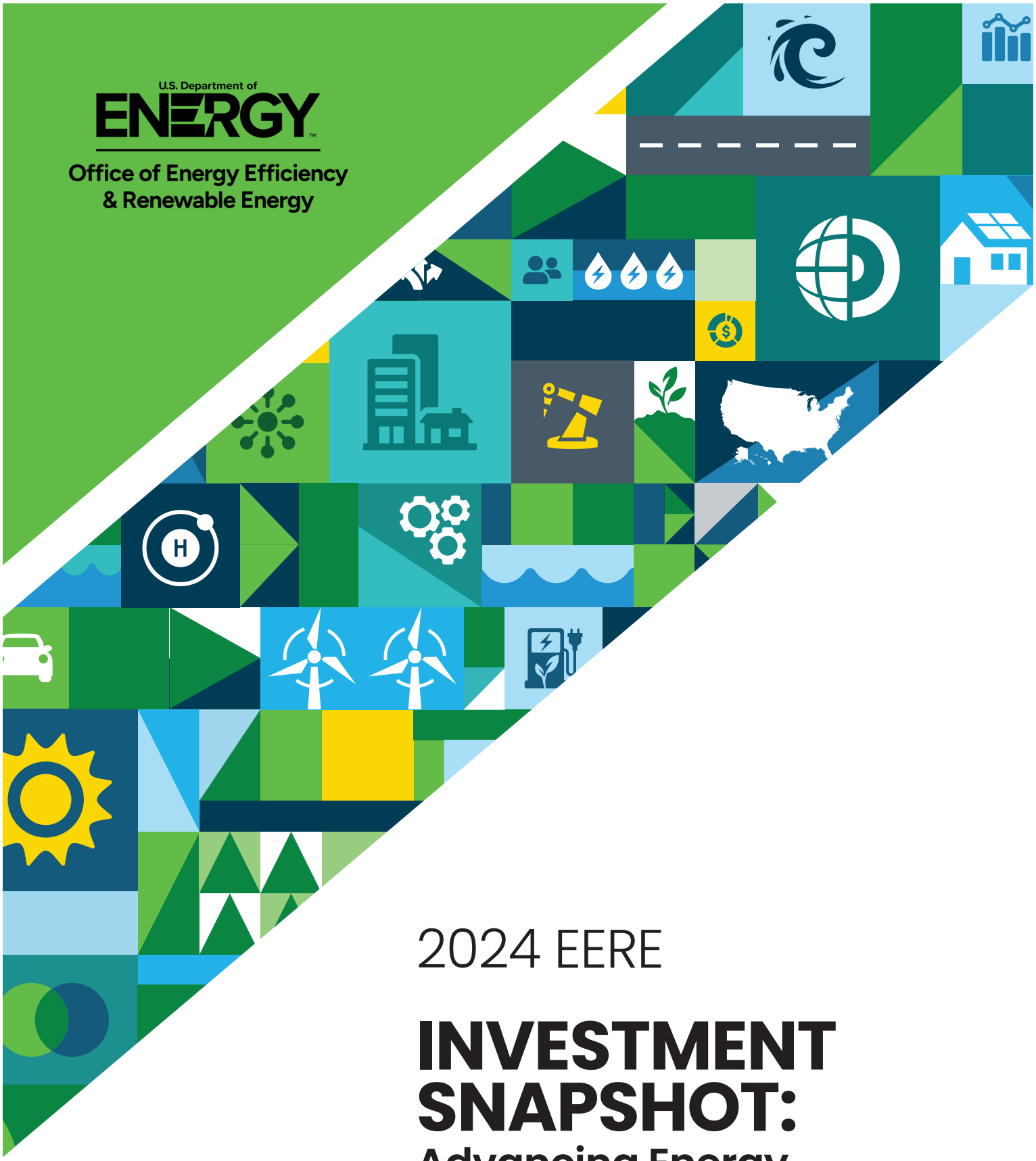
U.S. Department of ENERGY

Office of Energy Efficiency & Renewable Energy



2024 EERE

INVESTMENT SNAPSHOT:

Advancing Energy Innovation Across America

Leadership Letter

The way the world uses energy is changing—and fast. Where others see this simply as a challenge, Americans see a once-in-a-generation opportunity. We see innovation in clean, efficient, and low-emission energy improving almost every aspect our lives. We see millions of jobs and healthier communities. We see stronger, more competitive industries, producing goods right here in the United States. We see a grid that is safer and more reliable, and supply chains that are more secure and protect our national interests.

The team I lead at the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) is helping Americans seize these opportunities and maximize the benefits of energy innovation.

At EERE, our mission is to accelerate the research, development, demonstration, and deployment of technologies that advance energy innovation across a range of industries. This *2024 Investment Snapshot* serves as a snapshot of how EERE is working to achieve its critical mission. Our almost $3 billion annual budget allows us to make large, meaningful investments in energy innovations across the country. Our teams are world-leading subject matter experts who work collaboratively with communities, industry, and research institutions. And we have a track record of bringing cutting-edge innovation from the lab to the street, for the benefit of all Americans. The progress you see showcased in this report will not stop this year. The energy innovations supported by EERE will continue to benefit Americans in the years and decades to come, as they become the standard for industries and markets around the world.

I hope you enjoy reading about our progress—seeing all this amazing work in one place, and knowing it is only a slice of all that we have accomplished, fills me with great pride. The only thing more exciting than everything we have already achieved, is knowing there is so much more to come.

I invite you, and all Americans, to join me on that journey.

JEFF MAROOTIAN
Principal Deputy Assistant Secretary
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Table of Contents

Executive Summary

The Office of Energy Efficiency and Renewable Energy (EERE) has—for over four decades—driven groundbreaking advances in energy innovations that power our grid with low-carbon renewable energy, modernize the electricity system, create cost-effective and sustainable transportation systems, make our buildings and industries cleaner and more affordable, and expand domestic manufacturing and supply chains. EERE's applied research, development, demonstration, and deployment projects provide essential support to the American innovators and businesses ensuring the United States leads the way to the energy sector of the future.

The benefits of EERE's investments in cleaner, more efficient, and more reliable energy technologies are deep, far reaching, and of vital importance to all Americans.

- Domestic investment in energy innovation **creates jobs, drives economic growth, and makes our industries more competitive**. Around 3.5 million Americans already work in clean energy jobs, and the investment of tens of billions of dollars in the United States each year to build, install, and maintain energy technologies will spur future job and economic growth.
- Reducing energy consumption and providing affordable clean energy options **lowers costs for households and businesses**. Since 1980, energy efficiency technologies and improvements have saved Americans around $800 billion in energy costs. And today, the median U.S. homeowner will save almost $50,000 over 25 years after installing solar panels.
- Expanding the deployment of clean energy across the country **makes our communities and country healthier and safer**. Energy innovations reduce air pollution that kills an estimated 300,000 Americans each year, lessen the impact of life-threatening extreme weather events, and are essential to building an independent domestic energy system that is reliable, resilient, and secure.

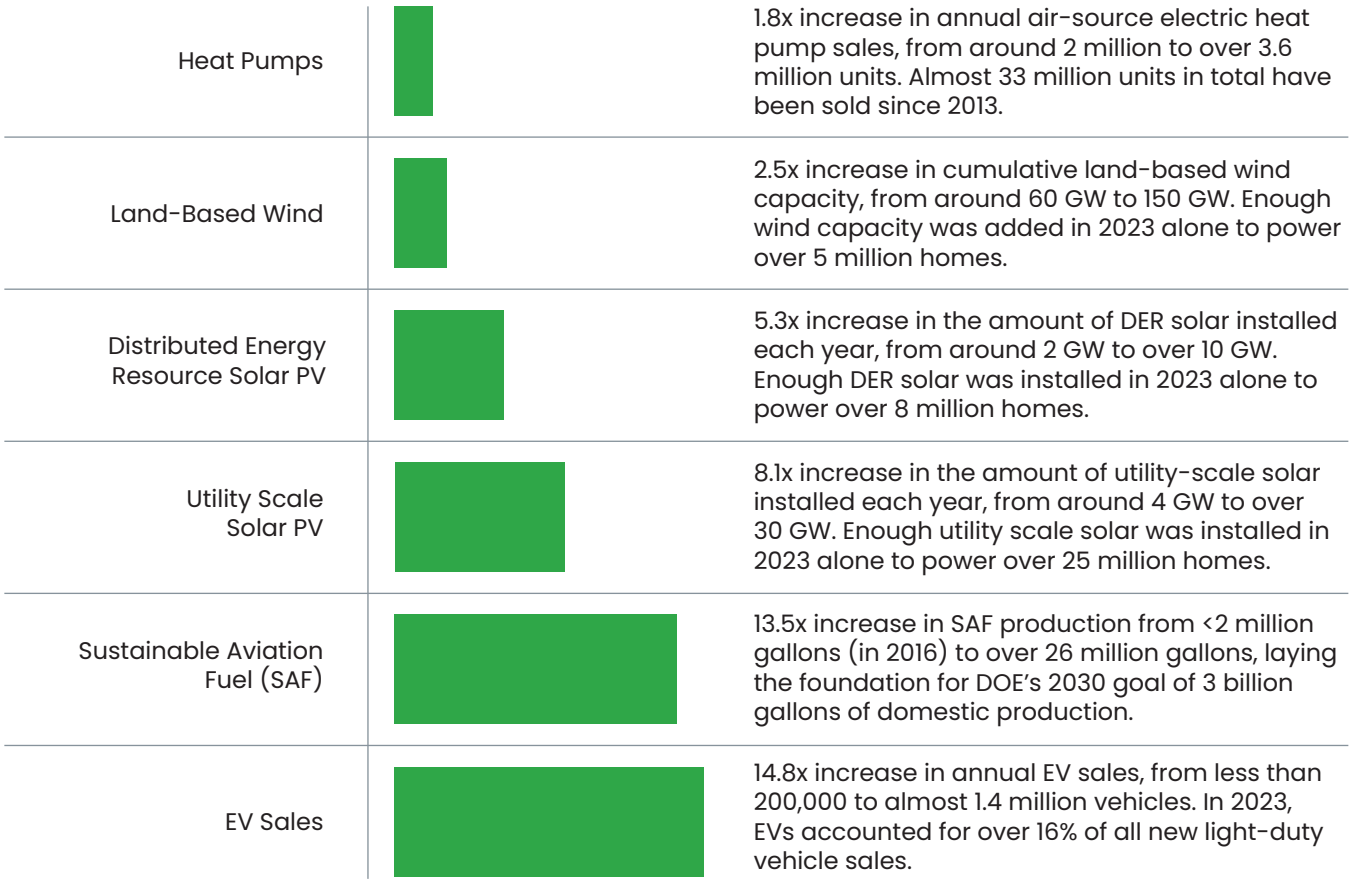
EERE has played a critical role in delivering these benefits by advancing energy innovations from the earliest stages of scientific research through to widespread integration into everyday life. The impact of EERE's work is tangible, measurable, and benefits millions of Americans, and in recent years has included:

- **Delivering breakthroughs in energy innovation**. EERE funding led to the successful testing of geothermal energy innovations that could provide clean, low-cost power to over 65 million homes, and EERE funding led to the development of a mining technology that could allow the extraction of enough lithium domestically to manufacture 5 million electric vehicles (EVs) per decade.
- **Moving technology breakthroughs from the lab to the street**. EERE programs have helped major U.S. truck manufacturers incorporate fuel efficient technologies into new vehicles, and provided financial and technical support for companies opening new manufacturing facilities that incorporate and produce cutting-edge energy technologies. EERE has also helped almost 200 entrepreneurs start energy innovation-focused companies and provided the support needed for them to succeed (including raising $2.7 billion in capital and creating almost 2,500 jobs).
- **Making existing technologies and processes cheaper and more effective**. EERE's work has helped drive down costs for a range of technologies, including EV batteries (down 79% over the last decade), utility-scale solar (down 73%), distributed solar (down 26%), and onshore wind (down 41%).
- **Enabling the wider adoption of cutting-edge energy innovations**. EERE's technical and financial assistance programs have helped place more than 1.6 million alternative fuel vehicles on the road (saving 14 billion gallons of gasoline and reducing greenhouse gas, or GHG, emissions by 72 million tons), made thousands of buildings more energy efficient (averting 155 million tons of GHG emissions and saving more than $15 billion in energy costs), sped up the domestic production capacity of sustainable aviation fuel, and helped deliver an estimated $187.4 million in annual utility bill savings through the expansion of community solar.

EERE has delivered this impact not only through the effective deployment of its funding, but by convening and collaborating with a diverse range of partners. Since 2019, EERE has leveraged $1.4 billion of federal investment to secure $1.1 billion in private sector investment for key projects, and since 2021 has distributed $302 million in funding to 106 institutions of higher education across the country. Ongoing partnerships with DOE's national research laboratories, state and local governments, workers and organized labor, and local communities and community-based organizations have and will continue to be critical to the effective delivery of EERE's mission and priorities.

EERE has made immense progress in advancing the invention and use of energy innovations and will continue to deliver tangible results through its almost 2,000 active projects across the country. But there is more work to do if America is to reap the full benefits of the global shift to a clean and efficient energy future. EERE will continue to use its resources, research capabilities, and experience to position the United States as the uncontested leader in this arena.

Figure 1: Increase in U.S. deployment of select energy innovations, 2013–2023



Source: U.S. Environmental Protection Agency, Wood Mackenzie/SEIA, Air-Conditioning, Heating, and Refrigeration Institute, Lawrence Berkeley National Laboratory. EVs include hybrid, plug-in hybrid, and battery electric vehicles.

Introduction

Energy Innovations for the 21st Century

Around the world, countries are racing to develop and utilize innovative technologies that transform how they generate and use energy in homes and businesses, transportation systems, and across industries. These energy innovations create clean and reliable power, improve grid safety and resilience, make existing products and industrial processes more effective and efficient, transform domestic manufacturing capabilities, and secure supply chains. Realizing the full benefits of such energy innovations is imperative to making our communities healthier, our country safer, and our workforce and economy stronger.

Thanks to our world-class research facilities, entrepreneurial businesses, and ongoing federal action and investment, the United States is well positioned to be at the forefront of this effort. The U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) is dedicated to ensuring we lead the world in energy innovation across a broad range of sectors, including renewable power generation, transportation, buildings, manufacturing, and critical supply chains. Working together with other DOE offices, EERE has used targeted investments in applied research and development (R&D), demonstration and deployment expertise, in-kind technical assistance, and its unique convening power to act as a driving force towards groundbreaking advances in energy innovation.

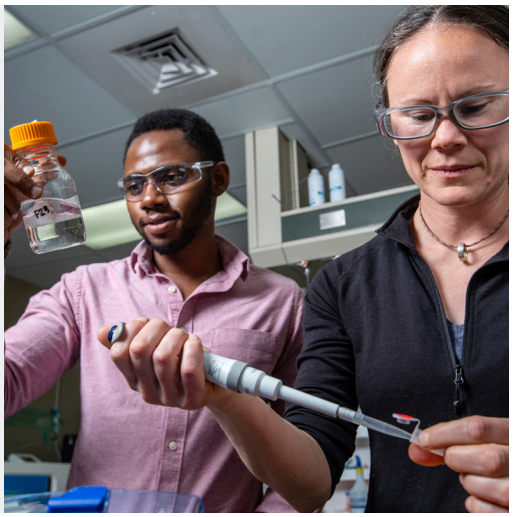
Using a range of quantitative and qualitative information, this report documents EERE's progress driving forward energy innovation in select industries and technologies and how the market for those technologies is evolving alongside investment and activity from EERE and other DOE offices. While each field in EERE's portfolio has seen remarkable progress, the report focuses on EERE progress and achievements as a whole and shows how continued investment in EERE can continue to yield measurable and demonstrable benefits for the American people.

The Benefits of Energy Innovation

The demand for and adoption of energy innovations is improving the lives and livelihoods of Americans across the country. It is driving economic growth, creating wholly new industries, products, and associated supply chains, creating millions of new good-paying jobs, and spurring billions of dollars in investment. The United States is positioned to lead this 21st century economic transformation with domestically made technologies and products, American workers, and U.S. entrepreneurship—all made possible by ongoing support from the federal government. The benefits of this investment in cleaner, more efficient, and more reliable energy technologies are deep

EERE and Energy Innovation

Energy innovation refers broadly to the development of products and processes that increase efficiency, lower costs, reduce harmful emissions, increase safety and reliability, and create jobs across the economy. DOE advances energy innovation across many industries, with EERE focused primarily on transportation, the industrial sector, buildings, and renewable power generation. Such innovation can result in the invention of wholly new products and processes, or improvements to existing ones.



Researchers study plastic degradation. *Photo courtesy of Werner Slocum, NREL*

and far reaching. Fewer contaminants in our air and water are helping foster healthier communities across the country. Vehicles, appliances, buildings, and manufacturing processes are becoming more energy efficient and cheaper to run. No matter where you look, our communities are becoming safer and more resilient, our homes more comfortable, and our businesses and industries more competitive globally.

Creating Jobs

Energy innovations are catalyzing economic growth and creating millions of jobs. The U.S. economy added 142,000 clean energy jobs in 2023, taking the total number of Americans working in clean energy to 3.5 million.[1] In 2023, clean energy jobs accounted for more than half of all new energy jobs, and almost 5% of all new jobs created in the U.S. economy. Clean energy jobs are being added in large and well-established sectors (such as energy efficiency, which added almost 75,000 jobs to employ over 2.3 million workers in 2023) and in fast-growing sectors of the economy (such as battery electric vehicles, which saw 13% job growth year-on-year).[2] In electric power generation, 79% of all jobs added in 2023 were in clean energy technologies. Clean energy workers also benefit from relatively high, and growing, unionization rates (12.5% vs. the national workforce average of 7%). Employers estimate the number of clean energy jobs will continue to increase, led by growth in the energy efficiency (+8%), electric power generation (+6.6%), and automotive (+4.5%) sectors.[3]

Accelerating Investment and Economic Growth

This job growth is linked to the growing global market for clean energy, emissions-reducing, and energy-efficient technologies and industrial processes that will be worth at least $23 trillion by 2030.[4] Investment in the manufacturing and deployment of a range of energy innovations—many of which were seeded or supported by federal funding—has skyrocketed from $78 billion in 2018 to over $240 billion in 2023.[5] Alongside spending on the deployment of established technologies is private sector investment in emerging clean energy and climate-adjacent companies, or "climate tech." Venture capital (VC) firms invested over $140 billion in climate tech companies between 2021 and 2023, more than 15 times larger than the $8 billion invested between 2013 and 2015.[6]

For many of the world's largest companies, acting on, investing in, and committing to clean energy, emissions reduction, and energy efficiency technologies, processes, and jobs is now core to business strategy. Microsoft and Amazon will invest $3 billion in entrepreneurs and companies developing and deploying climate technologies and services.[7] Siemens will invest $100 million helping small- and medium-sized U.S. businesses in the industrial sector to decarbonize.[8] By the end of 2022, more than 300 companies had signed contracts to purchase 77.4 gigawatts (GW) of clean electricity, up from about 10 GW five years earlier.[9] Over 200 organizations, including 3M, Kohls, and Target, have partnered with DOE to reduce portfolio-wide greenhouse gas (GHG) emissions (scope 1 & 2) by at least 50% within 10 years.[10] And 11 of the largest air passenger and cargo carriers in the United States have committed to increasing their use of sustainable aviation fuel (SAF), with some also investing directly into the companies who produce this fuel.[11] The private sector's commitment to energy innovation will continue to drive investment and economic growth for years to come.

Rebuilding U.S. Industry and Competitiveness

To meet the growing demand for new energy technologies and compete effectively in emerging global industries, American industry will need to prove itself once again by improving existing processes and products while building new capabilities and capacity. A growing domestic clean energy and energy efficiency workforce, a more secure supply chain, and American entrepreneurship will help U.S. manufacturers become more competitive on costs, quality, and expertise.

We are already seeing an unprecedented amount of investment in U.S. industry to meet domestic and global demand for energy innovations. This investment is ramping up energy technology

production and creating new processes for manufacturing established products using cutting-edge facilities and advanced processes. For example, since 2021, investments of over $120 billion in the domestic battery manufacturing supply chain have laid the groundwork for 90,000 new U.S. jobs. These investments will enable the domestic production of 10 million electric vehicles (EVs) per year, support a burgeoning electric automotive industry, and enable more energy storage capacity at homes, businesses, and across the grid.[12] Looking forward, global demand for low-emissions alternatives to traditional products will create entirely new markets for the United States to lead. One such example is the market for low-carbon "green" steel, which could grow from 15 million metric tons (MT) in 2021 to more than 200 million MT by 2030.[13]

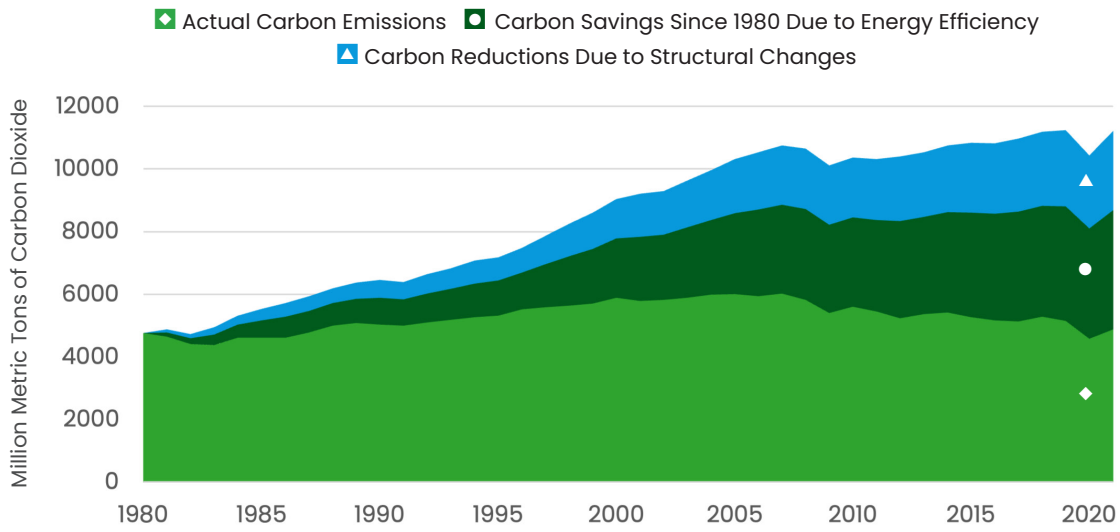
Lowering Energy Costs for Households and Businesses

Energy innovations are playing a significant role in lowering Americans' energy costs. They are reducing the amount of energy used by households and commuters, businesses and industry, and providing more affordable and accessible renewable energy options.

Energy consumption in the United States would be around 60% higher today without the energy efficiency technologies and improvements adopted since 1980. This corresponds to an estimated saving of approximately 60 quadrillion British thermal units of energy per year, equivalent to around $800 billion in energy costs using today's prices.[14] Steady advances in the efficiency of heating, ventilation and cooling systems, household appliances, industrial equipment, and vehicles have contributed significantly to these savings—since 1990 the steel industry has reduced its energy intensity by 35%,[15] while clothes washers have become 80% more energy efficient.[16] Thanks to these types of cost-saving energy innovations, energy consumption per household has declined by almost 20% since 2005.[17] Electrification of everyday technologies will continue to save households money; for example, the average battery electric vehicle owner will save more than $2,000 on fuel costs each year compared to the owner of an equivalent size gas vehicle, and EV owners can expect to save $6,000 on maintenance and repairs over their vehicle's lifetime.[18] These savings are significant given that transportation fuel accounts for more than half of household spending on energy.[19]

The growing adoption of renewable energy technologies can also lower electricity bills—the

Figure 2: CO_2 emissions avoided due to energy efficiency, 1980-2021



Source: EIA (2022) Monthly Energy Review, ACEEE (2015) Energy Efficiency in the United States: 35 Years and Counting

median U.S. homeowner will save almost $50,000 over 25 years after installing solar panels, a benefit more widely available due to the 78% reduction in the cost of rooftop solar since 2005.[20] And pairing the installation of rooftop solar with roof replacement can save homeowners an average of $4,000 in upfront installation costs.[21] Additional investment in efficient appliances, lighting, heating, ventilation, and air conditioning (HVAC), as well as insulation and air sealing, can save the average household a further 40% to 50% on their energy bills.[22]

Creating Healthier Communities

Today, we have a clearer understanding of the health impacts of fossil fuels on American families and communities. Each year, an estimated 300,000 Americans die from the effects of air pollution produced by burning fossil fuels.[23] Reducing the use of fossil-fuel energy, or replacing it entirely with clean energy, will improve health outcomes and save Americans up to $77 billion per year in total health impacts.[24]

Cutting emissions is especially important to improving the health and wellbeing of Americans living in low-income and disadvantaged communities. More than half of the most emissions-intensive industrial facilities in the United States, such as cement, steel, and chemicals manufacturing, are located close to these communities. Proximity to industrial facilities regularly exposes these communities to more contaminants, particulate matter, and carcinogens linked to higher rates of premature death, cancer, and chronic respiratory conditions.[25]

The last decade has seen remarkable progress in public health due to the deployment of energy innovations. Clean, renewable power is helping to replace retiring legacy energy infrastructure, and in doing so is improving air quality and health outcomes for asthma and other cardiorespiratory conditions.[26] Energy efficiency measures in homes and buildings are helping ensure good air quality, healthy temperatures, and lower humidity levels. And looking forward, the accelerating adoption of EVs can help lower exhaust emissions of nitrous oxides and harmful fine particulates, which can cause severe respiratory diseases.[27]

Protecting Our Communities From Climate-Related Disasters

By cutting emissions today, we can moderate the impact of extreme weather, higher average temperatures, and rising sea levels to ensure a safer future for the next generation of Americans.

In the five years between 2018 and 2023, weather and climate disasters such as droughts, cyclones, flooding, and wildfires cost the United States over $700 billion and caused over 2,000 deaths.[28] In 2022 alone, these events displaced an estimated 3.4 million Americans from their homes.[29] As climate change worsens the severity of such events, their financial and human cost will continue to grow. Worse still, by 2070, heat exposure could lead to twice as many deaths as air pollution if GHG emissions continue to increase.[30] The sooner the United States shifts to a clean, low-carbon energy system—with help from unparalleled investments through the Infrastructure Investment and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Law, and the Inflation Reduction Act (IRA)—the faster we can moderate the risks to our communities and damage to property from the effects of climate change.

The clean, low-emissions, energy-efficient technology innovations that can help mitigate further climate change can also help communities adapt and be more resilient to the effects of extreme weather. In Puerto Rico, the Federally Qualified Health Centers that used solar power remained open during an island-wide power outage in April 2022.[31] And in Atlanta, a study found that a single-family home built to high energy-efficiency standards would remain habitable for five times longer than a typical home during a seven-day cold event.[32] Taking further action to make buildings across the country more resilient could save countless lives during future power outages and extreme heat and cold events.

Building an Independent Energy System That Is Reliable, Resilient, and Secure

Energy innovations will not only help meet growing electricity demands, but also guard our grid, supply chains, and other critical infrastructure against the threats posed by volatile markets, cyber attacks, terrorism, and instability abroad.

Recently, many communities have begun managing energy demand and supply more effectively and in real time to mitigate risks to the grid. For example, modernized grids can incorporate small-scale electricity generation and storage devices, known as distributed energy resources (DERs), to become more resilient to extreme swings in energy use and prevent natural or human-caused outages. With the latest technologies, we can even use EVs to provide power to buildings in an emergency.

Energy innovations will also strengthen our national security—clean energy for our homes, businesses, and transportation system can be produced right here in the United States, protecting our energy system from disruptions caused by international conflicts and hostile entities. A reliable energy system requires a secure supply of critical materials, many of which are currently sourced from other continents and sometimes less stable regions. Process and technology innovation can help American industry source more of these materials domestically, use them efficiently, and even find viable alternatives with fewer risks. In doing so, industry will be able to minimize or even mitigate the negative impacts of extracting critical materials on local communities and the environment.

Workers install rooftop solar panels. *Photo courtesy of Joe DelNero, NREL*

EERE At Work – Delivering the Benefits of Energy Innovation

EERE and Energy Innovation

EERE oversees implementation of a nearly $3 billion annual budget to advance the applied research, development, demonstration, and deployment of projects that support the adoption and commercialization of energy innovations. These innovations power our grid with low-carbon renewable energy, create sustainable transportation systems, reduce energy consumption and GHG emissions from our buildings and industries, and drive growth and improvement in domestic manufacturing and supply chains.

In addition to its critical role in the development of energy innovations that Americans use at home and at work, EERE devotes considerable resources to our most complex energy challenges. From aviation fuel to cold-climate heating to heavy industry, EERE is using every method at its disposal to clean up the most emissions-intensive sectors of our economy and prepare them to thrive in the 21st century energy economy. The success of this work would not be possible without the direct support and collaboration of partners in federal, state, and local government; communities across the country; academia; and the private and nonprofit sectors. Our partners include:

- The **17 DOE national laboratories, other offices within DOE, and other federal agencies**, with whom EERE partners to deliver high impact federal initiatives such as the eight Energy Earthshots™, which push the boundaries of energy innovation to accelerate technology breakthroughs. This includes close coordination with the National Renewable Energy Laboratory (NREL), where EERE is responsible for the bulk of research and operations.
- **State and local governments**, which help EERE provide information and expertise on the energy options that work for their constituents through programs such as the Renewable Energy Siting through Technical Engagement and Planning (R-STEP) program, where EERE provides states with funding and technical assistance for large-scale renewable energy siting.
- **Colleges and universities**, where EERE provides substantial assistance for both faculty and students. Since 2021, EERE has provided over $302 million in funding to 106 institutions of higher education across the country to advance R&D and technical assistance in energy innovation. EERE also funds on-campus programs, such as DOE's Collegiate Wind Competition, that help prepare college students for jobs in the energy economy.
- **Workers and organized labor**, who are the backbone of a just transition to clean energy and a low carbon economy. EERE provides and funds various workforce development activities, such as, such as the Battery Workforce Initiative, Clean Energy Innovator Fellowship program, and Energy Skilled program. These programs support workforce development and provide pathways to good-paying jobs, many of which do not require a college education and protect the right to collective bargaining.
- **Private sector companies**, who co-invest and partner with EERE to develop and scale energy innovations. Since 2019, the value of EERE's financial assistance awards with the private sector has exceeded $2.5 billion, with $1.4 billion of federal investment being complemented with $1.1 billion in private capital. EERE non-financial assistance programs also help companies bridge technical and process gaps needed to advance energy innovations. For example, EERE's Better Buildings Initiative™ has helped organizations save more than $15 billion, avert 155 million tons of GHG emissions, and reduce water use by 14 billion gallons by adopting energy efficiency technologies and practices.[33]

EERE leadership visit a wind turbine testing facility at NREL. *Photo courtesy of Werner Slocum, NREL*

- **Local communities and community-based organizations**, who work with EERE to understand the impacts and opportunities from adopting energy innovations that work best for them. For example, the Energy Transitions Initiative Partnership Project (ETIPP) works alongside remote and island communities seeking to transform their energy systems and increase energy resilience.

EERE's Work and Achievements

Working with and through its partners, EERE has delivered tangible, measurable benefits for millions of Americans, and provided a springboard to continue advancing the benefits of energy innovation. Below are a few examples across a range of projects to show the depth and breadth of EERE's achievements in recent years.

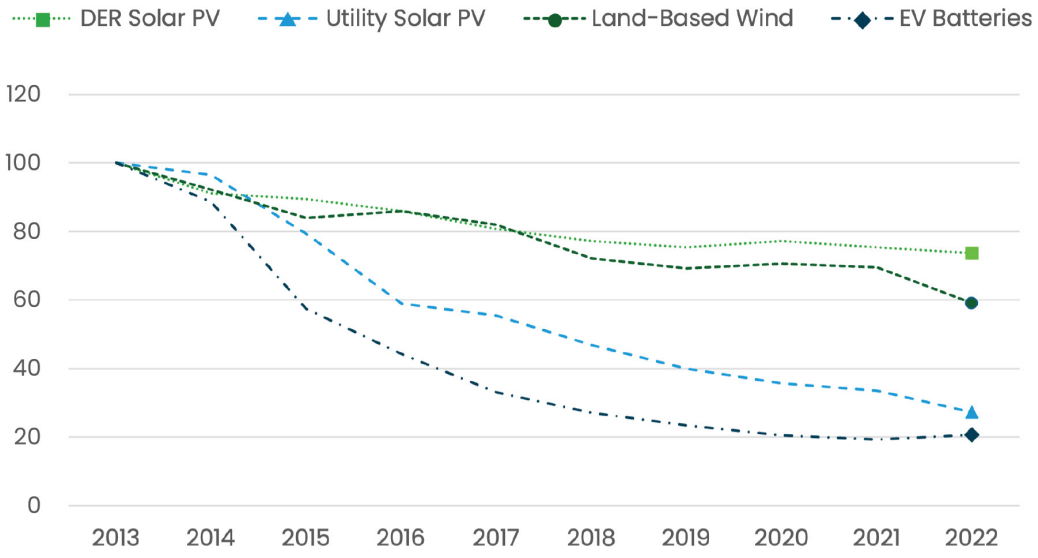
1. Breakthroughs in energy innovation have and will continue to transform our economy and society. Many of today's groundbreaking energy innovations have emerged directly from EERE's work on the **invention, development, and testing of new technologies**, for example:

    - EERE is funding the discovery and invention of new drilling and reservoir creation technologies and methodologies that can deliver efficient, low-cost geothermal energy. Following several partnerships with EERE, Texas-based clean energy startup Fervo Energy completed a successful well testing of their enhanced geothermal system (EGS) concept. This breakthrough in EGS commercialization can enable access to enough clean geothermal power to supply more than 100 million American homes once deployed at scale.

- Working with the American Battery Technology Company (ABTC), EERE has helped develop a new technology that enables the extraction of lithium from claystone, a sedimentary rock. Lithium is a critical material for the manufacturing of batteries that power consumer electronics, EVs, and the electric grid. Further evolution of this technology could enable ABTC to extract and refine enough battery-grade lithium in the United States to power 5 million EVs per decade, strengthening our domestic supply chains at a time when demand for batteries is increasing rapidly.
- EERE's funding is directly supporting private sector innovation. EERE-funded patents have had a significant influence on later patents owned by major companies such as General Motors (114 EERE-funded patent families), General Electric (105 families), Novozymes (91 families), and Caterpillar (63 families). In fact, almost 1,000 patents have resulted directly from EERE funding, which has helped fill research gaps in areas such as large-scale concentrating solar power, reducing biomatter into fuel, heat pumps, hydrogen storage, and drilling technologies.

2. Following the invention, development, and testing of new technologies, EERE helps **bridge the gap to commercialization**, by reducing both technical and adoption risks, increasing a technology's adoption readiness, and making sure these energy innovations are successfully transferred from the lab to the street as they are prepared for widespread use. For example:
   - EERE works with entrepreneurs to form, launch, and scale new companies that leverage transformative energy technologies. EERE's Lab-Embedded Entrepreneurship Program (LEEP) helps the developers of early-stage clean energy startups and emerging technologies access the world-class resources at DOE national labs to increase functional performance, drive capital flow, and bring their ideas to market. LEEP has delivered financial and in-kind support to 176 innovators who have created 154 new businesses, 97% of which were acquired or are still successfully operating. Since its launch in 2015, LEEP has generated $2.73 billion in follow-on funding, created 2,343 jobs, and delivered over 40 times return on investment for taxpayers.

Figure 3: Decline in costs of select energy innovations, 2013–2022, indexed to 100

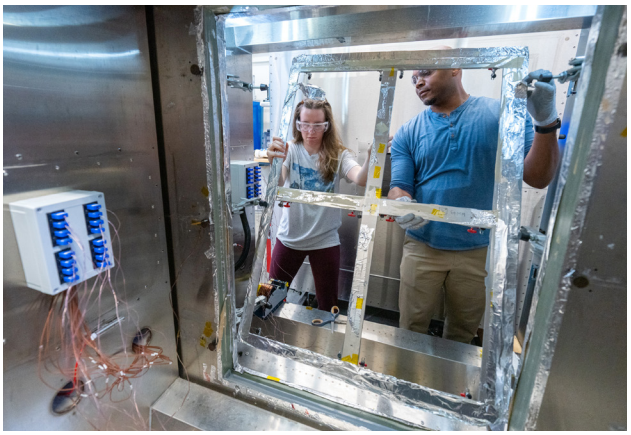


Source: Lawrence Berkeley National Laboratory, Argonne National Laboratory

- EERE forges successful partnerships with some of the world's largest companies to bring cutting-edge research and development to their products and operations. Through the SuperTruck 2 program, EERE partnered with truck manufacturers in the United States to develop significantly more efficient freight vehicles. All participants achieved more than 100% freight efficiency increase relative to 2009 levels, and these improvements are now being incorporated into new vehicles. For example, in 2023 Volvo debuted a truck that achieves a 134% increase in efficiency over a 2009 baseline. These types of public-private partnerships are turning technical possibilities into real-world, scalable products and technologies.
- EERE partners with companies across the country to drive innovation in the industrial sector and expand their capacity to manufacture cutting-edge products in the United States. Together with Lincoln Electric, EERE identified an opportunity to develop and demonstrate an alternative means of manufacturing metallic components needed for hydropower, wind energy, nuclear energy, and other zero-emissions technologies. Building off EERE's support and funding, Lincoln Electric opened a new 65,000 square foot manufacturing facility in Cleveland, Ohio, that positions the company to compete against similar manufacturers around the globe.

3. Even after the successful development and deployment of energy innovations, there are opportunities to make them better. EERE drives continuous improvement to **make technologies and processes cheaper and more effective**, which in turn makes them more useful and affordable for American households and businesses. For example:

    - Through ongoing research and partnership with DOE national laboratories, universities, and industry, EERE has played a critical role in driving down delivered costs for a broad range of energy innovations. Building off decades of success, in just the last 10 years costs have declined significantly for many technologies including distributed solar (down 26%), onshore wind (down 41%), utility-scale solar (down 73%), and EV batteries (down 79%). Making these energy innovations more affordable can directly increase adoption. For example, the reduction of EV battery costs has played a significant role in EVs accounting for 16.3% of all new light-duty vehicle sales in 2023, a 500% increase in less than 10 years.[34]



Pictured: EERE and NREL building technology researchers.
Photo courtesy of Werner Slocum, NREL

    - EERE also works to drive continuous improvement in the functional performance of many technologies, appliances, and household items that Americans use every day. Even for simple, well-established technologies like windows, EERE has driven major improvements that provide tangible benefits to building owners and occupants. Decades of EERE-supported research and industry partnerships have led to the development, deployment, and commercialization of energy-efficient, thin triple-pane windows that are 500% more efficient than the 1970s-era windows still present in many buildings today. These efficient windows lower utility bills and make buildings more comfortable.

4. Through its industry partnerships, technical assistance, and deployment of funding, EERE enables the **wider adoption of cutting-edge energy innovations**. Below are a few examples of EERE's work to bring affordable, effective energy innovations to consumers and industry:

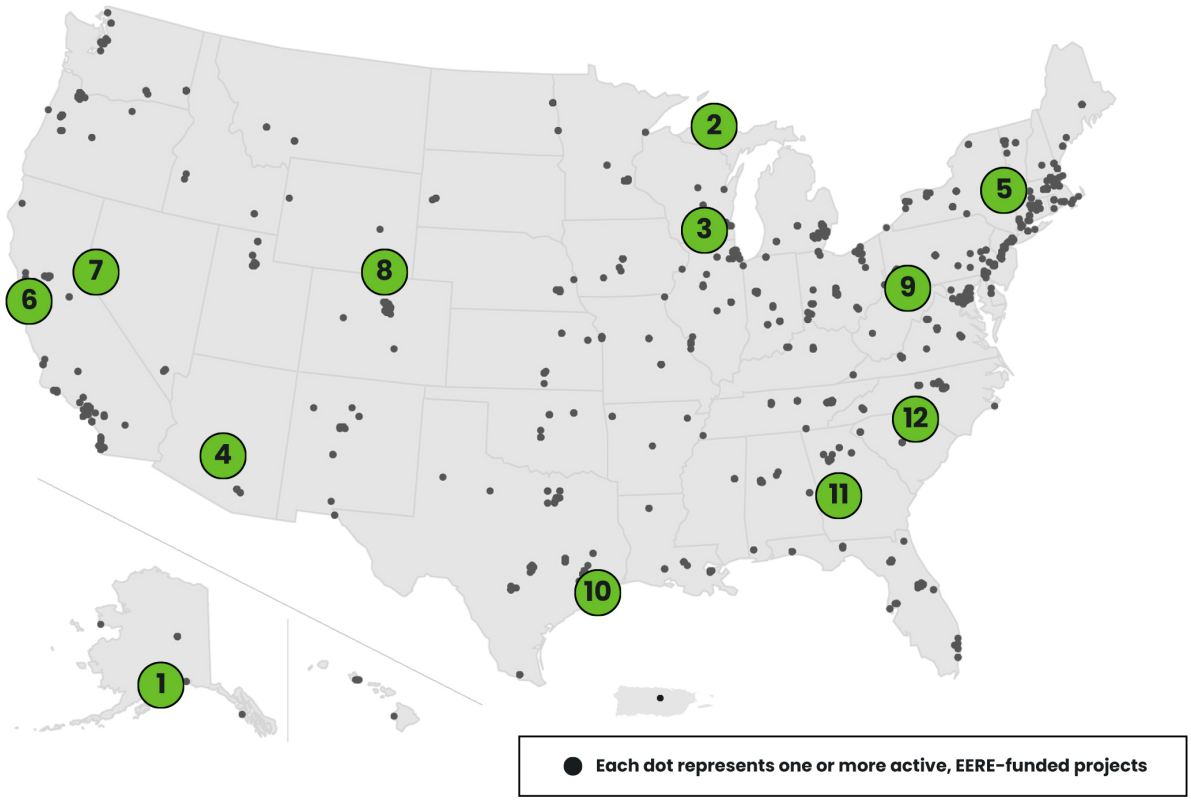
- Through the Clean Cities and Communities partnership, EERE is advancing the nationwide deployment of affordable, efficient, and clean transportation. The program, which provides partnership, funding, technical assistance, online tools, and other information resources to urban, suburban, and rural communities across the country, has helped place more than 1.6 million alternative fuel vehicles on the road, saved 14 billion gallons of gasoline, and reduced GHG emissions by 72 million tons.[35] This work advances U.S. energy resilience and reduces vehicle emissions while supporting regional economic development and job growth.
- EERE is also working to support and speed up the adoption of new fuel technologies that will help airlines significantly reduce their emissions. With SAF now a safe and proven "drop-in" replacement for traditional jet fuel, scaling the supply of this biofuel to meet rapidly growing airline demand is essential. EERE's work has helped grow the domestic supply of SAF from less than 5 million gallons in 2018 to more than 25 million gallons in 2023, and based on industry announcements, the United States will have 3 to 5 billion gallons of production capacity by 2030.[36] Since 2021, EERE has awarded $151 million in funding for SAF projects—matched by $156 million in private sector funding—including funds for a demonstration-scale SAF production facility.
- Through its National Community Solar Partnership (NCSP), EERE is bringing the economic and environmental benefits of solar energy to those who could not otherwise access it because they rent their home, live in a multifamily building, or have unsuitable roofs, for example. NCSP is achieving this by growing community solar, which provides solar energy generated at local facilities shared by multiple community subscribers. NCSP has helped grow the installed capacity of community solar from less than 1 GW_{AC} in 2013 to more than 7.2 GW_{AC} in 2023, enough to power 1.7 million U.S. households. NCSP has been especially focused on bringing community solar to low-income and under-resourced communities to help reduce energy burden, increase resilience, and create equitable workforce development opportunities.

Building Momentum

Working effectively with its research, industry, and community partners, EERE has made immense progress in advancing the development and use of energy innovations. But much more needs to be done to reap the full benefits of the global shift to a clean and efficient energy future. EERE will continue to use its resources, research capabilities, and experience to position the United States as the uncontested leader in this arena. In the graphic below, 12 projects—selected from EERE's almost 2,000 active awards—illustrate the ongoing breadth and depth of EERE's work to deliver future benefits from energy innovation for all Americans.

Building off the achievements highlighted in this report, EERE will continue to help lower energy costs for families and businesses across the United States; strengthen and expand domestic manufacturing and its associated supply chains; make our electric grid and sources of clean energy safer, more resilient, and more reliable; and deliver the health and environmental benefits of drastic GHG emissions reduction. Even after the United States decarbonizes its grid, there will be need for continuous innovation, and EERE will continue to research, develop, and help deploy solutions to tomorrow's challenges.

Figure 4: A map of EERE's almost 2,000 active awards across the country, with 12 projects highlighted



1 EERE's Energyshed program helps communities understand the benefits of using locally generated energy and identify new clean energy projects to meet local needs. In Alaska, the program is working with twelve underserved communities to gain consensus for three large scale energy projects in collaboration with regional Native corporations and technical advisors.

2 In support of the domestic battery manufacturing industry, EERE is working with a university, a mining company, and a car manufacturer to develop and demonstrate a process to recover battery materials from end-of-life lithium-ion batteries and battery scrap materials. This work could enable the future use of recovered materials in new battery manufacturing.

3 America's 129 million buildings use 40% of the nation's energy. EERE will use $61 million of funding across 10 projects to develop "Connected Communities" of grid-interactive, efficient buildings that use advanced analytics to reduce peak energy demand and lower utility bills and grid system costs. In Madison, the program is being rolled out through public, private, and utility partnership.

4 In 2023, DOE announced that Arizona State University would lead the seventh Clean Energy Manufacturing Innovation Institute. The institute will use up to $70M in federal funding over five years to research, development, and demonstration projects to electrify process heating and decarbonize the industrial sector.

5 **EERE is partnering with General Electric to develop more efficient, smaller, and lighter-weight wind turbine drivetrains that will make wind power more affordable and efficient. EERE has committed $20 million to help build and test a new prototype that, among other benefits, eliminates the need for foreign-sourced rare earth materials in such products.**

6 **Building off a successful pilot in San Diego, EERE will continue to fund California-based clean energy company CalWave as it scales up technology that could eventually lead to multimegawatt wave energy farms delivering clean electricity to coastal communities and power grids.**

7 **To harness the huge potential of geothermal energy, EERE's INGENIOUS project is funding work to accelerate discoveries of new, commercially viable hidden geothermal systems in the Great Basin Region while reducing the exploration and development risks for all geothermal resources.**

8 **EERE is working with industrial giant Caterpillar to demonstrate a first-of-a-kind stationary hydrogen fuel cell system that can provide backup power to data centers. This demonstration, at a Microsoft site in Wyoming, is a leap forward in hydrogen fuel cell technology and could help address the growing energy and resiliency needs of data centers across the country.**

9 **Steelmaking is energy- and emissions-intensive, requiring high process temperatures and a source of carbon to drive reactions. In Pennsylvania, EERE is funding Carnegie Mellon University to further advance the use of hydrogen-based technologies that could deliver breakthroughs in decarbonized steel manufacturing.**

10 **EERE's Advancing Equity Through Workforce Partnerships program is working to expand solar deployment while supporting an inclusive workforce. In Texas, the program will develop a pre-apprenticeship program to recruit, train, and retain a diverse workforce in construction trades needed by utility-scale solar energy projects, with a focus on increasing employment in rural areas.**

11 **To continue scaling up SAF production, the DOE awarded $108 million in funding to 13 SAF projects in 2023. The largest of these awards is for Georgia-based AVAPCO, who will build a biorefinery that produces 1.2 million gallons of SAF per year using wood chips, scaling up a production process developed through ongoing support from EERE.**

12 **The DOE is backing PowerAmerica–a semiconductor research institute–with $150 million to drive innovation in power electronics products and systems. This work could lead to dramatic energy savings in industrial processes, data centers, and consumer devices; increase the driving range of EVs; and help integrate renewable energy onto the grid.**

Includes active awards as of May 30, 2024. Location of project is approximate. Some discrepancies may exist between the final location of the funded project and the funded entity.

Deep Dive on EERE's Achievements

The data and case studies in this section of the report document EERE's recent successes in delivering the benefits of energy innovations to communities, companies and industry across the country.

Utility Solar

Driving Down Costs and Rapidly Expanding Capacity of Utility-Scale Solar

Solar energy is one of the fastest-growing industries in the country, with ongoing cost reductions helping to accelerate deployment and create thousands of new jobs. In 2023, the median system price of large-scale, utility-owned photovoltaic (PV) systems fell to $1.27/watt alternating current (W_{ac})—an 80% reduction since 2010.[37] Utility-scale solar and utility-scale solar plus storage systems are now among the least expensive energy generation sources in the country. These cost reductions have helped push America's total installed PV capacity to 177 gigawatts direct current (GW_{dc}), 60–70% of which is utility-scale solar, and solar energy now supplies 6% of the nation's annual electricity.[38]

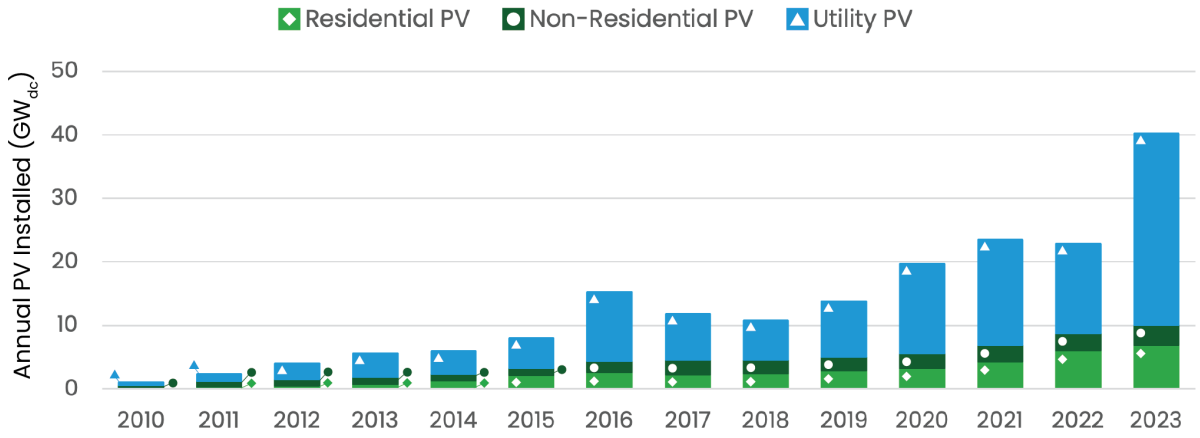
EERE technology investments have helped make this happen, driving down hardware costs, improving system reliability, and reducing soft costs for large-scale solar energy systems. EERE's Photovoltaic Research and Development annual funding program alone has invested more than $150 million since 2016 to reduce the cost of solar system components, such as inverters, connectors, cables, racks, and trackers.

To further expand solar deployment, EERE will continue to invest in programs that decrease solar costs and improve performance, reliability, and resilience. For example, the Interconnection Innovation e-Xchange (i2x)—which seeks to facilitate transmission connections for solar, wind, and storage—is developing roadmaps for improving interconnection practices, the first of which was released in April 2024. i2x has already engaged more than 530 organizations, held more than 20 solution-exchange meetings, and provided workforce training for grid engineers.

Reducing Financial and Environmental Costs for New Utility-Scale Solar Development

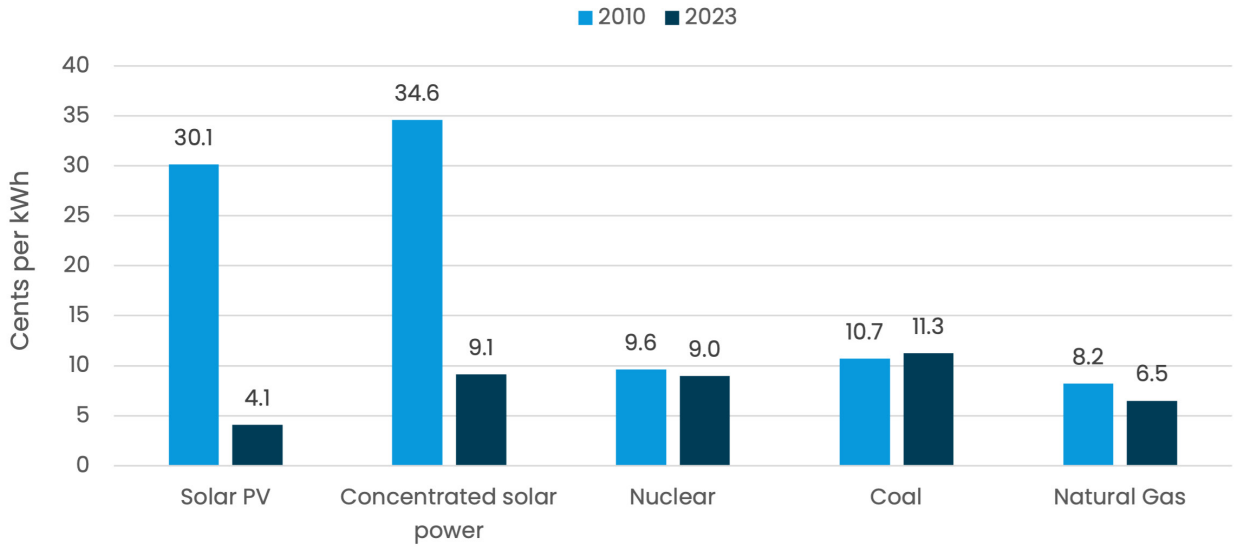
EERE investments are helping drive down the costs of new utility-scale solar projects. EERE has supported the development of innovative technologies that reduce overall system costs and mitigate the risks of grading (or flattening) land for solar developments.

Figure 5: U.S. annual solar PV installations by market segment, 2010–2023



Sources: Wood Mackenzie/SEIA: U.S. Solar Market Insight: 2023 YIR. EIA "Electric Power Monthly" Tables 6.1.A and 6.1.B

Figure 6: Levelized cost of electricity, 2010 vs. 2023



Source: Lazard: Levelized Cost of Energy Analysis — Version 16.0. April 2023. National Renewable Energy Lab: 2023 Annual Technology Baseline (ATB). 2023.

These technologies are now being used by companies such as Nevados Engineering, who have developed a product and installation process that allows solar arrays to be installed on uneven terrain, greatly reducing the need for grading and reducing the environmental impact of the system. Last year, the company signed long-term deals with solar developers to install trackers on 8 GW of utility solar developments in rural Virginia and Pennsylvania and was awarded the 2024 Virginia Governor's Environmental Excellence Awards gold medal.

With the help of EERE funding, Terabase Energy developed a new field factory that brings automation to solar power plant installation, using robotic arms to lift heavy solar panels and connect them to solar trackers, saving time, energy, and money. In 2022, Terabase's work culminated with an open-field demonstration of solar plant construction in Texas, where the Terafab system built 10 MW of a 400 MW site. The demonstration led to $44 million in follow-on investment from the private sector and enabled Terabase to complete the first commercial deployment of its Terafab system in Arizona in November 2023.

Making Concentrating Solar-Thermal Power Cheaper and More Powerful

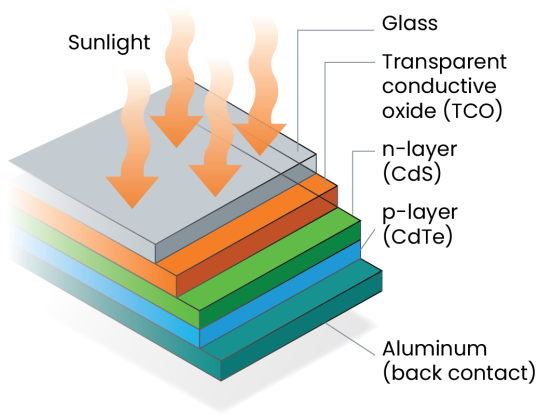
Concentrating solar-thermal power (CSP) technologies are used to generate electricity by converting energy from sunlight to power a turbine, and the same basic technologies can also be used to deliver heat to a variety of industrial applications. EERE has played a critical role in the development and advancement of this technology, with the levelized cost of CSP already falling from 21¢/kWh for first-generation plants with no thermal energy storage (TES) in 2010, to around 9.5¢/kWh (with TES) today, according to cost models.[39]

EERE will continue to improve the performance, reduce the cost, and improve the lifetime and reliability of materials, components, subsystems, and integrated solutions for CSP technologies, and has invested more than $150 million in the development of the next generation of CSP systems, with a first-of-its-kind demonstration plant at Sandia National Laboratories scheduled to begin operations in January 2025 (pictured on page 18). EERE is also investing in a project managed by Heliogen, which

The next-generation CSP tower at the National Solar Thermal Test Facility is scheduled to begin testing in early 2025. *Photo courtesy of Sandia National Laboratories*

will serve as a demonstration of an sCO_2 power cycle, integrated with TES. The project will operate at a turbine-inlet temperature of 600°C and use conventional, stainless-steel alloys widely available today. By generating operational data of a TES-driven sCO_2 power cycle, this project will accelerate the commercial adoption of this novel technology.

Figure 8: Illustration of the components of a cadmium telluride solar module



Developing Solar Panels with Lower-Cost and Shorter Supply Chains

Since the 1980s, EERE has funded universities and DOE national laboratories to develop cadmium telluride (CdTe) PV, which has a lower cost and a shorter, more secure supply chain than silicon-based PV. EERE investment in foundational materials research, product testing, and product validation against industry standard qualification tests have positioned the United States as the global leader in CdTe PV.

These EERE-funded advances in CdTe PV have had a significant impact on the PV industry. They have helped establish 6.4 GW of domestic CdTe manufacturing capacity, including production by the largest domestic PV module manufacturer and the largest CdTe manufacturer in the world, First Solar. As a result of IRA, another 7.9 GW in planned capacity has been announced, including an expansion by First Solar in Ohio (0.9 GW) and new facilities in Louisiana and Alabama (each 3.5 GW). Today, around 20% of PV modules deployed in utility-scale systems are made of CdTe, and EERE will continue to invest in initiatives that ensure the United States is producing cutting-edge, cost-competitive CdTe PV products.

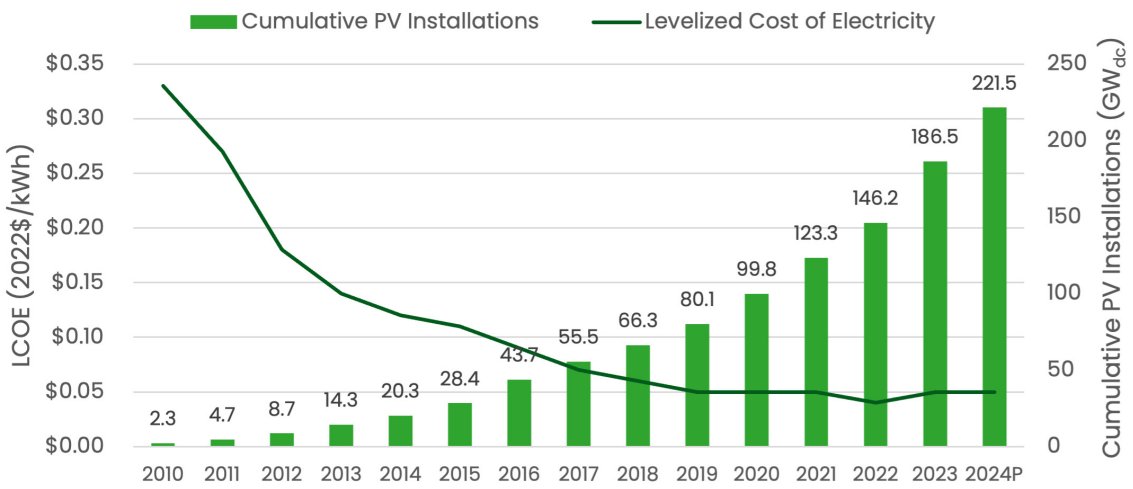
Distributed Solar

Bringing Affordable, Clean, Solar Power to American Homes and Families

Since 2005, annual installations of residential PV systems have increased by around 36% per year, and at the end of 2023, there were approximately 4.7 million residential PV systems in the United States.[40] These residential systems save homeowners money, create local jobs, and support America's shift to a clean energy system. At present, however, only 3.3% of American households own or lease a PV system.

For over a decade, EERE has been accelerating the deployment of affordable, residential and commercial solar systems through funding and technical assistance, including the Solar Energy

Figure 7: U.S. solar PV deployment and system prices, 2010–2023 (actual), 2024 (predicted)



Sources: Wood Mackenzie/SEIA: U.S. Solar Market Insight: Q4 2023. National Renewable Energy Lab System Advisor Model was used to depict electricity costs as the levelized cost of energy (LCOE) for a utility-scale system in a mid-America location with average solar resource, without benefit of tax credits.

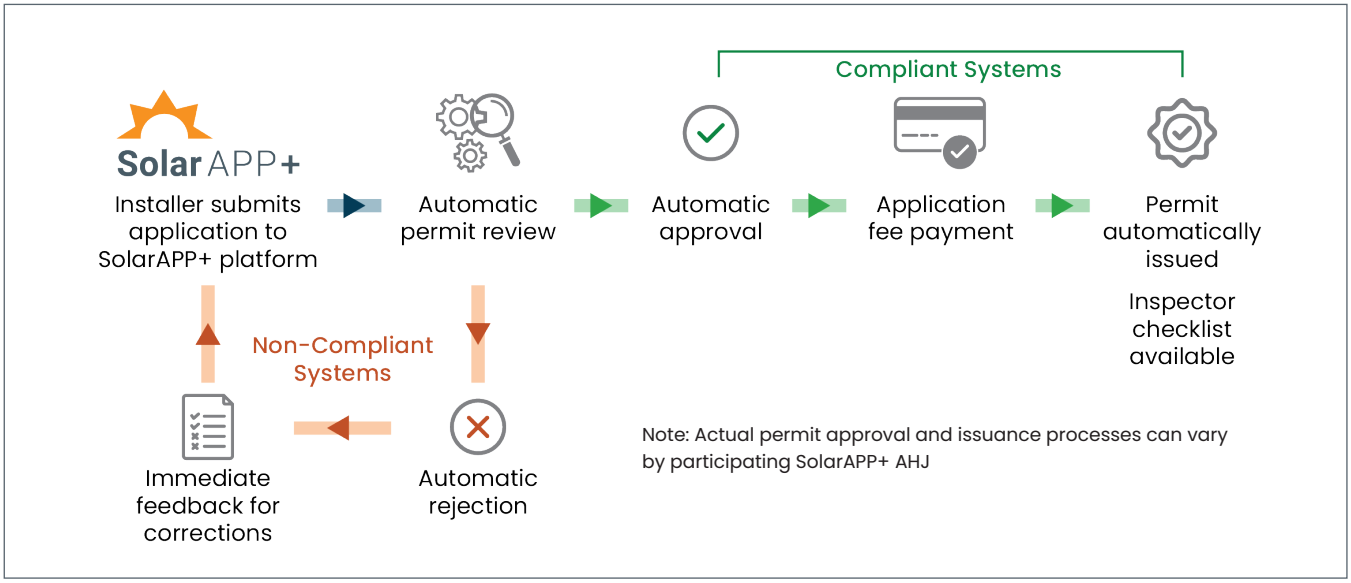
Innovation Network, which assembles multi-stakeholder teams that research and share solutions to real-world challenges associated with solar energy adoption. EERE's work has enabled a broad decline in solar costs and corresponding increases in capacity and also helped ensure that the benefits of distributed solar extend to every corner of the country. In Hawaii, for example, EERE-funded work has allowed more than 2,500 Hawaiian Electric customers to connect their residential solar systems to the power grid—a feat that the utility had once considered impossible.

Accelerating Solar Installations Across 520 Cities, Towns, Counties, and Regional Organizations

Expanding the number of households and businesses benefiting from solar energy means overcoming one of the biggest barriers to solar installation: siting and permitting. SolSmart, a national recognition and technical assistance program funded by EERE, helps local governments make it easier for residents and businesses in their communities to go solar and has been hugely successful in addressing this challenge, with installations of solar being 17% higher per month in SolSmart-designated communities compared to non-designated communities. To date, more than 520 cities, towns, counties, and regional organizations in 43 states, the District of Columbia, and the U.S. Virgin Islands have participated in the program.[41]

EERE is also overcoming solar installation challenges through its Solar Automated Permit Processing+ (SolarAPP+) web-based platform, which automates residential rooftop solar permitting for local governments and other regulatory authorities. Since the platform's launch in 2021, users have reduced the amount of time is takes to permit, install, and inspect a residential rooftop solar project by 31%, or about 14.5 business days. To date, 183 regulatory authorities have either implemented or piloted the platform.

Figure 9: Example of SolarAPP+ permit application and approval process



Source: National Renewable Energy Laboratory

Making Solar More Accessible and Equitable for Communities Across the Country

Many American households and businesses do not have access to solar energy because they rent, live in multi-tenant buildings, have roofs that are unable to host a solar system, or experience some other complicating factor. Community solar—local solar facilities shared by multiple community subscribers—provides these households and businesses with equal access to the economic and environmental benefits of solar energy generation.

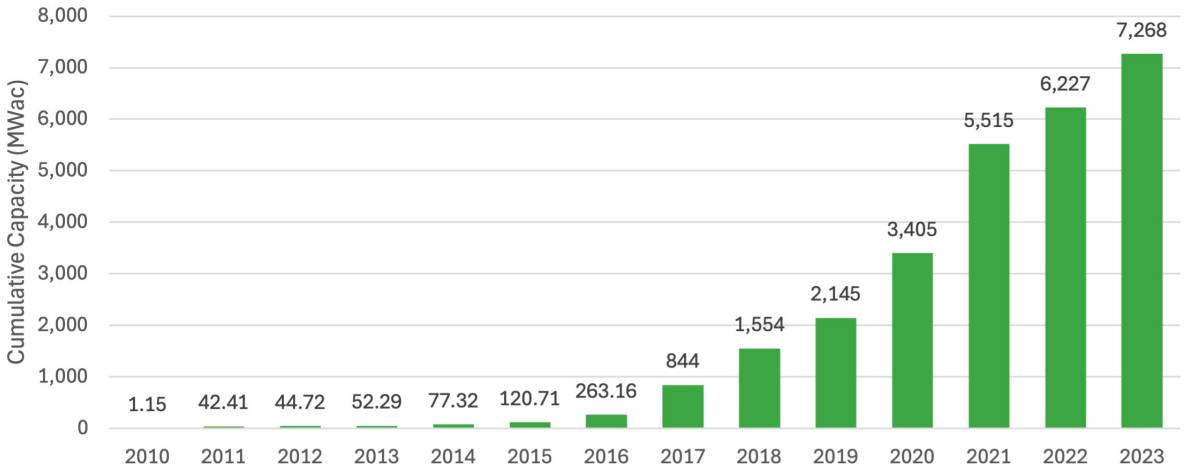
Through NCSP, EERE is ensuring that community solar provides cost saving, workforce development, resilience, and economic development benefits to communities across the country, and particularly to low-income households. At the end of 2023, there were more than 7.2 GW_{AC} of community solar capacity throughout the United States—enough to power approximately 1.7 million households. These projects also provided an estimated $187.4 million in annual bill savings to subscribers.[42] Community solar could eventually serve as many as 53.2 million households and 311,750 businesses who could not otherwise access solar energy.[43]

Bringing Resilient Power to Puerto Rico

In 2017, Hurricane Maria caused a devastating, seven-month power outage in Adjuntas, Puerto Rico. In the following years, Adjuntas installed two community-owned microgrids, which have helped ensure hundreds of residents have access to critical services when outages occur. An EERE-funded team at Oak Ridge National Laboratory developed and implemented an optimized microgrid controller to manage the electric power flow from rooftop solar-power generation, to battery storage, to critical load for 15 businesses, including a pharmacy, bank,

Photo courtesy of Maximiliano Ferrari, ORNL

Figure 10: Increase in U.S. cumulative interconnected capacity of community solar, 2010–2023



Source: WoodMackenzie, Community Solar Outlook H1 2024 (February 2024). NREL Sharing the Sun Project List, accessed 4/22/24. NREL. SolarTogether, Florida Power & Light, accessed 5/7/24. Sharing the Sun: Community Solar Deployment and Subscriptions (as of June 2023), NREL. SolarTogether, Florida Power & Light, accessed 5/7/24.

and bakery, within a network of microgrids. The laboratory is partnering with local community organizations to connect the two existing Adjuntas microgrids and extend electric service to more households for as long as possible, which will strengthen the resilience of these microgrids and provide more reliable power to Puerto Ricans.

Geothermal

Advancing Drilling Rate Improvements to Lower the Cost of Drilling Geothermal Wells by 50%

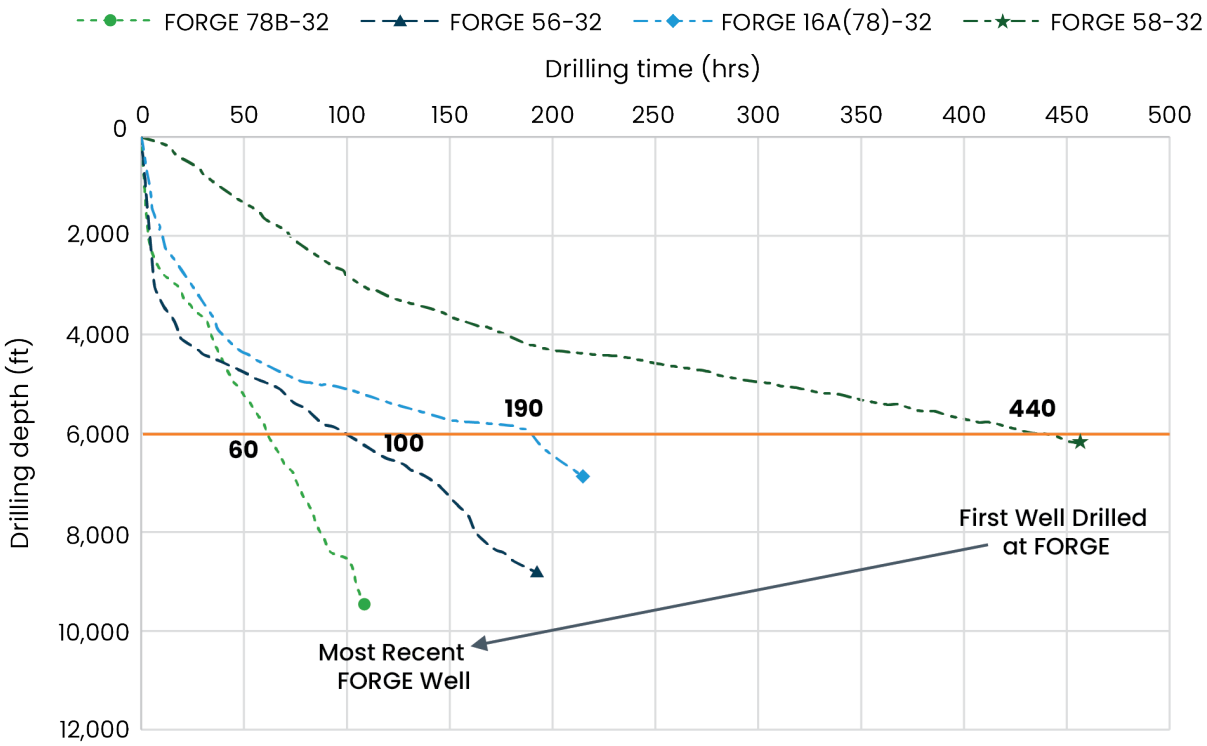
Enhanced geothermal systems (EGS) are critical to the energy transition. To expand deployment of EGS and unlock next-generation, clean geothermal technologies, the industry must substantially reduce drilling costs, which account for as much as 50% of development costs. The Frontier Observatory for Research in Geothermal Energy (FORGE), EERE's flagship EGS program, has demonstrated a seven-fold decrease in drilling time—from 440 hours to 60 hours at an equivalent depth of 6,000 feet.

In 2022, researchers at Texas A&M University trained FORGE in "limiter redesign" drilling methods, which had previously revolutionized the oil and gas industry. Limiter redesign allowed FORGE drillers to monitor for and remedy inefficiencies in drilling—addressing these inefficiencies in combination with the use of advanced drill bits produced the stunning 700% decrease in drilling time. The geothermal company Geothermal Resources Group has since used this method to drill two wells to an equivalent depth of 6,000 feet in the Salton Sea in less than half the time required to drill a well with conventional methods. An EGS startup, Fervo Energy, has reduced drilling costs by about 50% at its Cape Station Project in Utah, leveraging the breakthrough drilling process demonstrated by EERE and FORGE that is dramatically improving the commercial viability of next-generation geothermal power.

Identifying an Abundant, Secure, Domestic Source of Lithium in California's Salton Sea Geothermal System

The United States currently relies on imported lithium, and the global demand for lithium is increasing rapidly. An EERE study found that California's Salton Sea region could produce more than 3,400 kilotons of lithium—more than enough to support a complete, nationwide transition to EVs. In addition to quantifying the region's potential as a domestic lithium source, EERE's comprehensive assessment will inform the development of strategies for sustainable extraction while mitigating environmental impacts.

Figure 11: FORGE drilling data for four wells, drilling depth and drilling time



Source: University of Utah, Department of Energy

EERE's analysis also found that direct lithium extraction (DLE)—the process by which lithium is extracted from geothermal brines—is safe and efficient. Compared with current lithium mining processes, DLE emits almost no carbon dioxide, takes less time for extraction (only hours or days), has a higher recovery rate (70–90%, versus 40–80% for other methods), and requires less water per ton of lithium extracted. Extracting lithium from geothermal brines thus offers the opportunity to pair clean, renewable electricity generation with the retrieval of a critical mineral essential to the energy transition.

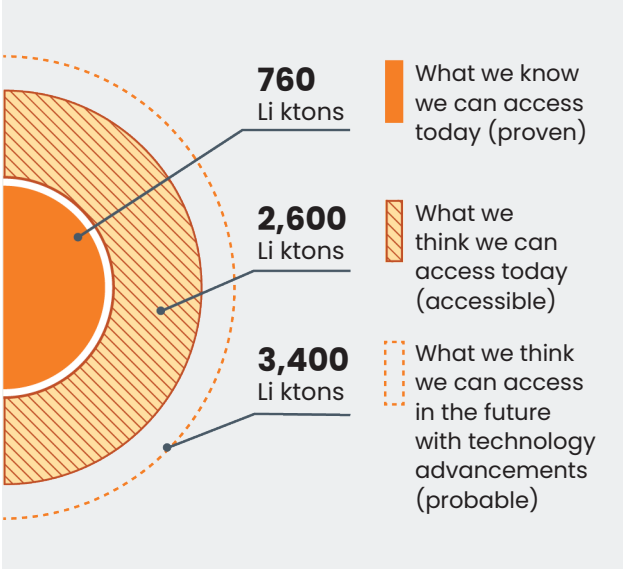
If technology advances can fulfill the Salton Sea's full potential, the United States will enjoy access to a secure, independent, and domestic source of this critical mineral with minimal risk of supply chain disruptions.

Expanding the Potential for Geothermal Power Production Through R&D Investments

The advancement of EGS as a unique source of clean, firm power hinges on our ability to create distributed, interconnected pathways through rock beneath the earth's surface. Adapting the oil and gas industry's cutting-edge stimulation technologies are essential to making this a reality, but successfully transferring these technologies to high-temperature geothermal environments requires continued research and breakthroughs such as FORGE's achievement in 2022.

The FORGE team successfully created an EGS reservoir in a large diameter (7 inches) and deviated (65 degrees) well at temperatures greater than 200°C. Private industry has taken notice of this technology breakthrough; in 2023, Fervo successfully demonstrated commercial EGS power

Figure 12: Estimates of the lithium brine resource at the Salton Sea Geothermal Reservoir



Source: Department of Energy. One ton of lithium has the same amount of lithium as 5.32 tons of LCE.

production at a project in Nevada, made possible by multi-zone stimulation advances borrowed from the FORGE site and their own, oil and gas adapted technology. The impacts of these investments continue to echo through the geothermal industry. In the spring of 2024, FORGE announced the successful connection of two wells using these technologies and techniques, demonstrating a replicable process that could expand geothermal power production across the country.

Building Momentum in the Pipeline of New Geothermal Development

In many ways, the best measure of the health of the U.S. geothermal industry is the parcel and leasing acreage available for the development of geothermal resources. EERE's championing of R&D, deployment, and permitting innovations has massively expanded the pipeline of near-term geothermal projects on public lands.

The Bureau of Land Management (BLM) at the Department of the Interior collaborates closely with EERE to improve geothermal permitting through initiatives like the Interagency Geothermal Permitting Working Group (IGPWG). The IGPWG is improving permit data collection and reporting, identifying stakeholder engagement best practices, and leveraging interagency technical resources.

Accessible land for geothermal energy has markedly increased across a number of states since 2020. Nevada set a record for a single geothermal lease sale in 2022 with nearly 193,000 acres leased, generating over $3 million in revenue. In 2023, Nevada held another auction that resulted in increases in both highest bid per parcel as well as per acre.

The Utah FORGE site is pictured during April 2024 stimulation activities. *Photo courtesy of Lauren Boyd*

Land-Based Wind

Lowering the Cost of Land-Based Wind Through Blade, Turbine, and Power Plant Level R&D

Since the early 1990s, EERE has been making wind turbines more efficient, cost effective, and reliable. Over time, EERE has worked closely with industry and the U.S. national laboratories to develop longer and lighter blades, more reliable drivetrains, and plant-level optimization solutions. With support from EERE, the average cost of land-based wind energy has decreased by 67% since 2009, while the total installed capacity of land-based wind energy has more than tripled. The total installed capacity of land-based wind energy reached 150 GW in 2023, while the average levelized cost of land-based wind energy decreased to $32/MWh.

As an early example of our high impact investments in wind technology, EERE collaborated with Knight and Carver's Wind Blade Division and Sandia National Laboratories to develop an innovative wind blade called the Sweep Twist Adaptive Rotor (STAR) which increased blade energy capture by 12%.[44] Decades later, EERE's achievements with Knight and Carver were a precursor to a range of improvements that are commonplace in today's wind turbine technology and blades, most notably bend-twist-coupled wind turbine blades and flatback airfoils. These technology advances, along with advanced controls, have enabled the production of longer, lighter, and cheaper wind turbine blades and ultimately, the growth of wind turbine rotor diameters, which in the United States now average more than 130 meters.[45]

EERE has also worked to tackle a significant wind industry challeng—gearbox failure rates—to improve reliability and lower the costs of wind power. Over the decades, EERE has awarded almost $50 million to projects that bolster gearbox reliability, resulting in design changes that were quickly adopted by industry and resulting in significantly reduced frequency of gearbox failures.[46] Moreover, workshops and meetings hosted by the National Renewable Energy Laboratory (NREL) and EERE spawned the Gearbox Reliability Collaborative, which has worked to drive down operations and maintenance costs by nearly 15% between 2018 and 2022 and more than 30% since 2008.[47] The Collaborative continues to meet and work today, with the prospect of further cost improvements in sight.

Supporting the Expansion of Wind Energy by Reducing Environmental Risks

To support the environmentally sustainable development of wind energy, EERE invests in innovative, cost-effective technologies to help understand and minimize risks to wildlife from land-based and offshore wind farms. The lower the risk, the more safely and quicky wind energy can expand.

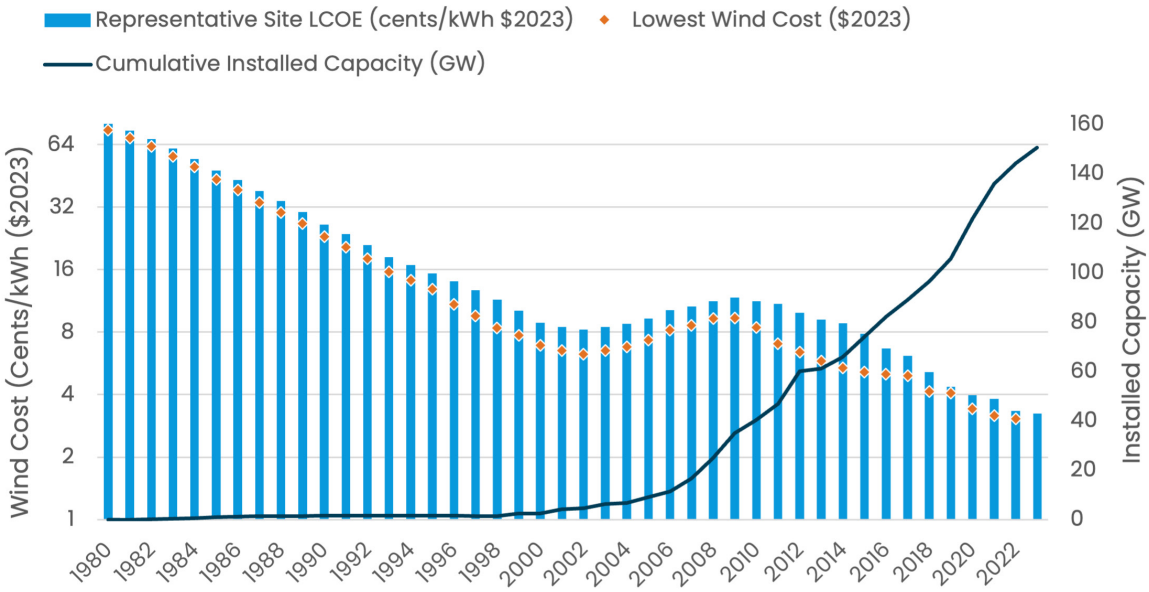
One such solution is the development of an ultrasonic bat deterrent technology, which EERE has supported from conception to commercial deployment at wind farms across the world. Since 2015, EERE has invested in improvements to the hardware and functionality of bat deterrent technology that can reduce bat fatalities by 50%.[48] While work continues in this important field of research, domestic wind developers have since adopted the technology in regions where bats are particularly at risk for collisions with wind turbines.

Boosting Confidence in Performance, Safety, and Cost Effectiveness of Small and Medium Wind Turbines

Cost reduction and power performance improvements are critical for small and medium wind turbines to remain an economically viable distributed energy option. In addition, third-party certification is necessary to commercialize turbine design, to provide consumers with confidence that they will operate as advertised, and to qualify for federal and state incentives. Since 2013, the total installed capacity of U.S. distributed wind energy has increased by over 47% to 1.1 GW, with 29 MW installed in 2022.

The EERE-funded Competitiveness Improvement Project (CIP) provides financial and technical assistance to manufacturers of small and medium—sized wind turbines to help them increase energy production, reduce hardware

Figure 13: U.S. wind energy cost and cumulative installed capacity, 1980–2023



Source: Berkeley National Laboratory, National Renewable Energy Laboratory

costs, and accelerate the commercialization of next-generation technologies. Since 2012, CIP has awarded over $15.4 million in funding to 64 subcontracts and 26 companies. With the support of the CIP, Bergey Windpower redesigned their 10-kW turbine to 15 kW, doubling the annual energy production of the turbine and reducing the LCOE by 50%, and positioned the industry for new growth in the 2020s. The ability of the CIP program to successfully drive down cost, as was achieved by Bergey Windpower, has been especially critical for positioning small turbines to compete with other distributed generation resources in rural and agricultural areas with good wind resource and significant localized load.

Offshore Wind

Growing the Offshore Wind Energy Pipeline Through Ongoing R&D Investments

Over the last decade, the domestic offshore wind pipeline has grown dramatically, with an estimated capacity of over 80 GW today. Offshore wind could ultimately provide over 4,000 GW of generating capacity and serve as a foundational source of clean energy for highly populated coastal regions. EERE's R&D portfolio has been critical to helping the industry overcome key barriers to offshore wind deployment, including lowering the LCOE, addressing potential impacts on wildlife, and tackling technical challenges related to project installation and grid interconnection. EERE has also been working to coordinate supply chain planning and development between states, and today there are 17 announced offshore wind manufacturing facilities in development with over $4 billion of investment planned.

A key initiative supporting the offshore wind industry is the EERE-funded National Offshore Wind Research and Development Consortium. This public-private partnership leverages government and private sector funds to address wind plant technology advancement, wind resource and physical site characterization, and technical solutions related to installation, operations, maintenance, and supply chains. In 2022, the Consortium worked with Crowley, a U.S.-based logistics, marine, and energy solutions company, to achieve compliance with the Jones Act, a law that regulates shipping in and among U.S. ports. Achieving this compliance, specifically for wind-turbine installation vehicles, has been a notable

challenge for the offshore industry and project developers. Crowley implemented its new method to build the South Fork Wind Farm off Long Island, NY, in 2024, helping bring online 132 MW of offshore wind power, enough to power around 70,000 homes. As a maritime union employer, Crowley also utilized members of the Seafarers International Union to support this project.

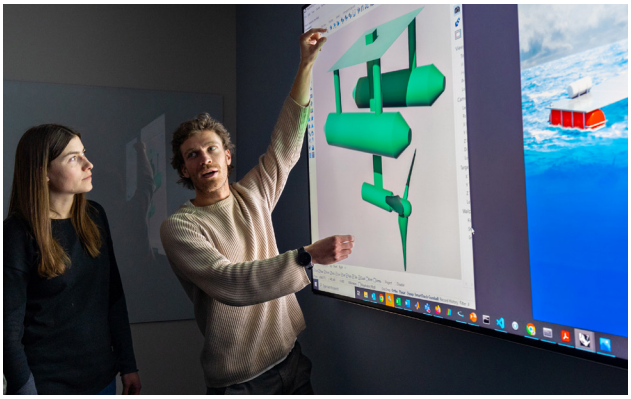
Ensuring the Reliability of Larger Blades for Boosted Offshore Wind Power

Along with investments in blade technology, EERE has also achieved success with its investments in blade reliability testing in support of the upscaling of offshore wind projects. In 2011, DOE invested more than $27 million to build the Wind Technology Testing Center (WTTC) facility in Boston, MA.[49] Initially able to test blades up to 90 meters in length, WTTC can today test even larger blades—up to 120 meters in length—thanks to EERE funding. Blades of this size can help expedite the deployment of offshore wind as larger blades help lower project installation costs.

Marine Energy

Marine energy—harnessed from the natural movements of waves, tides, and currents from rivers and oceans—can increase the reliability and resilience of our power grid. As the United States adopts more clean energy, it will be important to utilize all avenues of marine energy's potential.

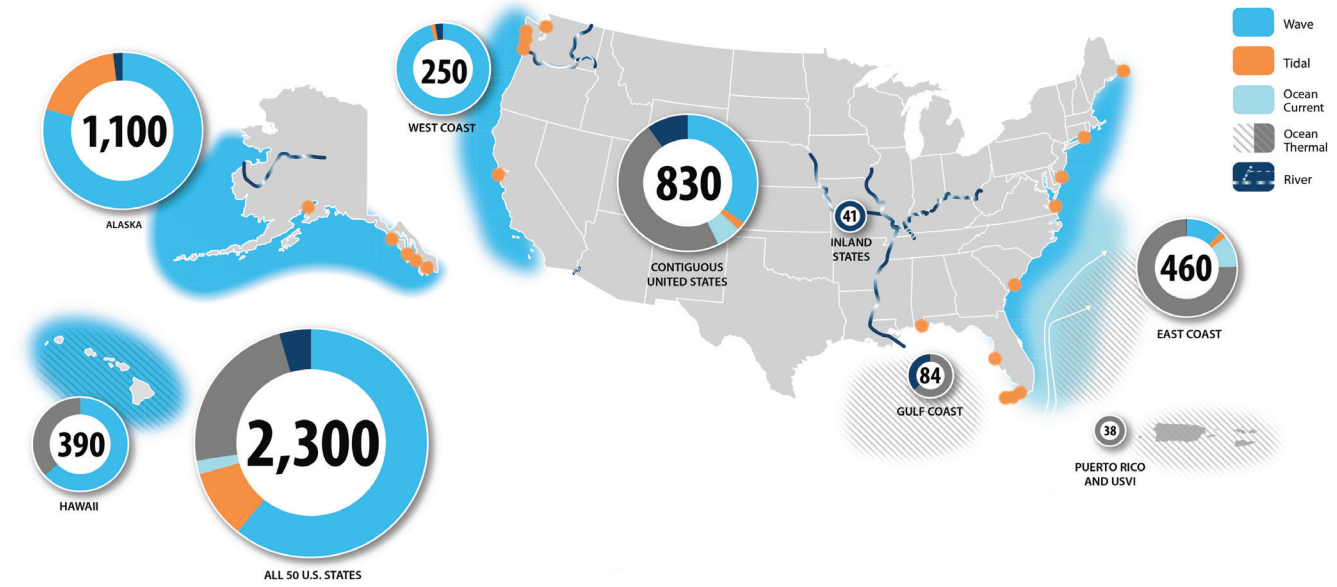
The opportunities to harness these resources are abundant. The total available marine energy resource in the United States is equivalent to approximately 57% of all U.S. power generation in 2019. If only a portion of this potential is realized, marine energy could significantly contribute to the nation's energy supply.



Researchers work on marine energy technology design. *Photo courtesy of Werner Slocum, NREL*

The Massachusetts Clean Energy Center's Wind Technology Testing Center (WTTC) offers a full suite of certification tests for utility-scale turbine blades and blade sections. *Photo courtesy of WTTC.*

Figure 14. Technical power potential of U.S. marine energy resources in TWh/year.



Source: National Renewable Energy Laboratory

Completing First-of-a-Kind Marine Energy Technology Demonstrations

With EERE's support, several marine energy technologies and companies have achieved sizeable performance improvements, set new records for testing duration and survivability, and developed devices that can provide power and water to remote, coastal, and island communities.

CalWave, a wave energy developer and recipient of EERE funding, completed the longest marine energy technology deployment to date in the state of California in 2022. Throughout this 10-month deployment, CalWave's system proved its durability by surviving two extreme storms without intervention and remaining operational for 99% of the deployment time. The data collected from this deployment will be used to inform design and installation procedures for CalWave's large x100 device, which could generate more than 500 megawatts of power. Successful deployments such as CalWave's will pave the way for the future of marine energy and could eventually lead to multimegawatt wave energy farms delivering clean electricity to U.S. coastal communities or power grids.

EERE has also enabled the advancement of technologies that use marine energy to provide non-power benefits to communities, such as desalinated water. Completed in 2022, the WPTO Waves to Water Prize was a competition designed to accelerate the development of small, modular, wave energy-powered desalination systems. The overall winner of the competition, Oneka Technologies, developed and deployed a prototype that can turn ocean water into drinking water using the inherent energy in waves. The device, adaptable

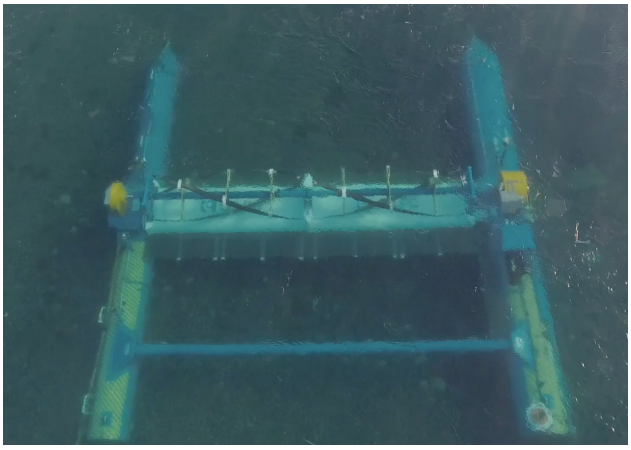
CalWave Power Technologies, Inc. successfully completed the company's and California's first at-sea, long-duration wave energy project with its xWave wave energy device. *Photo courtesy of CalWave Power Technologies, Inc.*

to most ocean conditions, has the potential to produce up to 7,000 liters of clean water per week, enough clean drinking water for more than 250 people per week. In 2023, EERE selected Oneka for additional funding to optimize its wave-powered desalination device and prepare it for commercial application in the coming years.

Empowering Coastal Communities Through Energy Resilience

To help communities realize the potential of clean energy sources like marine energy, EERE launched ETIPP in 2020. ETIPP works to ensure that all communities—no matter their size or location—have the tools they need to navigate the transition to clean energy. This effort has supported 32 communities since its inception, helping to modernize their energy systems and improve their energy resilience.

For example, Igiugig, Alaska, an Alaskan Native Tribe on the Kvichak River, collaborated with ETIPP to explore their potential to leverage marine energy. The Village, which for the past 50 years has depended on diesel fuel to power its homes and businesses, is now working through ETIPP to understand how to optimize its microgrid by balancing increased renewable energy generation with smart-grid electronics and energy storage. This collaboration builds on previous DOE support for Igiugig, including an EERE-funded project that helped the Igiugig Village Council deploy the Ocean



ORPC's RivGen 2.0 deployed in Igiugig, Alaska, to harness energy from the free-flowing current of Kvichak River. *Photo courtesy of ORPC*

Renewable Power Company's (ORPC's) 35-kilowatt, river-current system in 2019. ORPC plans to apply lessons learned from this initiative to other tidal energy projects in remote communities. In 2024, EERE selected ORPC to receive $3 million to deploy two tidal energy devices in Alaska's Cook Inlet, with the chance of accessing an additional $29 million to build the site. ORPC plans to collaborate with the Homer Electric Association, a member-owned electric utility serving the central and southern areas of Alaska's Kenai Peninsula.

Driving Marine Energy Innovation Through More Than 150 Projects

EERE's funding and technical assistance for marine energy innovators is resulting in technology breakthroughs that could revolutionize marine energy in the coming decades. The U.S. Testing Expertise and Access to Marine Energy Research (TEAMER) program accelerates the idea-to-market process by giving technology developers and researchers access to marine energy testing facilities and leading experts in the field. Since its inception, the TEAMER program has allocated $18.9 million in funding to 166 marine energy projects, proving to be a valuable resource for the marine energy industry as it lowers the barrier to entry for innovative marine energy solutions to prove their devices work.

In 2021, while investigating potential sites and partners for its first U.S. tidal deployment, Orbital Marine Power sought support from TEAMER to assess potential sites and environmental concerns. TEAMER paired Orbital with experts at the Pacific Northwest National Lab (PNNL), who helped the company identify methods for mitigating the environmental impact of its device. After this collaboration, the Orcas Power and Light Cooperative (OPALCO) opted to use an Orbital device at a potential marine energy site in Washington state. The tidal project, which is supported by $3 million in EERE funding and could receive an additional $29 million for further development, will help the remote communities in Washington's San Juan Islands meet their increased power needs with balanced, local, and renewable generation.

Breaking Ground on a World-Class Wave Energy Test Facility

Testing marine energy devices in a realistic environment is a challenging step in commercial product development. From finding a safe weather window to navigating a time consuming and occasionally costly permitting process, wave energy developers face an ocean of obstacles when trying to deploy their devices for open water tests. Similar to how a sports team requires a practice field to improve their performance, the wave energy sector needs a dedicated test space and infrastructure to overcome the challenges associated with ocean engineering and accelerate the deployment of marine energy. EERE has worked to expand testing options for marine energy developers, and the United States will soon have its first pre-permitted and accredited, grid-connected wave energy test facility. Located off the coast of Oregon, PacWave South is a world-class test facility capable of accelerating the speed of developing and deploying marine energy technologies while also saving developers' time and money by leveraging a test facility that has already been approved by regulators. The site is permitted to test up to 20 wave energy converters at a time with a maximum power output of up to 20 MW. The site will connect to the Central Lincoln Public Utility District's distribution grid, allowing energy generated from device tests to power local homes and businesses.

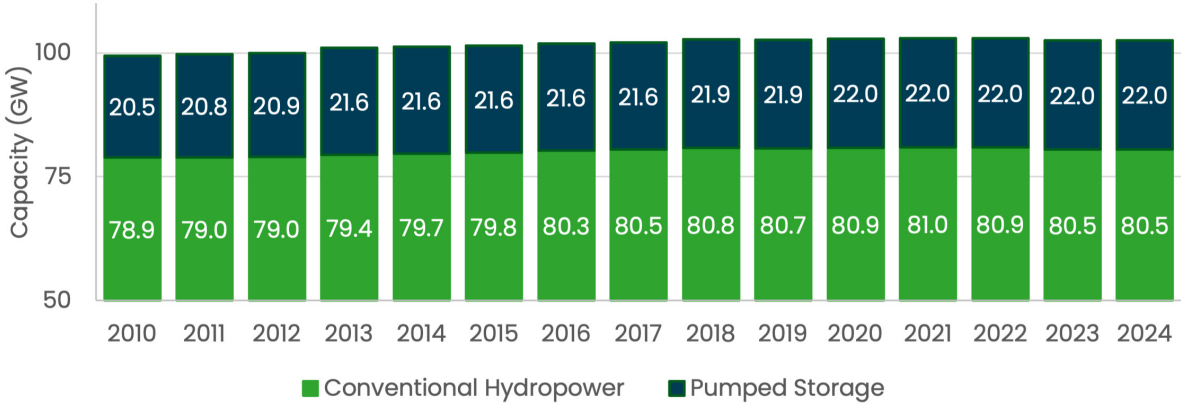
Hydropower

Hydropower is a reliable, flexible, renewable energy source that serves a critical function in the integration of variable generation on the grid. As of 2022, there are 2,252 conventional hydropower plants with a total generating capacity of 80.58 GW in the United States, enough to power nearly 30 million homes. America's 43 pumped storage hydropower (PSH) plants have a combined generating capacity of 22 GW and a storage capacity of 553 GWh, which accounts for more than 90% of domestic utility-scale energy storage, making PSH the largest contributor to U.S. energy storage capacity.

Expanding U.S. Hydropower Capacity

Conventional hydropower capacity in the United States increased by 2.1 GW from 2010 to 2022—enough to power 1.5 million homes. Roughly 1.6 GW of this growth came from upgrades to existing plants and infrastructure, which were made possible in part by EERE's fleet modernization work, including public-private partnership and the use of EERE analysis and decision support tools. EERE also supports projects that will increase hydropower's flexibility and offers technical assistance to projects as they continue to develop.

Figure 15: U.S. conventional hydropower and pumped storage capacity, 2010–2024



Source: Oak Ridge National Laboratory

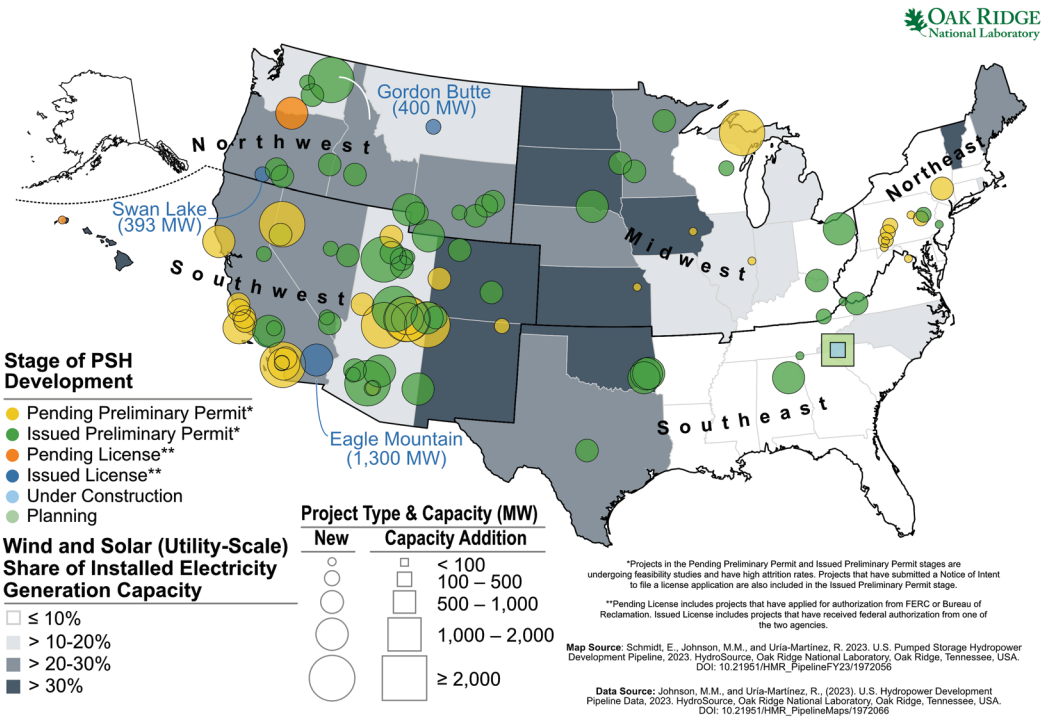
Supporting the Existing Hydropower Fleet: Modernization and Upgrades

DOE manages three hydroelectric incentive programs that help ensure that the U.S. hydropower fleet continues to provide clean electricity, improve dam safety, and reduce environmental impacts all while keeping operation costs low for owners and operators. Building upon the scientific and technological advancements enabled by EERE R&D, the three incentive programs—which EERE played a key role in setting up and/or managing before successfully transferring to DOE's Grid Deployment Office—will invest $754 million in the U.S. hydropower fleet, with over 80% of funding devoted to improving, maintaining, and enhancing current hydropower facilities. Selections as of August 2024 include $71.5 million for 46 efficiency-improvement projects and $36.7 million in production incentives for 66 facilities. Across the efficiency-improvement selectees, efficiency is expected to increase an average of 14%, nearly five times the mandatory 3% efficiency rate required by the IIJA. Together, the projects supported by the incentives program represent a total plant capacity of 1.9 GW.

Pumping Up Hydropower Storage

EERE is helping build on the success of PSH, which already provides nearly all the utility-scale storage in the United States. With EERE support, domestic PSH capacity has increased by 1.4 GW since 2013. Roughly 97% of this growth came from upgrades to existing facilities. From 2019 to 2022, the number of projects in the PSH development pipeline increased by 43%, reaching a total of 96 projects with a combined storage power capacity of 91 GW, enough to provide electricity for over half a million homes. Figure 16 displays the location, size, and development stage of each PSH project (including both new facilities and upgrades to existing facilities) in the development pipeline. These proposed projects have typical storage durations of 8–12 hours.

Figure 16. Map of U.S. pumped storage hydropower development pipeline, 2023



Source: Schmidt, E., M. M. Johnson, and R. Uria-Martinez. 2023. U.S. Pumped Storage Hydropower Development Pipeline, 2023. HydroSource, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.

EERE has published analyses on promising new design approaches for PSH as well as data on optimal sites for new PSH development. These studies, along with technical assistance opportunities, including one that awarded $4.3 million to PSH stakeholders, support organizations assessing new PSH development. EERE has also funded work on cost reduction strategies for new PSH projects. One such project, proposed by Rye Development and focused on repurposing an old coal mine for PSH, was recently selected for further funding by DOE's Office of Clean Energy Demonstrations. The project will create over 1,500 jobs and provide new opportunities for the former coal community.

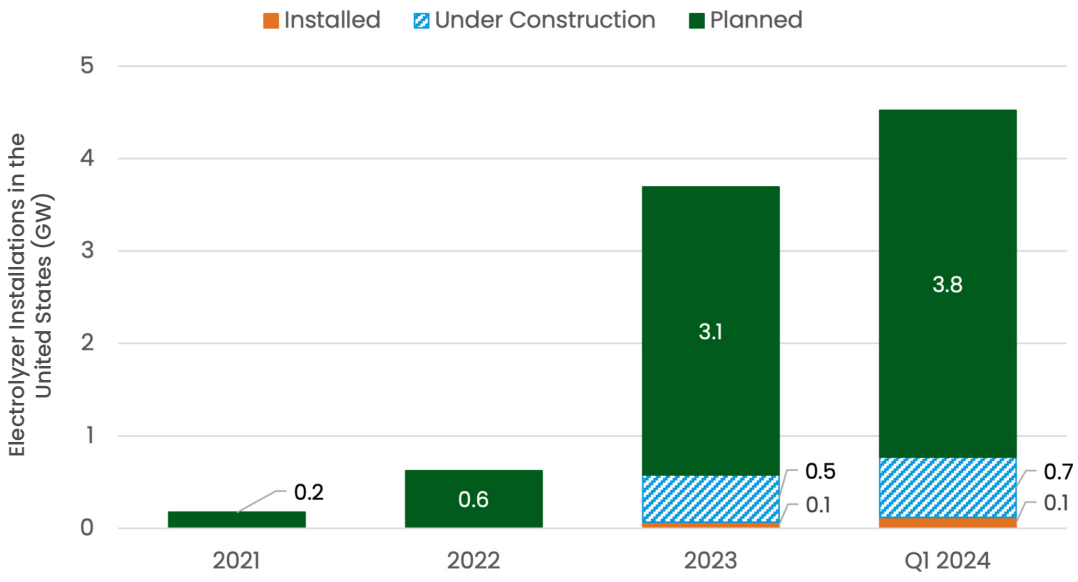
Powering Existing Dams

At present, 97% of American dams—or roughly 89,000 of the nation's 92,000 total dams—are not equipped to generate hydropower. Converting suitable dams could create 12 GW of new renewable energy to the nation's grid, and developers recognize the opportunity, as non-powered dams (NPDs) account for 95% of all proposed hydropower generating capacity. While retrofitting NPDs typically requires less time and cost compared to new construction, a key challenge to powering NPDs is ensuring the health of the surrounding ecosystem. EERE has taken a significant step toward addressing this concern by funding technology that helps fish safely navigate through facilities. EERE supported a PNNL test that validated Natel Energy's restoration hydropower turbine, a turbine designed to allow safe fish passage. The test, conducted at the Bureau of Reclamation's Monroe Drop irrigation canal site, found a 100% survival rate for fish up to 15 inches long. These tests provide owners and operators with data to cite when applying for licensing or relicensing.

Hydrogen and Fuel Cells

Clean hydrogen, which generates very low or zero GHG emissions, can be produced in every part of the country and from virtually any energy resource, including renewables, nuclear, or fossil energy with carbon capture. It can be used in many applications, particularly for hard-to-decarbonize sectors, as a transportation fuel, as a source of high-temperature industrial heat, or as a chemical feedstock or reactant. One key application for clean hydrogen is in fuel cells, which efficiently convert the chemical energy of hydrogen into electricity and have stationary and transportation applications.

Figure 17: Planned and installed deployments of electrolyzers that can produce clean hydrogen, 2021-Q1 2024



Source: Hubert, M., & Arjona, V. (2024). DOE Hydrogen Program Record# 24001

Electrolysis is the process of splitting water into oxygen and hydrogen, which can then be used for energy. When this process is powered by low emissions sources, like renewable electricity, the resulting hydrogen is produced with very low GHG emissions, making electrolysis a very promising technology for clean hydrogen production.

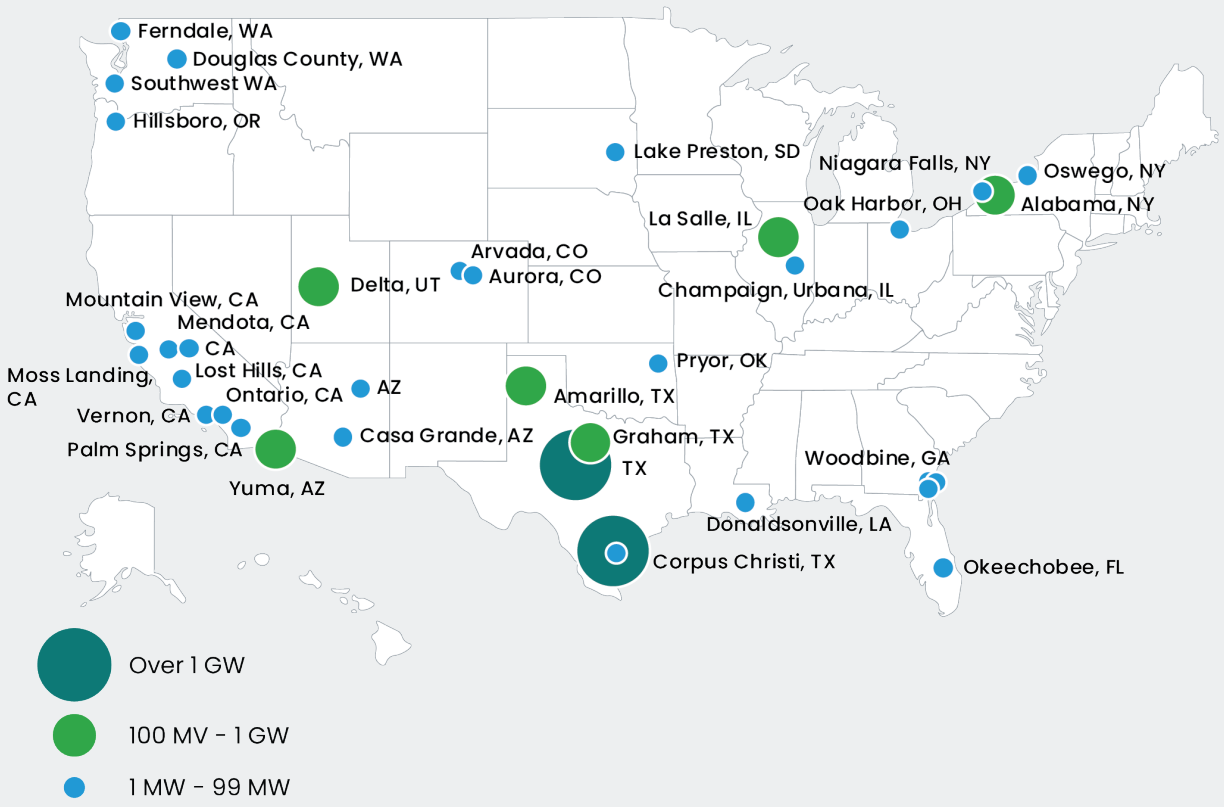
Rapidly Expanding Electrolyzers Across the Country

The scale up of clean hydrogen production and end-use are key to achieving our national goals of 10 million MT of clean hydrogen per year by 2030, 20 MT per year by 2040, and 50 MT per year by 2050, as outlined in the U.S. National Clean Hydrogen Strategy and Roadmap which was required by the IIJA and released in 2023.

Domestic electrolyzer capacity has increased significantly in recent years, with over 4 GW currently installed, under construction, or planned, a 20-times increase since 2021. EERE's R&D investments have been key in supporting the growth of the hydrogen and electrolyzer industry, advancing manufacturing technologies for electrolyzers, strengthening domestic supply chains, improving reliability, and promoting methods that can facilitate deployment (such as analysis tools to evaluate cost and emissions, and educational programs for workforce development).

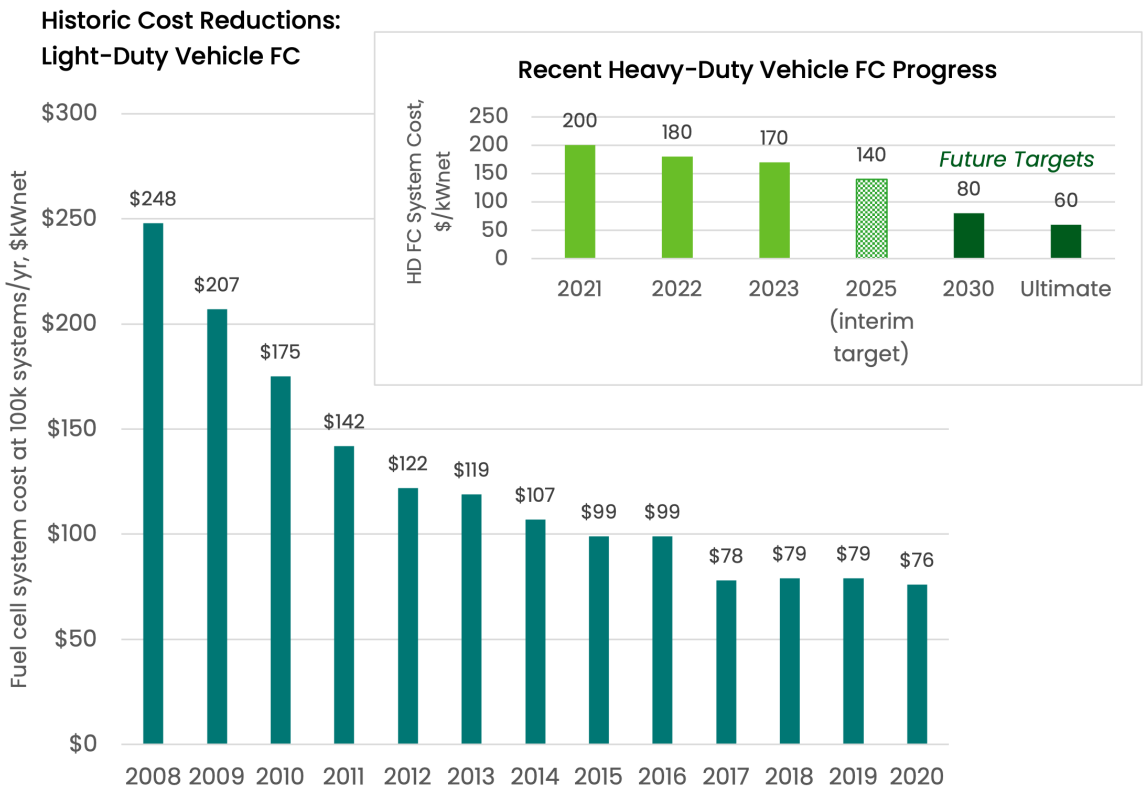
To reduce cost and enable deployments, EERE recently allocated $750 million in IIJA R&D funding to 52 projects that will advance manufacturing technologies for electrolyzers and fuel cells, as well as technologies that can be used to recover and recycle their materials. The projects funded through these investments are expected to enable approximately 10 GW/year of electrolyzer manufacturing—enough to support the annual

Figure 18: Map of announced electrolyzer deployments across the United States



Source: Hubert, M., & Arjona, V. (2024). DOE Hydrogen Program Record# 24001

Figure 19: Cost reductions in light-duty and heavy-duty fuel cell vehicles



Source: National Fuel Cell Technology Evaluation Center, Argonne National Laboratory. Durability-adjusted cost of an 80-kWnet PEM fuel cell system based on projection to high-volume manufacturing at 100,000 units/year, reported in 2016.

production of roughly 1.3 million MT of hydrogen. As clean hydrogen becomes a more readily available fuel alternative, these new installations will create jobs and reduce community exposure to harmful pollutants.

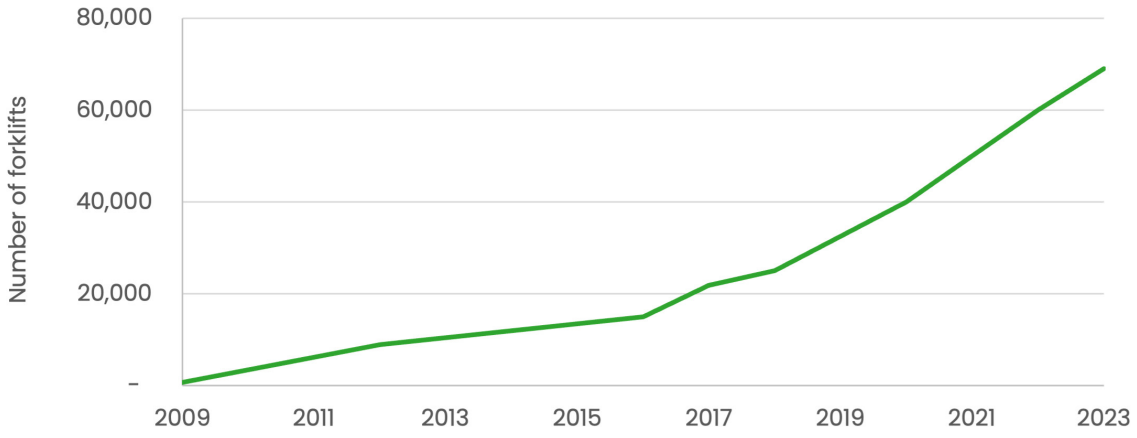
These selections will also enable 14 GW/year of fuel-cell manufacturing, which is enough to support 50,000 fuel-cell trucks, or about 15% of annual sales. And they will help advance EERE's ambitious cost targets for clean hydrogen: $2/kg by 2026 and the Hydrogen Shot goal of $1/kg by 2031—a reduction of over 80% relative to the current cost. These IIJA-supported projects across electrolyzers and fuel cells total $1.6 billion across 24 states, including cost share, and will enable over 1,500 direct jobs and thousands of indirect jobs, benefiting 32 disadvantaged communities across the nation.[50]

Reducing Costs and Accelerating the Deployment of Fuel Cells

EERE-funded innovations have reduced modeled costs of fuel cells and accelerated their deployments in early-market applications. EERE-funded R&D on light-duty vehicle fuel cells has enabled approximately 70% reduction in modeled costs at scale since 2008. EERE's R&D efforts are now focused on making fuel cells more viable for medium- and heavy-duty trucks, for example, EERE has invested $50 million through the Million Mile Fuel Cell Truck Consortium to improve the efficiency, durability, and cost of fuel cells.

As fuel cell costs have declined, fuel cell vehicles have become more affordable and accessible to consumers. For example, since EERE's initial investment for first-of-a-kind fuel cell forklift demonstrations in 2009, industry-led deployments have grown more than 80 times to roughly 70,000 commercial systems.

Figure 20: Increase in U.S. deployment of fuel cell forklifts, 2009-2023



Source: Department of Energy

Bioenergy

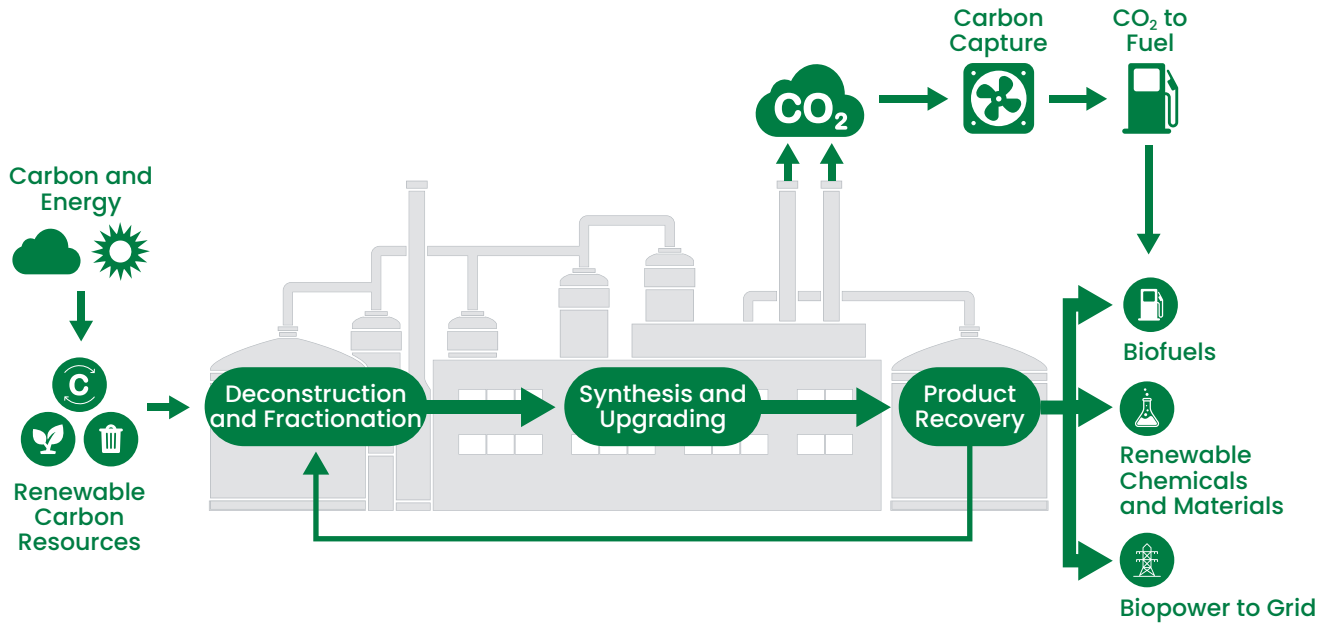
A variety of biomass and wastes can be converted into sustainable, high-performance biofuels and renewable chemicals and materials. EERE technologies have facilitated the growth of the biofuels sector with novel, pre-treatment technologies, new microorganisms that efficiently convert biomass to biofuels, and catalysts that allow waste gases to be converted into SAF. EERE complements these initiatives with world-class analytical products such as the Billion Ton Report, a comprehensive accounting of U.S. biomass and waste resources that identified how EERE-supported technologies could enable the utilization of over 1 billion tons of biomass and waste feedstocks to produce biofuels, biochemicals, and biopower.

Accelerating Innovation in and Production of Sustainable Aviation Fuels

Decarbonizing aviation is unusually difficult because commercial aircrafts require high-energy densities to operate safely. To achieve their near-term decarbonization goals, airlines and jet-engine manufacturers are working to scale up the production of SAF. SAFs can be used within existing infrastructure, processes, and functionalities (known as drop-in fuels). They produce significantly less GHG emissions than conventional, petroleum-derived jet fuel. Most importantly, they also meet safety standards established by the American Society for Testing and Materials.

In line with ambitions set out in DOE's SAF Grand Challenge, which calls for the production of 3 billion gallons of SAF a year by 2030 and 35 billion gallons a year by 2050, EERE is working to scale up SAF production by reducing production costs and identifying new methods of SAF production. For example, EERE funding helped develop, test, and perfect a new method for producing SAF using ethanol, called "alcohol-to-jet." This investment paid off—the technology has been commercialized and the company LanzaJet has, with further EERE funding, recently cut the ribbon on the world's first ethanol to SAF production facility in Soperton, Georgia. The facility can produce 10 million gallons of SAF a year and will help boost the rapidly growing domestic SAF industry, which saw SAF production rise from less than 5 million gallons in 2020 to more than 25 million gallons in 2023. The facility will also provide the local economy with an estimated $5 million in new wages and benefits, and $70 million in annual economic activity.[51]

Figure 21: Pathways for utilization of renewable carbon resources, including biomass and waste



Source: U.S. Department of Energy Bioenergy Technologies Office Multi-Year Program Plan 2023

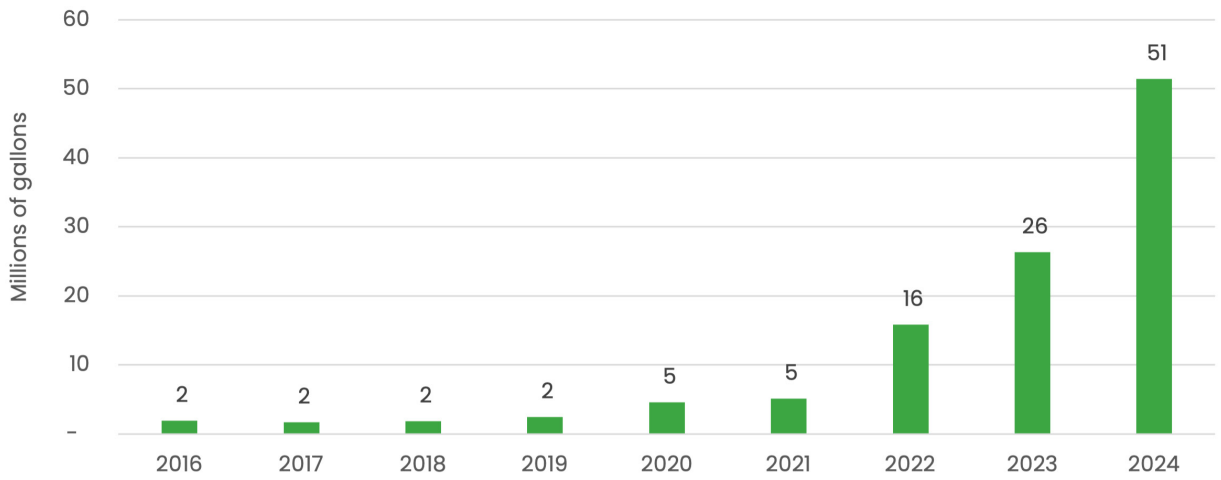
Looking forward, EERE will continue to invest in the acceleration of the SAF industry. EERE is funding five demonstration-scale and two pilot-scale projects that will scale up innovative conversion processes that can produce SAF. These investments will grow SAF production and the supply chain associated with it.

Reducing Emissions Through More Sustainable Production of Nylon

Nylon is one of the most ubiquitous materials in modern society. It is found in clothes, textiles, cars, and other applications, and the global nylon market is worth $31 billion. Conventional nylon production relies on the reaction of carcinogenic, fossil fuel and hydrocarbon-based compounds. These compounds contain strong acids that present safety and health risks and emit nitrous oxide, a GHG that is 273 times more potent than carbon dioxide.

EERE has worked to develop and scale the production of "sustainable nylon," which can minimize or negate these toxic emissions. Sustainable nylon is made from waste streams that otherwise require costly disposal or from sustainable biomass sources, and the manufacturing process often avoids the use of hazardous compounds. Since 2011, over $27 million in EERE funding for sustainable nylon applied R&D has enabled companies such as Genomatica to develop and commercialize sustainable nylon production technologies. In 2021, Genomatica announced a collaboration to build the first sustainable nylon manufacturing plant in the United States. The $300 million Iowa plant will deploy a sustainable nylon production process that reduces GHG emissions by more than 93% versus conventional nylon and reduces emissions by more than 400,000 tons of carbon dioxide (or equivalents) a year.

Figure 22: Increase in U.S. SAF production, 2016–2024

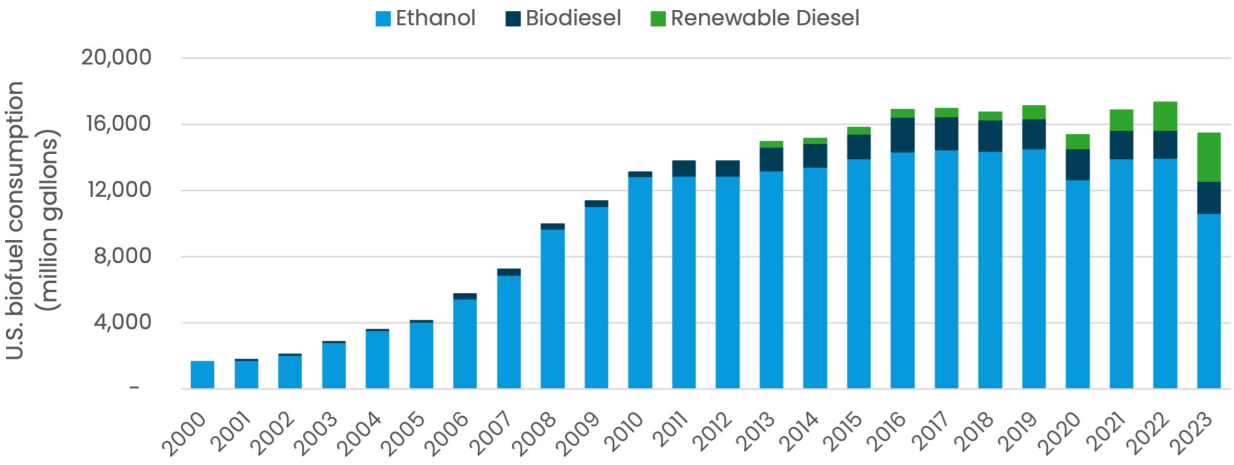


Source: U.S. Environmental Protection Agency. "Public Data for the Renewable Fuel Standard." 2024 is partial year data through June 2024.

Boosting Ethanol Production Capacity in Support of a Multi-Billion Dollar Industry

Ethanol is a renewable fuel made from plant materials that is used as a biofuel additive for gasoline. Today, more than 98% of U.S. gasoline contains ethanol. The United States is the world's leading ethanol producer, accounting for 53% of global production in 2023. Domestic production of ethanol accounted for nearly 72,500 jobs across the country, contributed $54 billion in economic activity, and added $33 billion in household income. EERE-funded R&D has helped the ethanol industry develop novel, pre-treatment technologies and microorganisms that can more efficiently convert biomass into ethanol. These process improvements and technological advances resulted in an 18% improvement in production capacity from 2010 to 2021 without having any impact on food production. In 2023, the consumption of ethanol in the transportation sector reduced GHG emissions by 56.5 million MT—an amount roughly equivalent to the emissions produced by 12 million cars.[52]

Figure 23: U.S. biofuel consumption, 2000–2023



Source: Energy Information Administration, Alternative Fuels Data Center

Integrated Energy Systems and the Grid

Making Energy Systems More Reliable and Affordable Using Simulation and Emulation for Advanced Systems (SEAS) Open-Source Software

Golden Valley Electric Association (GVEA), the local utility that serves Fairbanks and other Interior Alaska communities, manages a small electric grid with some of the highest—and most volatile—energy costs in the country. In 2022, GVEA sought out help from EERE's Clean Energy to Communities program to analyze the impact of closing a 50-MW coal plant by 2025 and replacing it with three power sources: wind generation, new energy storage, and imports of additional power from south-central Alaska. With EERE's consultation and financial support, a team from NREL used software to determine how large-scale wind power could be added to the grid without affecting its performance. That software was NREL's Simulation and Emulation for Advanced Systems (SEAS). SEAS is the only software that simulates and validates energy transmission and distribution solutions across the buildings, transportation, and renewables sectors and the grid. With the insights gained from the SEAS model, GVEA is positioned to reduce emissions while addressing affordability and reliability.

Demonstrating Hybrid Systems at NREL Campus: Flexpower

The natural variability of wind and solar energy can create uncertainties and challenges for operators. Flexpower is a power plant design that combines variable renewable energy and energy storage technologies into a hybrid system that performs similar to or better than fuel-based power plants to deliver power. The $5 million project, which was funded by EERE and DOE's Office of Electricity through DOE's Grid Modernization Initiative, sought to determine if hybrid plants can be transformed into flexible energy sources while providing all essential reliability and resiliency. Since initiating the project in 2021, the team conducted Flexpower hybrid plant tests at NREL's campus in Colorado using NREL-developed controls. They also conducted a regional study to demonstrate the benefits of Flexpower plants at system level.

ARIES

NREL and EERE developed a visionary research platform called Advanced Research on Integrated Energy Systems (ARIES). ARIES allows researchers to explore what a future grid could look like when variable generation or other energy technologies are added to the system and how they will interact with existing technologies. ARIES takes in the full picture—from community energy needs to technology developers and service providers—rather than evaluating clean energy and technologies in isolation. This innovative approach uncovers opportunities and risks in the spaces where energy technologies and sectors meet, such as plug-in vehicles, industrial sites, and other locations along the grid.

Photo courtesy of Josh Bauer and Bryan Bechtold, NREL

Pictured: Energy Systems Integration Facility (ESIF) at NREL. *Photo courtesy of Joe DelNero, NREL*

Supporting Resilient Alaskan Distribution System Improvements Using Automation, Network Analysis, Control, and Energy Storage (RADIANCE): GMLC Initiative

Cordova, Alaska, occupies a peninsula on the Gulf of Alaska and is separated from the mainland by high mountains. The local grid, which relies on hydropower and diesel fuel, had older controls and sensing infrastructure and was less flexible and resilient than needed, especially for Cordova's dynamic fishing industry and emergency services.

Thanks to ARIES and the Grid Modernization Laboratory Consortium's RADIANCE project, Cordova modernized its microgrid in five years. With support from NREL, PNNL, Idaho and Sandia National Laboratories, and DOE's Office of Electricity's Energy Storage Program, Cordova updated its metering infrastructure, controls, and operations. Its upgrades include energy storage, better controls for hydropower resources, and a fleet of meters, sensors, and advanced zonal controls. The latter use smart metering infrastructure to manage recovery, improve resilience, and support the city's fishing economy by serving seasonal and critical loads.

Using ARIES, Cordova validated its improved microgrid against plausible events, such as power loss from an earthquake or avalanche and allowed the local electric cooperative to observe and control the network with more precision. ARIES gave Cordova the confidence it needed to update its microgrid management. ARIES also provided DOE and its national labs the extraordinary capability to emulate the grid and integrate new technology, while launching some of the world's most powerful tools for power system transformation. The success of RADIANCE for Cordova offers a promising foundation for future microgrids to be deployed and other projects to reference.

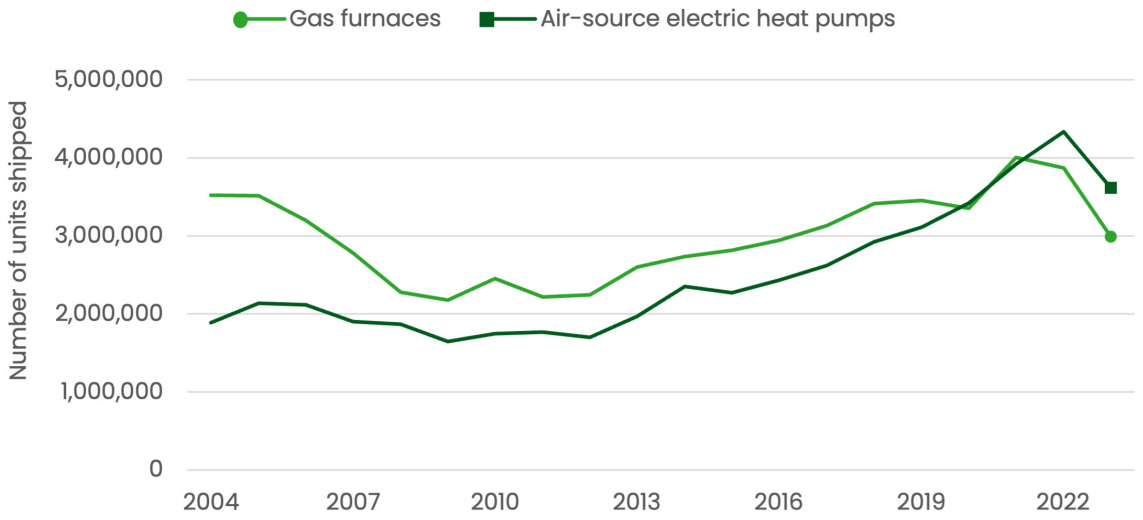
Building Efficiency and Electrification

Residential and commercial buildings are among the largest sources of carbon dioxide, accounting for more than one-third of domestic GHG emissions and 74% of electricity use. Decades of EERE investment have substantially reduced emissions from buildings, making them cheaper to run and safer to occupy.[53]

Commercializing Energy Efficient Heat Pumps to Deploy Across the Country

In the United States, the energy devoted to heating and cooling buildings accounts for around 35% of all energy consumption. Heat pumps are an energy-efficient, often more affordable alternative to conventional furnaces, and their growing adoption is helping to reduce building energy use. In 2022 and 2023, U.S. shipments of air-source electric heat pumps overtook those of gas furnaces, and there is an opportunity to expand the use of heat pumps even further by improving their performance in cold climates, including at temperatures as low as -15°F degrees. To continue making heat pumps more efficient and effective, and drive even higher rates of adoption across the country, EERE launched the Residential Cold Climate Heat Pump Challenge in 2021.

Figure 24: U.S. manufacturer shipments of gas furnaces and air-source electric heat pumps, 2004-2023



Source: Air-Conditioning, Heating, and Refrigeration Institute

To tackle this challenge, EERE launched the Residential Cold Climate Heat Pump Challenge in 2021. In partnership with leading industry players, this challenge has resulted in eight cold-climate heat pump prototypes moving from laboratory design to field testing. As these prototypes enter the market, they will substantially reduce the amount of energy used to heat and cool U.S. homes and offices, as well as the cost of utility bills. EERE investments will continue to support heat pump advances by expanding innovation infrastructure and test capabilities to help manufacturers move prototypes into production. To reduce upfront costs, EERE also partners with utilities on the development of incentives, from tax credits to block grants, that bring heat pumps to families who need them most. Looking forward, EERE is also working to accelerate the adoption of rooftop heat pumps at commercial buildings through a dedicated accelerator program. Launched in 2024 with manufacturing partners, the program will partner with large companies including Amazon, Whole Foods Market, IKEA US Retail LLC, and Target.

Creating a Window of Opportunity to Realize Energy Savings

Windows have a significant influence on a building's overall energy performance and provide an opportunity for efficiency improvement and comfort. Since the early 1990s, DOE has been instrumental in developing and deploying energy efficient windows. DOE authorized the National Fenestration Rating Council to implement a voluntary rating program which has been the benchmark for promoting innovation, and today over 90% of windows are designed and rated using DOE's suite of advanced software tools. EERE funding helped develop the now ubiquitous transparent low emissivity coatings that improved window energy efficiency by 50%, saving tens of billions of dollars in energy costs over more than two decades. And most recently, EERE has worked with industry partners to commercialize thin triple pane windows that are 500% more efficient than the single clear windows of the 1970s that are still installed in many buildings today. The lightweight glass and thin overall glass package allow manufacturers to upgrade existing windows without modifying their frames, significantly lowering installation barriers. Today, new factories are being developed to build these advanced windows.

EERE funding has also led to the development of dynamic solar control which has led to over $2 billion in private sector investment, and with recent tax credits are poised for rapid market uptake. Electrochromic windows also offer over 25% peak electricity reduction in commercial buildings and enormous health benefits.[54]

Developing Efficient Appliances and Equipment to Save Americans Billions of Dollars

DOE is legally required to set minimum energy efficiency standards for appliances and equipment through EERE's Appliance and Equipment Efficiency Standards Program. The program covers products used by consumers and businesses every day, including air conditioners, clothes washers and dryers, lighting, ovens, and refrigerators, and in total represent 90% of home energy use, 70% of commercial building energy use, and 30% of industry energy use. By setting and updating these standards, thereby making over 70 categories of products more energy efficient, EERE has helped:

- Avoid the emission of 5 billion tons of carbon dioxide, equivalent to the annual CO_2 emissions from over 1 billion gasoline-powered automobiles.
- Save consumers and businesses $1.6 trillion on utility bills, expected to grow to $2.8 trillion by 2035 (in 2023 alone, Americans saved $104 billion).
- Reduce a typical annual household energy and water bill in 2023 by $560.

Creating Widespread Lighting Energy Savings, From Better Sources to Better Controls

In 2023, energy efficient lighting saved U.S. customers over $14 billion by reducing their energy usage. R&D programs run by EERE have been a key enabler of these savings through innovations that improve power conversion efficiency, optimize spectral power distribution based on application, and improve optical delivery efficiency. For example, EERE launched the Lighting Prize in 2021 to develop next-generation LED luminaires and lighting controls in commercial buildings that improve performance, energy savings, and affordability. One of the winners of the prototype phase of the competition, MWConnect, designed a new wireless lighting control system with an easy-to-use, intuitive interface. This product was launched commercially in 2024 and can deliver energy savings in excess of 50% in many commercial buildings through easy integration with energy management systems. More lighting innovations are on the horizon: EERE opened the Manufacturing & Installation phase of the Lighting Prize in April 2024, with a $10 million investment to accelerate next-generation commercial lighting deployment in real buildings at scale.

A heat pump demonstration takes place inside a -40°F chamber. *Photo courtesy of Werner Slocum, NREL*

Electric Vehicles

Reducing Battery Costs Dramatically to Jump-Start the Electric Vehicle Industry

Reducing costs and improving performance of batteries is a key enabler for deployment of EVs. When EVs entered the mass market in 2010, the battery was the key cost component and limitation on range and performance. EERE has invested in lithium-ion battery R&D for several decades through research at the national labs and in partnership with universities and industry. Longstanding investment in batteries has contributed to dramatic improvements in cost, lifetime, charging rate, and energy density, and ultimately resulted in battery pack cost decreases of over 85% since 2010.[55]

This significant cost decline in batteries has helped dramatically accelerate the sales of EVs in the United States, which totaled over 1.46 million in 2023, an increase of more than 50% from the prior year.[56] EVs are significantly more efficient than their conventional vehicle counterparts, are cheaper to fuel and maintain, and help diversify our nation's transportation energy demand, while achieving widespread environmental benefits.

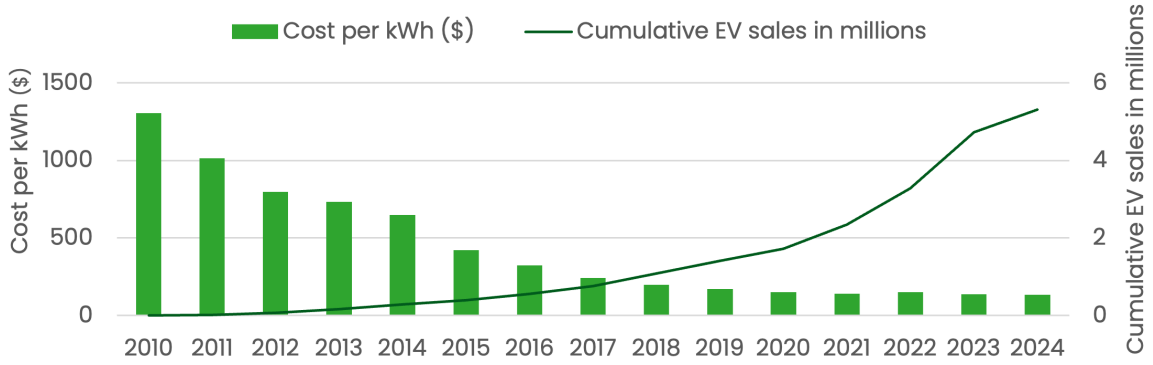
EERE continues its push to lower battery costs by promoting a vertically integrated approach to battery research and development covering the whole value chain of the battery ecosystem. Projects are focusing on performance and sustainability, including processing of raw materials, discovering alternative materials and chemistries, the design and manufacturing of battery cells and packs, followed by end-of-life considerations and battery recycling. Looking forward, EERE's goal is to reduce the cost of battery packs to less than $75/kWh while maintaining vehicle range of at least 300 miles, decreasing charge time to less than 15 minutes by 2030, and increasing the chemistry options to include more earth-abundant minerals all to achieve a battery cell manufactured cost of $60/kWh.

Expanding Access to EV Charging for All Americans

Greater access to EV charging directly addresses the most cited barrier to EV adoption.[57] In 2007, there were less than 500 publicly accessible EV chargers in the United States. As of July 30, 2024, there were over 190,000 public charging ports, an annual growth rate of 27%.[58]

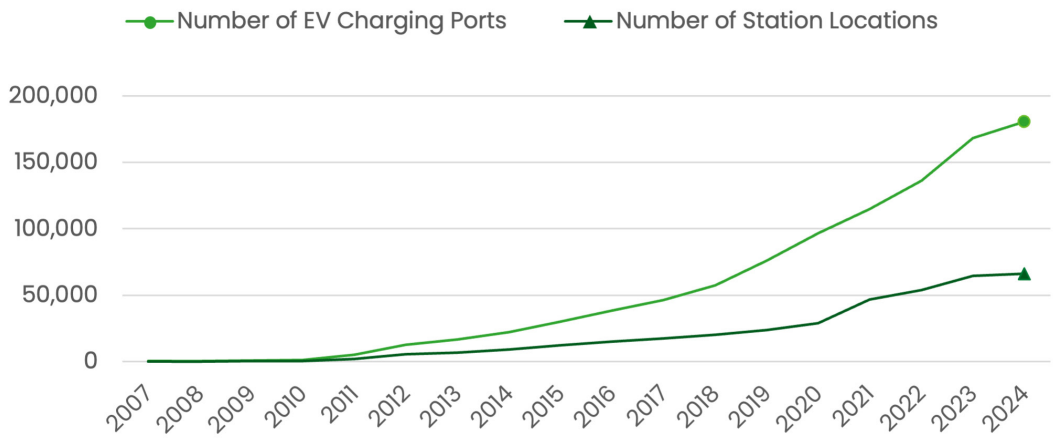
With help from the Joint Office of Energy and Transportation—created through the IIJA to facilitate collaboration between DOE and the U.S. Department of Transportation—federal program guidance, minimum standards, and many technical work products including the development of SAE's new J3400 connector standard have been developed to ensure a common, high-quality EV charging experience.

Figure 25: EV battery costs vs. cumulative sales of personal EVs (battery electric and hybrid), 2010–2024



Source: Argonne National Laboratory, BloombergNEF. 2024 sales data through May.

Figure 26: Increase in number of public EV charging stations in the United States, 2007-2024



Source: Alternative Fuels Data Center, afdc.energy.gov/stations/states. 2024 data as of July 30, 2024

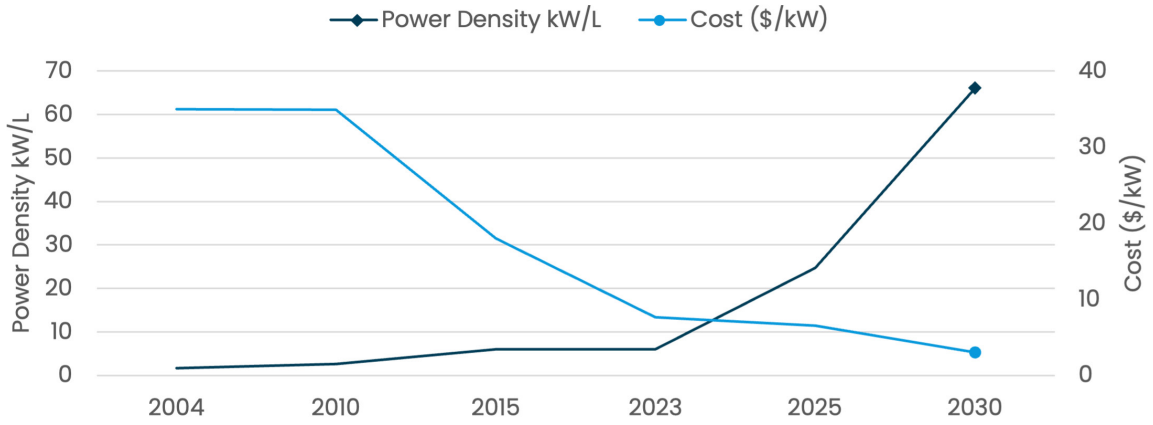
DOE is bridging the energy and transportation sectors by working with all stakeholders to increase effectiveness, simplify implementation, and drive critical outcomes. Federal funding, targeted at filling critical gaps, coupled with technical resources, creation of a national database for EV charging data, and successful implementation of new federal minimum standards, will ensure consistency and instill the values of convenience, affordability, reliability, and equity into the national EV charging network.

Improving Power Electronics

Electricity stored in EV batteries is used in the electric-drive system to move the vehicle. Efficiency improvements in ETDS, including power electronics and electric motors, will allow EVs to travel greater distances without increasing the battery size. In early EVs, power electronics were expensive, bulky, and less reliable and efficient. EERE's investments since 2004 have generated substantial improvements in power density, increasing from 1.7 kW/L to 24.7 kW/L expected in 2025. Further EERE-funded research in power electronics and electric motors is increasing the power density, performance, reliability, durability, and efficiency of electric drivetrain components, including traction inverters and motors, while reducing costs.

To achieve improved operation at lower costs, EERE is supporting research on the integration of wide-bandgap devices into power modules and the elimination of heavy, rare-earth materials in electric

Figure 27: Electric traction drive systems (ETDS) cost and power density, 2004–2023 (actual), 2025 and 2030 (forecast)



Source: U.S. Drive, Department of Energy

motors. Research into the recycling of power-electronic and electric-motor materials, with a focus on new designs that incorporate recyclability as an important design criterion, is also underway. To guide its R&D investments, EERE has established an overarching goal to improve the power density of electric drives by a factor of 10 (relative to a 2015 baseline) while reducing cost by 50% and doubling the lifetime mileage for light-duty vehicles, from 150,000 miles to 300,000 miles by 2025.

Light- and Heavy-Duty Vehicles, Excluding EVs

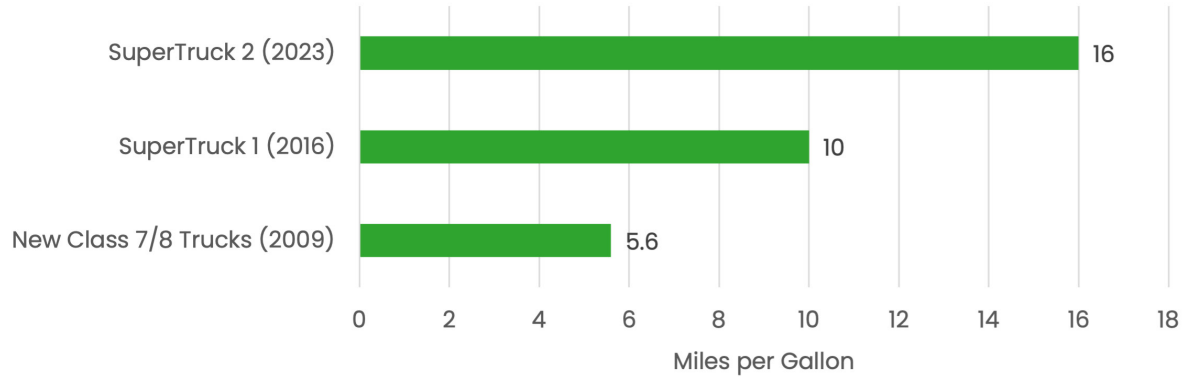
Reducing Fuel Costs Dramatically for Long-Haul Trucks

Class 8 long-haul trucks (known colloquially as semi-trucks) are the highest fuel consumers in heavy-duty transportation and a significant contributor to overall transportation-related GHG emissions. Despite accounting for just 1% of on-highway vehicles, these trucks used about 17% of highway petroleum in 2008.[59] Furthermore, their fuel efficiency was low—less than 5.5 miles per gallon prior to the launch of DOE's "SuperTruck" program in 2010. This program has, in partnership with U.S. truck manufacturers, demonstrated cost-effective technologies that double the fuel economy of a Class 8, long-haul truck. Some of these technologies are now being used by leading truck manufacturers to build American-made trucks that can travel much further on a gallon of fuel, resulting in reduced operation cost for truckers.

EERE launched the SuperTruck program in 2010 to develop technologies for long-haul trucks to significantly improve their fuel efficiency. The first phase of the program, SuperTruck 1, began with four trucking companies and successfully completed in 2015. The second phase, SuperTruck 2, ran between 2016 and 2023 and saw all participating companies achieve more than 100% freight efficiency improvement and a 30% improvement in engine efficiency, relative to their 2009 baseline.

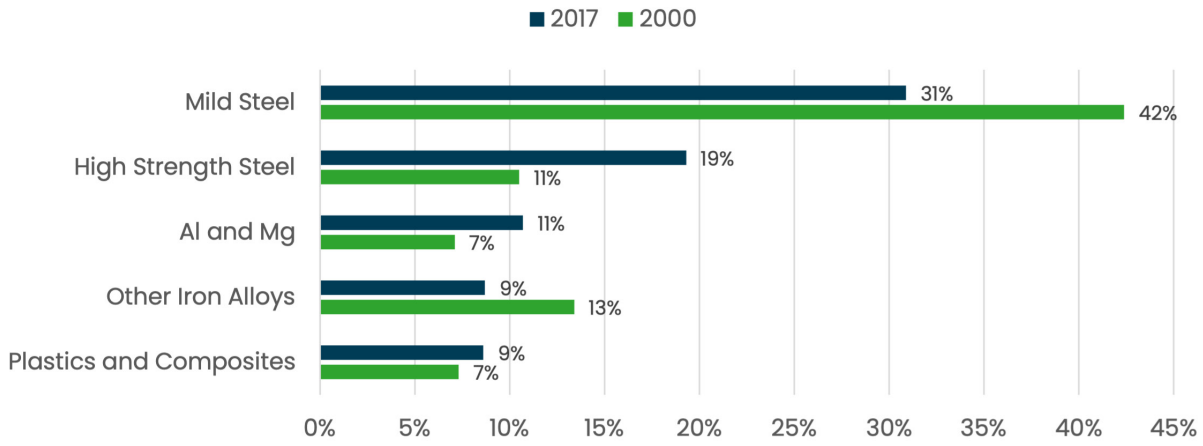
The initial phase of the program saw participants' trucks achieve more than 10 miles per gallon of diesel fuel and commercialize more than 20 other fuel-efficient technologies. Many trucks built today utilize these technologies. All SuperTruck 2 participants achieved or exceeded their freight-efficiency targets with a combination of high efficiency engines, advanced aerodynamics, and lightweighting, or building lighter trucks to achieve greater efficiency, range, acceleration, braking, and handling. They also used 48V mild-hybrid systems that will facilitate a transition to electrification, improve fuel efficiency, and reduce cold-start emissions. Some teams also achieved 55% brake thermal efficiency, an engine-efficiency breakthrough in heavy-duty vehicles. Together, these technologies have propelled heavy-duty fuel efficiency to new heights, including more than 16 miles per gallon of diesel fuel, nearly triple the preexisting milage.

Figure 28: Improvements in fuel efficiency of Class 7/8 trucks



Source: Argonne National Laboratory, Cummins-Peterbilt, Navistar

Figure 29: Average material consumption for a domestic light vehicle (% of total materials, model years 2000 vs. 2017)



Source: Transportation Energy Data Book, Edition 40, Table 4.20

Making Vehicles More Fuel Efficient With Lighter Materials

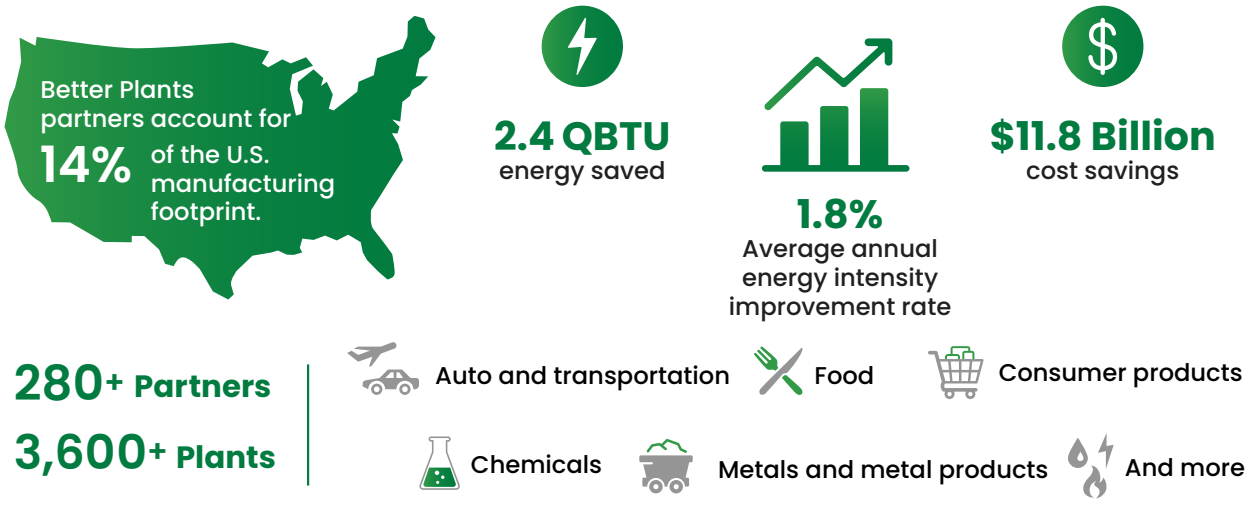
Lightweighting, the development of improved materials and material-processing technologies with the potential to reduce the total mass of a vehicle, can improve vehicle energy efficiency and reduce GHG emissions, while maintaining safety and performance. A 10% weight reduction can improve a vehicle's energy efficiency by 6–8%.[60] EERE is working to achieve such weight reductions by replacing heavier "mild steel" with other, lighter materials.

Lightweighting benefits all vehicles regardless of size or powertrain configuration. Class 8 trucks benefit from lightweighting by increasing the freight efficiency, or tons of cargo delivered per mile per unit of energy consumed. Battery EVs benefit from lightweighting because the energy efficiency improvement can reduce the size of the battery required for a given range, which also reduces the demand for critical materials. EERE research programs focus on replacing heavy steel components with materials such as high-strength steel, aluminum, or glass-fiber-reinforced polymer composites, which can decrease component weight by 10–60%. In the longer term, advanced materials such as magnesium and carbon-fiber-reinforced composites would reduce the weight of some components by 50–70%.

EERE-funded work has developed several generations of advanced high strength steels for automobile bodies. This work has led to stronger, lighter, and safer vehicles. It has also helped optimize vehicle designs by enabling improved aluminum castings and sheets and reduced the costs of carbon fiber composites and combining multiple materials. Today's materials portfolio includes materials for vehicle structures, components, and electrification materials, electrical steels (used for motors and transformers), and magnetic materials.

EERE heavy-duty projects have demonstrated a 20% weight reduction in a Class 8 trucks and trailers, contributing to a freight efficiency improvement of 136%. EERE projects in automotive lightweighting are on track to reduce car glider weight by 25% compared to a 2015 baseline by 2025.

Figure 30: Better Plants initiatives success



Source: Department of Energy

Manufacturing Process Efficiency and Energy Utilization

The industrial sector accounts for 11% of U.S. GDP and supports more than 11 million jobs. This vital sector is also among the most energy-intensive in the economy, consuming more than one-third of all end-use energy. For more than a decade, EERE has partnered with industrial subsectors to improve energy performance, save manufacturers money and resources, and make American companies more competitive in the global marketplace.

For example, EERE's Better Plants Program works with manufacturers and water utilities to set ambitious energy savings goals and provides technical assistance to help these facilities achieve their targets. The program has helped more than 270 manufacturers save $10.6 billion in energy costs and 2.2 quadrillion Btu of energy, enough to power 61 million average American homes for a year. EERE has also launched complimentary energy-management initiatives and created new tools and resources to help manufacturers develop tailored, facility-level approaches to energy savings.

In addition to its technical assistance programs, EERE has spent more than a decade investing in research, development, and pilot-scale demonstrations for innovative, energy-efficient technologies that have helped American industry streamline their operations, save energy, and seize opportunities in the global marketplace.

EERE's long partnership with the U.S. steel industry has helped to pave the way for American companies to become among the world's most energy-efficient steelmakers. For example, EERE has supported

Plant Superintendent Art Ruiz points to the rows of reverse osmosis modules that can produce up to 27.5 gallons of fresh waver for the city of El Paso, TX. This facility is the site of pioneering pilot studies supported by NAWI to transform the waste brine from the desalination process into valuable industrial chemicals. *Photo courtesy of Pete S. Fiske, Director of the National Alliance for Water Innovation*

the development of an integrated virtual blast furnace through a series of R&D projects with industry and research institutions. This tool uses high-performance computing and new sensor technologies to simulate the interior conditions of an industrial furnace, allowing operators to reduce their energy by an average of 10%. If adopted widely, U.S. steelmakers could save a collective 142 trillion Btus of energy, equivalent to over 1 billion gallons of gasoline.

EERE is also working to help industrial facilities radically lower the cost and energy use of water-treatment technologies. Through its National Alliance for Water Innovation (NAWI) hub, EERE is building strong public-private partnerships to deliver clean water to American communities and consumers and fully optimize water treatment and supply systems. Through NAWI, EERE is funding the development of a low-salt rejection reverse osmosis technology to recycle salty waters efficiently and cost-effectively, like wastewater, into drinking water. This emerging water treatment technology has the potential to reduce the overall cost of producing clean water by up to 63%.

EERE and NAWI are also supporting the development of a chemical process to transform waste brines into valuable industrial chemicals. This novel process could produce more clean drinking water for water-stressed communities, reduce the brine waste produced from treating water, and increase the sustainability of non-traditional water treatment by turning a waste stream into valuable resources for the industrial sector.

Industrial Emissions Reduction

The U.S. industrial sector accounts for one-third of all energy-related domestic GHG emissions. Curbing these emissions will require innovative technology solutions that are tailored to the diverse needs of various industrial subsectors, including many that rely on decades-old infrastructure. American industry must also implement these technological adaptations faster and more cost-effectively than its global competitors.

EERE has taken a leading role in setting the national agenda for the transformation of American industry. In 2022, EERE led the development of the Industrial Decarbonization Roadmap, the federal government's first comprehensive analysis of the key technologies and industries that will enable a net-zero industrial sector. Since the publication of this strategy, EERE has invested more than $500 million in applied research, development, and pilot-

Staff from EERE, Purdue University Northwest, and Cleveland-Cliffs pose in front of an industrial furnace at the Indiana Harbor complex in Northwest Indiana, one of the largest steelmaking facilities in North America.. *Photo courtesy of Cleveland-Cliffs Inc.*

Photo courtesy of Shutterstock

scale demonstrations. The Roadmap, together with the Pathway to Commercial Liftoff Report for Industrial Decarbonization, is serving as the foundation for DOE Office of Clean Energy Demonstrations' $6 billion Industrial Decarbonization program.[61]

EERE is leveraging its longstanding partnerships and expertise in the steel industry to develop novel decarbonization technologies, such as electric arc furnaces and clean hydrogen direct reduced iron. For example, EERE is supporting a first-of-its-kind hydrogen-fired steel reheating furnace with the potential to significantly reduce GHG emissions across the steel industry.

EERE is also making strides to decarbonize chemicals manufacturing. EERE developed the Rapid Advancement in Process Intensification Deployment (RAPID) Clean Energy Manufacturing Institute in 2017 to bring industry, academia, and government together to advance process technologies and enable more resilient, affordable, and efficient chemical manufacturing. Through RAPID, EERE is supporting the use of chemical reaction dynamics studies to design more efficient reactors to make to make ingredients for products such as plastics, coatings, and paints. These efficient reactors have the potential to reduce energy intensity by 25% and lower capital costs for chemical manufacturers by more than 65%.

Critical Materials, incl. Sourcing, Recycling, Processing, Refining

Critical materials serve as building blocks for many energy innovations. They are used in the manufacturing of magnets for wind turbines, batteries for EVs and grid storage, semiconductors for solar panels, electrolyzers for hydrogen fuel cells, and more. To enhance U.S. global competitiveness, combat climate change and reduce vulnerabilities in its supply chains, EERE is working to ensure that U.S. industries develop, commercialize, and deploy advanced technologies for processing critical materials. Three examples of this work are below.

Building a Hub for Critical Materials Innovation

The Critical Materials Innovation Hub (CMI Hub) is a public-private consortium, funded by EERE, that convenes DOE national labs, academia, and 37 industry partners to strategically address supply risk for critical materials through diversifying supply, developing alternative materials and technologies, and increasing recycling. Research funded through CMI Hub has influenced subsequent technological

developments in fields such as metals recycling, lithium recovery, advanced aluminum alloys, and additive manufacturing. With 202 invention disclosures leading to 50 U.S. patents and 20 technology licenses, the scientific community looks to the CMI Hub for de-risked technologies that can then be developed and commercialized. While the Hub focuses on early-stage research and development—a process that typically takes 5 to 10 years—it has licensed several innovations to industry in a much shorter timeframe, demonstrating the relevance and importance of its R&D and its strong connections to an evolving market.

Addressing Critical Materials Recovery From Spent Batteries and Electronics Scrap

Recovering valuable metals from spent batteries and used electronics, or "electronics scrap" (e-scrap) is crucial for sustainability and will help the United States secure a reliable, domestic supply of critical materials necessary for technologies such as EVs, solar panels, wind turbines, consumer electronics, and more. To improve the efficiency and reduce the environmental impact of battery and e-scrap recycling, EERE has invested in the development of multiple recycling technologies, two of which are now entering the market.

First, the membrane solvent extraction (MSX) technology—a patented CMI Hub-funded innovation—provides a highly selective, cost-efficient, and environmentally friendly alternative to conventional recycling methods. Momentum Technologies, a company which holds an exclusive license for MSX technology globally, is developing processing plants close to waste sources, vastly reducing logistics costs (as high as 60% of battery recycling costs) and enhancing material recovery rates (yields recovery rates of 95%). This approach not only recycles metals like cobalt and lithium effectively, but also adheres to circular economy principles by minimizing waste and reusing end-of-life products responsibly. A demonstration plant with the annual capacity to process 200 tons of black mass is anticipated to be open in Carrollton,

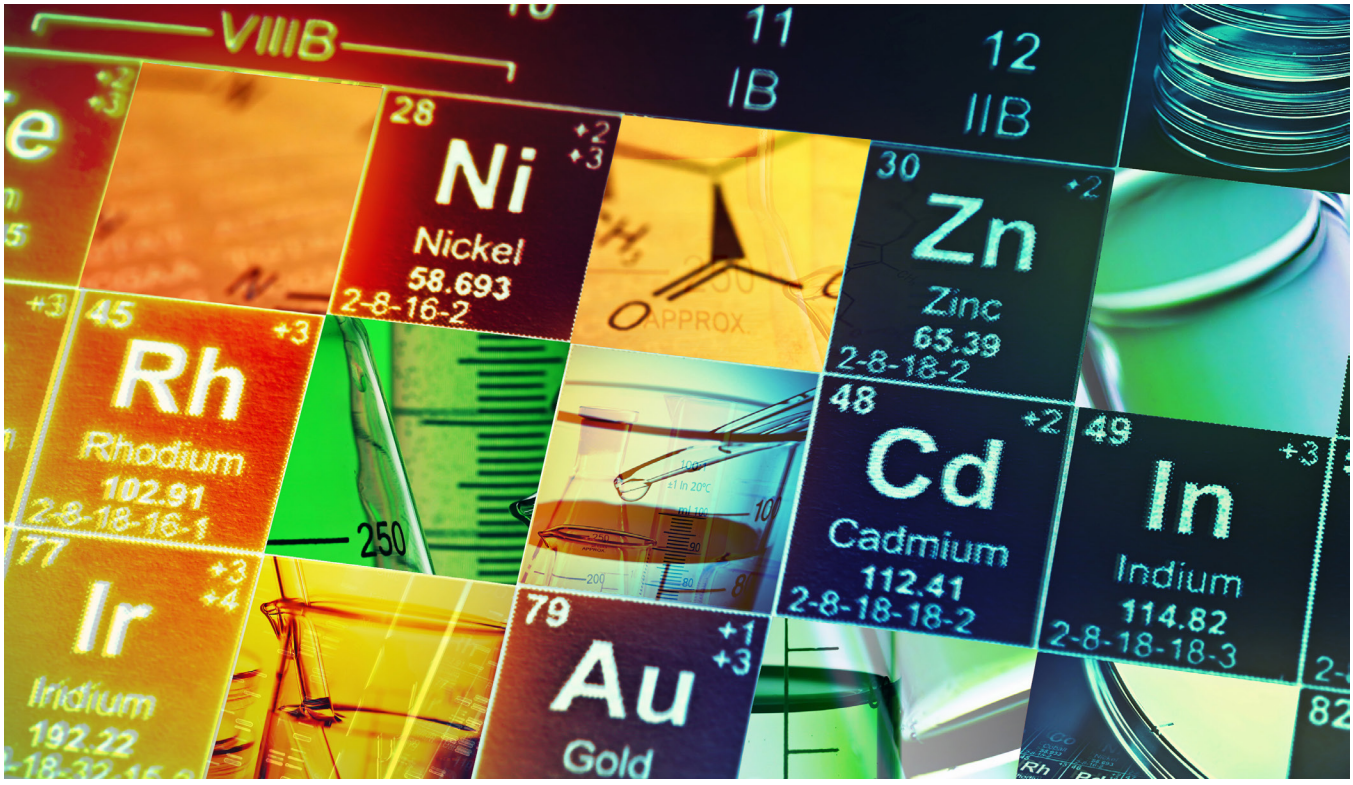


Photo courtesy of Shutterstock

Texas, in the summer of 2024. The first full-scale facility with the capacity to process 1,500 tons of black mass per year is expected to be operational by the second quarter of 2025.

Second, the CMI Hub-funded acid-free dissolution recycling (ADR) offers a highly selective, sustainable, one-step process to recover rare-earth oxides from e-scrap. This patented technology eliminates the use of hazardous acids typically involved in recycling and creates a more efficient recycling process.

Private sector company TdVib LLC has received substantial support to scale this technology, including over $1.2 million to de-risk the process and support regional development of recycling methods that use the technology. TdVib's efforts to scale up the recycling process without any acids, and limit—or even eliminate—the generation of waste makes for an overall environmentally friendly process. ADR also removes the need for pre-heating, which sets it apart from other recycling processes used to demagnetize rare earth element (REE) magnets. The ability to eliminate pre-heating lessens the impacts of pollution, while also decreasing energy usage. In 2022, the Iowa State University Research Foundation and TdVib signed an exclusive license agreement for the ADR process technology. Efforts are underway to produce three to five tons of rare-earth oxide in the next couple of years, which is a crucial part of the REE magnet supply chain for clean energy technologies, such as electric motor vehicles. As of 2023, Ames National Lab and TdVib continue to work together through the EERE-funded CMI Hub to explore the application of the ADR process to recover critical materials from other dilute waste streams, such as end-of-life medical devices.

Addressing the Need for Battery Materials Manufacturing

As demand for energy storage grows—for EV batteries, utility-scale grid storage powered by renewables, and the consumer electronics we rely on every day—so does the demand for the materials that make up these essential technologies. Lithium is in particularly high demand and in low supply domestically, and while recycling can contribute to supply, it will not meet current demand. To tackle this challenge, ABTC has been developing over 10,000 acres of claystone, a sedimentary rock that contains the critical material lithium.

Supported by an initial $4.5 million EERE grant, ABTC has demonstrated how to produce multi-tons per day of battery-grade lithium hydroxide from claystone. And thanks to that initial demonstration, ABTC plans to further evolve this technology by constructing a commercial-scale refinery that can produce 30,000 tons of lithium hydroxide per year, equivalent to the amount that goes into 500,000 high-performance EVs.

The completion of construction and start of commissioning of the lithium hydroxide commercial-scale plant will expand access to a domestic lithium resource, strengthening our supply chains as battery production ramps up.

Economy-Wide Advances and Benefits Supported by EERE's Work

The cumulative benefits of EERE's work across technologies and geographies are reflected in broad economy-wide advances that deliver health, economy, and safety benefits to all Americans.

Jobs and Economic Growth

In 2023, there were 3.5 million Americans working in the U.S. clean energy economy, an increase of 142,000 since 2022 (+4.2%) and of 400,000 since 2020. These Americans are employed in a range of jobs including renewable energy generation, storage, and transmission, energy efficiency, and electric and hydrogen fuel cell vehicles production. Together these jobs accounted for 42% of the total 8.1 million U.S. energy jobs in 2023.[62]

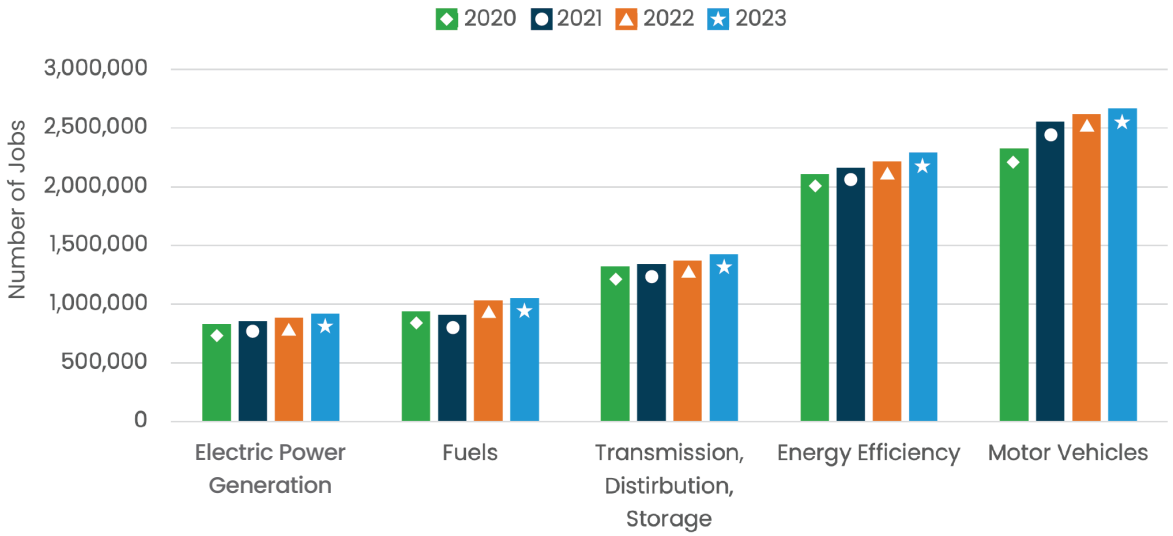
Recent growth in clean energy technologies has been rapid—employment in clean vehicle increased by 24,826 (+11.4%) from 2022 to 2023, and 79% of all electric power generation jobs added in 2023 were in clean energy technologies such as solar and wind.[63] With significant investment already committed to the clean energy economy, NREL estimates that jobs in just four clean energy technologies—solar PV, onshore wind, grid-connected battery storage, and building energy efficiency—could increase by over 100% between 2020 and 2030.[64]

EERE's work is not only supporting the creation of these jobs, but also helping prepare workers across the country to fill them. EERE collegiate competitions and intern programs spur interest among college students in growing industries across the clean energy economy. Since 1988, EERE has run the Advanced Vehicle Technology Competition, DOE's flagship workforce development program for automotive engineers. This program has helped more than 30,000 graduates from 111 educational institutions find roles in industry while building a pipeline of diverse talent needed for the United States to remain competitive in the global marketplace.

Investment and Economic Growth

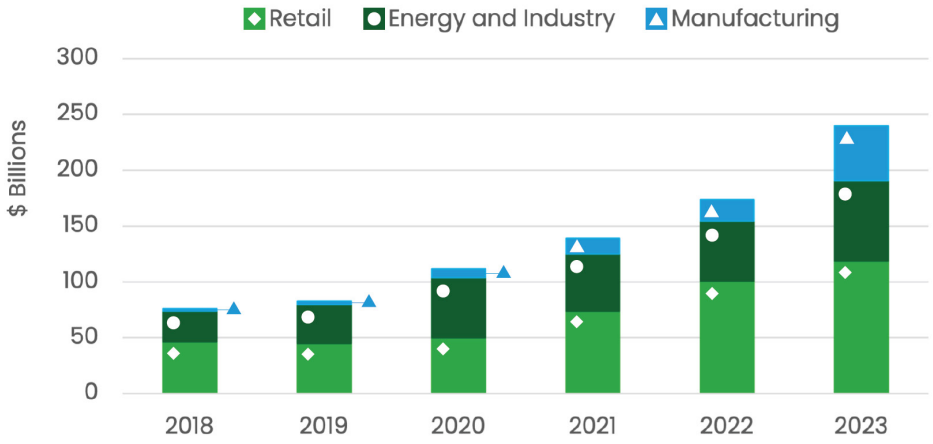
In 2023 there was $244 billion of investment in the United States in the manufacturing and deployment of clean energy, clean vehicles, building electrification, and carbon management

Figure 31: U.S. energy sector jobs, 2020–2023



Source: U.S. Energy and Employment Report

Figure 32: U.S. investment in select energy innovations, 2018–2023

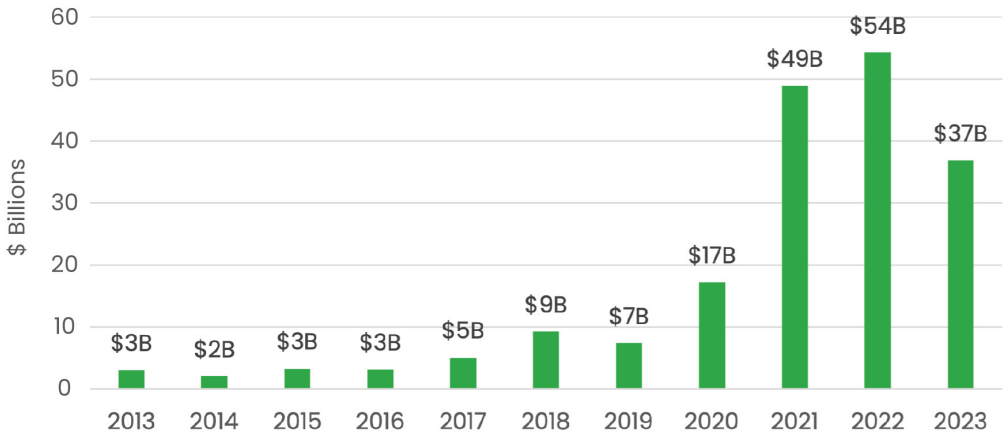


Source: Rhodium Group-MIT/CEEPR Clean Investment Monitor

technology, up from $78 billion in 2018. These investments accounted for 4.5% of all private investment in structures, equipment, and durable consumer goods in the United States in 2023, up from 3.3% in 2022.[65] And in the first quarter of 2024, the United States has seen $71 billion of investment, a 40% increase relative to the same period in 2023.[66] EERE has played an important role in developing many of the technologies receiving this investment, and driving down costs and improving efficiency in order to support their widespread adoption. This includes historic and ongoing support for and investment in solar and wind power, electrolyzers, EV batteries, and critical minerals.

"Climate tech" is an industry term that describes companies providing products and services to help mitigate climate change, including industrial decarbonization, renewable energy, biofuels, and grid infrastructure. Venture capital (VC) investment in these companies has grown tenfold since 2013, up from $3 billion to more than $30 billion in 2023. This rapid growth reflects increasing private sector interest and confidence in commercializing the types of technologies that EERE has spent decades researching, developing, and prototyping. Climate tech now accounts for 10% of total VC investment, up from less than 2% in 2013[67], and the companies that VCs invest in today could grow into future mainstays of our economy, driving job and investment growth.

Figure 33: Venture capital investment in climate tech companies, 2013–2023



Source: PitchBook Data, Inc. Data has not been reviewed by PitchBook analysts.

Strengthening U.S. Industry

Since the passage of IRA and IIJA, over 700 investments worth more than $200 billion have been announced in the domestic manufacturing of key energy technologies, including batteries, EVs and their component parts, EV chargers, heat pumps and other clean HVAC, hydrogen, land-based and offshore wind, and solar. These investments and projects will help transform the U.S. domestic manufacturing landscape, creating tens of thousands of good paying jobs—many of which are unionized—across the nation.

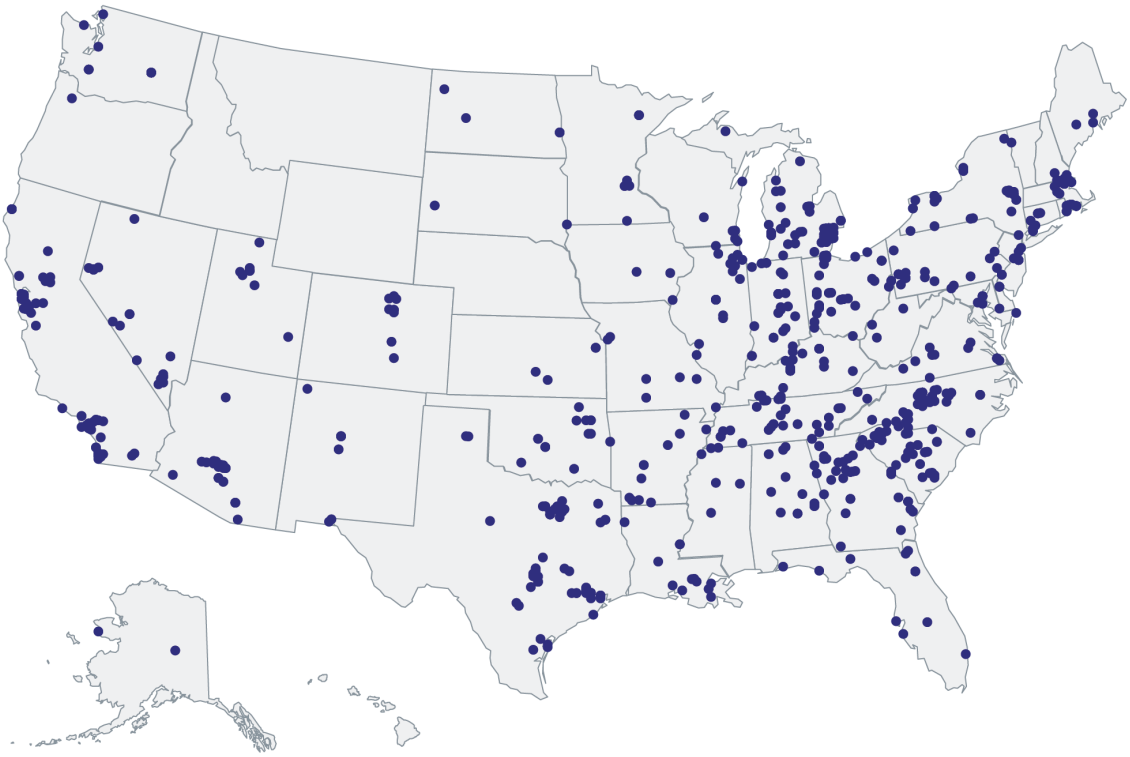
Companies investing in new U.S. manufacturing facilities include those directly supported by EERE, such as SkyNano, whose advanced manufacturing practices turn carbon emissions into a valuable feedstock for applicants such as batteries, tires, and coatings. SkyNano graduated from EERE's LEEP, which connects entrepreneurs with world-leading scientists and facilities at U.S. national laboratories to greatly accelerate the path to market for new products and technologies. Building off support from EERE and LEEP, SkyNano recently held a ribbon-cutting for a new manufacturing facility in Louisville, Kentucky.

Support for Local Communities

Through a range of funding opportunities and technical assistance programs, EERE and DOE have brought the benefits of the energy transition to local communities across the country.

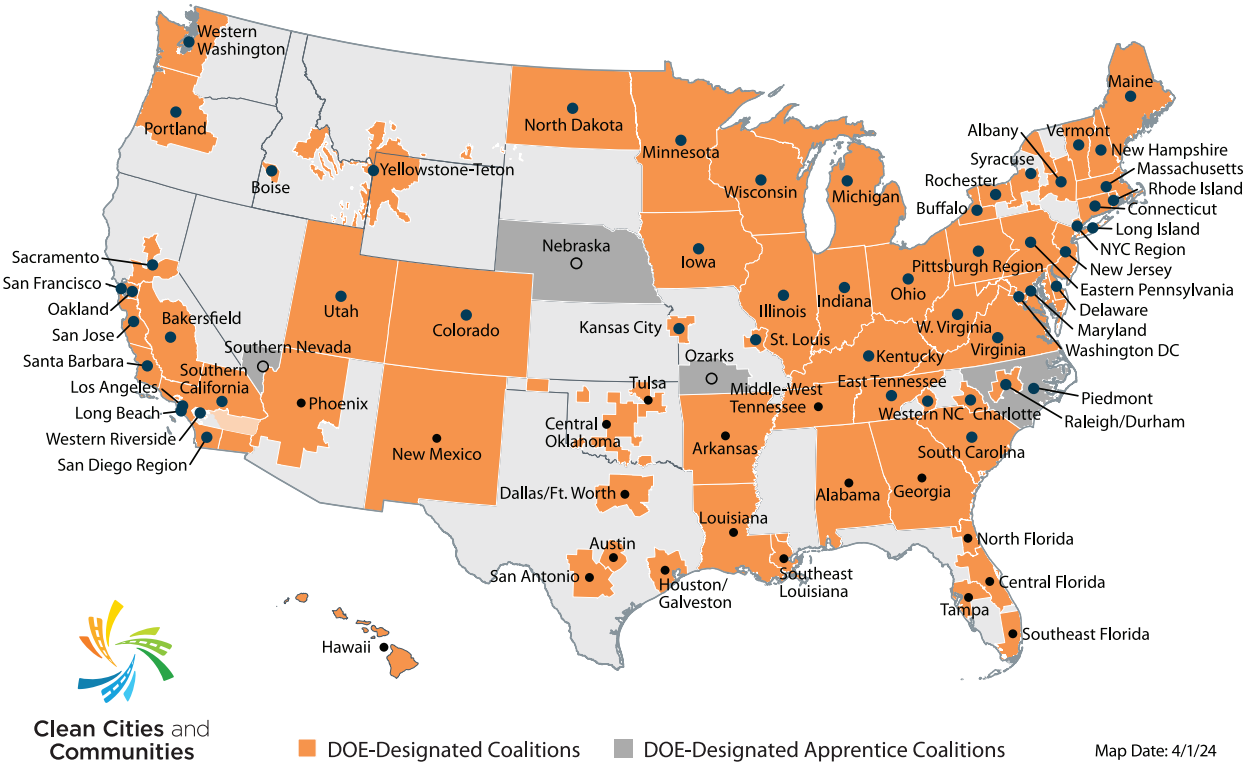
Clean Cities and Communities is a DOE partnership to advance clean transportation nationwide. More than 75 DOE-designated Clean Cities and Communities coalitions work locally in urban, suburban, and rural communities to strengthen the nation's environment, energy security, and economic prosperity. About 90% of the U.S. population lives within the boundaries of these coalitions. In partnership with EERE, coalitions deploy

Figure 34: Map of announced manufacturing investments in select energy technologies since the passage of IRA and IIJA in 2021



Source: Department of Energy

Figure 35: Map of clean cities and communities coalitions



Source: Office of Energy Efficiency and Renewable Energy. "About Clean Cities and Communities." U.S. Department of Energy. Blue = fully designated coalitions; grey = apprentice coalitions.

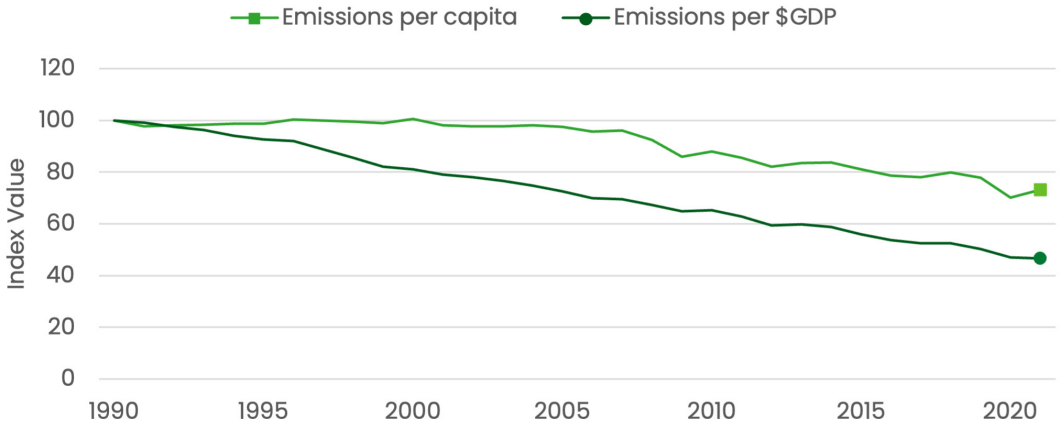
affordable, efficient, and clean transportation fuels; energy efficient mobility systems; and other fuel-saving technologies and practices. Since DOE established Clean Cities and Communities in 1993, coalition activities have reduced GHG emissions by 72 million tons and achieved a cumulative impact in energy use equal to nearly 14 billion gasoline gallon equivalents.

Another EERE program, the Better Buildings Initiative, is working with communities and businesses across the country to make our nation's homes, commercial buildings, and industrial plants more energy-efficient by accelerating investment and sharing successful best practices. The program has saved participants over $18.5 billion in energy costs and over 16.2 billion gallons of water. Better Buildings partners with over 50 state and local governments to deliver community benefits, over 50 organizations that provide multifamily housing (including the Minneapolis Public Housing Authority, District of Columbia Housing Authority, and the New York City Housing Authority), and a range of other organizations, such as the Green Bay Metropolitan Sewerage District and City of Charleston Water System, who deliver essential community services.

Emissions / Pollution Reduction

From 1990 to 2021, GHG emissions per dollar of goods and services produced by the U.S. economy (the gross domestic product or GDP) declined by 53%. This change reflects, among other factors, improvements in energy and industrial efficiency, the increased deployment of renewable energy, and the ongoing electrification of buildings and transportation. EERE's work has and will continue to play a vital role continuing to reduce GHG emissions.

Figure 36: U.S. greenhouse gas emissions per capita and per dollar of real GDP, 1990–2021



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