American Energy Innovation Council

Partners in Ingenuity:

CASE STUDIES OF FEDERAL INVESTMENTS ENHANCING PRIVATE-SECTOR ENERGY INNOVATION

July 2014

In the last half-century, American companies have developed the technologies and established the businesses that largely shape the world's energy systems today. American energy leadership has benefited significantly from long-standing federal support for research and development (R&D) and decades of public-private partnerships that help drive innovation. Acting as a catalyst or instigator, government innovation investments quicken the cycles of discovery and invention.

As the American Energy Innovation Council (AEIC) outlined in its previous reports, *Catalyzing Ingenuity* and *The Business Plan*, private-sector innovation cannot address the nation's energy challenges on its own. Private markets generally do not exist for society-wide interests, such as ensuring long-term economic competitiveness, maintaining energy security, or protecting the environment. Moreover, the private sector has tended to systematically under-invest in energy development R&D relative to the societal benefits that could be realized through such investment, because businesses and investors can capture only a fraction of the value of their innovation. Markets will undoubtedly drive innovation, but they will do so more rapidly when public policy addresses these twin challenges.

The AEIC staff's case studies on the federal government's role in energy technology innovation, which are summarized below, illustrate that public-private partnerships are recurring components in the successful development and market entry of advanced energy technologies. They demonstrate that federal energy innovation investments have produced enormous benefits to the U.S. economy and underscore AEIC's support for increasing such investments going forward.

The government can play the role of catalyst to private-sector innovation—enabling the private sector to develop new technologies more rapidly than would otherwise occur. This role commonly takes the form of lowering risks of new technology to the private sector, such as through seed grants, loans, and cost-sharing of demonstration projects; speeding diffusion of technical knowledge, such as through research partnerships; and standardizing information to help markets work better, such as through labeling and certification efforts.

Sometimes, the government plays the role of an instigator—creating new economic possibilities for private-sector activity. This role commonly takes the form of creating new knowledge that market participants lack incentives to pursue, such as through basic science and applied research, and driving demand for private-sector technology innovation, such as through direct procurement or performance standards.

In both of these roles, the government and private sector complement each other. The private sector translates ideas into products and markets; thus, feedback from private partners is critical for productive public-sector activities. Furthermore, these cases show that the dividing line between private-sector and government efforts often blurs. For example, public-private partnerships generally use cost-sharing, generating R&D efforts that neither party on its own would undertake. Similarly, government funding of R&D through national laboratories and universities invests many young scientists and engineers with skills that they subsequently take to the private sector. In some cases, the government has been the biggest or the sole customer of particular energy technologies, resulting in a collaborative effort with the private-sector vendor. Case studies summarized in this document include:

- Unconventional gas exploration and production;
- Aeroderivative gas turbines;
- Alternative vehicle technologies;
- Advanced diesel internal combustion engines, and;
- Low-emissivity windows.

This document presents summaries of each case; the full case studies can be found at americanenergyinnovation.org.

Unconventional Gas Exploration & Production

The outlook for North America's natural gas supply has improved dramatically in recent years, as horizontal-drilling and hydraulic-fracturing technologies have made it possible to commercially develop unconventional gas reserves, particularly shale gas reserves. These gas basins are located in diverse geographical areas, spanning at least 31 states in the continental United States. Whereas domestic production was thought to be on a declining trajectory as recently as 2007, the United States is now believed to have sufficient gas resources to meet domestic demand for decades at current rates of consumption.

While the private sector has driven the continuous improvements and breakthroughs in exploration and production technologies for unconventional natural gas, unconventional gas production through these combined techniques became commonplace only in the 1990s, after years of federal support and further innovations. The federal government substantively aided private efforts in several ways: basic science and resource mapping, coordinating and complementing industry efforts, applied research and development, and tax credits for unconventional gas.

Basic science and resource mapping: In 1976, Congress funded the Energy Research and Development Administration (now the Department of Energy) to launch the Unconventional Gas Research (UGR) program. Designed as a collaboration with academia and industry, the UGR developed an inventory of the unconventional gas resources across several regions. In particular, the Eastern Gas Shales Project determined the recoverable reserves of Devonian shale gas and financed experimental shale wells—at a time when most firms in unconventional gas recovery had little or no research budgets. The resulting maps and technical reports both proved the extent of shale gas resources and shared technological know-how with industry, demonstrating market potential and lowering risks to early entrants.

Coordinating and complementing industry efforts: The Gas Research Institute (GRI) was funded by a charge on interstate gas sales (as approved by the Federal Energy Regulatory Commission in 1976). Designed as an industry research collaboration, GRI managed and financed natural gas-related research and development jointly with the Department of Energy (DOE). Experimental horizontal wells for shale gas—drilled conjointly with DOE, GRI, and individual companies—proved methods for the industry at a time when no firm was willing to try on its own. Moreover, these partnerships were crucial for speeding up diffusion of new drilling practices among the dozens of well operators.

Applied research and development: Starting in the early 1980s, major oil and gas companies began to decrease their R&D spending, driven in large part by a decision to "buy versus build" new technology. DOE funded R&D activities through both national labs and universities that contributed to a steady stream of technology innovations during this time, resulting in notable contributions, such as microseismic mapping and advanced drill bits. Some DOE and national labs personnel moved into the private sector following breakthroughs in their basic R&D work; additionally, numerous graduates of government-funded university research programs in unconventional gas moved into industry.

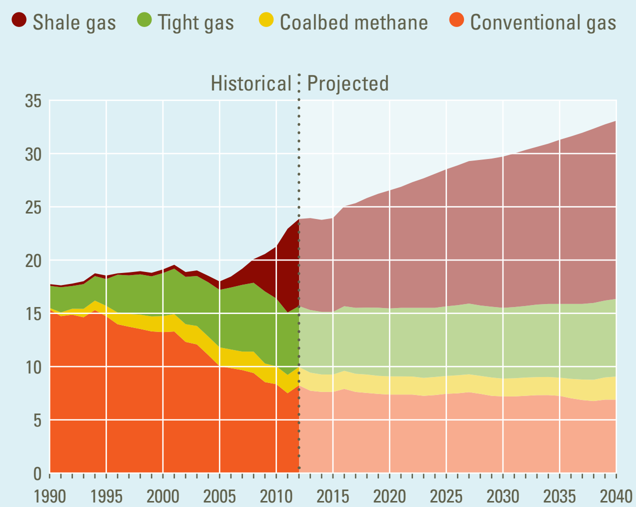
Tax credits for unconventional gas: The Windfall Profits Tax Act of 1980 established a production tax credit (called the Section 29 credit) for unconventional gas. Although the range of companies that could take advantage was limited, the tax credits reduced risks and increased returns to unconventional gas, enabling new gas shale projects to pass risk-weighted economic hurdles common to the resource. This attracted new sources of capital and increased exploration and development activity, tripling production of unconventional gas from 1980 to 2002 and driving further technological innovations through learning-by-doing.

When prices for natural gas rose in the early 2000s, making the economics of unconventional gas production more favorable, the combination of technological innovation and promotional policies in the previous two decades enabled a swift and dramatic response by industry. Since 2000, proven natural gas reserves have increased more than 70 percent, almost entirely due to shale gas resources. Natural gas-fired power plants are projected to account for more than 60 percent of new electric capacity additions between 2011 and 2035, and the United States is now expected to become a net exporter of natural gas in the next decade.

One lesson from the history of unconventional gas is that the federal government does not supplant private-sector innovation, but rather lowers risks to the private sector and provides complementary inputs that quicken the pace of private-sector discovery and innovation. More importantly, the history of unconventional gas technology development demonstrates how many threads of effort came together from sometimes unexpected sources over a period of decades before resulting in identifiable successes. The federal government undertook R&D without being able to predict the full scope of its applications, and technologies developed in one area transferred to other domains. Years or decades passed before the benefits of some technological advances were fully realized. Innovation did not occur on a linear path. The history of unconventional gas technology development suggests government support for R&D cannot simply be predicated on a near-term time-horizon, A-to-B mindset if it is to support major energy technology breakthroughs and energy market transformations.

Production of Natural Gas by Source

(Trillions of cubic feet)

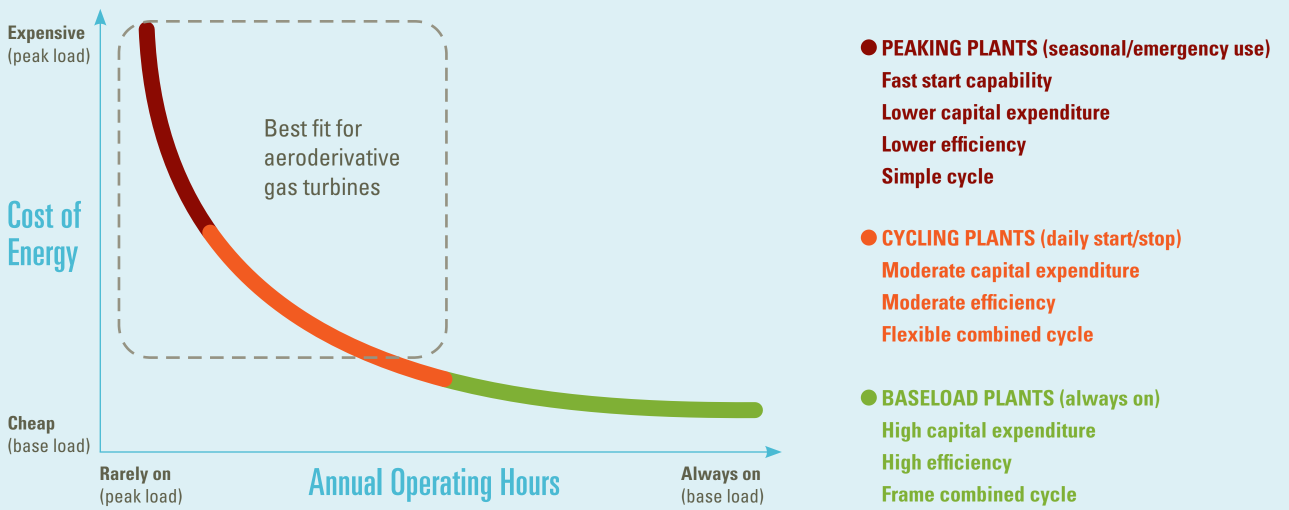


Aeroderivative Gas Turbines

For more than a half-century, gas turbine engines pioneered for military jet fighters have hung under the wings of commercial airliners. For nearly as long, these aircraft engines have been adapted to drive electricity generators, pump oil and gas, and power ships. These aeroderivative gas turbines are a part of the larger industrial gas turbine market, valued at $15.6 billion worldwide in 2010. Gas turbines provide more than 20 percent of electricity generation in the United States, are essential for oil and gas production, and power Navy ships around the world; aeroderivative turbines in particular are increasingly used for electric grid stability. Meanwhile, aircraft engines from which these turbines derive are responsible for the commercial and defense aviation engine market in the United States, valued at more than $26 billion.

The development of aeroderivative gas turbines is inseparable from the development of aircraft engines, which was led by the military and bolstered by the rise of commercial aviation. Industry-government partnerships to advance aircraft engine technology

Operational characteristics of gas-fired electricity generation



Source: Adapted from Rolls-Royce Energy Systems

have driven the evolution of aeroderivative gas turbines through several mechanisms: competitive military procurement, military R&D management, technology testing and validation, and public-private partnerships.

Competitive military procurement: In the 1940s and 1950s, competition was fierce and the military bought tens of thousands of gas turbine engines. Vigorous military demand allowed firms to explore a variety of initial designs, and development accelerated. Key innovations freed engineers to create and refine the high-pressure compressors needed for aircraft engines, which distinguish aeroderivative gas turbines from most other industrial gas turbines. The efforts of the 1940s and 1950s resulted in innovative engines defining the overall design still used today.

Military RD&D management: Gas turbine engines posed a complicated engineering challenge, and procurement efforts alone were not able to sustain the innovation needed to meet increasing military demands. In the 1960s, the U.S. Air Force led research and demonstration efforts focused on improving the core components of gas turbine engines. These efforts significantly assisted the launch of commercial aircraft engine lines that would become the parent engines for the most widely used aeroderivative gas turbines. NASA also worked with the Air Force to advance the engineering science used to design compressor blades and cooling regimes for turbine blades.

Technology testing and validation: The U.S. Navy helped to ruggedize aeroderivative gas turbines through materials engineering research and testing. Although some operating conditions, like high salinity, are unique to marine applications, the materials engineering knowledge cultivated through these efforts was valuable more generally for further adapting aircraft engines for industrial service in harsh environments. As a result, aeroderivative turbines were proven for service using non-aviation fuels, further demonstrating their reliability in various industrial applications like oil and gas production and electricity generation.

Public-private partnerships: Beginning in 1991, the GUIde consortium helped overcome certain damaging vibration issues afflicting military aircraft engines and threatening industrial gas turbines. The GUIde consortium succeeded because it addressed an industry-wide problem that individual firms otherwise lacked the means to resolve. University researchers received from industry the data and guidance needed to develop practical models for mitigating vibration phenomena earlier in the engine design process. The government had a key role in organizing a cooperative framework and facilitating the codification and diffusion of technical knowledge.

With the rise of commercial aviation and millions of flight hours thus accumulated, engine builders learned to improve manufacturing and maintenance procedures that further strengthened aeroderivative gas turbine performance. By the late 1980s, a confluence of factors had lowered natural gas prices, and aeroderivative gas turbines were being used year round in cogeneration configurations, providing simultaneous electricity and building heat at airports and other large facilities. Today, the rapid start-up and load-following capability of aeroderivative gas turbines provides a viable way to integrate variable renewable power sources into the grid.

The development of aeroderivative gas turbines occurred in a unique context of military innovation during the exceptional circumstances created by World War II, the Korean War, and the Cold War. Military imperatives drove technological development and involved massive expenditures of public funds unlikely to be reproduced today, absent a clearly articulated and broadly supported public good. Moreover, not all technologies are suited to the kinds of multidisciplinary partnerships and incremental gains evident in aeroderivative gas turbine technology. Nevertheless, this case provides a central lesson that aligning research with customer priorities and user needs is not a downstream or translational activity, but rather central to a successful energy R&D process.

Alternative Vehicle Technology Partnerships

Oil accounts for one-third of the energy consumed by the United States, most of it by the transportation sector. Continuing dependence on oil has subjected American consumers to considerable economic volatility. As a result, a large share of the federal government's research, development, demonstration, and deployment activities to reduce oil dependence have focused on making vehicles more efficient and developing alternatives to oil, such as biofuels, natural gas, electricity, and hydrogen.

This case study examines the light-duty vehicle-technology and hydrogen fuel cell programs of DOE, paying particular attention to the broad collaborative R&D partnerships among the federal government, U.S. automakers, and fuel providers through the Partnership for a New Generation of Vehicles (1993–2002), the FreedomCAR and Fuel Partnership (2002–2011), and the U.S. DRIVE Partnership (2011–present). The case finds that, while the Partnership for a New Generation of Vehicles, the FreedomCAR and Fuel Partnership, and U.S. DRIVE are popularly thought of as three discrete efforts undertaken by different presidential administrations, they are more accurately described as a single, evolving, and expanding partnership. The different programs varied in emphasis and approach as administrations changed.

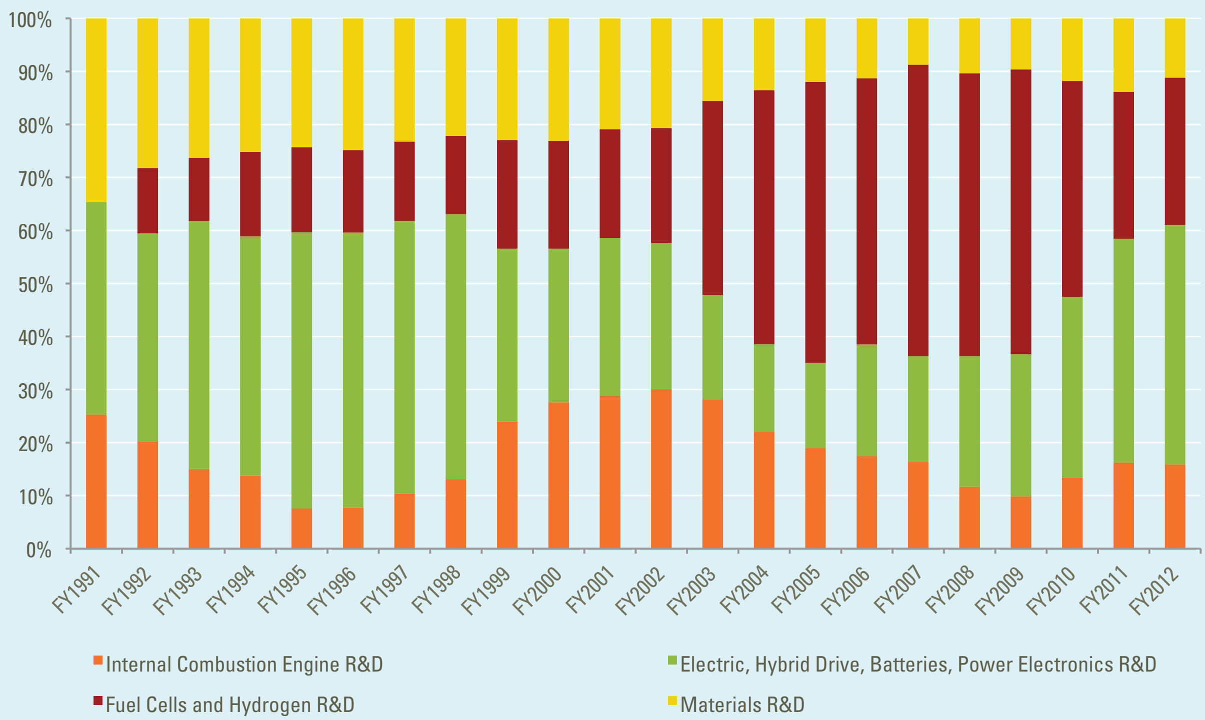
This paper describes the origins and nature of U.S. vehicle-technology programs, tracks the evolution of vehicle-technology R&D partnerships, and concludes with a discussion of the efficacy and worthiness of such partnerships. The Partnership for a New Generation of Vehicles focused on a near-term, singular "supercar" product goal. Learning from the failures to achieve this headline goal, FreedomCAR and U.S. DRIVE focused on systems and components that could be applied across a variety of vehicle platforms. FreedomCAR switched to longer-term pre-commercial fuel cell research, whereas U.S. DRIVE refocused to nearer-term electric vehicle research. Despite these differences, all three partnerships maintained a diverse R&D portfolio and allocated substantial resources to all four major vehicle-technology areas.

While this case does not offer a plausible estimate of the overall contribution of the partnerships to economic activity, the council finds that the partnerships account for a steady increase in technological accomplishments and progress toward performance, reliability, and cost targets for batteries, fuel cells, and other key enabling technologies for advanced light-duty vehicles. Vehicle fuel cell technology costs declined more than 50 percent from 2006 to 2012, and lithium ion battery technology costs declined more than 50 percent from 2008 to 2012; these cost reductions are attributable in large part to the R&D under the partnership umbrella. There have also been synergies in various technological achievements; for example, lightweight materials research and improvements in electric motors and power electronics have benefited all types of alternatively fueled vehicles, as well as conventional vehicles. The "innovation ecosystem" that includes the vehicle-technology R&D partnerships and the work carried on beyond them has demonstrably increased the use of advanced technologies in the conventional light-duty fleet. Moreover, the partnerships did so while fostering a healthy collaborative partnership between the government and automakers—in spite of a preexisting relationship that had been fairly antagonistic.

This case does not suggest that new vehicle technologies would not have emerged in the absence of DOE public-private automotive partnerships. Moreover, regulatory requirements promulgated by the U.S. Department of Transportation, the U.S. Environmental Protection Agency (EPA), and the California Air Resources Board have been and will remain important forcing mechanisms that require automakers to go well beyond the pre-commercial activities performed under the partnership. It is clear, though, that the participation of automakers and their supplier teams in collaborative activities with government-funded and -led R&D has both helped to inform government regulators about the progress, prospects, and cost of candidate technologies while assisting automakers in the exploration of new approaches.

In sum, the generally favorable reviews by outside bodies like the National Academies, the increasing appropriations by Congress, the implementation of technologies in actual vehicles in the marketplace and the participation of a growing number of increasingly diverse partners constitute explicit and implicit confirmations of the efficacy of the work of the public-private vehicle-technology partnership and the DOE effort they guide. The evolving partnership is a model of private-sector consultation, and participation in the planning and evaluation of R&D deserves emulation in other areas of DOE's portfolio of pre-commercial energy research.

Relative Shares of Direct Federal Investment in Four Key Vehicle Technolgy Areas



Advanced Diesel Internal Combustion Engines

Modern diesel engines are hugely important to the U.S. economy and especially in the transportation industry, where they are widely used in trucks and other heavy-duty vehicles. Truck transportation, which is dominated by diesel engines, directly employed more than 1.3 million people and contributed $252 billion to national GDP in 2010. Tremendous technological advances made through research at national labs and by government-led coalitions lowered operating costs and catalyzed widespread adoption of diesel engines.

The diesel engine was invented in the 1890s, but it only began to play a major role in the U.S. economy during and after construction of the Interstate Highway System in the 1950s. Following the 1973 oil embargo, the government placed a new emphasis on technological development to improve fuel efficiency and to reduce dependence on foreign oil. Over the following decades, there were three main mechanisms by which the government supported the improvement of diesel engines:

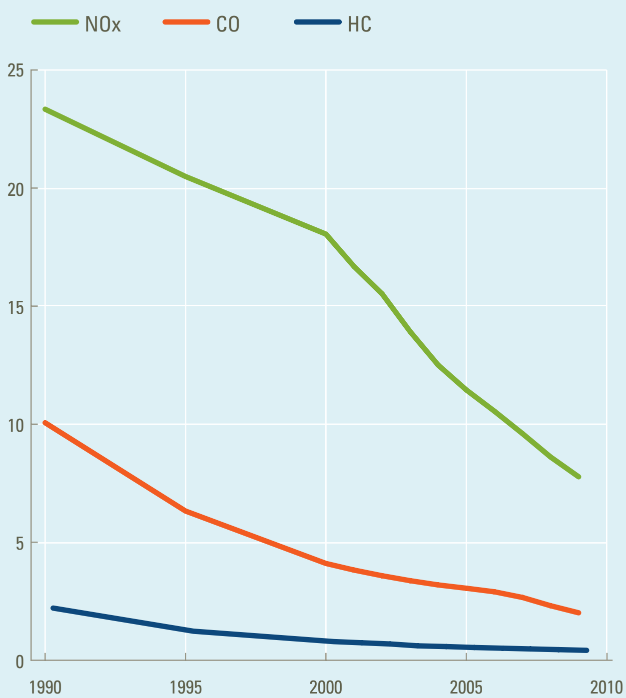
Basic combustion research: In the 1970s and 1980s, the extent to which engine manufacturers could refine their products was limited by a lack of fundamental knowledge about the combustion process. Basic research is risky and long-term, so it is difficult for private companies to justify to their shareholders. To address this need, the government founded the Combustion Research Facility (CRF), which began operations in 1981, and the Advanced Combustion Engine R&D program (ACE R&D), which started in 1986. These programs brought together researchers from national labs, universities, and the private sector to achieve advances in the fundamental understanding of combustion.

Simulation tools: The CRF and ACE R&D programs also developed computer software capable of simulating the combustion process, such as KIVA codes and the Cross-Cut Lean Exhaust Emissions Reduction Simulation. These tools were used by engine manufacturers such as Caterpillar, Cummins, General Motors, Ford, and Chrysler to develop cleaner and more efficient engines.

Research partnerships: In addition to the efforts above, the DOE played a critical role in bringing together private companies, government labs and agencies, and academia through partnerships that continued to refine engines through the 1990s and 2000s. These include the Partnership for a New Generation of Vehicles in 1993, the 21st Century Truck Partnership in 2000, the FreedomCAR and Fuel Partnership in 2002, and U.S. DRIVE in 2011. Additionally, DOE has convened smaller partnerships, such as the Cooperative Research and Development Agreement between Cummins, catalyst maker Johnson Matthey, and Pacific Northwest National Laboratory, to achieve rapid technical progress. These partnerships achieved advances that improved vehicle efficiency, reduced harmful emissions, and reduced dependence on foreign oil.

As a result of government-supported research, heavy-duty diesel trucks went from 37 percent efficiency in 1981 to 42 percent efficiency in 2007. Truck fuel economy increased almost 20 percent, from a low of 5.4 miles per gallon in 1981 to 6.4 miles per gallon in 2010. From 1990 to 2009, per-mile emissions of harmful nitrogen oxides, carbon monoxide, and particulate matter from the U.S. heavy truck fleet declined 67 percent to 81 percent, dramatically reducing adverse health impacts from diesel engines.

Pollutant Emissions from Diesel-Powered Heavy Trucks (g/mile).



From 1986 through 2007, the CRF and ACE R&D programs generated more than $70 billion in economic benefits to the United States while improving fuel efficiency, reducing emissions, and reducing U.S. reliance on foreign oil. Today, diesel engines use an array of technologies developed through the CRF and ACE R&D programs, and government-led diesel research is ongoing. The history of advanced diesel engines shows that government support of energy R&D generated a positive return on investment for the country while simultaneously achieving important health, environmental, and national security benefits.

Low-Emissivity Windows

Improving the energy efficiency of buildings has great potential to boost the U.S. economy, improve public health, and protect the environment. The energy used by buildings costs $418 billion annually and accounts for 39 percent of all U.S. carbon dioxide emissions. A major driver of building energy consumption is heat and cooling loss through the walls, roof, and windows. Losses through windows alone cost American consumers $40 billion per year.

Low-emissivity ("low-e") windows are effective at preventing these losses. Low-e windows use a transparent coating that blocks infrared radiation, keeping heat outside the building on hot days and keeping it inside the building on cold days. Relative to an ordinary, single-pane window, the best low-e windows can reduce heat loss by 85 percent.

Since the 1970s, the government has used four primary mechanisms to drive low-e window technology development and commercialization: basic research and seed investments, computer tools for simulating window performance, standardized testing procedures and performance ratings, and educational outreach to manufacturers and consumers.

Basic Research and Seed Investments: From 1976 to 1983, the government spent $2 million ($5.5 million in current dollars) to start a window research program at Lawrence Berkeley National Laboratory (LBNL). LBNL issued contracts to private firms to develop low-e technology and made its own facilities available for prototype testing. DOE provided $700,000 of seed funding to the start-up company Suntek Research Associates (later renamed Southwall Technologies), and LBNL worked in partnership with the company during its earliest stages. In 1981, Southwall released the first mass-market low-e window product, and their commercial success changed major window and glass manufacturers' opinions on low-e window marketability. By the mid-1980s, industry investment in low-e manufacturing facilities had grown to $150 million ($320 million in current dollars), with virtually every major window and glass company offering a low-e product.

Computer Tools for Simulating Window Performance: In addition to direct research support and physical prototype testing, Lawrence Berkeley National Lab created WINDOW, a computer model for simulating window performance. Virtual design and optimization of a product with simulation tools is much faster and cheaper than the traditional method of iterative prototype construction and laboratory testing. The software was released for free and quickly became an important tool used by private companies to efficiently test window designs. Today, more than 80 percent of all residential window designs are modeled using LBNL's simulation tools.

Standardized Testing Procedures and Performance Ratings: In the 1980s, there was no standardized system for evaluating and rating window performance. As a result, consumers lacked reliable assessments of window quality prior to purchase, and manufacturers found it difficult to convince consumers of the windows' benefits. To address these issues, window and glass manufacturers formed the National Fenestration Rating Council (NFRC) in 1989. The NFRC developed testing procedures, ratings, and a labeling system for energy-efficient windows, which were officially sanctioned by the U.S. government as part of the Energy Policy Act of 1992. The NFRC's system provides a level playing field with accurate and uniform ratings and labels that describe a window product's energy-related properties. The government's sanction of NFRC's system was a necessary precursor to voluntary standards, such as ENERGY STAR, and mandatory standards, such as state and local building codes, that helped drive adoption of low-e windows in the 1990s and 2000s.

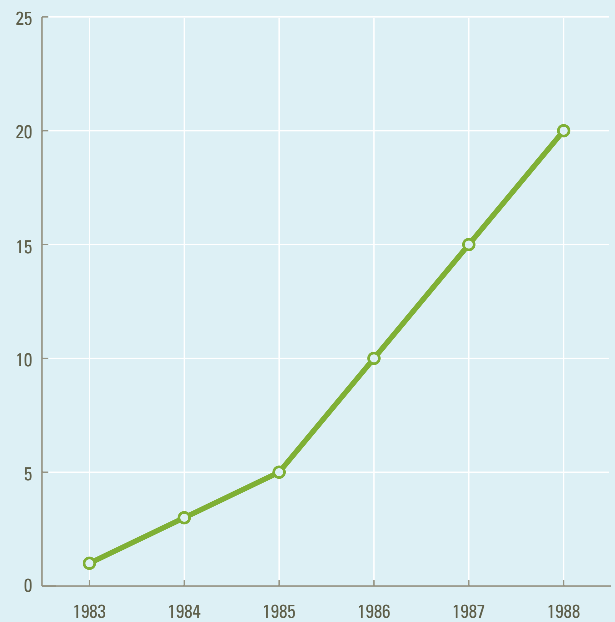
Educational Outreach to Manufacturers and Consumers: The U.S. government took steps to inform manufacturers, building designers, contractors, and the public about the benefits of low-e window technology. LBNL staff informed key decision-makers by presenting their research results at industry trade shows and in private meetings with code officials, utilities, and research and marketing staffs from a number of major window manufacturers. In 1992, the federal government established the ENERGY STAR voluntary labeling program to help customers identify the most energy-efficient products on the market. Windows were added to the program in 1998. The ENERGY STAR program has been tremendously successful at driving adoption of energy-efficient windows. From 2001 to 2010, the specifications for ENERGY STAR windows were revised three times, even as market share climbed from 35 percent to 81 percent of residential window sales. However, both industry and EPA have observed that the growth in market share is partially due to the slow rise in standards. In order to promote continued innovation, EPA is currently planning to reduce market share from 81 percent to 41 percent with windows' next specification revision.

Low-e windows are now an integral part of the U.S. building sector, commanding a market share of 80 percent of residential windows and more than 50 percent of commercial windows. DOE-sponsored research investments from 1976 to 1983 totaling just $2 million ($5.5 million in current dollars, about $0.7 million/year), along with annual investments of similar magnitude during the rest of the 1980s and 1990s, resulted in a net savings of more than $8 billion by 2000 ($10.7 billion in current dollars). The average payback timeframe for low-e windows is currently six to 16 years (depending on climate), and they may allow for the use of smaller and less expensive heating and cooling systems in new construction, potentially saving money from day one.

The history of low-e windows demonstrates the importance of the government playing an active role in developing new energy technologies. Sometimes, even after a potential technology is understood from a scientific perspective, the private sector may consider investing in the R&D necessary to commercialize that technology to be too risky. The government has the laboratories, staff, and financial resources to investigate many technologies simultaneously, and government can take a long-term view, making high-risk, high-reward bets that would not pay off in time to satisfy investors in private companies. Moreover, for consumers facing energy-efficiency technologies, the government's role in creating performance and/or certification standards is critical. Objective performance metrics give consumers the information they need to choose among products and enable states and localities to integrate the technology into their building codes. Voluntary standards and labeling programs, such as ENERGY STAR, help consumers distinguish between more and less efficient products, and should be tightened as the technology develops to incentivize continued innovation. By taking an active role in energy-efficiency R&D, from project inception all the way through ongoing standard-setting and labeling, the government can work with the private sector to achieve economic benefits, further U.S. technological leadership, improve public health, and protect the environment.

Residential Market Penetration of Low-E Windows, 1983–1988

(Percent of Sales)



Common Themes

A common theme is that successful public investments in energy innovation pay back many multiples of the resources put in. For example, although federal spending in unconventional gas R&D was around $220 million from 1976 to 1992 and the tax credits Congress used to incentivize unconventional gas production were perhaps $10 billion, unconventional gas now accounts for more than $30 billion in direct economic activity annually. Moreover, by hastening the development of unconventional gas, these benefits are generated right now during the post-2009 economic recovery as opposed to several years from now. Similarly, the federal government gave seed funding to the first low-emissivity window manufacturer in the nation, spurring the development of an industry that now boasts 80 percent market penetration and has saved billions of dollars in energy costs. Federal support to private-sector diesel-engine R&D resulted not only in significant reduction of harmful air pollutants, but also in billions of dollars in savings from increased fuel efficiency. And the American commercial aviation industry was built on massive U.S. military investments in developing reliable jet engines.

Moreover, public investment in energy innovation benefits far more than just "green" power. Energy-efficiency technologies enable U.S. businesses and consumers to shift their spending from energy bills to more productive ends. Improvements in oil and gas technologies can directly lower the pollution impacts of current infrastructure and economic activity, as well as spur renewal in other parts of the economy. New grid technologies can both avoid costly disruptions and enable integration of increasingly diverse energy resources. Furthermore, innovations in one area will invariably assist others. Just as technologies from mining and geothermal energy R&D informed unconventional gas R&D, current-day improvements in unconventional gas production are informing new geothermal R&D. Federal R&D efforts on aeroderivative gas turbines years ago enable backup generation for intermittent wind- and solar-electricity generation today. Undoubtedly, cleaner energy technologies remain a pressing priority for the United States. Public investment in development of these technologies is best undertaken as part of a vibrant R&D ecosystem with interactions across domains, rather than siloed and linear approaches.