innovation portfolio is heavily weighted towards the electric power sector. More than half of the agency's total applied-energy RD&D budget goes toward research on electricity generation and grid modernization, even though the power sector currently produces only about 30 percent of the nation's GHG emissions. As Congress increases DOE's budget, it should expand existing RD&D programs in the transportation, manufacturing, and buildings sectors and create new research programs that fill gaps in the federal innovation portfolio. Congress should also expand funding for RD&D at agencies focused on other carbon-intensive portions of the economy like agriculture.

Existing Clean Energy RD&D Programs at DOE

Today, transportation accounts for 32 percent of all GHG emissions in the U.S. It recently overtook the electric power sector as the nation's largest source of GHG emissions, and it also accounts for approximately one-quarter of DOE's applied energy-research investments. Emissions in the transportation sector have held steady since 2005 as increases in vehicle miles traveled and greater emissions from aviation and shipping have offset improved fuel economy for light-duty cars and trucks. Without increased innovation, this trend is likely to continue.

To reach net-zero emissions by 2050, DOE should set ambitious targets and direct additional funding and research to the development and commercialization of carbon-neutral transportation fuels, vehicle efficiency, and vehicle electrification. The Departments of Transportation and Defense should also play an important role in programs advancing key transportation technologies.

The industrial sector, the third-largest source of direct GHG emissions in the U.S., produces 26 percent of total emissions. (This number does not include indirect emissions from electricity consumption.) Industrial emissions have also held steady since 2005 at about 1.5–1.6 billion metric tons per year. Despite this lack of improvement, the industrial sector accounts for a relatively small share of the total clean-innovation portfolio. DOE's Advanced Manufacturing Office (AMO) houses the agency's only RD&D program that focuses on the manufacturing sector; its actions are focused primarily on reducing manufacturing's energy intensity. In addition, the office accounts for just 6 percent of DOE's total applied-energy RD&D investments, and is not authorized or funded to advance other technologies to reduce industrial emissions like green hydrogen and carbon capture.

Residential and commercial buildings consume more energy than any other sector of the U.S. economy: they use roughly 75 percent of the nation's electricity and account for 40 percent of its total energy demand. Direct (non-electricity) emissions in this sector comprise about 11 percent of total U.S. GHG emissions. But in FY 2019, Congress invested only $176 million—about 4 percent of DOE's total applied-energy budget—in RD&D to reduce energy consumption and carbon emissions from the buildings sector through DOE's Building Technologies Office (BTO). To achieve net-zero emissions by 2050, Congress should increase funding for federal clean-manufacturing and building-technologies programs.

New Clean Energy RD&D Programs at DOE

Harder-to-decarbonize sectors include aviation, shipping, long-distance road transportation, and heavy industry such as cement, steel, and chemicals. While these sectors account for a large and growing share of U.S. and global carbon emissions, they are not well represented in the federal energy-research portfolio. A study published in Science found that in 2014, these harder-to-abate sectors accounted for 9.2 billion metric tons of CO_2, or 27 percent of global carbon emissions. Congress should authorize and fund DOE to perform additional research in these areas.

Congress should also establish a comprehensive RD&D initiative for atmospheric-carbon removal. Carbon removal offsets residual emissions—especially non-CO_2 gases—that are impossible or prohibitively expensive to eliminate completely at the source. They also provide a hedge against the possibility that other climate-mitigation technologies fail to advance as quickly as they are needed. Between 1993 and 2019, the federal government invested only $10.9 million on direct air capture (DAC) technologies and $24.7 million on carbon mineralization.[12]

In FY 2020, for the first time, Congressional appropriators directed DOE to increase investments in a few particular carbon-removal approaches within existing research programs (in the office of Fossil Energy (FE) and the Bioenergy Technologies Office (BETO), for instance). This is a step in the right direction, but

12. Joseph S. Hezir, Tim Bushman, Addison K. Stark, and Erin Smith, "Carbon Removal: Comparing Historical Federal Research Investments with the National Academies' Recommended Future Funding Levels," (Bipartisan Policy Center and Energy Futures Initiative, 2019), https://bipartisanpolicy.org/wp-content/uploads/2019/06/Carbon-Removal-Comparing-Historical-Investments-with-the-National-Academies-Recommendations.pdf

it is not enough. Congress will likely need to authorize a new federal interagency program—like the U.S. Global Change Research Program, which manages climate change research across thirteen federal agencies—to explore all carbon-removal pathways and make the best use of federal capabilities across multiple agencies.[13]

Expanded Clean Agriculture RD&D Programs

Agricultural production comprises an important share of U.S. GHG emissions—about 9 percent of direct GHG emissions in 2018, and 12 percent when including indirect emissions from agricultural land use change, fuel combustion, and fertilizer manufacturing.[14] However, support for clean agricultural RD&D has been limited. U.S. Department of Agriculture (USDA) RD&D funding peaked in 2003 and has not historically emphasized climate-beneficial agricultural innovation.

Agricultural productivity growth—increasing the amount produced per unit of land, labor, water, fertilizer, and other inputs—substantially reduces agricultural GHG emissions, often at very low cost. Increasing crop and livestock yields enables farmers to meet growing food demand while reducing their cost of production and food prices, at the same time limiting land use change and related emissions.[15] Soil carbon sequestration is another emerging mitigation opportunity. Soils have tremendous capacity to hold carbon within the top few meters of soil—in fact, they currently hold three times more carbon than the atmosphere.[16] But they have recently become a net source of CO_2 emissions rather than a sink, because heavily-cultivated agricultural soils can lose 50 to 70 percent of their original organic carbon.[17] Better agricultural practices can reverse soil-carbon losses and improve nitrogen fixing, providing climate benefits while also improving soil structure, increasing crop yields, reducing fertilizer inputs, and reducing erosion.

Congress should increase investment in clean agricultural RD&D across the USDA, particularly at the Agriculture and Food Research Initiative (AFRI) and the Agricultural Research Service (ARS). Priority research opportunities include crops that can sequester more carbon and fix more nitrogen, soil carbon and fertilizer management practices, biochar and compost, fertilizer technologies, manure use, animal feed efficiency, plant-based and cultured meat, grazing management science, and plant genomics. Additionally, Congress should fully fund the Agriculture Advanced Research and Development Authority (AGARDA), which was modeled after other advanced R&D agencies such as DARPA and ARPA-E and is intended to support high-risk, high-reward innovative research that is too risky for the private sector. AGARDA was authorized in the 2018 Farm Bill but has not been funded in FY 2019 or FY 2020. Finally, Congress should increase technical and financial assistance to farmers to transition to best carbon, manure, and fertilizer management practices (through the Natural Resources Conservation Service (NRCS) Conservation Technical Assistance program, for example).

13. Energy Futures Initiative, Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies, (Energy Futures Initiative, 2019) https://www.dropbox.com/s/2y36ngfrcbpv37f/EFI%20Clearing%20the%20Air%20Full%20Report.pdf?dl=0

14. EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. (2020); Smith, P. et al. Agriculture, Forestry and Other Land Use (AFOLU). in Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. & Savolainen, S. Schlömer, C. von Stechow, T. Z. and J. C. M.) (Cambridge University Press, 2014).

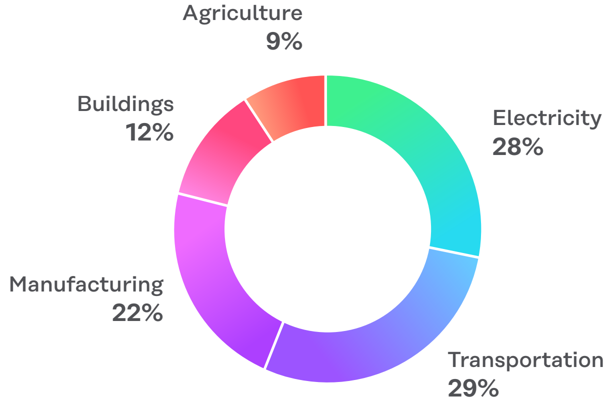
15. Baldos, U. L. C. Investing in Public R&D for a Competitive and Sustainable U.S. Agriculture. (2020); Baldos, U. & Hertel, T. Productivity Growth is Key to Achieving Long Run Agricultural Sustainability. Purdue Policy Res. Inst. Policy Briefs 4, (2018); Fargione, J. E. et al. Natural climate solutions for the United States. Sci. Adv. 4, eaat1869 (2018).

16. Advanced Research Projects Agency-Energy, "Rhizosphere Observations Optimizing Terrestrial Sequestration (ROOTS) Program Overview," (Department of Energy, 2016) https://arpa-e.energy.gov/sites/default/files/documents/files/ROOTS_ProgramOverview.pdf

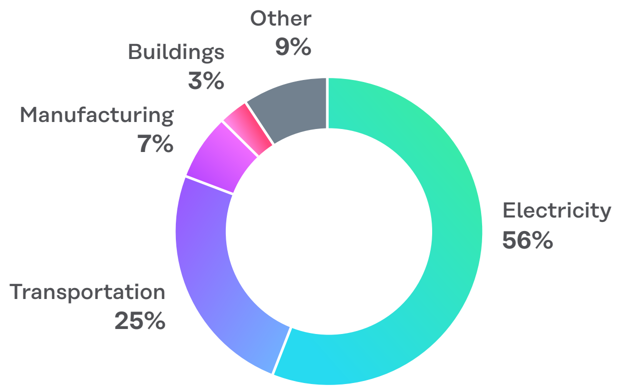
17. National Research Council, Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration, (The National Academies Press, 2015), https://doi.org/10.17226/18805 - p 43.

U.S. Greenhouse Gas Emissions and Department of Energy Research, Development, and Demonstration Spending According to Sector[18]

Greenhouse Gas Emissions (2017)



Department of Energy Research and Development Spending (FY2016)



4. Perform agency-wide multi-year innovation-portfolio planning.

At its core, DOE is a grant-making agency: it funds energy RDD&D in academia, at the National Labs, and in the private sector. Decisions on how to allocate the funds Congress appropriates are guided in part by multi-year research plans, but mostly through the agency's annual budget-formulation process.

Increasing agency funding to the level this playbook recommends, while making sure those funds can support as many potential net-zero technology breakthroughs as possible, will require a much more robust and comprehensive planning process.

18. Shah and Krishnaswami, "Transforming DOE in Response to the Climate Crisis," 9.

Current Practice

DOE's current budget process works in two directions at once: from the bottom up and from the top down. From the bottom up, many (but not all) individual technology offices such as the Solar Energy Technology Office develop five-year Multiyear Program Plans in consultation with researchers in academia, the National Labs, and the private sector. These plans identify research needs in the near- and mid-term, as well as strategies to achieve cost-reduction and performance-improvement targets. These research needs, in turn, are incorporated in an annual budget proposal.

From the top down, the White House provides the agency its budget request to Congress. Budget proposals from each individual office are compiled into the President's Budget Request for DOE. Congress receives this request, and using their own process, generally increases or decreases individual technology program offices from prior year funding levels at the same rate across DOE's energy programs. In other words, funding levels are mostly a function of the previous year's Congressional appropriation. This means they are slow to accommodate changing priorities.

Planning for Changing Priorities

In addition to funding more energy research in general, the government needs a funding-allocation process that can account for the rapid transformations that must take place in the energy system to reach net-zero emissions by 2050.

First, every DOE office should conduct multi-year portfolio planning that identifies cost, performance, and deployment targets as well as the research needed to achieve these targets. Experts in government, academia, and the private sector should validate these targets and research needs. In addition, these targets should be comparable across technologies so the agency can assess the relative progress and promise of each technology.

This portfolio should inform a unified, agency-wide strategic plan for energy research that maps national goals (like emissions reductions) and RDD&D needs onto future budgetary requirements. This long-term plan should prioritize the development of energy technologies that can address the climate crisis. While this will not be an easy task, others have proposed quantitative methodologies for designing an optimal DOE research portfolio to maximize benefits given a constrained budget.[19]

This process might also identify research pathways that are currently being underfunded (such as carbon dioxide removal technologies and industrial GHG sources) along with others that have been thoroughly investigated and need a transition strategy. A 2019 report coauthored by former Secretary of Energy Ernest Moniz identified a need for "clearer performance measures [that] will enable more effective entrance and exit strategies."[20]

19. Chan, G. and Anadon, L. (2016). "Improving Decision Making for Public R&D Investment in Energy: Utilizing Expert Elicitation in Parametric Models." https://doi.org/10.17863/CAM.7842

20. IHS Markit and EFI, Advancing the Landscape of Clean Energy Innovation.

These plans should be comprehensive enough to identify policies across the federal government—not just within DOE—that have the potential to boost new technologies and improve their deployment outcomes. In fact, DOE has attempted this type of comprehensive-planning effort before. In 2011, and again in 2015, the agency's Quadrennial Technology Review assessed the current state of energy technologies and research needs for the future but did not connect these needs to agency priorities and budgeting. In 2018, Congress passed H.R. 589, the Department of Energy Research and Innovation Act, which requires this type of portfolio analysis and strategic planning. DOE has not yet identified the steps it is taking to do this work.

This requirement indicates that Congress is starting to seek more transparency around DOE's budgeting process and more information to help it set final budget levels. This, in turn, can help Congress and other stakeholders increase their risk tolerance and comfort with emerging technologies.

5. Transform the Department of Energy's organizational structure.

For the past 20 years, DOE and its scientists have been directly responsible for many of the advances in clean energy technology that are helping to reduce the world's GHG emissions. However, given the scale and the urgency of the problem, DOE will need more funding as well as an internal structure that enables the agency to effectively use its resources. At present, the agency lacks dedicated and empowered assistant secretary level-leadership for several critical decarbonization areas—such as transportation, industry, and buildings—as well as for cross-cutting areas like large-scale carbon management. A reimagined DOE that overcomes these challenges can accelerate innovation in new solutions and ensure technology penetration in low-income and historically disadvantaged communities.

Restructure DOE for Better Translation of Fundamental Science into New Energy Technologies

Congress can solidify the link between basic and applied-energy research by requiring a single Office of the Under Secretary for Science and Energy. Over the years, the office has been combined or separated based on the administration in power, which has limited its efficacy. Maintaining the structure of a single office would better enable it to drive collaboration between DOE's energy research programs, align budgets to keep up with the changing demands of the energy sector, provide streamlined management of the laboratories associated with DOE programs, encourage cross-cutting research, and perform portfolio analysis and planning in support of climate-change goals.

Reorganize DOE's Renewables, Transportation, and Efficiency Portfolio

DOE's largest technology program, the Office of Energy Efficiency and Renewable Energy (EERE), receives over $2 billion annually from Congress and conducts a wider variety of missions than any other DOE applied-energy research office: research into renewables (wind, solar, geothermal, and water power), transportation (vehicle efficiency, vehicle electrification, biofuels, hydrogen and fuel cells), and energy efficiency (building efficiency and clean energy manufacturing). In contrast, other DOE programs address a more condensed set of challenges. (For example, the Nuclear Energy office focuses on three core, related challenges—extending the life of current nuclear power plants, designing new nuclear fuels and reactors, and addressing nuclear waste issues.)

The EERE office has outgrown its structure. For instance, one result of crowding these three substantial EERE programs into one office is under-investment in energy research in the transportation and buildings/industrial sectors relative to the GHG emissions from those sectors. To elevate the importance of these critical sectors, Congress should separate this one office into three—renewables, transportation, and buildings/industry—and increase their funding.

Specifically, Congress should elevate the offices of deputy assistant secretaries for Sustainable Transportation and for Buildings and Manufacturing to the role of assistant secretary. This would in effect split EERE into three assistant secretary offices (including an Assistant Secretary for Renewable Power), which is appropriate given the size of the office and range of technology challenges covered by these programs.

Depoliticize DOE Research Programs

Science, not politics, should guide the DOE—but as of the last official count in 2020, DOE had over 170 political appointees, including each of the leaders of its energy-research offices.[21] (Compare to other federal scientific agencies: in 2020, NASA had 21 political appointees, NSF had 2, and NIH had 1.)

Many of these senior DOE appointees require confirmation by the Senate—and while they wait to be confirmed, temporary leaders with varying management experience and priorities rotate in and out of these positions. For example, EERE's Assistant Secretary position was vacant from May 2016 until January 2019. This disruption slows the development of climate-technology solutions.

Congress should require that DOE hire senior energy-research leaders from across the government's highly qualified career Senior Executive Service. These leaders are selected for their management expertise and/or scientific knowledge, and they can bring steady leadership to DOE programs that is consistent with the vision of the department's Secretary and Under Secretary.

6. Stabilize funding for federal innovation programs.

Congress has supported an innovation-based climate agenda on a bipartisan basis, providing modest budget increases in each of the past five years. Funding for clean energy RD&D at DOE grew by about 41 percent between 2015 and 2020, or about 8 percent annually.[22]

But the annual budget and appropriations process results in large year-over-year fluctuations in program funding levels and injects large uncertainties into the portfolio-planning process. For example, annual changes in funding for the nuclear energy, fossil energy, and energy-efficiency programs at DOE over the last twenty years range from 75 percent to +200 percent.[23] Such extreme volatility limits the effectiveness of federal innovation programs and hampers the ability of their managers to implement long-term research agendas.

21. Committee on Homeland Security and Governmental Affairs, U.S. Government Policy and Supporting Positions, (U.S. Government Publishing Office; Washington, D.C. 2020) GPO-PLUMBOOK-2020.pdf (govinfo.gov)

22. https://itif.org/publications/2020/03/30/energy-innovation-fy-2021-budget-congress-should-lead

23. IHS Markit and Energy Futures Initiative, Advancing the Landscape of Clean Energy Innovation (Breakthrough Energy, 2019), https://www.b-t.energy/reports/advancing-the-landscape/

As such, Congress should supplement the annual appropriations process with alternative funding models that provide long-term stability and insulate the innovation portfolio from political uncertainty. Former Secretary of Energy Ernest Moniz has identified several options based on other successful federal RD&D programs:[24]

Earmark specific revenue streams to clean energy RD&D programs so that annual funding is predictable and stable and is not scored against appropriations caps. This approach has been used successfully for other federal programs. For example, the Ultra Deepwater and Unconventional Natural Gas and Other Petroleum Fund, authorized by Congress in 2005, was funded from a portion of federal oil and natural gas royalties and not subject to annual appropriations, though Congress exercised oversight of the program. And in 2013, Alaska Republican Senator Lisa Murkowski called for the creation of an "Advanced Energy Trust Fund" backed by revenue from oil and gas drilling on federal lands to support clean energy innovation.[25]

Establish a new public-benefits user charge, like the gas tax which funds the Highway Trust Fund, to support clean energy innovation. For example, a small fee of 2.5 cents per gallon of gasoline would raise $15 billion annually—more than twice what the federal government currently invests in clean energy RD&D. Similarly, a small "wires charge" on electricity could be used to fund grid modernization and clean-electricity programs. Several states currently use public-benefits charges to accelerate deployment of clean technologies. Alternatively, a small portion of a carbon price could be used to fund energy innovation programs. The two carbon-pricing policies that already exist in the United States—California's cap-and-trade program and the Regional Greenhouse Gas Initiative—do this to some extent.

Provide automatic advance appropriations to provide funding certainty for large, multi-year research projects. The DOE Clean Coal Technologies program in the 1980s and 1990s was funded through advance appropriations, which led to greater stability for public-private cost-sharing agreements.

Enable research programs to submit a "bypass budget," also known as a professional-judgment budget, that is based on scientific opportunity rather than the regular budget and appropriations process. Under the regular budgeting process, agencies first submit budget requests to the President through the Office of Management and Budget (OMB). OMB then works to reconcile competing budget priorities into a single consolidated proposal, the President's Budget Request, which is submitted to Congress. This process can pit unrelated federal programs against each other and subjects annual budgeting to the policy priorities of the administration. But in some cases, Congress has asked federal agencies to prepare their own budget—submitted directly to Congress and "bypassing" OMB—based on scientific and research opportunities. For example, the Consolidated and Further Continuing Appropriations Act of 2015 (P.L. 113-235) directs the NIH to submit an independent Alzheimer's research budget each year, and the Commodity Futures Trading Commission (CFTC) likewise submits its own budget based on an assessment of what it needs to execute its mission.[26] Congress could thus direct DOE and other agencies to develop and submit a separate budget directly to Congress based on scientific and research opportunities.

24. Ernest Moniz, Testimony before the House Energy & Water Development Appropriations Subcommittee, November 20, 2019, https://docs.house.gov/meetings/AP/AP10/20191120/110239/HHRG-116-AP10-Wstate-MonizD-20191120.pdf

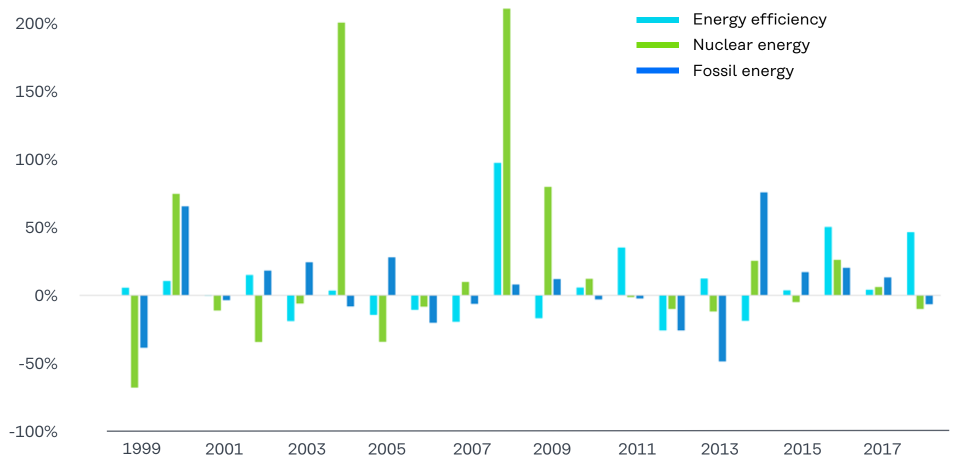
25. https://www.murkowski.senate.gov/press/article/murkowskis-us-energy-trust-fund-deserves-support

26. Congressional Research Service, "When an Agency's Budget Request Does Not Match the President's Request; The FY 2018 CFTC Request and 'Budget Bypass ,'" June 7, 2017, https://fas.org/sgp/crs/misc/IN10715.pdf

In addition, Congress' annual appropriation for DOE's applied-energy offices comes with earmarks, specific direction on research topics, and limits on funding by topic. For example, for the 2020 Appropriation, Congress told DOE's Vehicle Technology Offices that it was required to spend $5 million on "two-stroke opposed piston engines."[27] Even when these topics have merit, this level of Congressional specificity interferes with DOE program managers' efforts to fund research that has the most promise for transforming the nation's energy systems.

In sum: Congress should reform the way it appropriates funding to DOE for R&D. Providing general policy direction without prescribing or limiting areas of research would allow DOE scientists to optimize their research portfolios to maximize clean energy outcomes. Congress has already implemented this model for ARPA-E, one of DOE's most popular programs. It should transition DOE's other applied-energy programs to it as well.

Volatility in Funding for Select DOE Programs (Annual Percent Change)



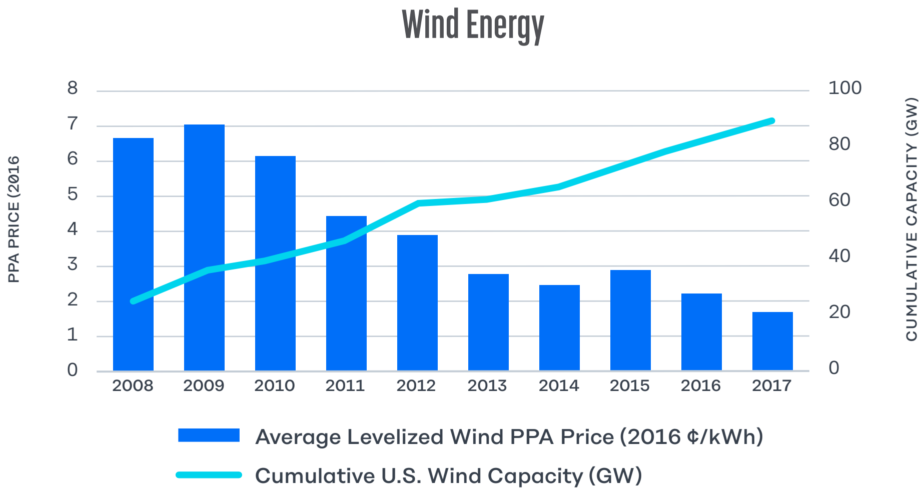
27. H.R. 1865 Division C Joint Explanatory Statement, p 31, https://docs.house.gov/billsthisweek/20191216/BILLS-116HR1865SA-JES-DIVISION-C.pdf

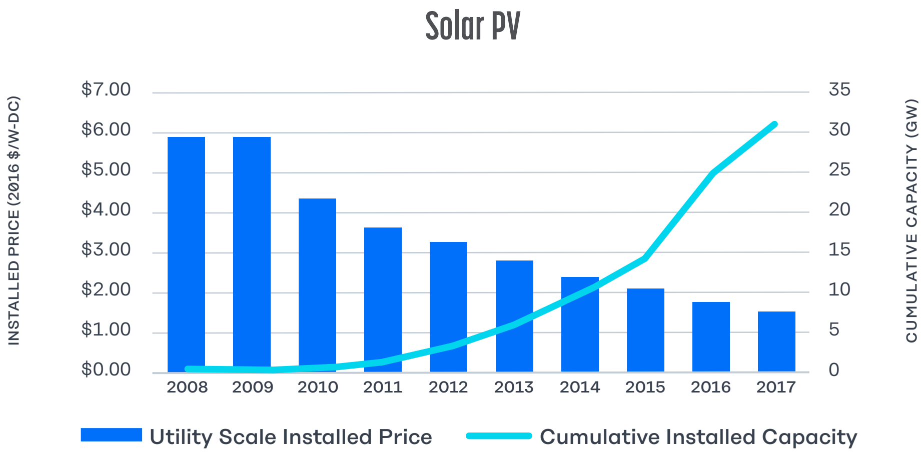
The Impact of Public Sector R&D

Federal investment in clean energy innovation lowers energy costs for consumers and businesses, increases the global competitiveness of clean-tech businesses in the U.S., improves energy equity and environmental justice for low-income communities, and reduces pollution—including the GHG emissions that cause climate change.

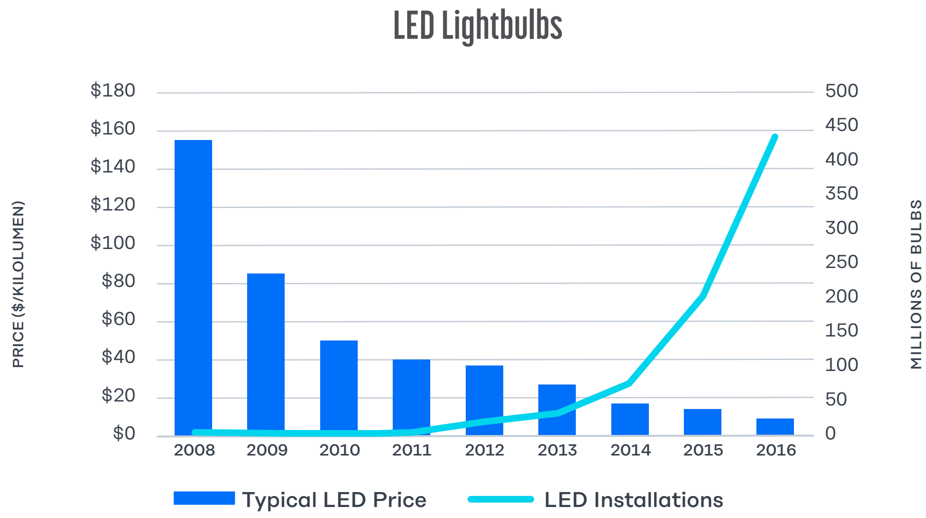
The United States has historically been a global leader in clean energy innovation: federal investments and public-private cooperation produced many technologies that now make major contributions to energy systems in the U.S. and around the world. Federally funded nuclear power RD&D, for instance, led to large-scale private investment in commercial power plants that now account for nearly 20 percent of U.S. electricity generation and 56 percent of zero-carbon power generation. Government research has helped slash the costs of four key clean technologies—solar, wind, LED lighting, and electric vehicles—between 55 and 94 percent since 2008, leading to impressive growth in adoption.[28]

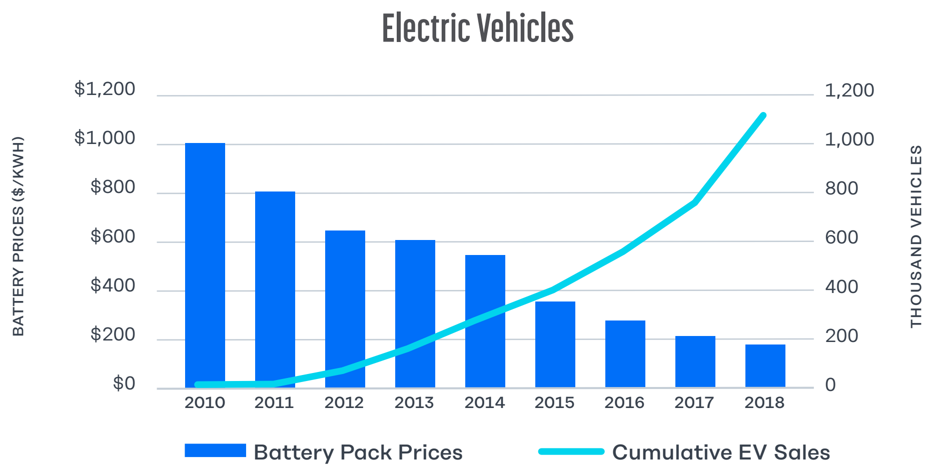
Cost Reductions And Capacity Building For Four Key Clean Energy Technologies





28. Natural Resources Defense Council, "Revolution Now: The Future Is Here for Clean Energy Technology," (NRDC) https://www.nrdc.org/revolution-now accessed January 13, 2020.





Numerous studies have documented the impacts of federal energy RD&D on U.S. and global energy systems.

- Federal support for shale-gas resource characterization and directional drilling, in tandem with industry-matched applied research and a federal production tax credit, led to the dramatic rise of shale gas from less than 1 percent of domestic gas production in 2000 to nearly 60 percent in 2016.[29]
- DOE-funded RD&D in flue-gas desulfurization (FGD) scrubbers resulted in over $50 billion in savings from public-health benefits and lower FGD costs. In turn, this helped make America a global leader in environmental technologies.[30]
- DOE research partnerships with major engine manufacturers to develop more efficient diesel engines saved the U.S. trucking industry 17.6 billion gallons of diesel fuel, which translated into $34.5 billion in reduced fuel expenditures and $35.7 billion in health and environmental benefits from lower pollution.[31]

29. Massachusetts Institute of Technology Energy Initiative, "The Future of Natural Gas" (Cambridge, MA: Massachusetts Institute of Technology Energy Initiative, 2011), 163, https://energy.mit.edu/wp-content/uploads/2011/06/MITEI-The-Future-of-Natural-Gas.pdf; Alex Trembath et al., "Where the Shale Gas Revolution Came From" (Breakthrough Institute, May 2012), https://s3.us-east-2.amazonaws.com/uploads.thebreakthrough.org/legacy/blog/Where_the_Shale_Gas_Revolution_Came_From.pdf

30. R.H. Bezdek and R.M. Wendling, "The return on investment of the clean coal technology program in the USA," Energy Policy 54 (2013) 104–112. http://dx.doi.org/10.1016/j.enpol.2012.10.076 ; Department of Energy, "Clean Coal Technology: From Research to Reality," accessed March 10, 2019, http://energy.gov/fe/downloads/clean-coal-technology-research-reality

31. Jeffrey Rissman & Hallie Kenna, "Advanced Diesel Internal Combustion Engines" (American Energy Innovation Council, 2013), http://americanenergyinnovation.org/2013/03/case-study-advanced-dieselengines/

- Investments in DOE's BTO between 2010 and 2015 culminated in the successful commercialization of 27 cleaner products, including energy-efficient water heaters, solid-state lighting, and energy-saving windows. A retrospective assessment of BTO investments between 1976 and 2015 across three technology areas—heating, ventilation, and air conditioning (HVAC); water heating; and appliances—found that BTO investments have yielded a benefit-to-cost ratio of more than 20 to 1.[32]

Going forward, federal RD&D programs will continue to drive down costs and accelerate deployment of clean energy technologies. But current funding levels are not enough to drive the pace of innovation needed to achieve decarbonization by mid-century. In 2017, DOE published the first integrated economy-wide assessment of the potential combined benefits of its entire technology RD&D portfolio, the Quadrennial Energy Review (QER).[33] The QER examined two different RD&D funding scenarios: one in which funding remained constant through 2040, and another in which funding was doubled. DOE found that maintaining constant funding would reduce emissions by 12 percent and residential energy bills by 25 percent; by contrast, doubling funding for energy RD&D, which would allow for more accelerated energy innovation, would reduce emissions by 30 percent and energy bills by 34 percent.

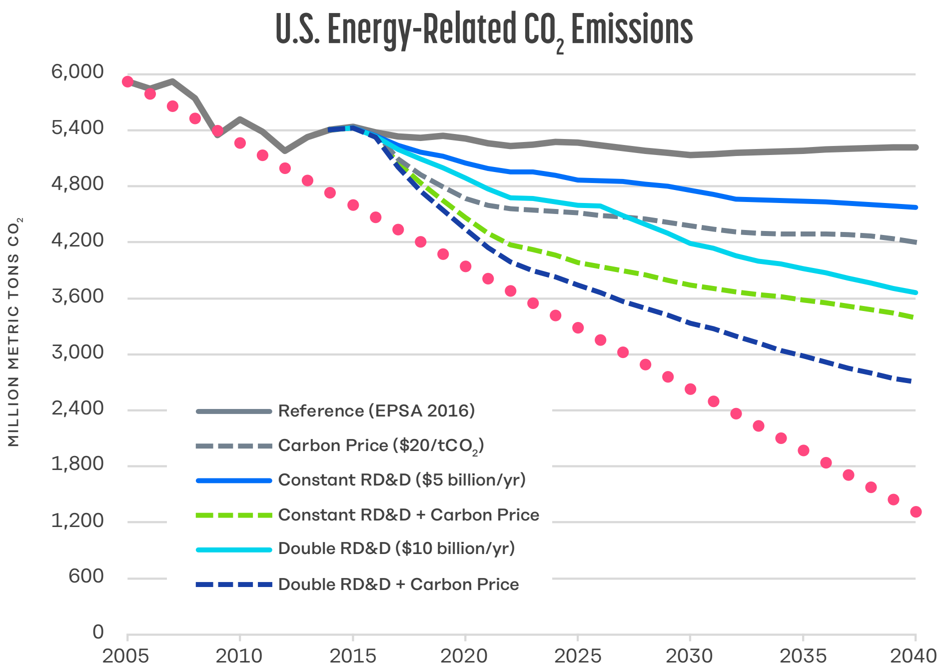
The QER study also assessed the impact of a carbon price—starting at $20/tCO$_2$ and increasing by 5 percent every year—both alone and in combination with the two RD&D scenarios. On its own, the carbon price lowered emissions but raised energy bills. But combined with energy RD&D, a carbon price drives more emissions reductions than either approach does on its own. In other words: by making clean energy cheaper, energy RD&D moderates the consumer impact of a carbon price, enabling deep emissions reductions while also reducing energy bills.

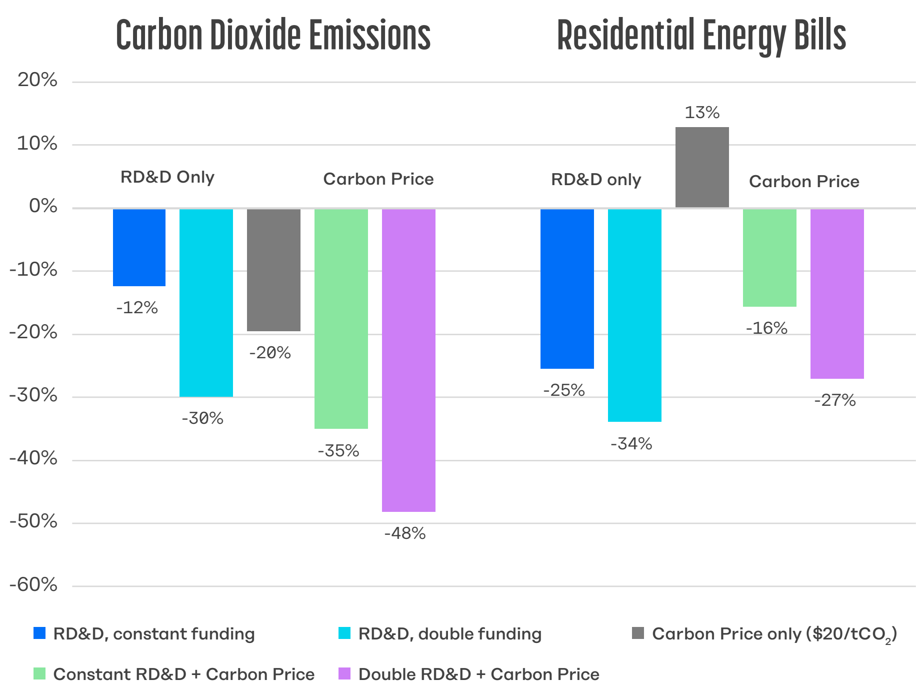
Still, even the most aggressive scenario the QER considered is not enough to put the U.S on a path to net-zero emissions by 2050. This underscores the need for greater ambition and greater investment in innovation.

32. Building Technologies Office, "R&D to Market Success: BTO-Supported Technologies Commercialized from 2010–2015" (DOE Office of Energy Efficiency and Renewable Energy, April 2017), https://www.energy.gov/sites/prod/files/2017/06/f34/BTO_Commercial_Technology_Report_April%20 2017.pdf; Michael Gallaher et al., Benefit-Cost Evaluation of U.S. Department of Energy Investment in HVAC, Water Heating, and Appliance Technologies (RTI International, September 2017), ES-2, https://www.energy.gov/sites/prod/files/2017/09/f36/DOE-EERE-BTO-HVAC_Water%20Heating_Appliances%202017%20Impact%20Evaluation%20Final.pdf

33. U.S. Department of Energy, "Energy CO2 Emissions Impacts of Clean Energy Technology Innovation and Policy" (DOE Office of Energy Policy and Systems Analysis, 2017), https://www.energy.gov/sites/prod/files/2017/01/f34/Energy%20CO2%20Emissions%20Impacts%20of%20Clean%20Energy%20Technology%20Innovation%20and%20Policy.pdf

Energy CO_2 Emissions and Residential Energy Bills Under Different RD&D Funding and Carbon Price Scenarios





Projected U.S. energy CO_2 emissions under various technology and policy (CP20: carbon price of $20 per tonne of CO_2, starting in 2017 and increasing at a rate of 5% per year in real dollars) assumptions. Also included is a dotted straight line indicating energy-sector reductions that are consistent with an economy-wide 80% reduction from 2005 levels by 2050. Historical energy CO_2 emissions are shown for 2005–2014 based on data from the U.S. Energy Information Administration (EIA).

Source: Energy CO_2 Emissions Impacts of Clean Energy Technology Innovation and Policy, DOE

PRIORITY INNOVATION POLICIES

Reforming the National Laboratory System

Overview[1]

Clean energy technologies must be developed, commercialized, and tested before they can be deployed on a large scale. However, when it comes to energy innovation, this process often stalls. The commodity nature of electricity and other forms of energy, the expensive and long-lived capital assets this kind of innovation requires, and the structure of electricity-market regulation all reduce research and development (R&D) spending from industry and other private sources. That means the government has a major role to play in promoting and developing energy innovation—and the Department of Energy's (DOE's) National Laboratory system is a critical component of a federal approach to commercializing clean energy technologies.

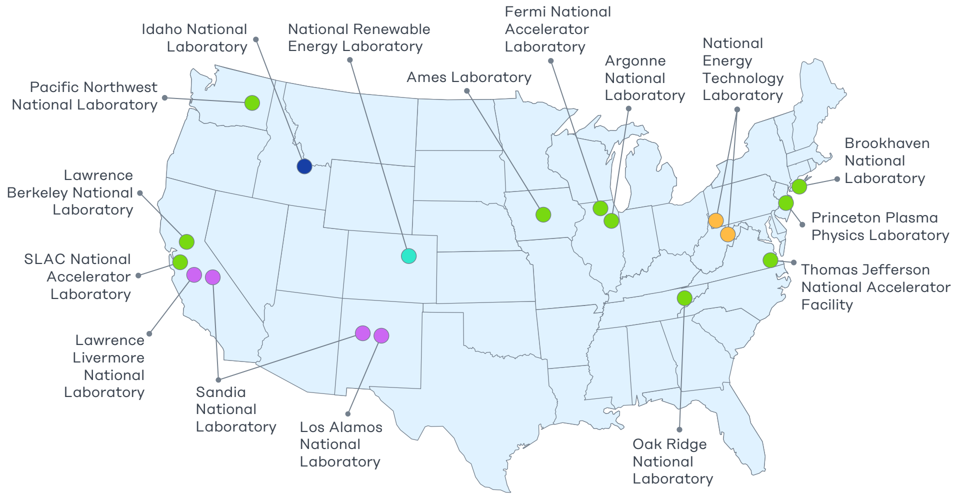
The 17 National Laboratories owned by DOE are sometimes called the crown jewels of the U.S. innovation system. Over 100 Nobel Laureates have been affiliated with DOE and its labs, which employ more than 20,000 scientists and perform about $14 billion of R&D each year.[2] Today, the National Laboratory system makes essential contributions to the national defense, advances fundamental science, and—crucially—plays a large role in promoting energy innovation. This track record means the labs can play a significant role in mitigating climate change.[3]

1. The research underpinning this brief, including most of the findings, figures, and related recommendations, were initially published in reports and publications emerging from an initiative at the Harvard Kennedy School's Belfer Center for Science and International Affairs. The initiative was supported by the Environment and Natural Resources and Science, Technology, and Public Policy Programs. The individual researchers involved were Professor Venkatesh Narayanamurti of Harvard University, Professor Laura Diaz Anadon, currently at the University of Cambridge, Professor Gabriel Chan, currently at the University of Minnesota, Sarah Jane Maxted, currently on staff at the Massachusetts Institute of Technology, and Dr. Amitai Bin-Nun, currently at Securing America's Future Energy (SAFE).

2. Department of Energy (2017). Annual report on the state of the DOE National Laboratories. U.S. Department of Energy.

3. Westwick, P. J. (2003). The National Labs. Harvard University Press.

Locations of the DOE National Laboratories



Source: U.S. Department of Energy

However, Labs were not specifically designed to work on commercializing energy innovations, so there will need to be significant policy reform to help them accomplish these goals.[4] In fact, there is broad acknowledgment from DOE leadership that while the Labs have had notable successes, the system can do far more to help commercialize technologies that can contribute to decarbonizing the energy system.[5] This assessment has been echoed in a series of high-profile examinations of the Lab system. These assessments have found that, while the Labs offer the nation "inestimable value" as an executor of R&D, there are "significant opportunities" to create more value in partnership with the private sector.[6]

Policy interventions include:

1. **Encouraging public-private collaboration** within the National Laboratory system.
2. **Using incentives and assessment** to focus research in the National Laboratory system on technology transfer and the development of commercial products.
3. **Aligning incentives and funding** to improve the quality and quantity of technology transfer between the National Laboratory system and outside partners.
4. **Focusing DOE funding** on commercializing energy technologies.
5. **Changing the research culture at National Laboratories** to boost technology-transfer outcomes.
6. **Encouraging entrepreneurial culture** among individual scientists at National Laboratories.

4. Anadon, L. D., Chan, G., Bin-Nun, A. Y., & Narayanamurti, V. (2016). The pressing energy innovation challenge of the US National Laboratories. Nature Energy, 1(10), 1-8.

5. Department of Energy (2016). "Departmental Response to the Final Report of the Commission to Review the Effectiveness of the National Energy Laboratories." U.S. Department of Energy. Available at: https://www.energy.gov/sites/prod/files/2016/02/f29/CRENEL%20Response%20-%20FINAL%20COMBINED_0.pdf

6. Glauthier, T.J. et al. (2015). Securing America's Future: Realizing the Potential of the Department of Energy's National Laboratories. Office of Scientific and Technical Information (OSTI), Oak Ridge, TN (United States).

Legislative Principles and Policy Recommendations

1. Encourage public-private collaboration for energy innovation and commercialization within the National Laboratory system.

All DOE National Laboratories, with the exception of the National Energy Technology Laboratory (NETL), are government-owned and contractor-operated (GOCO). Current lab operators include the University of California, Honeywell, and the Battelle Memorial Institute. (Past Management and Operating (M&O) contractors in the National Laboratory system have included AT&T, Lockheed Martin, and Dupont.) At the project level, too, the Labs collaborate with hundreds of companies. These operational models allow more flexible personnel and incentive policies and tap into the research-management expertise of large entities.

GOCO labs and the M&O contractors who operate them could play a big role in fostering a research culture focused on commercialization and improving Lab relations with industry.[7] However, increased Congressional oversight and highly prescriptive budgeting and approval processes have limited the flexibility of M&O contractors to run their labs in accordance with the industry's best practices.

It is impossible to improve energy-commercialization outcomes without close relationships with industry. For this reason, bringing in industry partners in appropriate roles for the Labs should be an important federal priority. Their activities should focus on energy-innovation activities that the private sector cannot perform well. For their part, since many National Labs are in remote areas outside of large coastal cities, they can help seed local innovation ecosystems and develop new industries.

Congress and DOE should place the work of commercializing energy technologies at the center of the National Labs' strategic focus. This means moving to less restrictive and expensive oversight models for the Laboratory system, which will make it easier to find and keep industry partners and develop collaborative strategic plans for energy innovation. Congress and DOE should also leverage their investments in National Labs to build regional innovation ecosystems that match federal technological competencies with the capabilities that already exist in local business, industrial, and academic communities.

2. Use incentives and assessment to focus research at National Labs on technology transfer and the development of commercial products.

In the private sector, corporations used to spend significant sums on early-stage R&D—sometimes even on topics relatively far afield from their industry's focus. This work served as the backbone of the nation's innovation system. However, the corporate central laboratory no longer plays this role—especially not when it comes to energy innovation. While the National Laboratory system cannot compensate for this decline more broadly, Congress and others agree that it *can* complement and augment private-sector investments in energy innovation.

7. Jaffe, A. B., & Lerner, J. (2001). Reinventing public R&D: Patent policy and the commercialization of national laboratory technologies. RAND Journal of Economics, 167-198.

Currently, however, there is no way to measure National Labs' performance on technology transfer and commercialization—processes that are essential to bringing energy innovation to market. DOE offices evaluate the labs they sponsor using an annual Performance Evaluation and Measurement Plan (PEMP), but the PEMP evaluates tech-transfer strategy only as a subcategory of another, higher-level goal.

DOE should evaluate any National Lab that receives funding for energy R&D with a focus on technology-transfer outcomes, and the results of these evaluations should impact performance incentives and M&O contract renewal. Also, when appropriate, DOE could encourage the M&O contractors operating National Labs to take a share of licensing fees in lieu of a fixed fee for Lab operation. This gives contractors an incentive to spin out Lab inventions into commercial products.

3. Align incentives and funding to improve the quality and quantity of technology-transfer outcomes between the National Labs and outside partners.

Research has shown that cooperation between science and industry, at universities and at the Labs, leads to more successful commercialization outcomes down the road.[8] Consequently, Congress, DOE, and the National Labs should take steps to increase cross-sector partnerships and improve their ability to develop and commercialize energy technologies.

Technology-transfer outcomes per dollar of research funding are in decline compared to the late 1990s, and there has been an especially marked decrease in new collaboration agreements ("CRADAs") and invention licenses. (See technology transfer metrics graph below.) To reverse these trends, DOE should formalize its interest in technology transfer by supporting it with concrete funding and programs.

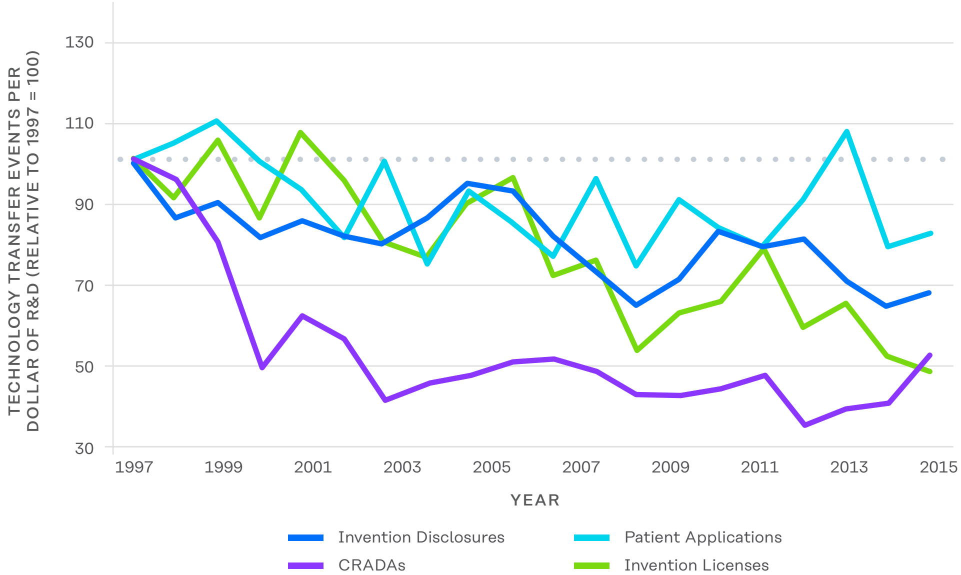
Current law requires DOE to dedicate 0.9 percent of its funding for applied-energy programs to a Technology Commercialization Fund (TCF) that will "provide matching funds with private partners to promote promising energy technologies for commercial purposes." However, because DOE currently requires each program's TCF funds to be spent by that same program, the money cannot always be put to use where it would make the most impact.

In 2015, the DOE set up an Office of Technology Transitions (OTT) to administer these funds. OTT has created an annual solicitation of about $25 million to support commercialization activities. It has also helped seed partnerships between the National Labs and the private sector.

DOE headquarters can focus on driving engagement with the private sector at a system-wide level, while individual Labs and scientists can highlight their own research to potential outside partners. At every level, the system should invest in the expertise and tools that will permit scientists, Labs, and the agency as a whole to execute cooperative research, licensing, and other agreements with outside partners quickly and effectively. These, in turn, will make it possible for more innovations to yield follow-on inventions.

8. Wright, B.D., Drivas, K., Lei, Z, & Merill, S.A. (2014). Technology transfer: Industry-funded academic inventions boost innovation. Nature 19 (March 2014).

DOE Technology Transfer Metrics (1997-2016)



Each line represents how many of each technology transfer events occurred in a given year, as compared to 1997. Quantities are measured per dollar of R&D (indexed for inflation) to account for changes in budget size.

Source: Update of figure from Anadon et al. (2016).

Congress and DOE should make more funding available to technology-transfer programs by raising the required contribution to TCF, providing greater flexibility for its use, and requiring the Basic Energy Sciences program to chip in as well. Finally, Congress should grant DOE, OTT, and individual labs the discretion they need to allocate funding, structure programs, and create collaborative agreements with private sector partners.

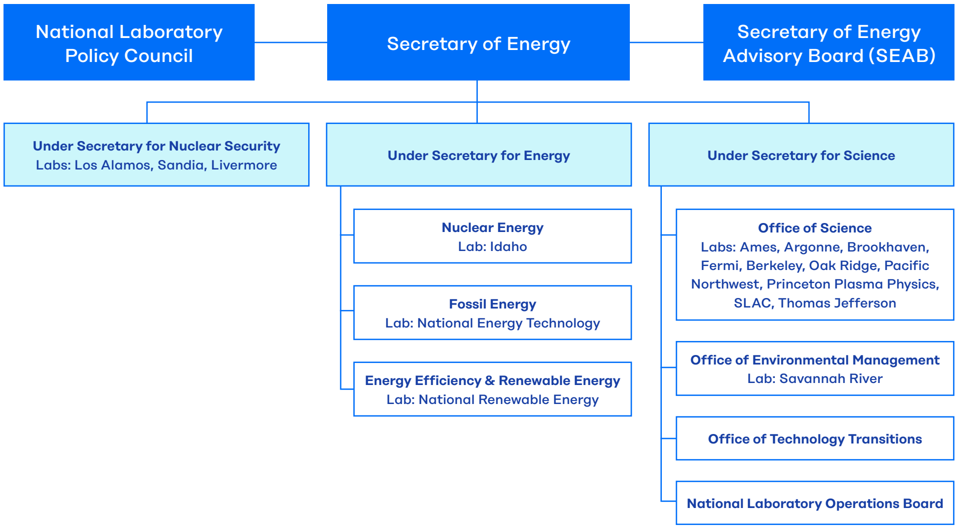
4. Focus DOE's attention and funding on commercializing energy technologies.

DOE manages the National Laboratories through their sponsoring offices, which disburse funding to the Labs. Therefore, it is important to communicate an increased focus on technology transfer across DOE and beyond senior leadership to the career staff who influence where DOE funding goes.

However, not every National Lab is managed in the same way. The Office of Science manages ten Labs—which includes both large, multipurpose labs with a broad research portfolio and some with a distinct and singular research mission (particle accelerators, for instance). The National Nuclear Security Administration (NNSA) manages three Labs, the Office of Environmental Management (which is responsible for mitigating nuclear-waste contamination in the DOE complex) manages one, and the three applied-energy Labs are managed by technology offices run by Assistant Secretaries reporting to the Secretary of Energy. The National Renewable Energy Lab is managed by the Office of Energy Efficiency and Renewable Energy (EERE), the Idaho National Lab is run by the Office of Nuclear Energy, and NETL (the sole government-operated National Lab) is run by the Office of Fossil Energy.

High-level strategy for the Labs is partially set by the Secretary of Energy in coordination with National Laboratory Policy Council, which is situated in the Secretary's office. Oversight of operations and best practices takes place through the Laboratory Operations Board.

DOE Organization Chart—Only Showing Offices Relevant to Lab Management



Modified version of chart from Anadon et al. (2016).

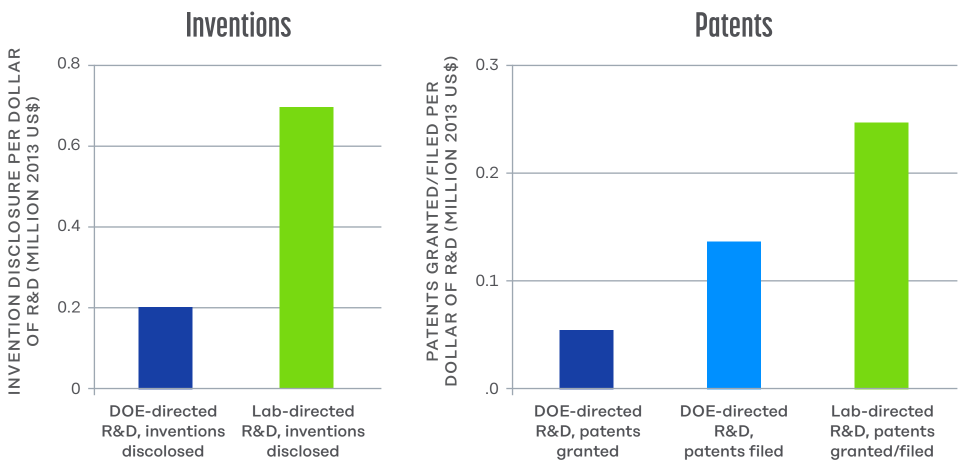
This disjointed management structure makes it very difficult to coordinate and communicate a change in focus across the entire National Laboratory system. Consequently, Congress should require that the DOE consolidate management of its Science and Energy departments by combining the separate Under Secretary positions for Science and Energy, which have been merged or separated thus far at the discretion of the administration. At the same time, Congress and DOE should consolidate energy-innovation strategy for all National Labs in the Office of the Secretary. (This role could potentially merge with the position of OTT director.) DOE should also consolidate and coordinate the management of all Labs with significant energy-innovation mission, strategically develop energy-innovation competencies by directing consolidated funding and activities for specific technology areas to a smaller number of Labs, and increase its use of Go/No-Go decision points in major energy projects and tie additional funding to successful milestone accomplishments at Labs.

5. Change the research culture at National Laboratories, using best practices to boost the efficacy of R&D funding aimed at improving technology-transfer outcomes.

DOE sponsors and oversees the majority of research activity at the National Laboratories, but some funding is driven by the scientists who work there. Scientists can draw from funds known as Laboratory-Directed Research and Development (LDRD) funds to pay for small-scale side projects of their own design. These LDRD projects have seen some remarkable successes: in fact, two LDRD-funded efforts ultimately resulted in Nobel Prizes.

Since policymakers perceive that scientists are less likely to want to work in the defense space, LDRD funds are generally framed as a recruiting tool for scientists at the three defense Labs managed by the NNSA. (The theory is that more personalized research projects can lure better scientists.) However, because LDRD's small grants fund projects scientists themselves believe could be promising follow-ups from existing research, they are very effective at generating both scientific and technology outcomes. In fact, a dollar in LDRD funding was more than three times more likely to result in a reported invention and about five times more likely to result in a patent.

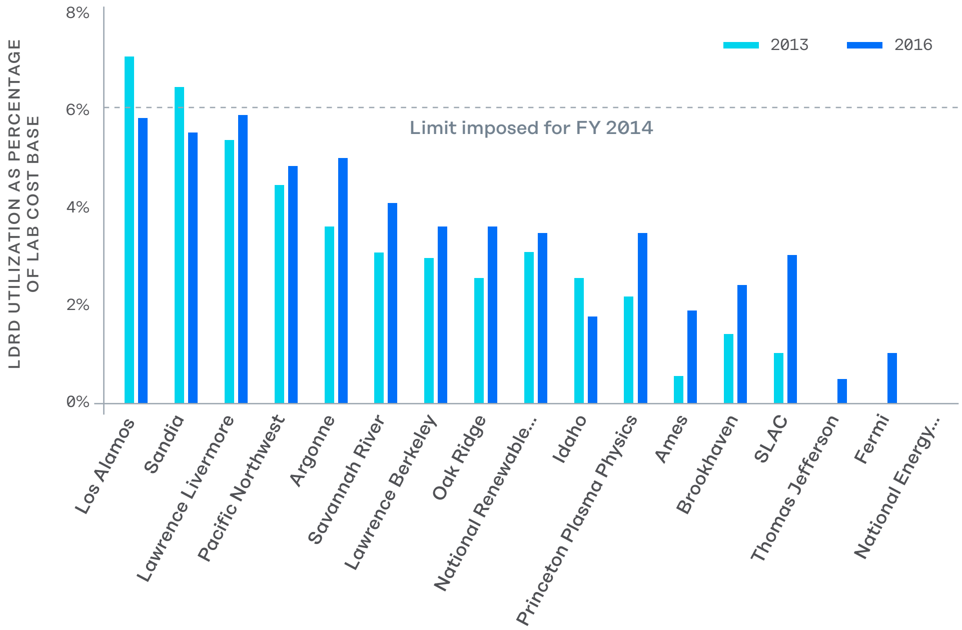
More Inventions and Patents Result from a Dollar of LDRD Funding than DOE-Directed Funding



Source: Reproduced from Anadon et al. (2016).

Researchers have likewise found that, in general, innovative organizations in government and the private sector source a significant component of their R&D agenda from bench-level scientists. Congress recently set an LDRD minimum of 5 percent for the three national-security labs, but to encourage this kind of promising research, it should raise the maximum LDRD limit to 10 percent. At the same time, DOE and Congress should encourage Labs with a significant energy-innovation focus to take greater advantage of the full LDRD allocation. (The figure below compares current LDRD utilization to its level before the cap was reduced in 2013.) Finally, National Labs should tailor LDRD solicitations and funding decisions to favor projects with potential applications for energy innovation.

LDRD Utilization at the National Laboratories



Source: Update of figure from [Bin-Nun et al. (2017)](#).

6. Encourage the development of an entrepreneurial culture among individual scientists at National Laboratories.

Policy can play a key role in reducing risk for scientists who seek to start private sector businesses to develop and bring to market technologies they invented while working in the National Lab system. These include more sophisticated and flexible intellectual property (IP) licensing policies, policies (like those already in existence at some Labs) that allow scientists to take "entrepreneurial leave," and expanded funding, similar to the National Science Foundation's Innovation Corps program, to support this type of work.

M&O contractors can likewise take steps to increase entrepreneurial activity in the National Labs they operate. For instance, when Lockheed operated Sandia and Idaho National Labs, it recruited other companies to raise and distribute a VC fund to invest in Lab-grown technologies. It also set up an incubator, known as the Technology Ventures Corporation, dedicated to turning these innovations into commercial products.

It is incredibly expensive for private sector startups and small businesses to leverage the resources of the National Laboratories and build partnerships with the scientists who work there. At the same time, research has shown these types of government partnerships can boost the ability of clean-tech startups to obtain follow-on funding from the private sector.[9] Consequently, along with expanding funding for scientists seeking to commercialize promising technologies they developed while working in National Labs, the government should also make it easier for those scientists to partner with startups and small

9. Doblinger, C., Surana, K., & Anadon, L. D. (2019). Governments as partners: The role of alliances in US cleantech startup innovation. Research Policy, 48(6), 1458-1475.

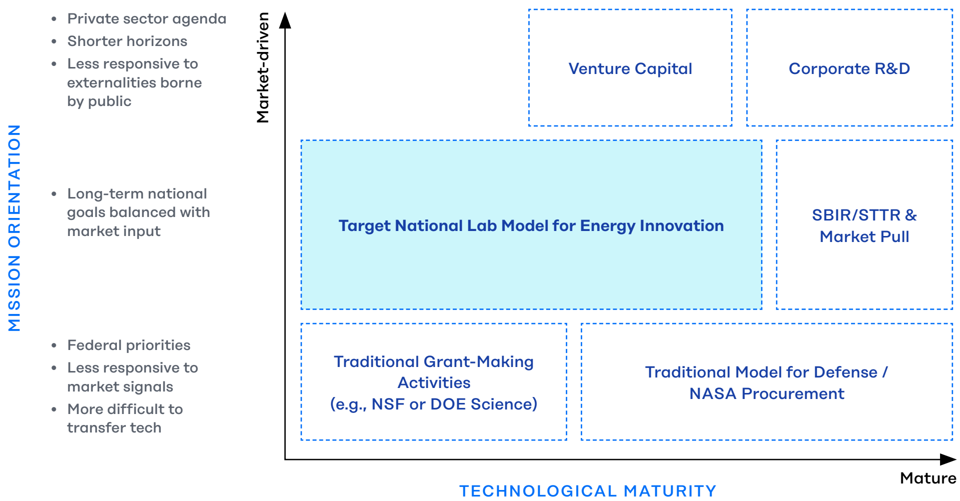
businesses and take entrepreneurial leave from their jobs. Meanwhile, National Lab operators should help raise funds for the development of technologies spun out of their labs—and if these efforts are successful, funders should be rewarded. Finally, Congress and DOE should invest in expertise at the Lab level to optimize IP transactions that can lead to technology development and commercialization.

The Impact of National-Lab Reform

Long-term trends in corporate R&D show that the private sector has largely moved away from developing technology all the way from idea to market. This is especially true in the energy sector.[10] This means there are few organizations that can shepherd technologies from fundamental inquiry to market-ready technology, especially in low-income and historically disadvantaged communities. Meanwhile, researchers are increasingly aware that technology development is circular, not linear: use-inspired research often leads to new fundamental discoveries with completely different applications.[11] As a result, a research organization that spans multiple stages of lifecycle development can better capture research outcomes. By bolstering their focus on an energy-commercialization mission, the National Labs can driver greater levels of innovation.

By integrating fundamental inquiry, use-inspired research, and technology maturation in a single organization, the Labs play a unique role in the innovation system—especially when it comes to energy technologies. They can connect fundamental inquiry, technology development, and market-driven goals with a public mission.

National Innovation System



A model of the National Innovation System with a view that the Labs should connect 1) fundamental inquiry and technology development and 2) market-driven goals with a public mission.

10. Crow, M., & Bozeman, B. (1998). Limited by design: R & D laboratories in the U.S. National Innovation System. Columbia University Press.

11. Narayanamurti, V. (2016). Cycles of invention and discovery. Harvard University Press.

The National Labs are well positioned to play this connective role. They are well-funded and possess a cadre of talented scientists in relevant disciplines; they also have the scale, capability, and experience to develop energy technologies at scale and effectively balance both the public's interest in energy innovation and the private sector's profit motive. In addition, their researchers work across many disciplines and at multiple stages of the development pipeline.

Historical Impact

In FY2019, DOE's Office of Science had a budget of $6.6 billion. This represents more than 40 percent of federal funding in the physical sciences and more than 30 percent of funding in the computational sciences and math. Most of this funding supported research in the National Lab system (though some went to building and operating unique facilities). In FY2015, National Lab research resulted in over 11,000 publications, engaged in over 2,000 partnership projects (including over 700 active formal cooperative research agreements), and had over 6,000 active technology licenses.

The Office of Science and the National Labs operate 40 user facilities, many of which are large, expensive facilities that are impractical for the vast majority of universities and companies to build and/or operate. These facilities are made available to the scientific community as a public service, and they are invaluable. In FY2014 alone, they were used by more than 33,000 researchers, including those affiliated with 55 Fortune 500 companies, 155 small businesses, and hundreds of other institutions.

The National Labs are deeply engaged in R&D across the range of the technological life cycle as well as in building the partnerships that lead to successful commercialization of new technologies. They are also central to the performance of applied-energy R&D in the United States. In the most recent year with detailed statistics available (FY2016), DOE recorded 1,760 inventions and filed for about 1,000 patents.

Overall, the National Labs and the researchers who work in them have a long track record of inventing highly impactful energy technologies.[12] For instance, the first nuclear power reactors were built by researchers at the Argonne National Lab, at a facility that is now part of the Idaho National Lab (the primary executor of research on nuclear energy). More recently, Lab-affiliated scientists invented the advanced cathode technology that underlies the increasing use of lithium-ion batteries in electrified transportation. A National Lab spinout invented a lightweight steel that is broadly used in the automotive industry to improve vehicle efficiency, and DOE's investments in extraction technology spurred the shale-gas revolution.

12. U.S. Department of Energy (2017). "75 Breakthroughs by the U.S. Department of Energy's National Laboratories." Available at: https://www.energy.gov/sites/prod/files/2018/02/f48/75%20Breakthroughs%20National%20Labs.pdf

The National Labs have been so successful, in part, because they are part of the federal government, and their researchers receive federal R&D funds. Corporate R&D programs often come under pressure to offer short-term returns on investments. By contrast, the labs are free to invest in long-term technological development. For example, while the solar photovoltaic cell was invented in the private sector, public needs (mostly in aerospace and defense) drove early demand. As a result, the Lab system has had a dedicated solar program since 1977—more than 30 years before solar reached even 0.1 percent of the electricity-generation capacity in the U.S.

National Labs also present an opportunity to seed new technology ecosystems outside the five cities—Boston, San Diego, San Francisco, San Jose, and Seattle—that have captured more than 90 percent of recent growth in "innovation sector" jobs.[13] They can serve as nuclei for innovation ecosystems in places like Albuquerque, NM, Knoxville, TN, Denver, CO, and Pittsburgh, PA—especially if the federal government carefully tailors their areas of technology focus to meet the needs and the strengths of their environments.

Measuring Impact Moving Forward

It can take many decades to realize which investments had the most impact. Therefore, DOE should develop an interim set of metrics and key performance indicators (KPIs) to assess their implementation along the way. For example, a robust program measuring the impacts of DOE and Lab policies on technology-transfer outcomes, as well as the long-term impact of technology transfer, is especially important. Continual measurement and refinement will be necessary to ensure that DOE activities meet their potential to improve the U.S. energy system.

13. Atkinson, R., Muro, M., & Whiton, J. (2019). The Case for Growth Centers: How to Spread Tech Innovation Across America. The Information Technology Innovation Foundation.

PRIORITY INNOVATION POLICIES

Stimulating Entrepreneurship

Overview

At present, the United States underinvests in clean energy technologies. For the earliest stage of clean energy research and development (R&D), conducted primarily at universities and the Department of Energy's (DOE's) National Laboratories, the federal government allocates about $7 billion in annual funding. For mature technologies like wind and solar power, U.S. capital markets currently deliver about $60 billion in annual investment. Both of these public and private investments should be 3–10 times greater (depending on the model used) in order to eliminate net greenhouse gas (GHG) emissions by mid-century.

The level of underinvestment is even more acute during the phase between R&D and commercial deployment. Between 2009 and 2018, venture-capital funds only invested about $250 million each year in about 125 early-stage (Seed and Series A) energy and power startups.[1] By comparison, during that same period, overall early-stage venture investment rose from $4 billion to more than $20 billion.[2] Since venture capital is often a necessary condition for the ultimate success of a technologically innovative, capital-intensive company, this gap keeps many clean energy entrepreneurs from ever leaving the starting gate.

In order to both stimulate and sustain the development of clean energy technologies at an appropriately ambitious speed and scale, federal policies must be designed to support entrepreneurs all the way from company formation to commercial success. This includes recruiting talented teams to clean energy entrepreneurship, directing more public funding to pre-venture startups, designing effective incentives for venture capital and later-stage investment, and creating large demand-side market signals for novel clean energy technologies.

Policy interventions include:

1. **Recruiting talented scientists** to clean energy entrepreneurship, prioritizing Black, Indigenous, and Latino communities as well as low-income and disabled populations.
2. **Increasing the scale and impact of pre-venture funding.**
3. **Providing incentives for equity investors** in clean energy technologies.
4. **Guaranteeing demand** for clean energy technologies.
5. **Maximizing the climate impact** of federal funding.

1. https://www.cleantech.com/

2. https://www.pwc.com/us/en/industries/technology/moneytree/explorer.html#/

Legislative Principles and Policy Recommendations

1. Increase funding to recruit talented scientists to clean energy entrepreneurship.

On-ramps to clean energy entrepreneurship—including modest incentive prizes, incubator networks, lab-embedded entrepreneurship programs, and customer discovery training—are all proven to draw and focus entrepreneurial talent on new technologies with high potential impact.

Entrepreneurship is an inherently risky path. Most startups fail—and that risk is even greater for a new technology that depends on an innovative scientific discovery working out at scale. Consequently, a number of different policy approaches are necessary in order to maximize success for clean energy innovation.

Effective clean energy entrepreneurship-incentive programs tend to recruit small teams rather than individuals, target innovations at the pre-company stage, provide relatively small grants ($50,000–$250,000) over 1–2 years, and offer value beyond money—including lab equipment, industry knowledge networks, and customer-discovery training. The goal of these programs is to give teams enough time, expertise, and community support to make an informed decision about founding a company and dedicating a decade or more to its growth. These programs should also provide an equitable platform for Black, Indigenous, and Latino researchers to receive funding and training to ensure that clean technologies represent the diversity of the U.S.

As such, DOE should revitalize and expand the following programs:

The Cleantech University Prize, funded and administered by DOE between 2011–2018, incentivized university students across the country to pitch clean energy startup ideas in eight regional competitions, feeding into a national competition with a $100,000 grand prize. DOE estimates that participants in these competitions have gone on to form more than 200 ventures, create more than 120 jobs, and raise over $120 million in follow-on funding. A relatively modest annual commitment of federal funds (<$1 million/year) would revitalize this high-yield recruitment strategy.

The Incubatenergy Network, initially funded by DOE and now run by the Electric Power Research Institute (EPRI), is a network of over 20 competitive clean energy accelerator and incubator programs located primarily in the United States. Each of these programs provides an on-ramp for entrepreneurial teams to learn from peers and industry experts at a very early stage, and each is typically focused on a particular region or industry. DOE's Office of Energy Efficiency and Renewable Energy (EERE) Technology-to-Market budget should be sustained at an annual level of at least $20 million in order to launch and grow new programs with similar potential.

Energy I-Corps is an entrepreneurial boot camp for researchers who work at DOE's National Laboratories. Teams of lab scientists are paired with industry mentors for a two-month intensive regimen in which they define the value proposition of their technology, conduct numerous customer-discovery interviews, and assess viable market pathways. At the end of this program, teams make a "go/no-go" decision on whether to form a company dedicated to the commercialization of the lab technology. This program should be expanded to include DOE-funded teams at universities and startups as well, with an annual funding level comparable to the $30 million I-Corps program at the National Science Foundation (NSF).

DOE has also funded Lab-Embedded Entrepreneurship Programs at three of its National Laboratories to "provide an institutional home for innovative postdoctoral researchers to build their research into products and train to be entrepreneurs." These three programs—Cyclotron Road at Berkeley Lab, Chain Reaction Innovations at Argonne National Laboratory, and Innovation Crossroads at Oak Ridge National Laboratory—allow first-time entrepreneurs with deep technical expertise to access extraordinarily high-value equipment, mentors, and training over the course of two years in residence. These teams and technologies tend to emerge in an excellent position to form companies and compete for grants and investment. Sustained federal funding at $50 million per year would support a new annual national cohort of 100 fellows at an expanded number of DOE laboratories and universities.

2. Increase the scale and impact of early-stage non-dilutive funding at the agency level as well as the program level.

Once an entrepreneurial team has formed a new company to bring a new clean energy technology to the marketplace, it is unlikely that venture capital (VC) investors will be ready to step in immediately. Instead, it typically takes at least another few years to reduce technological risk, develop a marketable product, and demonstrate customer interest—let alone generate revenue.

Public funding is essential at this pre-venture stage to provide enough "runway" (or time before insolvency) for the startup to meet the technical and market milestones that VCs will ultimately demand. Effective pre-venture funding programs tend to target innovative companies at the earliest stage (1–3 years old), provide non-dilutive grants ($250,000–$2,000,000) over 2–3 years, and offer value beyond money—including lab services, industry knowledge networks, and technology-to-market assistance.

Consequently, DOE should optimize and expand the following programs:

Most pre-venture funding for clean energy startups comes from long-standing programs within EERE and other applied research offices. The Advanced Research Projects Agency–Energy (ARPA-E), an independent component of DOE focused on high-risk/high-return research across industries, tends to award a greater proportion of its program dollars to early-stage companies compared to universities, national labs, and larger companies. Ambitious DOE R&D funding goals are described in detail elsewhere in this playbook.

The Small Business Innovation Research (SBIR) program is the federal government's largest annual funding opportunity available exclusively to startups and small businesses commercializing new technologies. It awarded over $3.1 billon to nearly 3,600 firms in FY2018—including about $300 million awarded to approximately 400 firms by DOE. This funding is non-dilutive (the government receives no direct financial upside) and is typically divided into an initial Phase I ($150,000–225,000 over 6–12 months) and a subsequent Phase II ($750,000–1,000,000 over 2 years). A number of operational reforms would increase the commercial and climate impact of the SBIR program at DOE.

Sunshot Incubator was a program within EERE focused exclusively on early-stage startups working to "develop and launch transformative photovoltaic, concentrating solar power, grid integration, system installation, and soft costs products and service." Participating companies achieved an impressive level of success in obtaining follow-on investment. Sunshot Incubator demonstrated that similar startup-focused programs in other technology areas can be successfully sustained at $15 million per year.

American-Made Challenges represent a relatively new model within EERE: they move clean energy entrepreneurs through a rapid tournament of three sequential prize competitions, from planning ($50,000) to proof of concept ($200,000) to pilot partnership ($500,000). Beginning with solar technologies, this model has now been used to generate startup activity in manufacturing efficiency, wave power, and other promising arenas. DOE should devote at least $10 million per year to establishing American-Made Challenges across EERE and other applied research offices.

The Small Business Vouchers program was an elegant way to incentivize both small startups and large national labs to collaborate on commercially promising research. By running a single competition where small businesses proposed their own technical projects, DOE took on the burden of finding the right experts at the right labs for the most promising partnerships and ensured that collaboration agreements were easy and quick to execute. Since these collaborations were worth $50,000–$300,000 at no cost to the small business, there was a strong incentive to participate. The program should be revitalized and extended across other DOE offices at an annual funding level of at least $30 million.

3. Provide incentives for equity investors in clean energy technologies, including match funding for venture capital and well-designed incentives for later-stage private equity.

The job of a VC fund is to invest someone else's money (usually an institutional investor, less often a high-net-worth individual) in a portfolio of young companies that deliver well-above-market returns in less than ten years. Most VCs fail to do so even when they are investing only in potential software "unicorns" or biopharma blockbusters. Clean energy innovation is even riskier, and it is unreasonable to expect that such investors will devote more resources to it without public incentives that increase the likelihood of adequate returns.

Designing effective public incentives for private equity is difficult and requires aligning at least three separate interests. The primary interests of the entrepreneur are speed and simplicity. For them, an overly complex fundraising process will not be worth the distraction. By contrast, the primary interest of the venture investor is realizing outsized returns. And the primary interest of policymakers and taxpayers is realizing public value, whether measured in terms of economic growth, job creation, climate benefits, or other shared goals.

As such, the federal government should work to optimize and expand the following programs:

Public/private matching funds: Some agencies have augmented their SBIR programs with a "Phase IIB" that lures venture investors with matching federal dollars. For example, NSF will provide a 1:2 match (up to $500,000) with private sector investment (up to $1 million) in startups that have graduated from Phase II. The National Cancer Institute, part of the National Institutes of Health (NIH), has a similar Phase IIB bridge program. Unfortunately, it is still rare to find federal programs like these that successfully draw venture capital into innovative technology companies. DOE should implement its own Phase IIB program to help remedy this.

Small Business Investment Companies (SBICs): SBICs are privately managed investment funds backed by a loan guarantee from the U.S. Small Business Administration (SBA). The SBA's contribution is typically 2:1 for each dollar of private capital raised by the fund, up to $175 million. Today there are about 300 SBIC funds investing some $30 billion in small businesses, but these tend to be relatively mature companies with low technology risk. Because SBIC funds are required to make semiannual interest and fee payments back to the SBA, they tend to focus their investments on mid- and later-stage small businesses that have positive cash flow. Past attempts to encourage SBIC funds to invest in more innovative early-stage startups were short-lived, suggesting that more significant design changes are necessary.

Opportunity Zones: The 2017 tax bill included major incentives to invest in low-income communities, which governors delineate within each state as Opportunity Zones. Investment funds that hold at least 90 percent of their assets in such Opportunity Zones can offer significant tax incentives to investors, including a temporary tax deferral and up to 15 percent tax exclusion for prior capital gains, as well as a permanent tax exclusion for new capital gains held for at least ten years. While these new Opportunity Funds are attracting significant investment, most of these dollars will flow to relatively predictable and low-risk real estate projects rather than innovative new companies. Future tax incentives should include more support for private sector investment in innovative clean energy technology companies as well.

4. Guarantee demand by creating "demand pull" mechanisms for upstream investors and entrepreneurs on par with the revenues expected of IPO-eligible software and biotechnology companies.

The policies described thus far—indeed, most government policies to promote innovation—all serve to "push" a new technology from R&D project to startup to mature company by subsidizing R&D and investment along the way. The most powerful incentive for any entrepreneur or investor, however, is the "pull" of paying customers and the value this demand creates. Few entrepreneurs or investors realize significant returns without an "exit" (either an initial public offering (IPO) or an acquisition by another company), and such events do not occur until the company can demonstrate—or at least plausibly predict—sizable demand for its product.

A software company can acquire customers, whether via millions of online consumers or large enterprise contracts, relatively quickly. A biopharma company takes longer to bring a new product to market, but each time it successfully passes an FDA trial, it is measurably closer to charging premium prices for a patent-protected innovation with few substitutes. A clean energy company, on the other hand, may be developing a deep technological breakthrough that, even if successful, will still be competing with incumbent commodities such as wholesale electricity or fossil hydrocarbons.

Therefore, it is unfortunate but not surprising that clean energy startups tend to deliver much lower returns than software and biopharma startups. Without massive revenue opportunities, most venture capital flows elsewhere.

Given this reality, federal policy can play a critical role in establishing very large market signals for clean energy investors and entrepreneurs, as well as creating an expectation of revenues on par with those achieved by IPO-eligible software and biotechnology companies. Such "demand pull" mechanisms can take the form of large incentive prizes, government-orchestrated buyer consortia, and milestone-based payments with government playing the role of first customer.

Successful government-funded demand-pull mechanisms achieve three core goals. First, they fulfill an essential federal-agency mission. Second, they stimulate a self-sufficient commercial industry. Third, they ultimately save taxpayer dollars.

The following demand-based approaches have tremendous potential as applied to climate and energy technology challenges, both within DOE (e.g., storage, buildings, generation) and among other federal agencies (e.g., agriculture, aviation, transportation).

Incentive prizes: In the short run, a well-designed incentive prize can catalyze private sector investment into competitor teams, sometimes exceeding the size of the prize purse. In the long run, the winners can stimulate massive corporate and investor interest in an entirely new industry by demonstrating the underappreciated readiness of a new technology. Canonical examples include the government-funded DARPA Grand Challenge for autonomous vehicles and the philanthropy-funded Ansari XPRIZE for private spacecraft. Recent clean energy technology prizes have been privately funded, including the Google Little Box Challenge for small-scale inverters and the Carbon XPRIZE for carbon capture and utilization. DOE and other agencies already have authority from Congress for prizes up to $50 million and they should exercise this authority much more frequently in promising technology arenas.

Buyer consortia: In some cases, even non-binding letters of interest from enough large potential buyers can catalyze technology innovation. With its Rooftop Unit Challenge, DOE partnered with Walmart, Target, and other large retailers to stimulate the market for 10-ton capacity commercial air conditioners that would dramatically outperform then-available models on cost and efficiency. The General Services Administration (GSA) provided a real-world warehouse test site, and the Pacific Northwest National Laboratory (PNNL) evaluated designs from five manufacturers, with the winning model delivering 26 percent energy savings. Similarly, the Wireless Metering Challenge brought more than 200 commercial building partners to spur the development of wireless sub-meters that cost less than $100 and meet DOE performance specifications. DOE should expand buyer consortia to other technology arenas beyond commercial building energy efficiency.

Government as first customer: At a large enough scale, the federal government can use milestone-based R&D awards and its own purchasing power to foster competition among entrepreneurial companies and ultimately create a new industry. For example, beginning in 2006, NASA pioneered a new approach to government procurement through its Commercial Orbital Transportation Services (COTS) program. NASA paid competing companies only when they achieved clear technology milestones on the path to developing spacecraft that could service the International Space Station, with the promise of even higher-value launch contracts for successful participants. This stimulated a flood of private sector investment and saved taxpayers nearly $4 billion compared with traditional single-source procurement practices. The United States had essentially no commercial space industry when NASA began this experiment. Today, SpaceX and its U.S. competitors lead the world. Similar potential exists in other new industries, such as advanced nuclear power and low-carbon aviation, where DOE can provide milestone-based R&D funding followed by milestone-based procurement agreements from NASA and DOD.

5. Conduct robust analysis and leverage existing tools to maximize the climate impact of federal funding.

It is currently extremely difficult to evaluate the emissions-reducing impact of a given technology even retrospectively, after analyzing decades of data. It is nearly impossible to do it predictively, when the product is in its infancy.

As a general matter, however, it is possible for investors and program managers to make an educated guess about the emissions-reducing potential of a given technology based on a model of how it could change the business-as-usual trajectory within a given industry. For example, Breakthrough Energy Ventures restricts its investment portfolio to "technologies with the potential to reduce at least half a gigaton of GHGs every year, or about 1 percent of projected 2050 global emissions."

One promising methodology for agency portfolio managers is CRANE (Carbon Reduction Assessment: New Enterprises), an open-source software tool that aims to standardize and streamline climate impact assessment of early-stage companies with innovative technologies. By modeling the net impact of a given product at an estimated future deployment at scale, CRANE calculates that technology's emissions reduction potential over time. (See detailed methodology here.)

Such models cannot predict whether a particular venture or technology will succeed or fail. But they can provide insight on whether an individual company or portfolio of companies could conceivably deliver significant emissions-reducing impact per dollar of federal funding.

The Impact of Stimulating Entrepreneurship

Already, with well-designed programs like the ones below, federal funding of clean energy startups has achieved remarkable return on investment. If the funding increases and program improvements recommended above were implemented, we would expect at least a doubling of clean energy startups across technology domains, with outsized commercial and climate impact in the long run.

Sunshot Incubator: Launched in 2007 by DOE, the Sunshot Incubator program provided early-stage funding and other support for startups with the potential to "significantly lower the total installed cost of solar energy systems." Within a 10-year period, DOE provided $138 million funding for over 100 companies, who then went on to raise more than $3.1 billion in venture capital and private equity investment. While it is difficult to establish initial government support as the sole determinant of subsequent capital investment, this ratio of nearly 22:1 in private-to-public dollars is impressive for a federal program.

Small Business Vouchers: DOE's Small Business Vouchers program subsidized cooperative research agreements between National Labs and over 100 competitively selected small businesses, with access to lab staff and facilities valued at $50,000–$300,000 per award. An independent evaluation of the program found that the proportion of participants advancing their product's technology-readiness level (81 percent) was significantly greater than among non-participants (43 percent).

Small Business Innovation Research: One of the most promising methodologies for measuring economic impact comes from DOE's Small Business Innovation Research (SBIR) program, which grants technology commercialization awards to energy-related startups and small businesses. Using data on more than 4,500 firms, one study compared applicants ranked just above and below the award cutoff, and found that Phase 1 awards ($150,000) are associated with increases of 250 percent in patenting activity, 19 percent in employment, 29 percent in payroll, 11 percent in wages, and 15 percent in revenue.

ARPA-E: As of early 2017, 580 ARPA-E project teams, which previously received a total of about $1.5 billion from the agency, had formed 56 new companies and raised more than $1.8 billion in private sector follow-on capital. An independent study found that ARPA-E-funded companies raised more money on average than other clean energy startups, with 5x better odds of being in the top 10 percent of private sector fundraising and triple the odds of receiving scale-up funding from other government agencies.

PRIORITY INNOVATION POLICIES

Demonstrating and Validating New Technologies

Overview

Promising clean energy technologies often suffer from a critical lack of funding after they have been proven to work in the laboratory but before they are deployable on a large scale. This has real consequences: until the cost and performance of new innovations can be demonstrated and validated in real-world conditions, potential buyers may choose more familiar, carbon-intensive options. The critical demonstration and validation phase of the innovation process provides developers with the data they need to refine their technology and jumpstart the market.[1] Unfortunately, it is also vastly underfunded.

The International Energy Agency (IEA) defines the demonstration phase as "the design, construction, and operation of a prototype of a technology at or near commercial scale with the purpose of providing technical, economic and environmental information to industrialists, financiers, regulators and policymakers."[2] Developers use this phase to overcome the technical challenges that face large and complex systems as they scale up. Often these challenges arise from integration and operation of multiple complex subsystems, even when these subsystems are composed of established technologies. Demonstration projects also aim to reduce the economic and institutional risks of deploying new technologies.

Carbon capture systems, advanced nuclear reactors, large-scale energy storage facilities, clean industrial processes, and smart grids are among the large-scale, complex, low-carbon technologies that will need to be demonstrated more often on their paths to the market.

By contrast, the cost and performance characteristics of less complex, more modular low-carbon technologies—new types of solar panels or smaller scale energy-storage systems, for example—are more often validated at testbed facilities, designed to assess new technologies, than demonstrated in new projects. In this context, "validation" refers to the creation of objective data about application-specific systems in realistic operating environments.[3] Testbeds allow innovators to "plug and play" their technologies to produce these data, which can then be shared with market, regulatory, and other players.

1. Hart, "'Across the Second Valley of Death': Designing Successful Energy Demonstration Projects."

2. International Energy Agency (IEA), IEA Guide to Reporting Energy RD&D Budget/Expenditure Statistics (IEA June 2011), 15, https://www.iea.org/reports/iea-guide-to-reporting-energy-rd-and-d-budget-expenditure-statistics

3. See DOE Fuel Cells Technology Office, "Technology Validation," https://www.energy.gov/eere/fuelcells/technology-validation. The Department of Defense budget classification "6.4" encompasses demonstration and validation (often lumped together as "dem-val"). See John D. Moteff, "Defense Research: A Primer on the Department of Defense's Research, Development, Test and Evaluation (RDT&E) Program," Congressional Research Service, July 14, 1999, https://apps.dtic.mil/dtic/tr/fulltext/u2/a477855.pdf

Many demonstration projects and validation testbeds are too risky and capital-intensive for the private sector to take on alone. The rewards of private investments in demonstration and validation are usually modest—especially since the information they generate is most beneficial to society when it is shared widely, which limits any competitive advantages that the investors may gain. Consequently, the federal government has an important role to play in facilitating demonstration and validation, often by committing substantial resources to projects and facilities.

It is not easy to initiate and manage large-scale demonstration projects: decision-makers must select technologies that are at the appropriate stage of maturity to benefit from such projects and stave off political pressures that arise because large projects inherently provide regional economic benefits, regardless of their technical merits. Cost overruns and schedule slippages are also common in demonstration projects, which may cost $1 billion or more. And when projects are unsuccessful, as is to be expected with some first-of-kind endeavors, they can still be difficult to terminate due to entrenched regional support.[4]

Federal funding and management of demonstration and validation energy projects and facilities has a mixed record in the United States.[5] But by applying lessons learned from the past and learning from the experiences of other countries and fields, the U.S. can create a strong demonstration and validation capability that accelerates multiple promising low-carbon energy technologies while managing the inevitable failures at an acceptable cost.

Policy interventions include:

1. **Developing a robust portfolio of demonstration projects** for complex, capital-intensive technologies that can promote deep decarbonization.
2. **Expanding federally managed, market-driven testbed resources** to accelerate the commercialization of clean energy technologies prioritizing deployment in low-income and historically disadvantaged communities.
3. **Encouraging vigorous information sharing** among all partners in demonstration and validation activities.
4. **Negotiating flexible cost-sharing agreements** between public and private funders of demonstration projects.
5. **Centralizing the Department of Energy's (DOE's) system of managing large-scale demonstration projects** to promote best practices and isolate projects from political influence.
6. **Linking demonstration and validation activities to upstream research and development (R&D) and downstream deployment programs** so that promising technologies move as rapidly as possible through the full innovation cycle.
7. **Fostering international efforts to share knowledge** gained from demonstration and validation activities.

4. Hart, "'Across the Second Valley of Death': Designing Successful Energy Demonstration Projects."

5. Linda R. Cohen et al., The Technology Pork Barrel (Washington, DC: Brookings Institution, 1991).

Legislative Principles and Policy Recommendations

1. Develop and maintain a robust portfolio of demonstration projects for complex, capital-intensive technologies that can promote deep decarbonization.

Federal funding for demonstration projects has been inconsistent. The most recent significant investment in demonstration was funded by the 2009 Recovery Act, and the most significant one before that was in the 1970s[6]—and the dwindling portfolio in place today does not reflect the urgency of reducing greenhouse gas emissions. In particular, hard-to-decarbonize sectors such as aviation, long-distance transport and shipping, steel and cement manufacturing and other industrial processes, and providing a reliable, firm electricity supply require technologies that are complex, capital-intensive, and will require demonstration. Yet while there is a growing pipeline of innovations ready for demonstration, at present the federal government often does little more than manage demonstration projects funded years ago or conduct preliminary planning for projects that are still years away.[7, 8]

We need a robust federal program of large-scale clean energy demonstration projects, ideally one that reflects global needs as well as national opportunities and manages risk through diversification and sophisticated project management.

Demonstration projects are expensive and multiple projects will be needed to demonstrate some technologies.[9] The share of total research, development, and demonstration funding that should be devoted to demonstration projects could be up to 50 percent.[10] Congress should allocate substantial federal funds to the portfolio on a multi-year basis while exercising oversight to ensure expert project management.

The agency should clearly articulate the criteria it uses to select these projects—like potential for decarbonization, maturity, and private-sector interest and commitment—and the portfolio it builds should be broad and flexible enough that the most promising technologies can evolve over time as their developers learn from the market and one another. To fully de-risk the best innovations, the portfolio should allow up to five demonstration projects within each "pathway."

Finally, DOE should develop a long-term plan for its demonstration portfolio that accounts for the long duration and high cost of individual projects, as well as the likelihood of failures that will require projects to be terminated.

6. Hart, "'Across the Second Valley of Death': Designing Successful Energy Demonstration Projects."

7. Colin Cunliff, "An Innovation Agenda for Deep Decarbonization: Bridging Gaps in the Federal Energy RD&D Portfolio" (ITIF, November 2018), https://itif.org/publications/2018/11/28/innovation-agenda-deep-decarbonization-bridging-gaps-federal-energy-rdd ; Steven J. Davis et al., "Net-zero emissions energy systems," Science 360 (2018): eaas9793, https://science.sciencemag.org/content/360/6396/eaas9793

8. Colin Cunliff, "FY 2020 Energy Innovation Funding: Congress Should Push the Pedal to the Metal" (ITIF, April 2019), https://itif.org/publications/2019/04/02/fy-2020-energy-innovation-funding-congress-should-push-pedal-metal

9. Gregory F. Nemet et al., "The valley of death, the technology pork barrel, and public support for large demonstration projects," Energy Policy 119 (2018): 154-167, https://www.sciencedirect.com/science/article/pii/S0301421518302258

10. National Academies of Sciences, Engineering, and Medicine, "Negative Emissions Technologies and Reliable Sequestration: A Research Agenda" (Washington, DC: National Academies Press, 2019), 233-234, https://www.nap.edu/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda; Elliot Diringer et al., "Getting to Zero: A U.S. Climate Agenda," (C2ES, November 2019), 10, https://www.c2es.org/site/assets/uploads/2019/11/getting-to-zero-a-us-climate-agenda-11-13-19.pdf

2. Expand federally managed, market-driven testbed resources to accelerate the commercialization of clean energy technologies.

Innovators use testbeds and simulation resources to validate that new energy technologies can work under real-world conditions. Testbeds are well-suited for modular technologies that must be tested in specific environments, such as some forms of direct air capture and energy storage. They are too expensive for most individual companies to operate on their own, but they provide significant benefits to entire industries.[11]

DOE already oversees dozens of testbed facilities and the demand for such services should continue to grow as clean energy resources expand. (For example, the National Carbon Capture Center founded by DOE and operated by Southern Company allows third-party developers to test carbon capture technologies in the operating conditions of a power plant, and it has contributed to research that cuts the projected cost of carbon capture by one third.)[12] The federal government and its partners should provide the capital expenditures to enhance and expand this shared testbed infrastructure. In many cases, users can and should bear most of the costs of operating these facilities.

Working with industry, DOE should assess the need for testbed facilities across all applied-energy domains, especially for technologies that combine great potential to support deep decarbonization and weak incentives for private sector investment. These include floating deep-water wind turbines, enhanced geothermal systems, marine and hydrokinetic technologies, biofuels, smart grid components, some advanced nuclear technologies, and some forms of direct air capture and energy storage. At the same time, DOE, the Department of Defense (DOD), and the Department of the Interior (DOI) should work together to assess the feasibility of identifying and pre-permitting testbed sites on federal lands.[13]

Finally, DOE should establish a national testbed and simulation network that can efficiently connect technology developers with testing capabilities and simulation resources at national laboratories, academic institutions, and industrial R&D centers.

3. Encourage all partners in demonstration and validation activities to share technical, cost, and performance data.

The most valuable product of demonstration and validation activities is knowledge—and sharing that knowledge publicly will help accelerate the development of these critical technologies.[14] When it comes to debugging technical problems that emerge during this stage of the innovation process, for instance, more perspectives mean better solutions. In any case, for any innovation, the more credible and complete the publicly available cost and performance information is, the more likely that investors will fund deployment at scale.

For example, what scientists learned from a series of early solar-thermal–electricity plants supported by DOE in the 1980s contributed to the industry's later rebirth.[15] Similarly, the smart-grid demonstration program funded by the Recovery Act adopted the principle of open knowledge-sharing to good effect.[16] Although some data (such as detailed technical specifications and formulae) will undoubtedly remain proprietary no matter what, greater openness strengthens

11. National Academies of Sciences, Engineering, and Medicine, The Power of Change: Innovation for Development and Deployment of Increasingly Clean Electric Power Technologies, (Washington, D.C.: The National Academies Press, 2016) https://www.nap.edu/catalog/21712/the-power-of-change-innovation-for-development-and-deployment-of

12. "Our Mission," National Carbon Capture Center, https://www.nationalcarboncapturecenter.com/our-mission

13. Jesse Jenkins et al., "A National Clean Energy Testbeds Program: Using Public Lands to Accelerate Energy Innovation" (Breakthrough Institute, November 2011) https://s3.us-east-2.amazonaws.com/uploads.thebreakthrough.org/legacy/blog/Testbeds.pdf

14. Gregory F. Nemet et al., "The valley of death, the technology pork barrel, and public support for large demonstration projects."

15. Gregory Nemet, "Technological improvements in Solar thermal electricity in the United States and the role of public policy," Energy Policy (2011), doi:10.1017/CBO9781139150880.017

16. DOE Office of Electricity Delivery and Energy Reliability, "Smart Grid Demonstration Program," https://www.smartgrid.gov/recovery_act/overview/smart_grid_demonstration_program.html

downstream investor confidence, enhances competition in the follow-on phase, and enables external oversight. Unfortunately, private sector investors are less likely to want to fund demonstration and validation projects whose results will be shared more broadly. To preserve these benefits to the public, government investment in demonstration and validation is essential.

Federal leadership can maximize the public benefits of demonstration and validation without slowing later market development. For one thing, federal agencies should use their leverage as funders of demonstration and validation activities, particularly large demonstration projects, to require private beneficiaries of these activities to share general technical data and detailed cost and performance data with stakeholders and the public. Congress should authorize agencies to bear a higher proportion of the cost of demonstration and validation activities than they would otherwise in order to induce private cost-share partners to share information. And demonstration and validation activities should be evaluated in part on how effectively information has been shared and whether this information-sharing has stimulated follow-on investment and improved other measures of customer and public confidence.

4. Negotiate flexible cost-sharing agreements between public and private funders of demonstration projects to account for risks and benefits to both sectors.

Public-private partnerships are an ideal way to fund demonstration projects. While these projects are generally too risky for private investors to fund fully, they provide important benefits that justify investors taking some share of the risk. Private cost-sharing also signals that a technology is mature enough to warrant demonstration and provides oversight and insulation from political influence, reducing the risk that failing projects will be sustained.

Congress has historically set cost-sharing ratios for federally funded demonstration projects somewhat arbitrarily. A better approach would be to negotiate agreements that reflect the varying risks and benefits across projects. The public share should be highest for the riskiest, most novel first-of-a-kind projects or project phases, lower for follow-on “first few” iterations, and lower still for less capital-intensive validation activities.[17] DOE should negotiate these cost-sharing arrangements with private partners and develop a transparent methodology for cost-share risk-adjustment, as permitted by Section 988 of the Energy Policy Act of 2005.[18]

5. Centralize DOE’s system of managing large-scale demonstration projects to promote best practices and isolate projects from political influence.

Although private sector partners execute demonstration projects, DOE’s applied-energy offices are usually responsible for their oversight and management, including approving additional federal funding at project milestones. DOE’s record in this regard is uneven: many projects have suffered cost overruns and schedule slippages, and some projects that failed to meet milestones continued to receive support because of the regional economic

17. Hart, “‘Across the Second Valley of Death’: Designing Successful Energy Demonstration Projects.”

18. IHS Markit and Energy Futures Initiative, Advancing the Landscape of Clean Energy Innovation, (Breakthrough Energy, February 2019), http://www.b-t.energy/reports/advancing-the-landscape/

benefits they provided and the political momentum these benefits created. The Clinch River Breeder Reactor in Tennessee—which ran for 14 years, absorbed more than $5 billion, and was never completed—is a famous case in point.[19]

DOE can improve the management of demonstration projects and accelerate the commercialization of new technologies by consolidating project management into one office or organization. A new department-wide Major Demonstration Office with its own appropriation, analogous to the Loan Program Office, to manage large-scale demonstration projects across multiple technology areas would build expertise in project management and better coordinate DOE's portfolios.

Plans for demonstration projects should be explicit about the technical, cost, and performance milestones they are expected to meet. A key factor in such plans should be the continued willingness of private partners to continue making project investments. The Major Demonstration Office and other DOE offices managing smaller-scale demonstration projects (along with Congress in exceptional circumstances) should conduct regular evaluations of projects against these milestones. Project managers should be encouraged to terminate projects that fail to meet them.

6. Link demonstration and validation activities to upstream R&D and downstream deployment programs, moving promising technologies through the full innovation cycle as rapidly as possible.

Differences in incentives, objectives, and funding often slow the progress of energy technologies from laboratory bench to widespread adoption. Upstream, researchers driven to publish their findings typically seek to test hypotheses or establish the feasibility of systems and concepts. Downstream, vendors seek to maximize profits over the long term and control costs and risks. Upstream, funding tends to be provided by the public sector through grants and contracts. Downstream, it comes from private investors and corporate balance sheets, sometimes subsidized by investment guarantees and tax incentives.

Finding ways to span these differences increases the likelihood that promising technologies will not be orphaned at any stage. Technical experts from private industry should participate in agenda-setting and reviews of energy R&D funding programs to tilt these programs toward creating technologies with a high potential for eventual deployment and to inform industry about what is in the pipeline. Private sector partners should continue to lead cost-shared demonstration partnerships so that projects focus on issues of commercial importance and partners gain hands-on experience that will be useful in follow-on commercial undertakings.

Meanwhile, interagency groups led by White House staff members should review the progress of key technologies and ensure that there are smooth handoffs from R&D funding agencies, like DOE, to agencies that participate in demonstration and validation activities, like DOD, to those that administer financial incentives, like the Department of the Treasury, or have regulatory responsibilities, like the Federal Energy Regulatory Commission (FERC).

19. Linda R. Cohen et al., The Technology Pork Barrel.

7. Foster international efforts to share knowledge gained from demonstration and validation activities in order to accelerate the adoption of new technologies.

Without information-sharing, demonstration and validation activities have little value. Technical information-sharing facilitates improvements in follow-on commercial projects, while cost and performance information-sharing strengthens customer and public confidence. International information-sharing has the potential to create substantial value by increasing the diversity of expert perspectives and market opportunities for the technologies involved. All this is particularly important for highly capital-intensive innovations, such as carbon capture technologies, which are so expensive that only a few demonstration projects are likely to be undertaken around the world, limiting the scope of learning.[20] However, national interests in promoting industrial competitiveness, along with proprietary interests, can inhibit information-sharing about such projects.

Measures to foster global information-sharing from demonstration and validation activities will require national diplomatic resources as well as the engagement of international industrial and technical bodies.

As such, DOE should provide technical and financial support to road-mapping efforts for key technologies organized by the IEA, Mission Innovation, and other intergovernmental bodies to establish milestones for demonstration and validation activities and measure their progress. DOE, DOD, the Department of Commerce, and other appropriate agencies should engage with their counterparts from a small number of leading nations as well as industry stakeholders to articulate principles of information-sharing from demonstration projects, including reciprocity and acceptance of intellectual property (IP) rights. The State Department should also work with DOE and other agencies, as appropriate, to explore multinational funding and management of very high-priority and high-cost demonstration projects.

The Impact of Demonstrating and Validating New Technologies

Expanded federally funded demonstration and validation activities would enable the widespread adoption of clean energy technologies. Technologies with the potential to be widely adopted in hard-to-abate sectors should be a high priority for federal policy, and many are approaching readiness for demonstration or validation. While the emissions impact of additional spending on demonstration and validation depends on a wide array of factors, including project results, follow-on policies, and market conditions, these brief case studies highlight the remarkable potential for significant emissions reductions from increasing federal support for these activities.

20. David M. Reiner, "Learning through a portfolio of carbon capture and storage demonstration projects," Nature Energy, Vol. 1 (2016), https://doi.org/10.1038/nenergy.2015.11

National Wind Technology Center at NREL

The National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL) has served as a wind testbed site for industry since 1993. The NWTC houses a series of unique facilities including dynamometers for testing drive trains in simulated wind condition, a controllable grid interface to test power controls, and a field site for testing of complete wind systems up to multiple megawatts in power rating. Collaborations between NWTC and industry have led to the development of utility-scale and small wind turbines, won multiple R&D 100 awards from R&D Magazine, and helped broaden deployment of wind energy across the U.S.[21] In 2018, wind power accounted for nearly 7 percent of U.S. electricity generation.[22] Globally, wind generation that year prevented an estimated 200 million tons of carbon emissions, equivalent to the emissions of 43 million cars.[23]

Advanced Nuclear Power

Even if variable renewables like wind and solar power diffuse to the maximum possible level, research suggests that substantial quantities of dispatchable clean generation will likely be required to balance their variability. Nuclear power is one of the few currently commercially viable sources of low-carbon dispatchable power, which could substitute for natural gas- or coal-fired generation in systems with high renewables penetration. Nuclear plants currently provide approximately 20 percent of the U.S. electricity supply, but current plants are inflexible and costly to build. Advanced nuclear designs would be safer, more efficient, and generate less waste. Small modular reactors offer lower initial capital costs, increased scalability, and siting flexibility. Such advances will require both demonstration projects and testbed facilities. DOE announced plans to build a Versatile Test Reactor to accelerate fast neutron reactor technologies.[24]

Direct Air Capture

IPCC modeling of global emissions pathways that limit warming to 1.5° C includes large-scale deployment of negative emissions technologies (NETs), and the National Academies of Sciences, Engineering, and Medicine (NASEM) reports that optimal emission-reduction scenarios require deploying NETs with a total capacity of ten gigatons of CO_2 per year by 2050. Direct air capture (DAC) is a promising solution because it can be deployed on a larger scale and far more flexibly than other NETs such as afforestation, which face permanence and land use limitations. Currently DAC costs remain prohibitive, far higher than any plausible carbon price. The greatest barrier to advancing DAC deployment is the absence of operational data for techno-economic analyses, which may be obtained through demonstration projects and validation testbeds. Pilot-scale projects can be designed to test the performance of DAC while varying technical processes, site locations, weather conditions, and plant configurations. NASEM recommends a program to support three pilot-scale projects per year at $20 million per project, with each plant capturing 1000 tons of CO_2 annually.[25]

21. NWTC, "NREL's Wind R&D Success Stories," http://mdcampbell.com/NRELWindR&DSuccesses.pdf

22. "Wind explained," U.S. Energy Information Administration, https://www.eia.gov/energyexplained/wind/electricity-generation-from-wind.php

23. "Environmental Benefits," American Wind Energy Association, https://www.awea.org/wind-101/benefits-of-wind/environmental-benefits

24. Nuclear Innovation Alliance, "Advanced Nuclear," https://www.nuclearinnovationalliance.org/advanced-nuclear

25. NASEM, "Negative Emissions Technologies and Reliable Sequestration: A Research Agenda."

PRIORITY INNOVATION POLICIES

Research and Development Tax Credit

Overview

In order to mitigate climate change, the world needs clean energy sources that perform as well as, or better than, fossil fuels for the same price. Right now, these innovations do not exist—and without significant investment in research and development (R&D), they never will.

While the U.S. government does fund some R&D directly through federal labs and grant programs such as the Advanced Research Projects Agency-Energy (ARPA-E), it is not enough. The clean energy innovations the world needs will not happen without private sector R&D to complement federal investment. Better and more generous tax incentives can spur this kind of business investment.

The federal government already employs a variety of tax incentives to spur specific clean energy innovations— solar and wind-energy tax credits, for instance—but the R&D tax credit (also known as the research and experimentation tax credit) covers eligible spending on any technology.[1] First enacted as a temporary provision of the Economic Recovery Tax Act of 1981, it credits federal taxes for the portion of a company's R&D expenditures that are experimental in nature.[2] That means it does not apply to money a company spends on doing non-technical research or on buying machinery or equipment. It also does not apply to experimental R&D funded by early-stage startups, since, until they start making money, they don't have any tax liability to speak of. (To begin to remedy this, the 2015 Protecting Americans From Tax Hikes (PATH) Act made the R&D tax credit at least partially refundable for small businesses by allowing them to take the credit against their payroll taxes if they did not have adequate federal tax liabilities.[3])

Some tax incentives also exist for collaborative R&D. At least a dozen nations—including Belgium, Chile, Denmark, France, Hungary, Italy, Japan, the Netherlands, Norway, Spain, and the United Kingdom—have established collaborative R&D tax credits designed to encourage industry investment in collaborative research, often including universities, and enrolled multiple partners to do so.[4] As part of the Energy Policy Act of 2005, Congress created a research credit that allowed companies to claim a credit equal to 20 percent of the total payments to qualified research consortia, universities, and federal laboratories for energy research. This credit applies to all research expenditures, not just "experimental" ones.

1. https://itif.org/sites/default/files/2019-tax-incentives-clean-energy.pdf

2. P.L 97-34. The credit is currently codified in Section 41 of the Internal Revenue Code. https://www.bergankdv.com/resources/blog/rd-credit-qualified-research/

3. P.L. 114-113.

4. Matthew Stepp & Robert D. Atkinson, "Creating a Collaborative R&D Tax Credit" (Information Technology and Innovation Foundation, June 2011), 5, http://www.itif.org/files/2011-creating-r&d-credit.pdf

However, relatively few firms take advantage of this credit. As of 2014, the most recent year for IRS data, businesses took just $133 million in credit (just 1 percent of the $12.6 billion total R&D credit claims).[5] This may be primarily because the federal government does little to popularize it: the main federal webpage that lists clean energy programs for businesses does not include this incentive, nor does Select USA, the main federal program to attract investment to the U.S.[6, 7] Likewise, the Federal Laboratory Consortium Website makes no mention of the fact that companies funding research at federal labs could qualify for this collaborative credit.[8]

Meanwhile, to become more globally competitive in innovation-based industries, many other countries have lowered the effective tax rate on research activity within their jurisdictions by enacting or expanding tax credits or deductions for investments in research.[9] As a result, the U.S. has steadily fallen behind in the relative generosity of its tax incentive for conducting research.[10] In the late 1980s the U.S. credit was the most generous among OECD members, but by 2018, the U.S. ranked 26th in R&D tax generosity.[11]

To spur clean energy innovation, reduce the after-tax cost of private investment in R&D, and boost U.S. international competitiveness overall, Congress should expand and reform the R&D tax credit in a number of ways.

Policy interventions include:

1. **Expanding the federal Alternative Simplified Credit for research.**
2. **Broadening the tax code's definition of basic research.**
3. **Expanding federal tax credits for collaborative energy research.**
4. **Making it easier for research-based startups, including clean energy startups, to use the R&D tax credit.**

Legislative Principles and Policy Recommendations

1. Expand the federal Alternative Simplified Credit for research.

The easiest way for companies to file for a R&D tax credit is to use the Alternative Simplified Research Credit (ASC). The ASC credits 14 percent of qualified research expenditures above half of base period expenditures—a relatively weak incentive. In fact, ASC subsidizes about 5 percent of an extra dollar of qualifying research in profit-making firms, compared to a median of 13 percent among all OECD nations.[12] That already-low rate will soon begin to fall even further. Recent tax reform requires companies to begin amortizing as opposed to expensing research over a five-year period starting in 2022.

5. https://www.irs.gov/statistics/soi-tax-stats-corporation-research-credit

6. https://programs.dsireusa.org/system/program?state=US

7. https://www.selectusa.gov/federal_incentives

8. https://www.federallabs.org/t2-toolkit

9. These studies include; Luke A. Stewart, Jacek Warda, and Robert D. Atkinson, "We're #27!: The United States Lags Far Behind in R&D Tax Incentive Generosity (Information Technology and Innovation Foundation, July 2012), https://itif.org/publications/2012/07/19/we%E2%80%99re-27-united-states-lags-far-behind-rd-tax-incentive-generosity ; Robert D. Atkinson and Scott M. Andes, "U.S. Continues to Tread Water in Global R&D Tax Incentives," (Information Technology and Innovation Foundation, August 2009), https://itif.org/publications/2009/08/13/us-continues-tread-water-global-rd-tax-incentives ; Robert D. Atkinson, "The Research and Experimentation Tax Credit: A Critical Policy Tool for Boosting Research and Enhancing U.S. Economic Competitiveness, (Information Technology and Innovation Foundation, September 2006), https://itif.org/publications/2006/09/05/research-and-experimentation-tax-credit-critical-policy-tool-boosting

10. The Organization for Economic Cooperation and Development (OECD) measures a country's tax generosity toward research with a measure called the B-index, first developed by Jacek Warda. (Jacek Warda, "Measuring the Value of R&D Tax Treatment in OECD Countries," Science Technology Industry Review," 27 (2001), http://www.oecd.org/sti/37124998.pdf . The B-index measures the level of pre-tax profit a "representative" firm would need in order to break even on one dollar of additional R&D spending on a present value basis. The generosity of the tax credit is then measured as one minus the B-index. See Organization for Economic Cooperation and Development, "Definition, Interpretation and Calculation of the B-index," (OECD) www.oecd.org/sti/b-index.pdf and http://www.oecd.org/sti/rd-tax-stats-united-states.pdf

11. https://itif.org/publications/2019/09/13/us-continues-lag-its-competitors-tax-credits-research-and-development

12. http://www.oecd.org/sti/rd-tax-stats-united-states.pdf

For comparison, to match the generosity of China's R&D tax credit, the U.S. would have to increase the ASC rate from 14 percent to between 35 and 40 percent.[13] One recent study estimated that if the ASC were raised to 40 percent, existing profitable firms would increase their research spending by almost 150 percent above what they would spend with no credit.[14] Moreover, researchers found that expanding the R&D tax credit would pay for itself from the additional revenue growth in 15 years.[15] In other words, the expanded credit would soon earn more than it cost.

Given the strong academic evidence of its effectiveness and ability to generate revenue, Congress should at least double the ASC from 14 percent to 28 percent.

2. Broaden the tax code's definition of basic research.

The law authorizing the R&D tax credit defines "basic research" as "any original investigation for the advancement of scientific knowledge not having a specific commercial objective."[16] Companies can receive a credit of 100 percent of what they spend on basic research, whether the company conducts that research itself or they provide funding to a university or federal lab. However, when it comes to applied research—research that has a specific commercial objective—a company can still receive full credit if it performs that research itself, but only 60 percent if it funds researchers at a university or federal lab.

Congress should eliminate the language that excludes applied research and allow 100 percent of expenditures on all scientific research made at universities or federal labs to qualify as research expenditures under the regular or ASC credits. This would immediately signal that research collaboration between the private sector and government or university facilities for clean energy innovation is a critical priority.

3. Expand federal tax credits for collaborative energy research.

Congress established a flat tax credit of 20 percent for all collaborative research involving energy because such research has higher spillovers: in other words, companies could not capture all of the benefits themselves. To spur more funding by industry of clean energy research at federal labs and universities, Congress should boost the rate to 40 percent.

4. Make it easier for research-based startups, including clean energy startups, to use the R&D tax credit.[17]

Many companies performing clean energy R&D are startups or young companies that do not have significant taxable revenue. As such, these companies often cannot take full advantage of the R&D tax credit.

Congress should take three steps to fix this problem:

First, Congress should amend Section 469 of the tax code to permit passive investors to utilize net operating losses and research tax credits of companies in which they invest. This reform would change provisions enacted in 1986 designed to prevent wealthy individuals from misusing the credit, such as

13. https://itif.org/publications/2019/10/23/understand-chinese-innovation-success-look-no-further-government-rd

14. https://www.tandfonline.com/doi/full/10.1080/0013791X.2017.1319001

15. ITIF modeled increasing the ASC to 20 percent and found it would create 162,000 jobs, generate 3,850 additional patents each year, and increase productivity by 0.64 percent and GDP by $66 billion per year. And the increased tax revenues from this additional economic activity would begin to exceed the expenditure loss from the tax credits within 15 years. Expanding to 28 percent would have even greater economic impacts. Information Technology and Innovation Foundation, "Winning the Race Memo: Corporate Taxes" (2012), http://www2.itif.org/2012-wtr-taxes.pdf

16. Section 41(e) (7) (A)

17. The authors wish to thank the Information Technology and Innovation Foundation (ITIF) for contributing solutions to this section, which is based on their previously published reports and resummarized here with their permission.

investing in firms that were never actually meant to be profitable. While well-intentioned, this reform also limited investment in clean energy startups that are not yet profitable. Instead, Congress should allow net operating losses to be credited from investments that were specifically for qualified R&D activities. In addition, qualifying companies should have fewer than 250 employees, less than $150 million in assets, and half its expenses committed to R&D. An Ernst & Young study found this proposal would increase investment in these companies by $9.2 billion, allowing them to create 47,000 jobs.[18]

Second, Congress should help small companies doing R&D to carry forward net operating losses. Section 382 of the Tax Code does not allow companies where there is a change in ownership from carrying these losses forward. This makes other potential investors less likely to invest. The same Ernst & Young analysis suggested this reform would result in $4.9 billion more direct investment and 25,000 more jobs at startup companies working on audacious new clean energy technologies.

Finally, Congress should expand the current incentive allowing some firms to take the R&D credit against their payroll taxes. Many young technology-based firms, including startups, cannot take advantage of the R&D credit because they do not make adequate profits against which to take it. While firms can carry over credits they cannot take for up to seven years, this does nothing to help them in their critical early days.

Congress has already considered legislation that would allow all firms with less than $5 million in gross receipts to take the credit against their Social Security tax liability of up to $250,000. But since the Social Security payroll tax is just 6.2 percent of wages, more such help is needed.

The Impact of Research and Development Tax Credits

The economic rationale for R&D tax credits is undeniable. Even notwithstanding potential breakthrough emissions-reducing technologies that may result, investing in R&D results in more knowledge and innovation, which in turn yields greater efficiency and cost-savings, more jobs and economic growth, increased global competitiveness, and even higher standards of living. Indeed, as noted earlier, increased R&D credits ultimately earn the federal government more than they cost.

Yet one of the main reasons why firms may not invest robustly in R&D is because many of these benefits are positive externalities: they benefit the public at large more than the company making the actual investments. One economic study found that private companies saw a median 27 percent return on investment (ROI) arising from 20 well-known innovations, while the median social rate of return was 99 percent.[19] Similarly, the Obama administration estimated that each dollar spent on R&D tax credits generates between two and three dollars

18. Ernst and Young, "Economic Impact of Tax Proposals Affecting Research-Intensive Start-Up Businesses and Qualified Small Business Companies," prepared for the Coalition of Small Business Investors, July 2013, p 8.

19. J.G. Tewksbury, M.S. Crandall, and W.E. Crane, "Measuring the Societal Benefits of Innovation, Science 209, no. 4457, (1980).

of social value.[20] In a review of other such studies, Professor David Popp of Syracuse University found that, while private ROIs range from 7 to 15 percent, social ROIs are as high as 30 to 50 percent.[21] Given the significant positive externalities from clean energy, it is certainly possible that the spillovers from clean energy R&D could be even larger.

As a recent report by the Information Technology and Innovation Foundation (ITIF) concluded:

> "Almost all scholarly studies conducted since the early 1990s find R&D tax incentives to be both effective and efficient. For example, a 2000 study by economists Bronwyn Hall and John Van Reenan found that from 1981 to 1991 the U.S. R&D credit generated an additional dollar in research for every dollar lost in tax revenue. The former U.S. Congressional Office of Technology Assessment concluded that it produces a dollar-for-dollar increase in reported R&D spending on the margin...
>
> "This situation is not unique to the United States. A study of Australian R&D tax incentives found that they created about one dollar of R&D for every lost dollar of tax revenue. A review of the literature found that the Canadian credit generates 98 cents in additional research for every dollar of tax credit and cites other studies showing effects as high as $1.80 and $1.90. The net gain to society was 11 cents for every dollar of credit. The same results hold for cross-country studies. Tax credits effectively stimulate additional business R&D."[22]

More recently a 2017 study by economists Yuchen Li, Yada Zhu and Thomas O. Boucher estimated that the ASC encourages profitable firms and startups to increase their research spending by 12.3 percent and 9.3 percent respectively.[23] A July 2019 report by Boston University economist Catherine Fazio and Jorge Guzman and Scott Stern of MIT found that even after controlling for variables, states with their own R&D tax credit saw a 7.5 increase in new businesses. Moreover, states who have kept their R&D tax credit in place for a decade saw the rate of new businesses surge by 20 percent.[24]

The same Fazio-Guzman-Stern study hypothesizes that the additional research motivated by the tax credit reduces the cost of the technology and the subsequent price at which the company sells its new product. Prior to the 2017 tax reform, they estimate higher consumer surplus in the form of lower prices amounted to 66.8 percent of the ASC's cost to the Treasury.

20. The White House and the Department of Treasury, The President's Framework for Business Tax Reform," (The White House February 2012), 12, https://www.treasury.gov/resource-center/tax-policy/tax-analysis/Documents/OTA-Report-Business-Tax-Reform-2012.pdf.

21. https://www.nber.org/papers/w25631

22. Luke A. Stewart, Jacek Warda, & Robert D. Atkinson, "We're #27!, 3. Joe Kennedy and Robert Atkinson, "Why Expanding the R&D Tax Credit Is Key to Successful Corporate Tax Reform," ITIF, July 2017, http://www2.itif.org/2017-rd-tax-credit.pdf. Bronwyn Hall and John Van Reenan, "How Effective Are Fiscal Incentives for R&D? A Review of the Evidence," Research Policy, 29, no. 4-5, (2000). Bronwyn H. Hall, "Effectiveness of Research and Experimental Tax Credits: Critical Literature Review and Research Design" (technical report, Office of Technology Assessment, Washington, D.C., 1995), 18 (italics in original) http://emlab.berkeley.edu/~bhhall/papers/BHH95%20OTArtax.pdf

23. https://www.tandfonline.com/doi/full/10.1080/0013791X.2017.1319001

24. Catherine Fazio, Jorge Guzman, & Scott Stern, "The Impact of State-Level R&D Tax Credits on the Quantity and Quality of Entrepreneurship," NBER Working Paper 23099, July 2019.

PRIORITY INNOVATION POLICIES

Technology-Neutral Innovation Tax Credit

Overview

Accelerating innovation in low-carbon technologies will make the transition to a net-zero energy system cheaper, faster, and more politically feasible. Policies that encourage the deployment of emerging technologies at scale are a key part of this process: as producers gain experience and information about new technologies, performance improvements and cost reductions should soon follow. But absent targeted public policies to promote early-stage deployment, producers often do not have incentive to develop or adopt new technologies, while consumers tend to shy away from using emerging products.

Clean energy tax incentives can help close this gap and spur the development and deployment of emerging technologies. They have bipartisan appeal and have been enacted by wide margins in Congress multiple times in recent decades. Most notably, federal production and investment tax credits have succeeded in promoting the development and deployment of wind and solar energy technology, which are now quickly gaining market share in the U.S. electricity sector.

Policymakers designing early-stage innovation tax credits should identify the critical applications of low-carbon energy systems and develop subsidies that harness market competition to support promising solutions for each application. These policies should be stable, since capricious changes chill the climate for private investment. Eligibility should decline as technologies are increasingly adopted in the marketplace.

Note that tax incentives may not always be an effective policy tool. For instance, for some applications in the agricultural sector, other fiscal incentives—including block grants and loan guarantees—may be more successful in driving market penetration for low-carbon technologies.

Also, tax incentives by themselves are insufficient to support clean energy technologies to their fullest potential. As part of a broader innovation strategy, they should accompany policies that promote the research, development and demonstration (RD&D) of emerging technologies. Tax incentives should also complement broad market incentives that encourage carbon-free energy, such as a price on carbon emissions. Finally, while politicians may prefer non-refundable tax credits, they are less efficient than either refundable tax credits or direct federal incentives to the private sector.

Policy principles include:

1. **Tailoring tax incentives** to encourage the development of critical applications for a decarbonized energy system.
2. **Making sure that only new, low-carbon, and effective technologies quality for tax incentives.**
3. **Rewarding technologies based on their performance** to keep government spending aligned with its objectives.
4. **Phasing out eligibility for tax incentives** as qualifying technologies mature.
5. **Making tax credits refundable** so developers do not need to have tax liability in order to receive them.
6. **Enhance stability and boost investor confidence** by leaving innovation tax credits in place permanently.

Legislative Principles and Policy Recommendations

1. Tailor tax incentives to encourage the development of critical applications for a decarbonized energy system.

Ideally, innovation tax incentives should be technology-neutral, since policymakers do not know in advance which technologies will best help achieve a carbon-free economy. On the other hand, they should not be neutral with respect to desirable outcomes. Scientists and policymakers *do* know what kinds of critical functions they need new technologies to meet, and so they should be able to tailor tax incentives to meet those challenges.

In fact, innovation tax credits can be applied to projects seeking to tackle each of the Five Grand Challenges. Policymakers should design tax incentives that harness market competition within categories tailored to the critical functions a deeply decarbonized power system will need. For example:

Electricity

One notable 2018 study on decarbonizing the electrical sector[1] divides energy resources into three categories:

1. *Variable renewable-energy resources,* or resources that harness renewable energy inputs that vary over time (like wind, solar photovoltaics, concentrating solar, and run-of-river hydro energy). These resources are typically characterized by low variable costs, including zero fuel costs.

1. Nestor A. Sepulveda, Jesse D. Jenkins, Fernando J. de Sisternes, & Richard K. Lester. The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation. Joule 2, 2403–2420, November 2018.

2. *Firm low-carbon energy resources,* or resources that can meet the demand for electricity at any time and for long durations. These resources include nuclear, geothermal, biomass, some hydro (with high capacity reservoirs), and fossil fuels combined with carbon capture technologies. Firm energy resources are most beneficial to carbon-free electricity systems in periods with low availability of variable energy resources.
3. *Fast-burst balancing resources,* or resources that can be used when relatively fast bursts of power or quick demand adjustments are needed to balance supply and demand (like batteries and demand response).

Policymakers can design early-stage deployment tax credits in the power sector that reward the development of all three energy resources: variable, firm, and fast-burst. For administrative reasons, demand-side resources may also need to be encouraged by separate policies (see below) to effectively make the fast-burst balancing resources category an incentive for energy-storage technologies.

Transportation

Policymakers can design tax incentives that can help commercialize new technologies and drive market penetration of electric vehicles and equipment, low-carbon fuels for all vehicles, and charging infrastructure. These transportation tax incentives should drive production of both the lowest-carbon vehicles and fuels and the long-term infrastructure needed to support these technologies as they become more widely adopted. Policymakers should focus on implementing tax incentives to:

1. *Drive penetration of electric vehicles and equipment.* Tax incentives should be inclusive of on-road and off-road vehicles and equipment for electrification from light- to heavy-duty categories.
2. *Shift to the lowest-carbon fuels.* Technology neutral incentives should drive demand in the lowest-carbon fuels including electricity, hydrogen, and advanced biofuels across vehicle applications including aviation and marine.
3. *Reduce demand for vehicle miles traveled.* Promoting supply-chain efficiencies and transit options can reduce vehicle miles and drive deep decarbonization.

Manufacturing

Policymakers should design tax incentives that encourage manufacturers and industrial facilities to reduce their carbon intensity. These incentives fall in four main categories:

1. *Low-carbon energy sources:* In the manufacturing sector, more than 75 percent of greenhouse gas (GHG) emissions result from the combustion of fossil fuels for processes like heating, steam generation, and hot water production. Tax incentives can reduce the cost of lower-carbon alternatives to traditional fossil fuels such as biofuels and electrofuels. They can also encourage the use of electricity with lower carbon intensity than the local grid mix (via onsite generation and power purchase agreements for zero-carbon electricity, for instance).

2. *Reductions in process emissions:* In addition to GHG emissions from fossil fuel combustion, the production of some materials generates process emissions in the chemical and/or physical transformation of raw materials. For instance, in the production of cement, the calcination process (in which limestone reacts with heat and produces lime and CO_2) generates substantial emissions. Tax incentives can encourage industries to adopt new processes that produce fewer or no emissions.
3. *Improvements in industrial efficiency:* In addition to using cleaner energy sources and reducing process emissions, manufacturers can significantly improve the efficiency of their processes and practices. Tax incentives can drive the adoption of emissions-reducing technologies that use less energy and/or raw material input to produce the same amount of a manufactured good.
4. *Capture of CO_2:* In some cases, the most cost-effective GHG reduction pathway may be the direct capture of CO_2 at manufacturing facilities. In these cases, an innovation tax credit can help drive greater deployment of these carbon capture technologies.

Buildings

1. *Low-carbon energy sources:* In the buildings sector, the majority of GHG emissions result from the combustion of fossil fuels for space heating. Tax incentives can reduce the cost of lower-carbon alternatives such as new heat-pump technologies and low-carbon fuels.
2. *Improvements in building efficiency:* As with the manufacturing sector, building heating and cooling systems can be made more efficient. Tax incentives can drive the adoption of technologies that reduce emissions by using less energy and/or fewer high-carbon materials, such as high-efficiency refrigerants and advanced envelope solutions.
3. *Low-carbon building materials:* Construction materials generate significant emissions. Some of these materials, such as steel and cement, involve heavy manufacturing and fall under that heading; however, the production of other low-carbon building materials like cross-laminated timber should likewise be eligible for tax incentives.

Agriculture

The agricultural sector is both a source and a sink of GHG emissions. It also requires different policy tools to motivate reductions that involve physical and biological processes. But policymakers can establish some tax incentives for technologies and programs that reduce agricultural emissions:

1. *Anaerobic digesters and technologies targeting enteric fermentation:* Agricultural facilities can reduce emissions of methane and nitrous oxides by controlling the way that manure decomposes with anaerobic digesters. Tax incentives are a proven pathway to help reduce the cost of this capital-intensive technology and, if appropriately structured, can drive innovation in digester technologies. The credit could also reward the use of biogas from these digesters for use in electricity generation or as a transportation fuel.

2. *Food-waste reduction technologies:* A host of early-stage technologies aimed at cutting food waste reduce the GHGs associated with the production and decomposition of food. Tax incentives can drive the market for these technologies and make them more viable economically. They should be based on a technology's demonstrated ability to reduce food waste.

To qualify for this tax credit, any technology should also be screened to ensure it is consistent with environmental justice principles, factoring in environmental outcomes beyond GHG reductions, safety considerations, and upstream GHG emissions.

2. Make sure that only new, low-carbon, and effective technologies quality for tax incentives.

Policymakers should establish clear guidelines for whether a technology is eligible for the tax credit. Eligible technologies must be new, low-carbon, and effective, and Congress should rely on the expertise within federal R&D agencies to define and enact these criteria. These experts could come from:

Electricity: A crosscutting initiative between the Department of Energy's (DOE's) Offices of Energy Efficiency and Renewable Energy (EERE), Fossil Energy, and Nuclear Energy.

Transportation: DOE Sustainable Transportation Technology offices, EERE.

Industry: DOE Advanced Manufacturing Office (AMO), EERE.

Buildings: DOE Building Technologies Office (BTO), EERE.

Agriculture: The U.S. Department of Agriculture (USDA) Office of Rural Development and the Environmental Protection Agency's (EPA's) AgStar program.

3. Reward technologies based on their performance to keep government spending aligned with its objectives.

The main goal of early-stage tax incentives is to boost the deployment of promising emerging technologies. To align the government's spending with this objective, technologies should be rewarded for performance where possible; if incentive payments are tied to spending levels or other metrics, they will only indirectly encourage the use of these technologies, which risks spending taxpayer dollars inefficiently. (Some technologies may benefit more from incentives tied to investment, but other policy mechanisms—like loan guarantees or demonstration projects—often work better in those cases.)

Electricity

Like the production tax credit (PTC) for wind and other technologies, tax incentives for variable and firm electricity resources can be awarded based on the energy they produce. Likewise, an investment tax credit (ITC) for storage technologies can encourage their adoption and expansion. These incentives should be generous enough to enable deployments that would not have occurred without the tax credits, but low enough to avoid spending taxpayer dollars unnecessarily. (DOE's programs mentioned earlier could help set and adjust these incentives.)

The Energy Sector Innovation Credit, proposed in 2020, provides one useful template. The initial level of the PTC for emerging technologies is equal to 60 percent of revenues from electricity sales (similar to the amount of the PTC for wind generation), while storage technologies are eligible for a 30 percent ITC.[2]

Transportation

To drive market penetration and spur widespread adoption of the lowest-carbon technologies, policymakers should allocate tax incentives for electric vehicles and low-carbon fuels based on output. These incentives should not have production caps, as these can penalize early entrants into the marketplace and reduce spillover benefits for those who follow them.

Consumers should also be able to take full advantage of tax incentives for electric vehicles and low-carbon fuels no matter their federal tax liability, and buyers should be able to carry forward tax incentives to receive the full benefit. The size of the tax incentive for electric vehicles and fuels should be enough to cover the price differential for advanced technologies but should decline over time as economics of scale grow and adoption becomes more widespread.

Tax incentives targeting infrastructure and efficient mobility can be awarded based on investment and production. In this case, investment incentives can also drive the deployment of charging infrastructure, supply-chain efficiencies, and low-carbon modes of transit. The Energy Policy Act of 2005 allocates tax incentives to promote alternative fuels and advanced vehicle production including federal cost sharing for infrastructure and vehicle costs.

Manufacturing

Tax incentives for industrial technologies should also be awarded based on their output rather than investment. In consultation with AMO, the Internal Revenue Service (IRS) should establish clear metrics of output for each industry (such as tons of steel produced) to which a production tax credit can be applied based on the relative reduction of carbon intensity compared to a baseline.

Buildings

Likewise, tax incentives for building technologies should be awarded based on output rather than investment. The IRS, in consultation with BTO, should establish clear metrics of output for building technologies.

Agriculture

Tax incentives have limited application for technologies in the agricultural sector. Where tax incentives do apply, whether they are applied to output or investment depends on the specifics of the technology or program. For technologies related to anerobic digestion and enteric fermentation, the tax incentive can be based on investment in emissions-reducing technology rather than an output metric. For technologies aimed at reducing food waste, too, the credit should apply on the basis of investment.

2. H.R.5523 - Energy Sector Innovation Credit Act of 2019. 116th Congress (2019-2020) https://www.congress.gov/bill/116th-congress/house-bill/5523/text

TABLE 1:

Summary Of Early-Stage Deployment Tax Incentives

SECTOR	CATEGORY	EXAMPLE	BASIS OF INCENTIVE	INITIAL INCENTIVE	INCENTIVE RECIPIENT	PHASE OUT CRITERIA
Electricity	Variable energy resources	Offshore wind	Energy production	Percentage of annual sales revenue	Generator (utility-scale or distributed)	Market share threshold
	Firm energy resources	Advanced nuclear				
	Storage	Flow batteries	Investment	Percentage of qualified investments	Installer of storage technology	Capacity limitation
Transportation	Electric vehicles and equipment	EVs	Production	Percentage of annual sales	Equipment manufacturer and equipment purchaser	Market share threshold
	Low-carbon fuels	Advanced biofuels	Production and investment		Fuel producer and fuel purchaser	
	Reduce vehicle miles traveled	Charging infrastructure	Investment	Percentage of qualified investments	Firm/individual that installs infrastructure	
Manufacturing	Low-carbon fuels	Hydrogen refined steel	Production of manufactured good	Per-unit credit, scaled on the basis of reduction in emissions intensity over baseline	Industrial firm	Market share threshold
	Process emission reductions	Alternative binding materials for cement				
	Efficiency	Highly recycled building materials				
Buildings	Low-carbon energy	Integrated heat pumps	Production of manufactured good	Per-unit credit, scaled on the basis of reduction in emissions intensity over baseline	Manufacturer	Market share threshold
	Efficiency	Ceramic aerogels				
	Building materials	Cross-laminated timber				
Agriculture	Anaerobic digesters	—	Investment	Percentage of qualified investments	Digester purchaser	Market share threshold

4. Phase out eligibility for tax incentives as qualifying technologies mature.

Innovation tax incentives enable new clean technologies to compete on a level playing field with incumbents. As a new technology matures, this rationale for the policy gradually disappears. For more mature technologies, broader incentives that reward any carbon-free resources (such as carbon prices) are enough to ensure a level playing field for low-carbon options.

Phasing out the tax incentives as technologies mature also enables even newer technologies to emerge, thus avoiding "lock in" of the initially subsidized generation of technologies. In addition, this limits the costs of the incentive: as long as the market penetration of subsidized technologies is relatively low, total expenditures on the subsidy will be relatively small.

Innovation tax incentives should therefore include clear guidelines for phasing out the incentives for any eligible technology. For example, policymakers could make eligibility contingent on market share. In any case, to provide policy certainty, the legislation should include a uniform phase-out schedule across all technologies that avoids "cliffs" in which incentives disappear suddenly.

The framework proposed in the Energy Sector Innovation Credit Act in January 2020 provides a useful template. In that proposal, eligibility for tax credits depends on the percentage of annual domestic electricity produced by a given technology in the previous year. A technology is eligible for the full tax incentive until it achieves a market share of 0.5 percent, beyond which the technology receives a progressively lower tax incentive until it becomes ineligible for the incentive when it reaches 2 percent market share. Technologies are eligible for a maximum of ten years.

The Energy Sector Innovation Credit Act also provides a template for a storage innovation tax credit. The storage incentive is constrained by a national capacity limitation of 10,000 megawatts, with some discretion left for federal agencies to allocate the incentive among a diverse set of technologies. Alternatively, capacity limits could be set for each technology that qualifies for the storage incentive.

5. Make the tax credits refundable so developers do not have to have tax liability to receive them.

Historically, only companies or organizations with tax liability have been able to directly benefit from clean-electricity tax incentives in the United States. In practice, this has forced developers without tax liability to partner with third-party tax equity investors in order to receive the subsidy. These middlemen take a portion of the money, effectively lowering the incentive for the project developers.

Cutting out these tax-equity middlemen would enable a more effective subsidy per dollar of government spending. This could be accomplished by making the tax credits refundable, which means the tax credits would have value regardless of tax liability.

6. Enhance stability and boost investor confidence by leaving innovation tax credits in place permanently.

Policymakers should strive for policy stability, avoiding abrupt changes that can reduce investor confidence. Indeed, uncertainty over whether incentives would be renewed has limited the success of prior tax incentives. In particular, the PTC either expired or nearly expired several times in recent decades, causing booms and busts in wind project construction.

To avoid this, the legislation should put the tax incentive in place in perpetuity. While the policy details may need to be adjusted occasionally, those changes should be gradual and announced well in advance. That way, as technology developers and investors are weighing new opportunities, they will have confidence that the incentives will still exist when their technologies are entering the marketplace.

The Impact of Innovation Tax Credits

The impacts of innovation tax incentives, like other innovation policies, cannot be estimated with a meaningful degree of precision. In general, though, strong evidence suggests that innovation incentives are a critical piece of a broader strategy to unlock the economic and emissions benefits of low-carbon innovation.

For example, Stanford's Energy Modeling Forum 24 model intercomparison study (EMF 24) brought together nine energy-modeling groups to examine a range of questions related to the decarbonization of the energy system in the U.S.[3] The 2014 study found the costs of achieving 50 percent emission reductions are about twice as high with pessimistic technology-cost assumptions than with optimistic assumptions. Put another way, innovation tax credits that help make newer technologies more affordable and more widespread will greatly reduce the overall cost of decarbonization. Similarly, experts at DOE published a study in 2017 analyzing technology and policy decarbonization pathways in the U.S. With a constant $20 per metric ton carbon price in place, projected emissions reductions in 2040 were over twice as large in a scenario where each DOE clean energy program was assumed to achieve its technology goals, compared to a base scenario with little assumed innovation.[4]

Looking at historical experience, some tax credits have clearly successfully contributed to accelerating the deployment of clean-electricity technologies. Most notably, the renewable electricity PTC and ITC have helped to spur the growth in wind and solar-power facilities respectively. Installed wind capacity grew from under 20 GW in 2007 to nearly 100 GW in 2018,[5] while solar capacity grew from virtually zero to over 60 GW over the same period.[6, 7] Combined, solar and wind generated about 8 percent of US electricity in 2018, up from 0.8 percent in 2007.[8] Various other policy drivers have supported renewable energy, but, even controlling for other causes, various studies have concluded that the PTC and ITC have substantially contributed to the growth of wind and solar.[9]

3. https://web.stanford.edu/group/emf-research/docs/emf24/EMF_24.pdf

4. United States Department of Energy. "Energy CO2 Emissions Impacts of Clean Energy Technology Innovation and Policy." January 2017. https://www.energy.gov/sites/prod/files/2017/01/f34/Energy%20CO2%20Emissions%20Impacts%20of%20Clean%20Energy%20Technology%20Innovation%20and%20Policy.pdf

5. U.S. Energy Information Administration. Electric Power Monthly. https://www.eia.gov/electricity/monthly/

6. Ryan Wiser & Mark Bolinger, Lawrence Berkeley National Laboratory. U.S. Department of Energy. "2017 Wind Technologies Market Report: Summary." August 2018. https://emp.lbl.gov/sites/default/files/2017_wtmr_briefing.pdf

7. Solar Energy Industries Association. "U.S. Solar Market Insights." March 2019. https://www.seia.org/us-solar-market-insight

8. U.S. Energy Information Administration. Electric Power Monthly. https://www.eia.gov/electricity/monthly/

9. Gilbert E. Metcalf, "Investment in Energy Infrastructure and the Tax Code," Tax Policy and the Economy 24 (2010): 1-34. https://doi.org/10.1086/649826. Claudia Hitaj. "Wind power development in the United States." Journal of Environmental Economics and Management, 2013, vol. 65, issue 3, 394-410. https://econpapers.repec.org/article/eeejeeman/v_3a65_3ay_3a2013_3ai_3a3_3ap_3a394-410.htm

However, other early-stage deployment tax credits have been less successful. For example, since 2005, new nuclear reactors have been eligible for a PTC of 1.8 cents per kilowatt-hour, but no nuclear reactor has yet been built that qualifies for the incentive.

The success of early-stage tax credits also depends on their costs. As the deployment of solar and wind power has risen, so too has the cost of the PTC and ITC: in 2018, they cost the federal government over $5 billion.[10] Phasing out the tax incentives as technologies mature will help constrain the costs of these policies.

10. U.S. Department of the Treasury. Office of Tax Analysis. "Tax Expenditures." October 2017. https://www.treasury.gov/resource-center/tax-policy/documents/tax-expenditures-fy2019.pdf

PRIORITY INNOVATION POLICIES

Project Financing

Overview

Financing is a major barrier for low-carbon energy or industrial projects. Many major industries in which carbon-emission reductions are important—because of the large volumes, available scale economies, and large amounts of CO_2 they produce—are also highly cost sensitive, risk averse, competitive, and capital intensive. Government support for decarbonization technologies can reduce the costs and risks to developers, encouraging further innovation. Federal support should prioritize projects in low-income and historically disadvantaged communities where funding has traditionally lagged.

The playbook sections on Demonstrating and Validating New Technologies and Research and Development Tax Credits explained how the public sector can support new decarbonization technologies as they move from the laboratory bench to initial commercial deployment (also known as First-of-a-Kind, or FOAK.) In order to bring innovations to maturity and achieve industry-wide acceptance, however, developers must often build several more iterations at commercial scale (sometimes known as Nth-of-a-Kind or NOAK, with N usually in the range of 2 to 5). Each iteration in the NOAK phase brings the technology closer to the point when firms are willing to offer normal, competitively priced contracts to engineer, procure, and construct (EPC) decarbonization projects, with financial institutions offering normal debt and equity financing terms to pay for the products. The public element of the public-private partnership becomes increasingly smaller and less intrusive. Beyond NOAK, the goal of project finance policy should be to drive the cost of a decarbonizing technology down by quickly raising production volumes. The key problem at this stage is to incentivize multiple manufacturers, well-established supply chains, and a thriving industry of contractors to become ready to install the technology. That means designing efficient, effective, broad-based incentives and subsidies that will spark widespread deployment while minimizing bureaucratic delays. (See the playbook section on innovation tax credits.)

Financing Challenges and Financial Market Participants

Any large-scale, low-carbon project must find funding. That funding is comprised of two basic types: debt and equity. Debt means either loans directly from bank or government lenders or bonds purchased and traded by pension funds, insurance companies, or bond funds. "Equity" is a term synonymous with ownership, including interests in a partnership or shares of stock in a corporation.

Debt is cheaper than equity, because debt outranks equity in terms of claims on a project's cash flows and assets. The first and highest priority claims are operating expenses: payments to suppliers, workers, insurers, repairmen, and tax authorities. Debt is second in line and equity is third. Moreover, if lenders are not paid interest and principal on time and as agreed, lenders can force the company into bankruptcy; and in bankruptcy, lenders usually have documented claims on specific assets such as mortgages on real property and liens on personal property (such as equipment). Equity is thus more expensive because owners are paid last, are not paid on any agreed schedule, and have no special rights if they are unhappy with the cash distributed to them—other than perhaps being able to fire project managers. Equity holders simply hope that they ultimately will get back their original investment amount plus some additional profits.

Risky projects that fail hurt lenders and equity owners, no matter whether projects are financed on a standalone basis or "on-balance sheet." Sometimes projects raise debt and equity on a standalone basis through the specialized project financing market. ("Project financing" simply means that lenders and equity solely rely on the success of the project itself, without having recourse to guarantees from any other source.) Alternatively, sometimes projects are funded via an internal allocation of funds in a large corporation, and in such a case it is said that the project has been "funded on the corporation's balance sheet." However, if a project is funded on-balance sheet, debt and equity still have to be paid: if the project is a disaster, the stockholders of the corporation will be hurt; and if the project is a big enough disaster, the corporation's lenders will be hurt as well. Thus, whether a low-carbon project is project financed or balance-sheet financed, it must meet certain threshold investment quality standards to be funded.

The objective of project-finance policy for decarbonization technologies is to reduce costs and risks so that either approach to funding is straightforward and inexpensive.

Policy interventions include:

1. **Extending cost-sharing grant programs** beyond FOAK to NOAK projects and allowing such projects to access publicly-subsidized or guaranteed loan programs as well.
2. **Giving decarbonized-energy projects access to the tax-exempt private activity bond market.**
3. **Giving decarbonized-energy projects better access to equity markets.**
4. **Establishing a Clean Energy Deployment Administration (CEDA)** with the authority and funding to mix grants, loans, and other tools to promote full successful commercial deployment of decarbonization technologies.

Legislative Principles and Policy Recommendations

1. Extend cost-sharing grant programs beyond FOAK to NOAK projects and allow such projects to access publicly subsidized or guaranteed loan programs as well.

Federal cost-sharing grant programs frequently boost FOAK projects. NOAK projects have not been eligible for such grants because these grants are not supposed to support "commercial technology"—and the legal definition of this term that grant program managers use has been so broad that any technology that has been demonstrated once qualifies. This definition often clashes with the perceptions of market participants, because FOAK projects rarely convince contractors, financiers, and prospective customers to build NOAK projects on fully commercial terms. Without follow-on funding, a FOAK project may turn out to be a one-off science experiment with no confirming studies.

Cost-sharing grants are imperative in many cases to get NOAK projects built and launch technologies into the market for real. Congress should remove legislative language that excludes NOAK projects and clarify its intent to the implementing agencies.

At the same time, federal rules forbid project developers who receive cost-sharing grants from also getting access to low-cost, long-term federal loans. They must choose between the two financial instruments—even though they complement one another and combining the two can be very helpful. Even generous grants usually cover only part of the project cost. The higher risk of NOAK projects compared to conventional projects may saddle them with lending terms that are so unattractive that the project cannot move forward. For instance, rather than 20- to 30-year fixed rate debt funding, a NOAK project may only be able to obtain relatively short-term, floating rate bank financing (such as a 5- to 10-year "mini-perm" loan). Such onerous borrowing structures make them uncompetitive in the energy marketplace.

Via the Federal Financing Bank, the Department of Energy's (DOE's) Loan Program Office (LPO) offers long-term fixed-rate debt at a low borrowing margin above U.S. Treasury bond rates. The LPO will typically also allow a higher proportion of debt in the capital structure than private markets will. That attractive debt funding can narrow the gap between NOAK projects and its higher-emitting competitors.[1] However, Congress can make the LPO's offerings more attractive and user friendly through various reforms, including by eliminating the prohibition of loans to a project that has received some other form of federal assistance, such as a cost-sharing grant.

2. Give decarbonized-energy projects access to the tax-exempt private activity bond market.

Tax-exempt bonds allow projects to be financed at a lower cost than market-rate bonds. Congress has previously authorized their use for privately owned or used projects such as landfills, recycling facilities, hazardous-waste facilities, industrial wastewater treatment, etc. that have significant public benefits. These types of bonds are distinguished from those issued to finance projects such as schools, firehouses, and sewers that are owned by the government, so they are called private activity bonds (PABs).

Congress could accelerate deployment of decarbonization technologies by giving them access to the tax-exempt PAB market under Section 142 of the tax code.

This change would be permanent, providing substantial security to technology developers.[2] It would also leave decisions about a project's commercial merits to rating agencies, investment banks, and investors, who are best positioned to assess them and thus acts as a broad-based incentive policy.

3. Give decarbonized energy projects better access to equity markets.

Most decarbonized energy projects are structured for U.S. income tax purposes as so-called flow-through vehicles: partnerships or limited liability companies (LLCs) that do not pay taxes directly. Instead, these entities pass any taxable profits, deductions, and credits to their owners, which are solely responsible for the tax liability. The alternative is to create a corporate structure. Corporations can be listed on a public stock exchange, giving them access to a key source of low-cost equity funding. Corporate stock is liquid as well: investors can easily buy and sell their shares. Corporations, however, are effectively taxed twice: first on its corporate income, second as personal income tax paid by its shareholders on any dividends they receive.

Project financers therefore typically face a choice between tax-efficiency on the one hand and deep, liquid capital on the other. However, some industries, particularly those in natural resource sectors such as oil and gas, are not faced with that choice. Congress has designated them to be eligible for the master limited partnership (MLP) form of organization, which combines the most attractive characteristics of the flow-through vehicle and corporation forms.[3] If low-carbon electricity generation and industrial processes were added to the list of "qualifying income" types, they could be structured as partnerships (avoiding double taxation) and still access public stock markets. This would have a meaningful benefit in lowering equity cost of capital.

1. See 10 CFR § 609.2 (a) - Definitions and interpretations.

2. Permanent in the sense that, unless Congress takes affirmative action to remove the clause in Section 142(a) that names the favored project type, access to tax-exempt debt continues. Further, if Congress removes access to new tax-exempt borrowing in a year (say 2035), bonds validly issued before 2035 are unaffected and are typically allowed to refinance in the tax-exempt market for the life of the equipment.

3. 26 USC 7704. See related IRS regulations for the 90% test.

4. Establish a Clean Energy Deployment Administration with the authority and resources to create financing packages in collaboration with the private sector for NOAK projects.

To provide expert management and oversight of complex federal clean energy project financing policies, the federal government should establish a Clean Energy Deployment Administration (CEDA). First suggested in 2009, when it won bipartisan support in Congress, CEDA would absorb the current capabilities and responsibilities of the DOE LPO and be given additional authority to accelerate large-scale, complex decarbonization technologies.

CEDA would be an independent agency within DOE. Its personnel rules and salary structure would be competitive with private industry, so that it could attract experienced financial, engineering, and commercial experts. It would be funded with a large upfront appropriation on the order of $10 billion and have access to a variety of direct and indirect financial tools. In addition, all fees, interest, loan repayments, return of equity capital, and capital gains accrued by CEDA would be "continuously appropriated" for reinvestment. This structure would give CEDA substantial flexibility to select projects and manage its portfolio based on results.[4]

In order for CEDA to build creative packages that blend public and private financing for NOAK (or even FOAK) projects, Congress would need to free it from the restrictions that currently limit LPO to technologies that are currently commercially viable as well as restrictions (described above) that forbid combining public grants and loan support for individual projects.[5] Legislators would also have to accept that CEDA would require a steady stream of new funding for NOAK projects, so that it could absorb risks that the private sector is unwilling to take. Otherwise, CEDA would have strong incentives to maintain its capital base by avoiding risky projects.

4. "Continuously appropriated" has a specific legal meaning here, which is that a federal "administration" does not have to hand over its receipts to the U.S. Treasury, and instead retains its receipts to pay for current operations and investments.

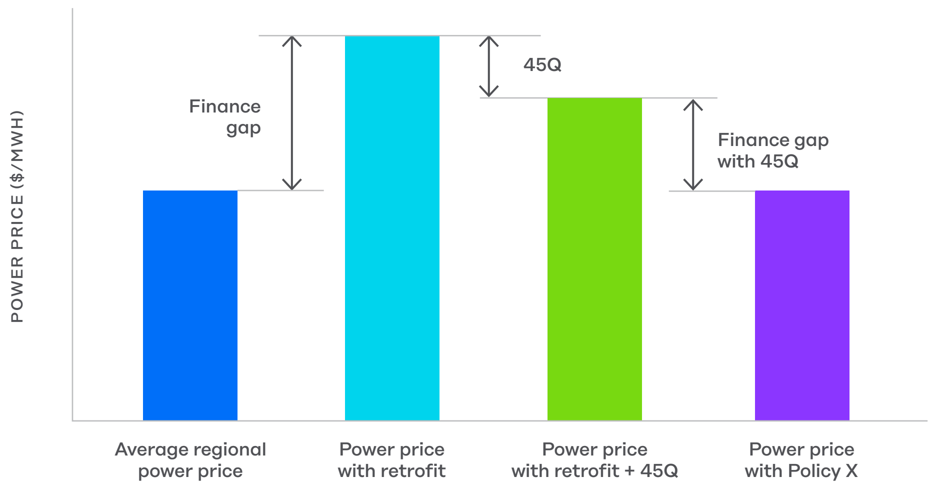
Several federal administrations are operated this way, with a relevant example being the Bonneville Power Administration, which runs the Pacific Northwest's transmission system and markets power generated by local Corps of Engineers and Bureau of Reclamation dams. See 16 U.S. Code § 838i.Bonneville Power Administration fund. https://www.law.cornell.edu/uscode/text/16/838i

5. See changed definition of "Commercial Technology" at Section 103(b) of S.1462 as it amends the definition of the EPA Act of 2005 at 1701(1). (https://www.energy.gov/sites/prod/files/2017/11/f46/Aggregate%20ROI%20impact%20for%20EERE%20RD%20-%2010-31-17%20%28002%29%20-%2011-17%20%28optimized%29.pdf)

The Impact of Project Financing

The impact of project financing policies will differ by technology. For example, the Columbia University report [Capturing Investment: Policy Design to Finance CCUS Projects in the U.S. Power Sector] outlines the impact of financing policies for carbon capture. The figure[6] below shows the financing gap for power plants with carbon capture retrofits. Financing for a power plant is feasible when selling at average regional electricity prices, but to install carbon capture equipment means that a project would need higher electricity prices to survive financially. This creates a financing gap. The financing gap is somewhat mitigated in this case by existing tax incentives for carbon capture under section 45Q, which provides $35–$50 per metric ton of CO_2 captured and geologically stored. Even with 45Q, there is still a remaining financing gap, and additional policies are required to achieve cost parity with average power prices.

Finance Gap Associated With A Power Plant CCUS Project



Note: For any given project, higher power prices are needed to generate the revenues needed for profitability.

Source: Julio Friedmann, Emeka Ochu, and Jeffrey D. Brown. Capturing Investment: Policy Design to Finance CCUS Projects in the U.S. Power Sector. Columbia University SIPA Center on Global Energy Policy. April 2020.

6. Average regional electricity prices at "X" per megawatt-hour in a competitive electricity market (first bar). If a power plant installs carbon capture and has no incentive, it would need to charge a price of "Y" to cover all variable and fixed operating costs, fuel cost, debt service payments, income tax, and equity returns. With 45Q incentives, the power plant with carbon capture can cut its power price somewhat (with the 45Q incentive value replacing some cash revenue from electricity sales) and only needs to charge "Z." Nonetheless a gap remains; without some additional incentive, the carbon capture project will founder. It can't raise power prices in a competitive market: It will be undercut. It can't charge a competitive power rate because equity investors will be shortchanged von their returns.

Government-funded cost-share grant programs are often most impactful in accelerating investment for emerging climate technologies. Other interventions—such as tax credits, PABs, and MLP structure—can improve attractiveness for private investment. The table below outlines the impact of several approaches for a natural gas combined cycle power plant with carbon capture retrofit.

Estimated Power Prices Needed For Financial Visibility Of Different Power Plants Using Different Policies

INCENTIVE	ELECTRICITY RATE ($/MWH)	EFFORT OF POLICY ($/MWH)	ASSUMPTIONS
Unabated NGCC	$43.70	—	—
CCUS witn no Incentive	$62.27	—	—
CCUS with 45Q only	$52.11	**$10.16**	$50
PTC (Without 45Q)	$44.36	$17.91	$24
ITC (Without 45Q)	$58.95	$3.32	30%
ITC (With 45Q)	$48.79	$13.48	30%
PAB (Without 45Q)	$62.86	$(0.59)	3.2%
PAB (With 45Q)	$52.71	$9.56	3.2%
MLP (Without 45Q)	$61.24	$1.03	4.0%
MLP (WitH 45Q)	$51.08	$11.19	4.0%

Source: Julio Friedmann, Emeka Ochu, and Jeffrey D. Brown. Capturing Investment: Policy Design to Finance CCUS Projects in the U.S. Power Sector. Columbia University SIPA Center on Global Energy Policy. April 2020.

PRIORITY INNOVATION POLICIES

Carbon Pricing

Overview

A price on carbon is a fee on each ton of carbon dioxide emissions that those responsible for the emissions pay for the damages they cause. The price aligns the decisions of producers, consumers, and investors with the country's emissions goals.

A carbon price is unique because it encourages emissions reductions wherever and however they can be achieved at a low cost, without needing to know beforehand what those opportunities will be. Specifically, the policy creates a financial incentive to take advantage of any opportunity to reduce emissions that costs less than the carbon price. In contrast, policies will be more costly if they dictate that emissions reductions must occur from specific sources, sectors, or technologies.

Implementing an economy-wide price on carbon is therefore critical to minimizing the overall costs of achieving net-zero emissions by 2050. Lower costs reduce the burden on all Americans and should enable emissions reductions at a more rapid pace. Carbon pricing policies have faced opposition from environmental justice advocates concerned that the policies are regressive and do not provide direct environmental or economic benefits to historically disadvantaged communities located near polluting facilities. In addition to achieving low-cost reductions and ensuring affordability, carbon pricing must address these concerns and include requirements for on-site greenhouse gas (GHG) and local co-pollutant reductions.

In sum, a carbon price would reduce emissions rapidly and dramatically in the near-term and accelerate private sector innovation in low-carbon technologies that will drive low-cost emissions reductions in the long-term. The carbon price can be an effective and efficient backbone of a broader climate strategy, and it can be designed to promote climate equity and align the U.S.'s portfolio of climate policies with its emissions targets.

Policy principles include:

1. **Establishing an economy-wide price on carbon.**
2. **Linking carbon prices to national emissions targets and outcomes.**
3. **Applying carbon pricing to as many sources of emissions as possible.**
4. **Providing direct economic and environmental benefit to historically disadvantaged communities.**
5. **Minimizing the number of entities that pay the fee.**
6. **Adopting measures to keep domestic industries on a level playing field** with foreign competitors.
7. **Using revenue from a carbon fee to protect those who cannot afford price increases** and to improve economic opportunity in fossil-dependent communities.
8. **Surrounding a carbon fee with other policies for achieving emissions reductions quickly** and cheaply.
9. **Encouraging increased sequestration of carbon dioxide (CO_2) emissions.**

Legislative Principles and Policy Recommendations

1. Establish an economy-wide price on carbon.

Implementing a well-designed carbon-pricing policy is far more important than the specific form that policy takes. Carbon fees, for example, would directly establish a price on carbon in dollars per ton of emissions. A price on carbon can also be implemented via cap-and-trade programs, which limit the total quantity of emissions per year. This limit is enforced using tradable emissions permits that any emissions source must own to cover its emissions. In a cap-and-trade program, the ensuing market for buying and selling these allowances creates the carbon price.

A carbon fee stabilizes prices so energy producers and entrepreneurs can make investment decisions without fear of unexpected changes to regulatory costs. In addition, because a carbon fee increases the cost of polluting, it can encourage more substantial reductions in emissions if emissions reductions are cheaper than expected. Cap-and-trade, on the other hand, does not encourage emissions reductions beyond the original targets. The main advantage of cap-and-trade programs is that, by setting an emissions cap that declines over time, they make it more likely that predetermined emissions targets will be achieved.

Policymakers need not choose between carbon-fee or cap-and-trade programs. Instead, they can design a hybrid policy that combines the benefits of both.

Making a carbon fee contingent on emissions outcomes retains nearly all the benefits of a pure carbon fee (like simplicity and regulatory certainty) while also increasing the likelihood that emissions targets will be achieved.

Another approach to a hybrid carbon-pricing policy is to limit uncertainty by adding “price floors” and “price ceilings” to a cap-and-trade program. Such policies can also make the number of tradable emissions permits contingent on the carbon-price levels. Some state-level policies in the United States (California and the Regional Greenhouse Gas Initiative) already offer variants of this approach.

2. Link carbon prices to national emissions targets and outcomes.

A carbon price should be designed to be consistent with nationwide emissions targets, from near-term goals to total decarbonization by 2050.

Regulators can estimate a carbon fee consistent with emissions targets using detailed models that translate CO_2 prices into changes in market prices across the economy, then project how producers and consumers will shift to less carbon-intensive actions in response to those price changes. Similarly, these models can be used to estimate the CO_2 prices required to reduce emissions on a desired pathway under a given set of assumptions about future technologies, prices, behavior, and policies. Such models are built using historical data, which can be a useful proxy for near-term projections because energy technologies and consumer behavior evolve relatively slowly. (Of course, they become less useful as the time horizon of the exercise lengthens because changes in technologies, consumer preferences, and policies will inevitably impact energy systems in unexpected ways.)[1]

Figure 1 below shows the results of a recent study that estimated the federal CO_2 prices needed, alongside a broader climate policy strategy, to put the United States on a pathway consistent with net-zero CO_2 emissions targets in 2060, 2050, and 2040. The study’s benchmark scenario shows that reaching a 2050 net-zero target requires CO_2 prices of $52 per metric ton in 2025 and $98 per metric ton in 2030. Across sensitivity scenarios, it shows the 2050 net-zero target requires CO_2 prices of $34 to $64 per metric ton in 2025 and $77 to $124 per metric ton in 2030, which are within the range of the existing carbon fee proposals to the U.S. Congress.[2]

Other possible approaches for setting CO_2 prices are less compelling. For example, in theory, carbon prices can be set based on estimates of the damages caused by emissions: the social cost of carbon, in other words. However, estimates of the social cost of carbon are often too imprecise to be useful in the context of setting carbon prices, ranging from under $0 to over $1000/ton.[3] Moreover, when a carbon fee is set to equal to a specific estimate of the social cost of carbon, the policy is unlikely to be aligned with domestic or international climate goals.

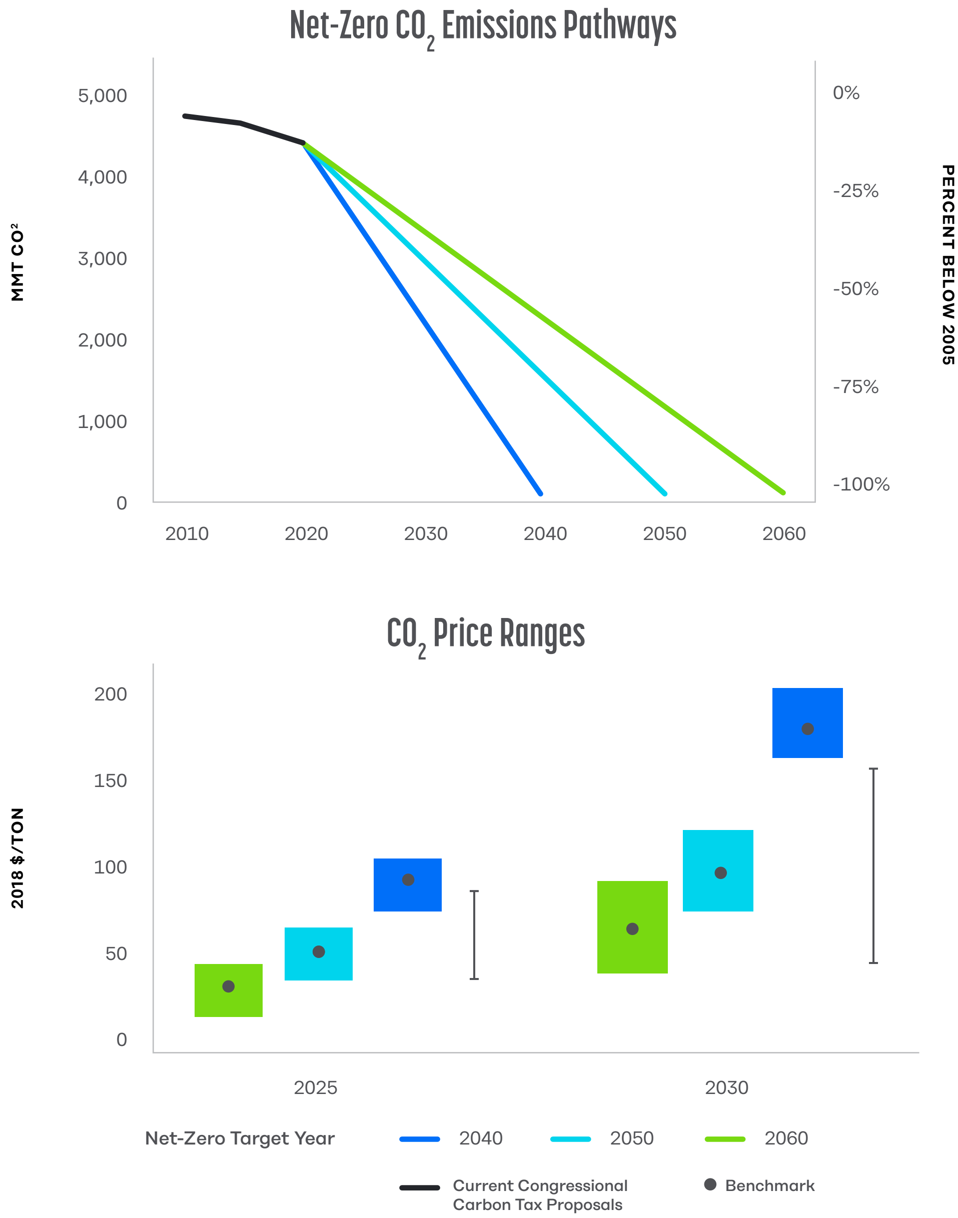
1. Macfarland et al. 2018.

2. Noah Kaufman, Alex Barron, Wojciech Krawczyk, Peter Marsters, & Haewon McJeon. A near-term to net zero alternative to the social cost of carbon for setting carbon prices. Nature Climate Change Volume 10, 17 August 2020, Pages 110-101.

3. Pei Wang, Xiangzheng Deng, Huimin Zhoue, & Shangkun Yue. Estimates of the social cost of carbon: A review based on meta-analysis. Journal of Cleaner Production Volume 209, 1 February 2019, Pages 1494–1507.

FIG. 01

U.S. Federal Co_2 Prices Consistent With Net-Zero Co_2 Targets



Source: Noah Kaufman, Alex Barron, Wojciech Krawczyk, Peter Marsters, Haewon McJeon. A near-term to net zero alternative to the social cost of carbon for setting carbon prices. Nature Climate Change Volume 10, 17 August 2020, Pages 110-1014.

At the same time, policymakers should design a mechanism that ramps up its stringency if the emissions covered by the carbon price do not decrease at the minimum pace stipulated in the legislation. The legislation should include annual emissions targets that chart a pathway to net-zero emissions in 2050. If these emissions targets are missed, future annual increases in carbon fees should become $5 per metric ton larger than originally scheduled until the targets are met again.[4]

4. Kaufman N, Larsen J, Marsters P, Kolus H & Mohan S. "An Assessment of the Energy Innovation and Carbon Dividend Act." Columbia University Center on Global Energy Policy. November 2019. https://energypolicy.columbia.edu/sites/default/files/file-uploads/EICDA_CGEP-Report.pdf

3. Apply carbon pricing to as many sources of emissions as possible.

A large majority of GHG emissions can be covered by a carbon fee with relative ease—including nearly all CO_2 emissions from energy use, which make up about 80 percent of U.S. emissions.[5] That includes nearly all emissions from coal, petroleum fuels, and natural gas produced in, or imported into, the U.S. based on the CO_2 emissions released during the fuel's combustion. A carbon fee can also cover facilities that emit greenhouse gas emissions while manufacturing products like metals, petrochemicals, and cement.[6]

In theory, it would be best if all sources of greenhouse gas emissions were covered by a national carbon fee, because a broader policy scope enables more low-cost emissions reduction opportunities and thus larger and cheaper emissions reductions. However, for certain categories of emissions, the administrative burdens associated with carbon pricing may be sufficiently large that alternative forms of regulation are preferred. These may include methane and nitrous oxide emissions from agriculture and livestock or methane leaks from fossil fuel systems.

4. Provide direct economic and environmental benefit to historically disadvantaged communities.

Carbon pricing policies have faced opposition from environmental justice advocates who worry that the lowest-cost emissions reductions are often not achieved in frontline communities and communities of color, where abatement costs may be higher. Carbon pricing designed to require on-site GHG and local air pollutant reductions can ensure that historically disadvantaged communities see direct environmental benefits. Likewise, policies that return carbon pricing revenue to be invested in these communities can provide direct economic benefits through increased employment opportunities in low-carbon energy and manufacturing.

5. Minimize the number of entities that pay the fee.

To minimize administrative burden, the number of entities that physically pay the fee should be kept as small as possible (contingent on covering as large of a portion of emissions as administratively feasible). That means finding "choke points" in the supply chains of carbon-intensive fuels and products. For example, coal can be priced at the mine mouth, petroleum products at the refinery exit, and natural gas at the exit from the gas processing plant. Imported fossil fuels could be priced where they first enter the United States. Fortunately, mechanisms are largely in place already to quantify emissions at such facilities.

5. U.S. EPA. 2019. "Inventory of U.S. Greenhouse Gas Emissions and Sinks." Washington, DC: U.S. EPA.

6. Joseph Majkut and David Bookbinder. The MARKET CHOICE Act: A Legislative Analysis from the Niskanen Center. Niskanen Center Policy Brief. July 2018. https://www.niskanencenter.org/wp-content/uploads/old_uploads/2018/07/NC-Brief-MARKET-CHOICE-Act-1.pdf

6. Adopt measures to keep domestic industries on a level playing field with foreign competitors.

An economy-wide climate policy raises concerns about the competitiveness of domestic companies compared to foreign companies whose products are not regulated comparably. A poorly designed climate fee could cause U.S. businesses to lose market share or flee the country, risking economic harm and emissions "leakage" (emissions sources relocating abroad).

Fortunately, there are multiple ways to avoid these adverse outcomes. The approach included in all eight carbon prices proposed in the U.S. Congress in 2019 is a border carbon adjustment (BCA). Under a BCA, policymakers define a set of industries that are most at risk based on their energy intensity and trade exposure (steel and cement, for example), require importers of these products to pay a fee, and provide rebates to exporters of the same products. This way, the United States can implement its carbon fee in the global marketplace.[8]

However, U.S. businesses do not need protection from foreign competitors that face comparable climate policies. International agreements could create zones that are exempt from import fees. The European Union and Canada are two of the three largest trading partners of the United States, and they are well ahead of the United States in terms of the stringency of their climate policies, so international agreements could exempt them from import fees.

7. Use revenue from a carbon fee productively, including to protect those who cannot afford price increases and to improve economic opportunity in fossil-dependent communities.

A carbon fee would produce a large new source of government revenue. For example, some federal proposals would generate about $70 billion in revenue when a carbon fee is relatively low, and more than $400 billion later on, when a carbon fee is higher.[9] Other proposals suggest additional government spending on infrastructure, clean energy innovation, or a host of other priorities for public spending. Revenue from a carbon fee may also be used in ways that create visible benefits to constituents that improve the political prospects of legislation, such as reducing "distortionary" taxes (those that discourage work or investments, such as payroll or income taxes) or the federal deficit, or sending equal "carbon dividend" payments to all Americans.

Three revenue uses are worthy of special consideration. First, the revenue from a carbon fee should protect those who cannot afford price increases. Many Americans who have trouble paying energy bills or maintaining adequate heating or cooling services cannot afford to pay more for those services. Unlike many other climate and energy policies, a carbon fee can counteract the impacts of increased energy costs. For example, using 10 percent of the revenue from a carbon price for equal carbon dividends to households in the bottom 20 percent of the income distribution can ensure the payments to these households are larger than the payments of the carbon price from these households.[10]

8. Noah Kaufman, Ph.D. Testimony Subcommittee on Environment & Climate Change of the Committee on Energy & Commerce, United States House of Representatives, 116th Congress. December 2019. https://energycommerce.house.gov/sites/democrats.energycommerce.house.gov/files/documents/Witness%20Testimony_12.05.19_Kaufman.pdf

9. Kaufman N, Larsen J, Marsters P, Kolus H & Mohan S. "An Assessment of the Energy Innovation and Carbon Dividend Act." Columbia University Center on Global Energy Policy. November 2019. https://energypolicy.columbia.edu/sites/default/files/file-uploads/EICDA_CGEP-Report.pdf

10. See page 4 of: Caron J, Cole J, Goettle J, Onda C, McFarland J, & Woollacott J. 2018. "Distributional implications of a national CO2 tax in the U.S. across income classes and regions: A multi-model overview." Climate Change Economics, 9(1), 1840004. Also, see page 15 of: Kaufman N, Larsen J, Mohan S, Herndon W, Marsters P, Diamond J, & Zodrow G. "Emissions, Energy, and Economic Implications of the Curbelo Carbon Tax Proposal." Columbia University Center on Global Energy Policy. Working Paper. July 2018. https://energypolicy.columbia.edu/sites/default/files/pictures/CGEP_CurbeloCarbonTaxBillAnalysis_0.pdf

Second, carbon fee revenue should be used to improve economic opportunities in communities whose economies rely on fossil fuel extraction and fossil-intensive industry. Coal communities in particular are likely to see immediate and significant harm from a price on carbon. Coal use in the electric power sector has already declined substantially, and even a moderately stringent climate policy could create significant risks for the U.S. coal industry. While the rapid decline of coal use would be great news for our public health and for the climate, these benefits would be a small consolation to regions of the country that are highly dependent on the coal industry, many of which are already struggling mightily due to the decline in production over the past decade (caused primarily by low natural gas prices). Though less geographically concentrated than coal, other fossil-dependent industries would be impacted by a carbon price. The decline of a dominant industry can further disrupt local governments' fiscal conditions, including the inability to raise revenue, repay debt, or provide basic public services.[11]

A portion of revenue from a federal carbon price could fund billions of dollars in annual investments that provide economic opportunity to fossil-dependent communities and direct assistance to workers, including fulfilling pension obligations. Alternatively, support for fossil-dependent communities could be provided in separate legislation, or as part of a broader program to support rural communities across the country that have similarly seen rapid declines in their dominant industries.

Finally, a third revenue use worthy of consideration is to fund the government expenditures required to support climate change mitigation and adaptation strategies, including significant investments in clean energy innovation.

8. Surround a carbon fee with other policies for achieving emissions reductions quickly and cheaply.

Even a carbon fee that covers nearly all U.S. emissions is just one part of an economy-wide climate strategy, because the price advantage of carbon-intensive products is just one of many barriers to reducing their use. Policy-makers should adopt measures that enable more cost-effective reductions of emissions than a carbon price would achieve on its own, like funding innovation in low-carbon technologies and strategies, supporting the emergence of low-carbon solutions, encouraging energy savings, and encouraging reductions in net emissions that the carbon price does not cover.[12] These measures must prioritize deployment of low-carbon technology and energy in marginalized communities.

11. Morris A, Kaufman N & Doshi S. "The Risk of Fiscal Collapse in Coal-Reliant Communities." Columbia University Center on Global Energy Policy. July 2019. https://energypolicy.columbia.edu/sites/default/files/file-uploads/RiskofFiscalCollapseinCoalReliantCommunities-CGEP_Report_080619.pdf

12. Justin Gundlach, Ron Minsk, & Dr. Noah Kaufman. Interactions between a Federal Carbon Tax and Other Climate Policies. Columbia SIPA Center on Global Energy Policy.

9. Encourage increased sequestration of CO_2 emissions.

Achieving net-zero emissions means that sources of greenhouse gases must be balanced by emissions sinks: either through naturally stored CO_2 (underground or in vegetation, soils, woody products, and aquatic environments) or through emerging technologies like direct air capture. Indeed, encouraging the sequestration of carbon dioxide, also referred to as “negative emissions,” is a critical piece of a decarbonization strategy.

A carbon-pricing policy can encourage carbon sequestration in numerous ways. A carbon fee can be waived (or refunded) for regulated entities that prove they have safely and successfully captured and sequestered their CO_2 emissions. For non-regulated entities, revenues from a carbon fee could be allocated to encourage capturing and sequestering CO_2 or to enhance the land carbon sink in other ways.

The Impact of Carbon Pricing

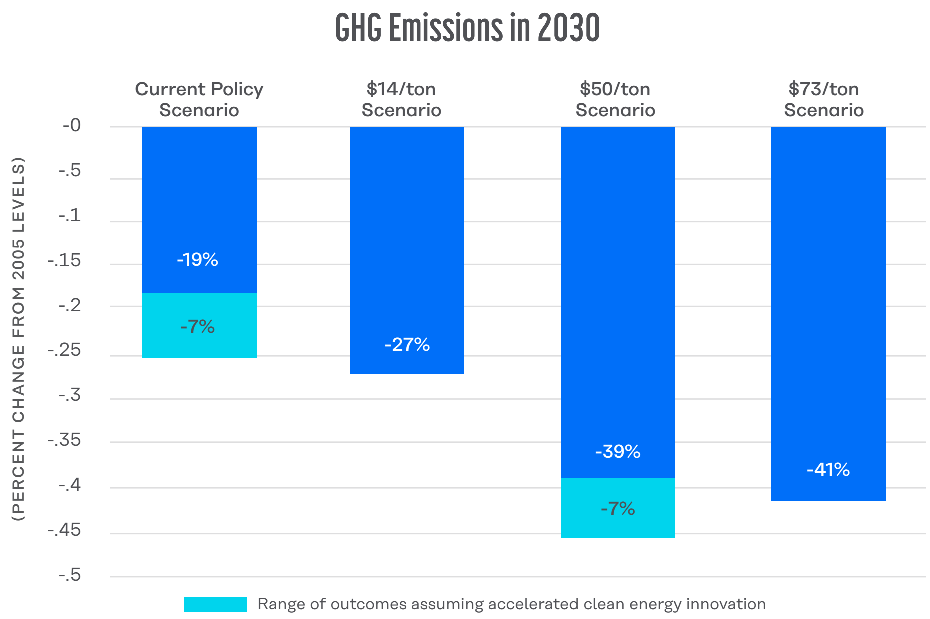
Emissions outcomes: The emissions reductions caused by a carbon fee depend on the policy’s design. Figure 2 below shows emissions reductions by 2030 from three illustrative carbon fees along with a current policy scenario. Under the $50/ton scenario, U.S. emissions fall to 39–46 percent below 2005 levels by 2030, depending on assumptions related to technological progress. That is the impact of the carbon price by itself, but far greater reductions could be achieved as part of a broader strategy and over a longer time horizon.[13]

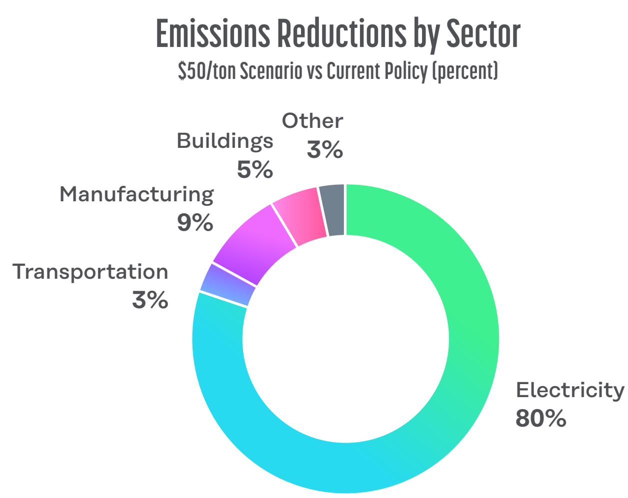
Over the first decade, the majority of emissions reductions caused by a carbon fee will occur in the power sector, where competitive markets, a relatively small number of corporate actors, and an array of clean energy technologies facilitate deep and immediate emissions reductions.

13. Kaufman N. & Gordon K. “The Energy, Economic & Emissions Impacts of a Federal US Carbon Tax.” Columbia University Center on Global Energy Policy. July 2018.

FIG. 02

Emissions Reductions From Illustrative U.S. Carbon Fees





Notes: The Current Policy scenario include federal and state policies in place as of June 2017. In the $14/ton scenario, the tax starts at $14/ton in 2020 and rises by about 3 percent annually. In the $50/ton scenario, the tax starts at 50/ton in 2020 and rises by about 2 percent annually. In the $73/ton scenario, the tax starts at $73/ton in 2020 and rises by about 1.5 percent annually.

Impacts on the national economy: A large-scale shift from high-carbon to low-carbon energy sources will have wide-ranging effects on the U.S. economy. A price on carbon is a necessary part of a low-cost climate change strategy because it encourages emissions reductions wherever and however they can be achieved at the lowest cost.

Economists have studied the potential economic impacts of carbon-pricing policies. Their models show that effects of a carbon tax on near-term macroeconomic outcomes like gross domestic product (GDP) are small and typically negative compared to a current policy scenario. These studies are highly imperfect—they nearly always exclude the economic benefits of avoided regulations and reduced air pollution, as well as any changes in technological progress stimulated by the tax.

Economic studies of carbon prices may be most useful in highlighting the trade-offs among policy design choices. How the carbon tax revenue is used is a differentiating factor in macroeconomic outcomes. Economic studies show that national economic outcomes are best when carbon tax revenues are used in ways that correct pre-existing inefficiencies in the U.S. economy. For example, using revenue to reduce payroll taxes or income taxes would not only return the revenues to taxpayers but also provide financial incentives for increased work.[14]

Figure 3 below shows the effects of a carbon tax on the U.S. GDP in three illustrative carbon tax scenarios compared to a current policy scenario. GDP impacts are less than 0.5 percent per year and they could be positive or negative, depending on the revenue use.[15]

However, these numbers mask significant variation in the impacts of a carbon fee. Some are caused by regional differences in energy production and consumption. For instance, rural communities will likely face larger energy-cost increases as a share of income than urban residents because low population density is typically associated with higher per-capita energy demand for transportation, heating, and cooling. Communities with rich renewable resources are more likely to capture the clean energy investment a carbon fee would incentivize, whereas the largest adverse impacts will be on regions dependent on the coal industry. Carbon-fee revenues can be used to mitigate such regional disparities.

At the same time, because low-income households spend relatively large shares of their total consumption on energy-intensive goods such as electricity, home heating fuels, and gasoline, carbon fees act as a regressive tax on those households. This is just one of many important distributional consequences that must be viewed through an equity lens to ensure that low-income and communities of color are prioritized in the return of revenue. Energy-price increases also reduce the revenues of businesses, an impact which is likely to disproportionately affect wealthier households. Also, many low-income households (particularly retirees) are shielded from energy-price increases because payments they receive from Social Security and other government-assistance programs increase with the price level.[16]

In sum, the most important driver of differing impacts of a carbon fee across the income distribution is how policymakers use the revenue it earns. If revenues are directed primarily at higher-income households (reducing the corporate tax rate, for example) the policy will be significantly regressive. By contrast, when all revenues are used for equal carbon dividends, the policy is progressive: lower-income households receive far more in rebates than they pay in additional taxes. For example, a recent study showed that with a $50/ton carbon fee and revenues used for equal carbon dividends, the tax

14. Kaufman N, Larsen J, Marsters P, Kolus H & Mohan S. "An Assessment of the Energy Innovation and Carbon Dividend Act." Columbia University Center on Global Energy Policy. November 2019. https://energypolicy.columbia.edu/sites/default/files/file-uploads/EICDA_CGEP-Report.pdf

15. Kaufman N. & Gordon K. "The Energy, Economic & Emissions Impacts of a Federal US Carbon Tax." Columbia University Center on Global Energy Policy. July 2018.

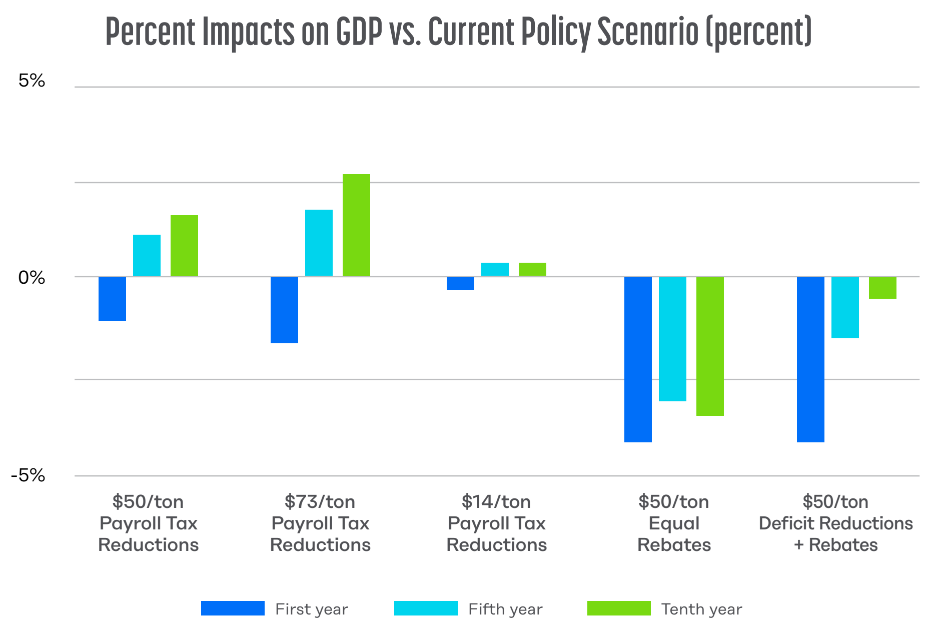
16. Ibid.

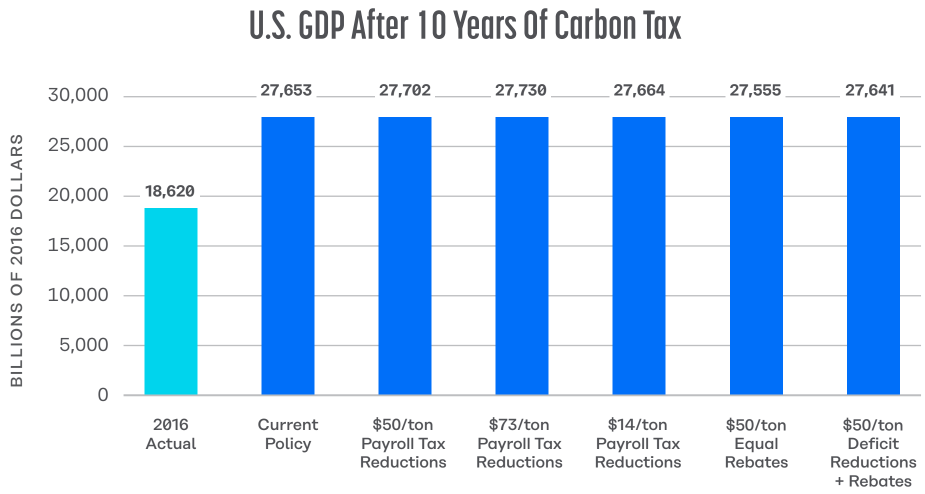
burden for low-income households (bottom 20 percent) decreases by 4–5 percent of pre-tax income, middle-income households come out slightly ahead, and high-income households (top 20 percent) pay 0.4– 0.6 percent more in taxes.[17]

Finally, policies should be designed to ensure that low-income households disproportionately benefit from reductions in air pollution caused by a carbon fee.

FIG. 03

Impacts On Gross Domestic Product Of Illustrative U.S . Carbon Fees





The Current Policy scenario inclue federal and state policies in place as of June 2017. In the $14/ton scenario, the tax starts at $14/ton in 2020 and rises by about 3 percent annually. In the $50/ton scenario, the tax starts at $50/ton in 2020 and rises by about 2 percent annually. In the $73/ton scenario, the tax starts at $73/ton in 2020 and rises by about 1.5 percent annually.

Source: Analysis by CGEP, Rhodium Group, Urban-Brookings Tax Policy Center, and Rice University's Baker Institute.

17. Ibid.

PRIORITY INNOVATION POLICIES

International Investment and Trade

Overview

The United States cannot fight climate change alone, because more than 85 percent of global carbon dioxide emissions are emitted outside the United States.[1] Achieving global net-zero emissions will require a coordinated push for clean energy transitions around the world. Efforts to date have not made much progress. For nearly three decades, countries have negotiated with each other through the United Nations Framework Convention on Climate Change (UNFCCC) but have failed to chart a global path to net-zero emissions. The pledges that countries made under the 2015 Paris Agreement are not sufficient to restrain global warming below 2°C.[2]

Still, even though U.S. emissions are small compared with global levels, the United States has great leverage to spearhead a global push for net-zero emissions. U.S. investments in innovative clean energy technologies can lower the cost of clean energy transitions around the world. And if the United States can develop, produce, and export innovative technologies to countries around the world, it will not only speed the global push for deep decarbonization but also reap domestic economic rewards.

Domestic policy alone will not suffice. U.S. foreign policy is critical to bridge the gap between domestic innovation and global clean energy transitions—and to cultivate globally competitive U.S. clean energy industries. Historically, U.S. policymakers have focused their international climate efforts on the UNFCCC process. This remains an important venue in which the United States should not only participate but also demonstrate leadership, for example by submitting a new pledge to achieve net-zero domestic emissions. But beyond rejoining the Paris Agreement, policymakers should design and execute a foreign-policy strategy to boost global clean energy innovation, foster the uptake of U.S. clean energy technologies, and speed clean energy transitions.

1. Union of Concerned Scientists, "Each Country's Share of CO2 Emissions," May 11, 2020, https://www.ucsusa.org/resources/each-countrys-share-co2-emissions

2. T. Vandyck, K. Keramidas, B. Saveyn, A. Kitous, & Z. Vrontisi, "A global stocktake of the Paris pledges: Implications for energy systems and economy," Global Environmental Change 41 (2016) 46-63, https://www.sciencedirect.com/science/article/pii/S095937801630142X

Policy interventions include:

1. **Leading international collaborations to invest in clean energy technology innovation,** including both bilateral and multilateral approaches to boost global public funding and coordination for clean energy research, development and demonstration.
2. **Coordinating global policies to build market demand to scale up emerging technologies,** including through regulatory coordination, public procurement, and harmonized technical standards.
3. **Promoting exports of U.S. clean energy technologies** through higher and more targeted export finance and investments across the innovation pipeline.
4. **Advancing a trade agenda that supports clean energy innovation and exports** by reducing barriers to cross-border clean energy trade while supporting countries' ability to invest in cultivating innovative domestic industries.
5. **Mobilizing global investment for clean energy transitions in emerging economies** by leveraging international financial institutions to use innovative tools for mitigating risks in those markets.
6. **Coordinating domestic and foreign policy** to best enable U.S. clean energy innovations to be adopted around the world.

Principles and Policy Recommendations

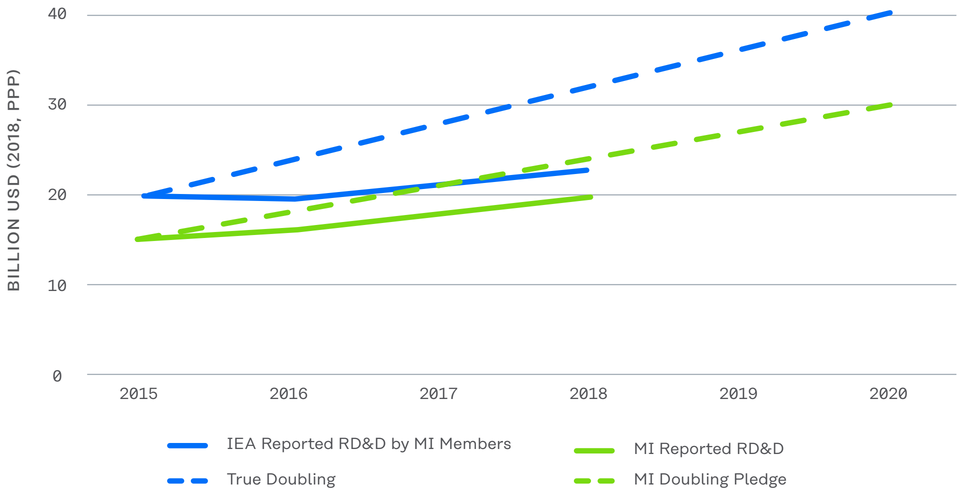
1. Lead international collaborations to invest in clean energy technology innovation.

Investments in clean energy innovation have extremely high leverage for reducing the cost of clean energy transitions. Yet global public funding for clean energy research, development, and demonstration (RD&D) has grown sluggishly in recent years. The United States should reinvigorate global efforts to boost government funding for energy RD&D while also investing public funds to mobilize private funding and speed technological progress. U.S. policymakers can project international leadership on the issue through multilateral and bilateral channels.

In 2015, the United States spearheaded the global Mission Innovation compact, in which twenty countries pledged to double public funding for energy RD&D over the next five years. Yet not only have countries failed to keep up with their commitments, but many countries underreported their initial RD&D funding levels, reducing their commitments from the beginning. (The figure below compares International Energy Agency estimates of RD&D funding with self-reported figures from member countries of Mission Innovation.) In recent years, the United States has stopped reporting its own clean energy innovation funding altogether, and it has fallen 50 percent short of its target to double clean energy RD&D funding to $12.8 billion (a commitment the U.S. government has formally withdrawn).[3]

3. Colin Cunliff, "Omission Innovation: The Missing Element in Most Countries' Response to Climate Change," December 2018, https://itif.org/publications/2018/12/10/omission-innovation-missing-element-most-countries-response-climate-change

Total Public Investment in Clean Energy RD&D from Mission Innovation Countries



Source: Information Technology and Innovation Foundation[4]

To be sure, the United States has not entirely disengaged from efforts to promote clean energy. It continues to participate in Mission Innovation as well as in the Clean Energy Ministerial, an international initiative focused on coordinating the clean energy deployment efforts of major economies. The United States has even led efforts in these two multilateral venues to advance carbon capture and nuclear energy technologies.[5]

But it can do much more on the international stage to advance the full spectrum of clean energy technologies critical for deep decarbonization. Ahead of the next major U.N. climate conference, known as "COP26" and slated to be held in the United Kingdom in November 2021, the United States should recommit to Mission Innovation and support a relaunch of the initiative. Such a "Mission Innovation 2.0" should comprise a set of commitments by member nations to make tangible progress on a range of clean energy technologies and to marshal private firms and investors as central participants.[6] For example, the United States might volunteer to lead a Global Challenge to develop clean fuels for long-distance transportation by road, sea, or air. Participating countries would commit to investing in RD&D and collaborating with private firms to meet specific cost and performance targets for clean fuels. By helping launch Mission Innovation 2.0 at the COP26 summit, the United States can elevate clean energy innovation alongside more traditional multilateral climate negotiations.

In addition to recommitting to multilateral collaboration on energy innovation, the United States should also invest in and strengthen bilateral energy RD&D collaborations. Through such collaborations, the United States and its international partners can harness complementary strengths, coordinate investment in mutual technology priority areas, and share best practices for designing innovation institutions.[7] For example, the United States might collaborate with Japan on hydrogen technology, South Korea on energy storage, and Canada on carbon capture, leveraging the relative strengths of each of

4. Colin Cunliff, "Omission Innovation 2.0: Diagnosing the Global Clean Energy Innovation System," September 2019, https://itif.org/sites/default/files/2019-omission-innovation-2.pdf

5. Clean Energy Ministerial, "Nuclear Innovation: Clean Energy Future," http://www.cleanenergyministerial.org/initiative-clean-energy-ministerial/nuclear-innovation-clean-energy-future-nice-future , accessed July 2020.

6. Spencer Nelson, "Reforming Mission Innovation," (Clear Path), https://clearpath.org/energy-101/reforming-mission-innovation/ , accessed July, 2020.

7. Daniel L. Sanchez & Varun Sivaram, "Saving innovative climate and energy research: Four recommendations for Mission Innovation," Energy Research & Social Science 29 (2017) 123-126, https://www.sciencedirect.com/science/article/abs/pii/S2214629617301421

these countries' energy innovation ecosystems and their key technology areas of focus. Collaboration opportunities also abound with countries in Europe and with the European Union. The EU and several of its member states are investing in demonstration projects for decarbonized industrial facilities, an area where the United States should deepen collaboration. On institutional design, the United States might work with Germany to adopt best practices for supporting private RD&D and manufacturing and support the United Kingdom in its plan to design a research agency modeled off the U.S. Advanced Research Projects Agency-Energy (ARPA-E).[8] Emerging economies are also important collaboration partners. For example, the United States should deepen its research collaboration with India, which can result in the development of technologies appropriate for decarbonization in the unique context of India's rapidly emerging economy.

In the case of China, the United States has previously engaged in bilateral energy RD&D collaboration on a range of topics with China, bringing together public research institutions, universities, and private corporations.[9] Although prospects for cooperation are currently limited in light of broader tensions, there may be future opportunities to identify a limited set of precompetitive areas for collaboration.

One might ask why the United States gains by spearheading multilateral and bilateral investments in energy innovation if it is competing with other countries to capture shares of growing global clean energy markets. The answer is that by collaborating with international partners to accelerate global clean energy innovation, the United States can spark a race to the top and reconfigure clean energy industries in line with the strengths of the world-class U.S. innovation ecosystem.[10] To be sure, the United States will need a suite of federal policies—many discussed elsewhere in this playbook—to foster clean energy innovation at home and avoid outsourcing high-value manufacturing. If it does so, the United States will be best poised to compete in clean energy industries that move toward an innovation-driven model of commercializing cutting-edge technologies.

2. Coordinate global policies to build market demand to scale up emerging technologies.

Spurring global investments in clean energy RD&D—"technology-push" investments that seed the innovation pipeline with new technologies—is necessary but not sufficient to promote the adoption of new and improved technologies around the world. In tandem, the United States should lead its international partners in coordinating "demand-pull" policies that help the private sector scale up and commercialize emerging technologies. Across a range of sectors, coordination can lower the barriers to clean energy technology adoption and build lucrative markets for U.S. clean energy exports.

In the transportation sector, countries have already made substantial progress on improving the fuel efficiency of new vehicles by coordinating regulatory standards. International coordination is common: for example, for the last two decades, India has based its fuel economy regulations on Europe's standards. Even more stringent regulations will be needed to drive adoption of zero-carbon passenger and heavy-duty vehicles. The United States should play a leadership

8. Erik Stokstad, "UK cues up big funding increases for R&D," (AAAS, March 2020), https://www.sciencemag.org/news/2020/03/uk-cues-big-funding-increases-rd

9. Joanna I. Lewis, "Managing intellectual property rights in cross-border clean energy collaboration: The case of the U.S.-China Clean Energy Research Center," Energy Policy 69 (2014) 546-554, https://www.sciencedirect.com/science/article/abs/pii/S0301421513013177

10. Sarah Ladislaw & Nikos Tsafos, "Race to the Top: The Case for a New U.S. International Energy Policy," (Center For Strategic & International Studies, July 2020), https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/200706_SRF_RacetotheTop_WEB_v2 FINAL.pdf

role in multilateral venues such as the Global Fuel Economy Initiative to push for more stringent global targets. Achieving international consensus on such targets would create attractive market opportunities for private firms and investors commercializing clean transportation technologies.[11]

Another coordination opportunity is public procurement of emerging clean energy technologies. Such procurement can provide a valuable early market opportunity for emerging technologies to reach commercial scale. International coordination can multiply the effects of individual government procurement policies, creating substantial markets to attract new innovations. For example, the United States could work with international partners such as the European Union to make a commitment to purchase cement, steel, and other industrial commodities with low embedded carbon content for public works. This would create a powerful market signal to incentivize the private sector to invest in decarbonized industrial plants.[12]

A fruitful (though low-profile) avenue for coordination is harmonizing international technical standards for clean energy products and services. This can make it easier to export technologies that are subject to the same standards across geographies. In the electric power sector, there is substantial scope for coordination on standards related to the smart grid, and over the last decade the United States has played a leadership role on this topic. In 2011, the U.S. Department of Energy (DOE) and National Institute of Standards and Technology (NIST) helped establish the International Smart Grid Action Network to develop globally harmonized standards for advanced power systems. The last major release of proposed standards was in 2014.[13] The U.S. should redouble its efforts to promote cooperation on standards, which will speed the evolution of power grids around the world and enlarge commercial markets for U.S. smart grid technology suppliers.[14]

Relatedly, the United States and its international partners should collaborate to reduce regulatory barriers to cross-border technology adoption. In the financial technology field, the United Kingdom and Canada have demonstrated a model to harmonize their regulatory standards to enable innovative companies in one jurisdiction to operate in another.[15] Drawing from this experience, the United States should collaborate with the United Kingdom, Canada, and other partners to design cross-border regulatory "sandboxes," which will permit innovative firms to test innovative technologies and business models, for example in the field of intelligent distributed energy resources.

To foster rich cooperation on building global demand for emerging clean energy technologies, U.S. foreign policy should exploit a diverse range of channels. Some collaborations will be bilateral and should start with partners with which the United States already has deep economic and diplomatic ties.

For example, Canada has outlined a comprehensive plan to stimulate market demand for emerging clean energy technologies—spanning public procurement, technical standards, and supportive regulations—offering a range of bilateral coordination opportunities with the United States.[16] Other collaborations will be multilateral, and the Clean Energy Ministerial is an ideal forum for the United States to reestablish its leadership among a club of the world's major emitters. Still other collaborations should include a range of subnational, private, and civil society actors, including industry trade groups and standard-setting bodies.

11. International Energy Agency (IEA), The International Council on Clean Transportation (icct), and the Global Fuel Economy Initiative (GFEI), "Fuel Economy In Major Car Markets: Technology And Policy Drivers 2005-2017," (IEA, icct, and GFEI, 2019), https://webstore.iea.org/download/direct/2458?fileName=Fuel_Economy_in_Major_Car_Markets.pdf

12. David G. Victor, Frank W. Geels, & Simon Sharpe, "Accelerating The Low Carbon Transition: The case for stronger, more targeted and coordinated international action," (Brookings, November 2019), http://www.energy-transitions.org/sites/default/files/Accelerating-The-Transitions_Report.pdf

13. National Institute of Standards and Technology (NIST), "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0" (NIST, September 2014), https://www.nist.gov/system/files/documents/smartgrid/NIST-SP-1108r3.pdf

14. NIST. NIST Smart Grid Advisory Committee 2019 Report. June 2019. https://www.nist.gov/system/files/documents/2019/08/02/nist_smart_grid_advisory_committee_2019_report.pdf

15. Kati Suominen, "Building a U.S.-UK FinTech Sandbox?," (Center For Strategic & International Studies, March 2018), https://www.csis.org/blogs/future-digital-trade-policy-and-role-us-and-uk/building-us-uk-fintech-sandbox

16. Innovation, Science and Economic Development Canada, "Canada's Economic Strategy Tables: Clean Technology," https://www.ic.gc.ca/eic/site/098.nsf/vwapj/ISEDC_CleanTechnologies.pdf/$file/ISEDC_CleanTechnologies.pdf

3. Promote exports of U.S. clean energy technologies.

International collaborations to speed global innovation and cultivate markets around the world for clean energy technologies will create economic opportunities for the United States. To seize those opportunities, U.S. firms must compete with firms around the world to capture shares of growing global markets. Many of those foreign competitors will enjoy support from their home governments. U.S. policymakers should step up support for domestic firms developing innovative clean energy technologies to successfully export their products around the world.

As countries recover from the coronavirus crisis, many have announced muscular economic support for clean energy industries. For example, Germany unveiled a national strategy targeting the "creation of a hydrogen economy and the leadership of German companies" and emphasizing investments in energy RD&D.[17] And the Chinese government has announced a "new infrastructure" package worth $1.4 trillion that will include investments in advanced energy industries and infrastructure. Its plans include building out high-voltage transmission and high-speed rail networks, extending subsidies for electric and hydrogen-fueled vehicles and deploying networks of vehicle charging infrastructure, and producing advanced batteries for vehicles and the electric grid.[18] Already, China leads the world in the production and export of solar panels, wind turbines, and lithium-ion batteries.[19]

To enable its firms to compete, the U.S. government should also provide funding for domestic clean energy industries to develop innovative technologies, demonstrate them at commercial scale, and manufacture them in the United States. Supporting the full innovation pipeline—particularly the later stages of technology demonstration, manufacturing, and scale-up—is critical for U.S. export competitiveness. Otherwise, innovations developed by U.S. firms may be manufactured in other countries, depriving the United States of the economic benefits from much of the clean energy value chain. By contrast, if the United States cultivates domestic industrial clusters that house both R&D and manufacturing facilities, the likelihood of retaining domestic supply chains and fostering globally competitive manufacturers rises.[20]

U.S. competitors make frequent use of another powerful tool to support their domestic champions: export finance. China's financial support to domestic exporters dwarfs that of all other countries. From 2015 to 2019, Chinese export credit activity amounted to 90 percent of the combined support from all G7 countries. In 2019, China provided roughly $90 billion in export assistance, more than 10 times the U.S. level. Other competitors, including Italy, Germany, the United Kingdom, France, South Korea, and even India all provided their firms more medium- and long-term export credit than the United States mustered. And because U.S. competitors devote substantial fractions of their export finance to clean energy industries—whereas the United States reserved nearly none of its export finance for clean energy exports in 2019—U.S. clean energy firms face an uphill battle to capture global market share.[21]

17. Federal Ministry for Economic Affairs and Energy, "Securing a global leadership role on hydrogen technologies: Federal Government adopts National Hydrogen Strategy and establishes National Hydrogen Council," October 2020, http://www.bmz.de/en/press/aktuelleMeldungen/2020/juni/200610_pm_031_Federal-Government-adopts-National-Hydrogen-Strategy-and-establishes-National-Hydrogen-Council/index.html

18. International Energy Agency (IEA), "Sustainable Recovery," (IEA, June 2020), https://www.iea.org/reports/sustainable-recovery

19. International Renewable Energy Agency (IRENA) and Global Commission on the Geopolitics of Energy Transformation, "A New World: The Geopolitics of the Energy Transformation." https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/Global_commission_geopolitics_new_world_2019.pdf

20. Gary P. Pisano & Willy C. Shih, "Restoring American Competitiveness," (Harvard Business Review, August 2009), https://hbr.org/2009/07/restoring-american-competitiveness

21. Export-Import Bank of the United States (EXIM), "Report to the U.S. Congress on Global Export Credit Competition," (EXIM, June 2020), https://www.exim.gov/sites/default/files/reports/competitiveness_reports/2019/2019-EXIM-Competitiveness-Report-FINAL.pdf

The United States should urgently increase financial support for U.S. firms seeking to export clean energy technologies. The U.S. Export-Import (Ex-Im) Bank is the primary U.S. export credit agency. It offers a range of financial credit enhancements, such as making guarantees of loans made by lenders to foreign buyers of U.S. goods and services. Congress reauthorized the Ex-Im Bank through 2026 and set a goal for Ex-Im to direct at least 20 percent of its financing authority to support ten strategic export categories to better compete with China; one of the categories includes renewable energy, energy efficiency, and energy storage.[22] Congress should further increase the funding authority for clean energy technologies and target the full spectrum of critical decarbonization technologies, including hydrogen, carbon capture, and digital energy technologies.

The U.S. Development Finance Corporation (DFC) offers another avenue for the United States to create export opportunities in emerging markets for U.S. clean energy technology producers. The 2018 legislation that created the DFC, which includes the organization formerly known as OPIC, afforded it powerful new financing tools. For example, DFC can take equity stakes in risky projects in emerging markets. The United States should direct DFC to marshal the financing tools at its disposal to support clean energy technology projects in rapidly developing economies, such as those in South Asia, Southeast Asia, and sub-Saharan Africa, that address critical decarbonization needs in those countries while also using U.S. technologies when possible.

4. Advance a trade agenda that supports clean energy innovation and exports.

In its trade posture, the United States should promote free and fair trade in clean energy technologies, and it should also support trade rules that enable the United States to invest in innovation and build advanced, exporting energy industries.

Achieving consensus on a broad, multilateral trade agenda will be difficult in the near term, because the international trading regime is currently under substantial pressure. In 2019, the World Trade Organization (WTO) Appellate Body, the highest entity that can deliver rulings in trade cases, stopped functioning because of a shortage of judges. In parallel, trade disputes, trade barriers, and retaliatory actions have grown more frequent in recent years.[23] This trend has been borne out in clean energy. For example, over the last decade, the United States, the European Union, India, and others have all imposed trade barriers on imports of solar panels, raising the cost of clean energy transitions.[24]

Setting aside the long-term trade agenda, the U.S. can take targeted steps in the near term to advance decarbonization and U.S. clean energy exports. One such step is for the United States to reduce tariffs at home and work with its international partners to reduce them abroad. U.S. tariffs on solar panels, for example, raise the cost of clean energy deployment and have failed to stimulate substantial U.S. solar manufacturing.[25] And when negotiating bilateral or multilateral trade agreements with international partners, the United States should reduce trade barriers to clean energy products and services. One focused multilateral initiative that the United States should lead is negotiating a global Clean Technology Agreement, following the example of the Information Technology Agreement that has lowered tariffs on electronics and other goods.[26]

22. Further Consolidated Appropriations Act, 2020, H.R. 1865, 116th Cong. (2019). https://www.congress.gov/bill/116th-congress/house-bill/1865/text

23. James McBride & Andrew Chatzky, "What's Next for the WTO?" (Council on Foreign Relations, December 2019), https://www.cfr.org/backgrounder/whats-next-wto

24. PV Magazine, "Supply distribution under trade barriers and the trend of market diversification," (April 2019), https://www.pv-magazine.com/2019/04/03/supply-distribution-under-trade-barriers-and-the-trend-of-market-diversification/

25. Ashley J. Lawson, Molly F. Sherlock, Michaela D. Platzer, Corrie E. Clark, & Tadlock Cowan, "Solar Energy: Frequently Asked Questions," (Congressional Research Service, January 2020), https://fas.org/sgp/crs/misc/R46196.pdf

26. Mark Wu & James Salzman, "The Next Generation of Trade and Environment Conflicts: The Rise of Green Industrial Policy," (Northwestern University Law Review, 2014). https://scholarlycommons.law.northwestern.edu/cgi/viewcontent.cgi?article=1022&context=nulr

Although tariffs can raise the cost of deploying clean energy technologies, the United States should be open to trade barriers when it comes to carbon-intensive goods. The European Union has announced plans for a carbon border adjustment mechanism, which will tax imports of carbon-intensive products from countries that do not price carbon at the level faced by European producers.[27] Such a mechanism could reduce "carbon leakage," which undermines the ability of stringent climate policies to reduce global emissions by outsourcing carbon-intensive manufacturing to countries with less stringent policies. The United States should work with the European Union and other countries such as Canada and the United Kingdom to create a club of like-minded countries dedicated to decarbonization. If the U.S. prices domestic carbon emissions in line with the policies of its partners, it can trade freely within the club while applying a border carbon adjustment to carbon-intensive imports from countries outside of the club. Over time, countries will face pressure to enact their own climate policies and gain access to freer trade within the club.[28]

Finally, the U.S. should advance trade rules that support of domestic policies to foster advanced clean energy industries and promote global exports of clean energy technologies. Many such policies, such as investments in clean energy RD&D, are already permissible under current international trade law and precedent; but some, such as domestic content requirements for public procurement of emerging technologies or manufacturing assistance to clean energy firms, might run afoul of WTO rules prohibiting certain types of subsidies.[29]

In the near term, the United States should lead an effort among WTO members to clarify how international trade rules apply to subsidies for clean energy technologies. It should also spearhead a time-limited agreement among WTO members to allow countries to support domestic clean energy industries in an extremely transparent fashion. In the past, opaque subsidies have made it difficult to determine whether, for example, Chinese firms were able to sell solar panels in global markets below their cost of production.[30] Therefore, any agreement that the United States supports should require countries to notify a WTO committee of new industrial support policies, transparently respond to queries from other countries, and submit to monitoring to ensure that their subsidies are used to promote innovative industries rather than to dump below-cost exports on global markets.[31] The United States should also support rules to bolster global intellectual-property protection, and the U.S. government should strengthen its capability to identify and respond to cases of intellectual property theft or forced technology transfer.

Moreover, the United States should lead negotiations to amend the OECD "Arrangement" agreement that constrains the export financing activities of member countries. In particular, the United States should push to extend the duration of loans for clean energy technology projects and permit export credits to finance a larger percentage of clean energy technology projects than is currently allowed. These changes could improve the competitiveness of U.S. clean energy technology exports and also enable the nation and its likeminded international partners to offer compelling clean alternatives to the carbon-intensive projects financed by China's Belt-and-Road Initiative.[32]

27. Ben Aylor, Marc Gilbert, Nikolaus Lang, Michael McAdoo, Johan Öberg, Cornelius Pieper, Bas Sudmeijer, & Nicole Voigt, "How an EU Carbon Border Tax Could Jolt World Trade," (Boston Consulting Group, June 2020), https://www.bcg.com/publications/2020/how-an-eu-carbon-border-tax-could-jolt-world-trade.aspx

28. William Nordhaus, "The Climate Club," (Foreign Affairs, June 2020), https://www.foreignaffairs.com/articles/united-states/2020-04-10/climate-club

29. Ilaria Espa & Sonia E. Rolland, "The E15 Initiative: Strengthening The Global Trade System," (International Centre for Trade and Sustainable Development and World Economic, February 2015), https://seors.unfccc.int/applications/seors/attachments/get_attachment?code=2PGUFCPSZXCLS2P3YWB11TRONA9Q10K

30. John Deutch & Edward Steinfeld, "A Duel in the Sun: The Solar Photovoltaics Technology Conflict between China and the United States," (Energy Initiative Massachusetts Institute of Technology, 2013), https://energy.mit.edu/wp-content/uploads/2013/05/MITEI-WP-2013-01.pdf

31. Kasturi Das & Kaushik Ranjan Bandyopadhyay, "Climate Change and Clean Energy in the 2030 Agenda: What Role for the Trade System?" (International Centre for Trade and Sustainable Development, October 2016), http://biblioteca.olade.org/opac-tmpl/Documentos/hm000657.pdf

32. Shayerah Ilias Akhtar, "Export-Import Bank: Overview and Reauthorization Issues," (Congressional Research Service, August 2019), https://fas.org/sgp/crs/misc/R43581.pdf

5. Mobilize global investment for clean energy transitions in emerging economies.

Emerging economies, such as India, Brazil, Indonesia, and South Africa, have rapidly increasing emissions but struggle to secure the investment needed to finance clean energy transitions. Excluding China, emerging economies accounted for one-quarter of global GDP over the last decade but only attracted 13 percent of global investment in low-carbon infrastructure.[33] Global efforts to curb climate change will fail if these economies cannot access capital to deploy clean energy technologies across a range of sectors. The United States should use its influence with international financial institutions to improve these economies' access to capital for clean energy infrastructure.

In some respects, many emerging economies are well-suited to clean energy transitions. Many are located in areas with excellent renewable energy resources, particularly solar radiation. Moreover, unlike developed economies that must overhaul extensive existing energy infrastructure, many emerging economies have yet to build much of their energy infrastructure. Yet many do not choose clean options. In 2018, clean energy investments in emerging markets fell more than 20 percent to $133 billion, even while those economies consumed more coal power than ever.[34] Too often, foreign investors shy away from clean energy projects in emerging economies owing to a range of risks.

International financial institutions—including global bodies such as the World Bank and International Finance Corporation as well as regional development banks such as the Asian Development Bank—can help. The U.S. and its allies hold the largest voting stakes in many of these institutions and can influence them to focus on developing innovative tools to mobilize capital for clean energy deployment in emerging economies.

For example, one proposal would promote solar energy deployment across emerging economies by pooling and insuring the risks to solar projects across twenty or more countries. Such a Common Risk Mitigation Mechanism would require the World Bank or another institution to provide a guarantee to investors that they would be paid back even if some projects failed as a result of political or other risks. But by pooling diverse risks across countries and requiring investors to pay an insurance premium, the scheme could pay for itself.[35] International financial institutions can also take a range of other approaches, such as structured finance products to standardize investments in clean energy, to mobilize capital toward emerging economies.[36]

33. Climate Finance Leadership Initiative, "Financing the Low-Carbon Future: A Private-Sector View on Mobilizing Climate Finance," (September 2019), https://data.bloomberglp.com/company/sites/55/2019/09/Financing-the-Low-Carbon-Future_CFLI-FullReport_September2019.pdf

34. Bloomberg New Energy Finance (BNEF), "Clean Energy Investment in Developing Nations as Financing in China Slows," (BNEF, November 2019), https://about.bnef.com/blog/clean-energy-investment-in-developing-nations-slumps-as-financing-in-china-slows/

35. Council for Energy, Environment, and Water, "Common Risk Mitigation Mechanism Feasibility Study," November 2017, https://www.ceew.in/sites/default/files/CEEW-CRMM-Feasibility-Study-14Nov17_0.pdf

36. Henning Wuester, Joanne Jungmin Lee, & Aleksi Lumijarvi, " Unlocking Renewable Energy Investment: The Role of Risk Mitigation and Structured Finance," (IRENA, 2016), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Risk_Mitigation_and_Structured_Finance_2016.pdf

6. Coordinate domestic and foreign policy.

To advance innovation at home and abroad, spur clean energy transitions around the world, and prosper from exporting clean energy technologies, the United States must coordinate its domestic and foreign policy strategies.

For example, the United States should coordinate its domestic energy RD&D activities with its international collaborations. If the U.S. chooses to invest at home in technologies such as carbon capture, energy storage, digital energy technologies, or others, it should also focus its international research collaborations in those areas. Similarly, the U.S. should pair domestic policies to encourage manufacturing and industrial development with international coordination to develop international technical standards and regulations in those fields and efforts to open new export markets for burgeoning domestic industries.

This will require deep coordination across the agencies of the federal government. For example, the DOE, which leads domestic clean energy RD&D investments, should work closely with the Departments of State and Commerce on international collaboration and export promotion, and should carefully coordinate its funding for RD&D in priority technology areas with programs at NIST to support manufacturing of those technologies and to spearhead international technical standards in those technologies to open new export markets. Finally, although foreign policy is largely the domain of the executive branch and domestic funding appropriations the domain of the legislative branch, the two branches should communicate often to align their priorities and strategies.

The Impact of U.S. Foreign Policy and International Cooperation

Across a range of fields from clean energy to global health, international cooperation has accelerated the development and deployment of new technologies to meet global challenges. In many cases, the United States has spearheaded global action, and well-conceived U.S. foreign policy has advanced the national interest.

The history of U.S. nuclear exports is a case in point. In the decades following World War II, the United States led the development of civilian nuclear power and then exported nuclear reactors around the world. Most of the world's nuclear reactors are still based on U.S. technology.[37] Although the United States has more recently ceded leadership in the nuclear industry, the experience has left valuable lessons for harnessing U.S. foreign policy to promote global clean energy innovation and deployment. First, the United States collaborated on RD&D with a range of international partners, such as Japan, South Korea, and Canada, to advance nuclear technology and build export markets abroad. As a result, U.S. firms were able to license technology, export equipment, and sell nuclear fuel to international partners for decades.[38] Second, the United States relied heavily on export financing, for example to build initial markets in Europe. Third, decades of experience have left a well-honed playbook for U.S. policymakers across

37. Robin Cowan, " Nuclear Power Reactors: A Study in Technological Lock-in," The Journal of Economic History 50 (1990) 541-567, http://dimetic.dime-eu.org/dimetic_files/cowan1990.pdf

38. Jennifer T. Gordon, "International Co-financing of Nuclear Reactors Between the United States and its Allies," (Atlantic Council Global Energy Center, January 2020), https://www.atlanticcouncil.org/wp-content/uploads/2020/01/Nuclear-Finance-final-web-version.pdf

the federal government to coordinate domestic and foreign policy to advance the global deployment of nuclear energy. For example, the Nuclear Regulatory Commission has spearheaded international collaboration on technical standards and licensing; the DOE has funded nuclear RD&D, the State Department has concluded civil-nuclear cooperation agreements with partners around the world; and the Ex-Im Bank has provided export finance.[39]

Coordinated international action has proven successful in the past at charting complex technology roadmaps and coordinating countries to meet sectoral targets and abide by technical standards. For example, the United States led a global collaboration through the Montreal Protocol to reduce the world's use of ozone-depleting substances. To do so, technical committees comprising scientific experts and industry professionals set roadmaps for reducing the use of such substances in different economic sectors. Another success story comes from the experience of the International Maritime Organization in the 1970s. By identifying new technology standards for tanker owners and port operators, the organization successfully reduced oil pollution from tanker ships. Today, it is once again making progress on environmental protection by reducing sulfur pollution from shipping fuels.[40]

Public procurement has also proven to be a fruitful avenue for international collaboration. A good example comes from the field of global health. To support the development and dissemination of innovative vaccines for the development world, an organization called GAVI has brought together governments and philanthropies around the world to pledge to pay for future vaccine doses. That advance market commitment succeeded in bringing to market the pneumococcal vaccine and immunizing millions of children around the world.[41] This mode of international cooperation could also create early markets for promising clean energy technologies in which the private sector might hesitate to invest if not for the guarantee that a market will exist for products that meet the required specifications.

39. International Trade Administration, "U.S. Approach to Financing: Role of the Export-Import Bank of the United States," (International Trade Administration), https://www.ifnec.org/ifnec/upload/docs/application/pdf/2016-06/d.farrell.u.s._approach_to_financing_role.pdf

40. David G. Victor, Frank W. Geels, & Simon Sharpe, "Accelerating the Low Carbon Transition: The case for stronger, more targeted and coordinated international action," (Brookings, November, 2019), http://www.energy-transitions.org/sites/default/files/Accelerating-The-Transitions_Report.pdf

41. Tania Cemuschi, Eliane Furrer, Nina Schwalbe, Andrew Jones, Ernst R. Berndt, & Susan McAdams, "Advance market commitment for pneumococcal vaccines: putting theory into practice," Bulletin of the World Health Organization 89 (2011) 913-918, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3260895/