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SEEING IS BELIEVING: CREATING A NEW CLIMATE ECONOMY IN THE UNITED STATES

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A growing body of evidence shows that economic growth is not in conflict with efforts to reduce emissions of greenhouse gases. Experience at the state and national levels demonstrates that well-designed policies can reduce greenhouse gas emissions while providing overall net public benefits, for example, through improved public health, as well as direct financial benefits to businesses and consumers. Policies are often necessary to unlock these opportunities, however, because market barriers hamper investment in what are otherwise beneficial activities. Our analysis illustrates that many more opportunities could be realized with the right policy interventions, including the strengthening of existing policies and programs. In addition, we find that continued technological advancements could allow for even deeper reductions in the years ahead, as long as policies are put in place to help bring them to maturity.

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OVERVIEW

This study examined several opportunities for reducing greenhouse gas emissions, including:

- Reducing the carbon intensity of power generation
- Improving electric efficiency in the residential and commercial sectors
- Building cleaner, more fuel-efficient passenger vehicles
- Improving production, processing, and transmission of natural gas, and
- Reducing consumption of high global warming-potential hydrofluorocarbons (HFCs)

These five measures can drive significant greenhouse gas emissions reductions. If done right, they can also lead to net economic benefits, even before the benefits of avoiding climate change are considered. The sectors considered here accounted for 55 percent of U.S. greenhouse gas emissions in 2012 and provide significant opportunity for emissions reductions.

For each measure, we examined recent developments and trends, identified current and emerging opportunities to reduce greenhouse gas emissions, highlighted some of the barriers to scaling these opportunities, and laid out strategies for driving a shift in investment. This working paper surveys peer-reviewed reports from academics, government laboratories, regulatory agencies, think tanks, industry associations, trade publications, and nongovernmental organizations, and complements that work with new analyses where warranted to help fill in the gaps.

This study is one of several in-country studies commissioned to support the research of the Global Commission on Energy and Climate, an international initiative to identify the economic benefits of acting on climate change. Its flagship project is the New Climate Economy, which identifies the opportunities for enhanced economic performance and climate action in urban, land use, and energy systems across a range of country circumstances.

DELAYING ACTION WILL HAVE SIGNIFICANT ECONOMIC IMPACTS

Climate change itself constitutes a significant risk to the nation's economy. We are beginning to see some of these impacts today. Globally, 12 of the 13 warmest years on record occurred within the last 15 years.[1] Some extreme weather and climate events, such as heat waves and wildfires in the West and heavy downpours in the Midwest and Northeast, are becoming more frequent and intense.[2] These changes will continue unless significant action is taken to reduce greenhouse gas emissions. For example, the conditions that led to the 2011 Texas heat wave, which cost $5 billion in livestock and crop losses, are 20 times more likely to occur today than in the 1960s.[3] Over the longer term, unless action is taken to reduce greenhouse gas emissions, climate-related damages are expected to mount considerably, resulting in up to a 20 percent reduction in per capita consumption globally.[4]

Delaying action will result in real costs from greater warming and increase the number of stranded high-carbon investments. A July 2014 report by President Obama's Council of Economic Advisers concluded that each decade of delay will increase the costs of mitigation by 40 percent on average, with higher costs for more ambitious climate goals. The council further found that with each year of delay "it becomes increasingly difficult, or even infeasible, to hit a climate target that is likely to yield only moderate temperature increases."[5]

WE DON'T HAVE TO CHOOSE BETWEEN ECONOMIC GROWTH AND AVERTING CLIMATE CHANGE

A September 2014 study by the Global Commission on Energy and Climate found that key drivers of further economic growth—namely greater resource and energy efficiency; investment in infrastructure; and enhanced innovation—can also be key drivers of greenhouse gas emissions reductions, if they are done right. This finding is supported by a growing body of literature that concludes that supporting economic growth and tackling climate change are not mutually exclusive, and indeed that in certain circumstances, well-designed climate change policies can actually boost economic growth. The ability to reduce greenhouse gas emissions while benefitting the economy has already been demonstrated through numerous policies and programs implemented in the United States. For example:

- **Capping emissions in the Northeast is reducing electric bills and creating jobs.** Energy efficiency and other investments made during the first three years of the Regional Greenhouse Gas Initiative, a regional cap-and-trade program for carbon dioxide emissions from power plants in nine Northeast and mid-Atlantic states, will save customers nearly $1.1 billion on electricity bills and create 16,000 net job-years while adding $1.6 billion in net present economic value to the region's economy, according to a study by the Analysis Group.[6]

- **Energy efficiency programs provide multiple benefits.** State energy efficiency programs regularly save consumers $2 for every $1 invested, and in some cases up to $5. But the benefits extend beyond direct financial savings to consumers. For example, according to the Wisconsin Public Service Commission, the state's energy efficiency program is expected to inject over $900 million into the state's economy and net over 6,000 new jobs over the next 10 years. After taking into account the benefits from reduced electricity and natural gas bills as well as avoided air pollution, total benefits are estimated to be three times greater than program costs.[7] Similar results are seen across the 24 states that have energy efficiency savings targets (see Chapter 2).

- **Improved cars and light trucks reduce pollution and save drivers money.** New standards for cars and light trucks will cause them to emit roughly one half as much carbon pollution in 2025 as vehicles sold in the United States today. The Department of Transportation and the Environmental Protection Agency (EPA) estimate that model year 2025 car and light truck owners will save a net $3,400 to $5,000 on average over the life of their vehicle (compared with a vehicle meeting model year 2016 standards) as a result of lower fuel costs. They further estimate that the standards will produce net savings of $186 to $291 per metric ton of CO_2 reduced for model years 2017–25 in 2030 and 2050, respectively. These standards will also help reduce America's dependence on oil by more than 2 million barrels per day in 2025 (which could help reduce U.S. oil imports) and result in $3.1 to $9.2 billion in benefits (net present value) from reducing non-greenhouse gas air pollutants.[8] Plus, the model year 2017–25 light-duty vehicle standards could result in a net gain of 570,000 jobs and an increase of $75 billion in annual gross domestic product by 2030, according to American Council for an Energy-Efficient Economy estimates.[9]

- **Reducing waste from natural gas systems can improve air quality and save money for industry.** EPA's 2012 standards for natural gas systems aimed at reducing emissions of hazardous air pollutants, sulfur dioxide (SO_2), and volatile organic compounds are also expected to significantly reduce methane emissions while saving the gas industry $10 million per year in 2015. This is because the value of the avoided emissions of natural gas is greater than the cost of controls, according to EPA analysis (annual savings are estimated at $330 million versus $320 million in compliance costs). When including the value of reduced air pollution, the net benefits increase considerably. EPA estimates that the standards will reduce emissions of volatile organic compounds by 172,000 metric tons in 2015 alone.[10] Some studies have suggested that the public health impacts from these emissions could be as high as $2,640 per metric ton nationwide, and even higher in some localities.

- **Industry has a history of developing cost-effective alternatives for refrigerants.** The global phase out of chlorofluorocarbons (CFCs) under the Montreal Protocol, which aims to protect the ozone layer, will result in an estimated $1.8 trillion in global health benefits and almost $460 billion dollars in avoided damages to agriculture, fisheries, and materials that would have been caused by depletion of the ozone layer (both cumulative estimates from 1987 to 2060). The CFC phase-out has also reduced greenhouse gas emissions by a net 135 billion metric tons of CO_2 equivalent between 1990 and 2010 (about 11 billion metric tons CO_2 equivalent per year annually). Consumers around the world were not faced with higher prices for new products, and some of the new products were cheaper to maintain than the replaced equipment because of higher efficiencies, product quality, and reliability.[11]

As shown in the sections that follow, these five examples are hardly unusual, and, in fact, are representative of a much broader trend of smart policies and actions that reduce greenhouse gas emissions while also delivering benefits to the broader economy.

SUSTAINED TECHNOLOGICAL PROGRESS CREATES NEW OPPORTUNITIES

In each of the five areas we examined, sustained technological progress continues to create opportunities to reduce greenhouse gas emissions while delivering net economic benefits. We profile a number of low-carbon options that are already cost competitive with, and in some cases cheaper than, their high-carbon alternatives. Continued maturation of these technologies could increase the number of markets where they can compete. Plus, a number of new technologies on the horizon could unlock much deeper reductions of greenhouse gas emissions. For example:

- **Natural gas and renewable generation is cheaper than coal in many markets.** New natural gas-fired power plants now cost 19-44 percent less than new coal-fired power plants.[12] Meanwhile, wind and solar are cost competitive in a growing number of markets. Recent price declines for solar photovoltaics are particularly pronounced, with module costs falling 80 percent since 2008.[13] Increased renewable energy generation has the potential to save American ratepayers tens of billions of dollars a year over the current mix of electric power options, according to studies by Synapse Energy Economics and the National Renewable Energy Laboratory.[14] Continued technological progress could increase the number of markets in which renewable generation can compete with existing fossil-based electric generation.

- **Product efficiency continues to improve, creating new opportunities for customers to save money.** A number of major appliances are 50–80 percent more efficient than they were just a few decades ago. Nevertheless, in many states, utilities can procure energy efficiency at one-half to one-third the cost of new electricity generation. Technological advancement continues to create new opportunities for consumers to save money. For example, prices for light-emitting diodes (LEDs) have fallen 80 percent since 2012.[15] These bulbs use one-seventh the amount of electricity as an incandescent bulb, saving consumers up to $140 for every bulb they replace.[16] Intelligent building energy management systems have the ability to reduce building electricity use by as much as 30 percent, and are beginning to take hold in the marketplace. If successful, wide bandgap semiconductors—used in power conversion in consumer electronics—could eliminate up to 90 percent of the power losses that occur in electricity conversion from AC to DC.[17]

- **Vehicles are getting more efficient, and new technologies could transform the light-duty vehicle sector.** Since the implementation of new CO_2 emissions and fuel economy standards for cars and light-duty trucks, the number of vehicles with a fuel economy of 40 miles per gallon or more has increased sevenfold. A growing number of vehicles use energy-saving technologies such as variable valve timing, gasoline direct injection, turbochargers, hybrid engines, and six- and seven-speed transmissions. Meanwhile, next-generation vehicles are moving ahead. Battery prices for electric vehicles have fallen by 40 percent since 2010. This trend is likely to continue; Tesla Motor Company plans to build facilities by 2017 to produce batteries that are 30 percent cheaper than today's batteries. Some industry analysts predict that long-range electric vehicles will become cost competitive with internal-combustion-engine vehicles by the early 2020s, even without federal tax incentives. Meanwhile, several large automakers continue to pursue fuel cells for light-duty vehicles, with commercialization expected in 2015–17.

- **Cost-saving measures can reduce waste from natural gas systems.** Methane emissions from natural gas systems can be reduced using technologies available today, such as dry-seal centrifugal compressors, low-bleed pneumatic devices, and infrared-camera-assisted leak detection and repair. By reducing the amount of product lost through leaks and venting, these measures can save the industry money. Emissions can be reduced by 25 percent or more through measures that pay for themselves in three years or less, and even deeper reductions are possible at just a few cents per thousand cubic feet of gas. However, opportunity costs and principal-agent problems present barriers to achieving the full potential of emissions reductions.

- **New alternatives for high global warming-potential hydrofluorocarbons (HFCs) are entering the marketplace.** The United States can reduce HFC emissions by over 40 percent from what would otherwise be emitted in 2030 entirely through measures possible at a negative or break-even price today, according to data from EPA.[18] Companies around the world—including General Motors, Coca-Cola, Red Bull, and Heineken, among others—are already beginning to employ some of these technologies. Some of these companies began doing so for environmental reasons, but as technologies have matured, many more are discovering the economic benefits of the alternatives. Convenience stores in Japan have reported 10 to 26 percent energy savings from using HFC alternatives, while some supermarkets have achieved 19 to 21 percent energy savings.[19] Meanwhile, even more technologies now in the pipeline are expected to be available within the next five years, and could allow for even deeper reductions in greenhouse gas emissions.[20]

POLICIES CAN OVERCOME MARKET BARRIERS AND FACILITATE INVESTMENT AND INNOVATION

While existing cost-saving opportunities are being pursued, in many instances market and other barriers get in the way and prevent widespread adoption. Some of the common barriers hampering the shift to low-carbon growth include: split incentives, ownership transfer issues, network effects, imperfect information, capital constraints, and externalities. For example:

- **Split incentives** can impede investments in cost-saving measures in the natural gas sector. This is because thousands of companies are active in the U.S. natural gas industry, from contractors that drill wells to pipeline operators to the local utilities that operate the million-plus miles of small distribution pipelines. With so many independent actors, the incentives for investment in emissions control technologies are not always well aligned because the companies that are able to reduce methane emissions are not always the same companies that reap the benefits of those investments.

- **Ownership transfer issues** can impede investment in energy efficiency, for example, when an investor does not expect to capture the full lifetime benefits of an investment. This is a significant barrier in residential buildings where energy efficiency measures have an average payback period of seven years, yet 40 percent of homeowners will have moved in that time.

- Widespread penetration of electric cars depends on the development of a robust network of charging stations. However, it is less profitable to build new charging stations when there are only a few drivers of electric vehicles. Therefore, policy intervention is required in the early stages to reap the longer-term societal benefits of the network. (This chicken-and-egg situation is commonly referred to as **network effects**.)

- In a number of sectors, including electricity generation, the persistence of pollution **externalities** gives an unfair advantage to polluting activities. Externalities occur when a product or activity affects people in ways that are not fully captured in its price, such as the full health effects of air pollution not being factored into the cost of electricity generation. Thus society, rather than the company, pays the cost.

Well-designed policies can overcome these market barriers and direct investment into beneficial technologies and practices. Likewise, they can influence the rate at which emerging technologies mature by driving research, development, and deployment, thus ensuring advancement through learning-by-doing, and helping overcome network effects, among other factors. In this working paper, we identify a number of policies that can help promote both existing and emerging technologies. By so doing, new policies can enhance the transition to a low-carbon economy while delivering net economic benefits and, in many cases, direct savings for consumers and businesses.

This working paper identifies a number of opportunities to reduce greenhouse gas emissions while fostering economic growth. However, we are not suggesting that the United States should limit its climate policies to just these win-win opportunities. Climate change itself imposes economic costs, and reducing each ton of greenhouse gas emissions has a value that is not currently internalized in the U.S. economy. Indeed, analysis by the Interagency Working Group on the Social Cost of Carbon for the United States found that the damage of each incremental ton of CO_2 emitted in 2020 is between $13 and $144 (in 2013 dollars).[21] Fully incorporating the value of the benefits of reduced greenhouse gas emissions into economic decisions and policymaking will ultimately lead to better outcomes for both the U.S. economy and environment. Nevertheless, as we show here, numerous actions can be taken today that will produce net positive economic benefits even before accounting for the avoided impacts of climate change.

PRELIMINARY RECOMMENDATIONS

1. Produce Cleaner Electricity

- To make good long-term decisions that minimize stranded assets and maximize return on investment, the industry needs **long-term regulatory certainty.** EPA has taken a step in this direction by proposing carbon pollution standards under section 111(d) of the Clean Air Act. Regulatory certainty could also be provided through legislative measures such as a clean energy standard, a greenhouse gas tax, or a greenhouse gas cap-and-trade program.

- The transition to a low-carbon future will be cheaper and easier with the right policy support. Specifically, we find that:

    - States and utilities should **enhance access to long-term contracts** by renewable energy providers, which could reduce the average electricity costs over the lifetime of typical wind and solar projects by 10–15 percent.[22]

    - Congress should **stabilize federal tax credits and eliminate inefficiency in their design** so that more of the value of the credit flows to project developers without increasing the cost to taxpayers.[23]

    - Financial regulators and lending institutions should work together to develop commercial investment vehicles that align the risk profile of low-carbon assets with the needs of investors to **reduce the costs of finance.**

    - States and utilities should update regulations and business models to **promote a flexible power grid**, allowing customers and utilities to maximize their use of low-cost variable generation such as wind and solar.

- EPA should **finalize greenhouse gas performance standards** for new and existing power plants. Together, these standards will: (1) help with the nation's efforts to reduce greenhouse gas emissions; (2) deliver public health benefits through improved air quality; (3) reduce the risk of technological lock-in and stranded assets; and (4) encourage investment in natural gas generation and renewables.

- The United States should **increase federal funding for research, development, and commercialization** of low-carbon and energy-saving technologies. This would help foster opportunities for American businesses and manufacturing by helping the country remain a world leader of innovation.

2. Reduce Electricity Consumption

- The United States should **scale up its existing initiatives**, which are already delivering benefits many times their costs. This includes, but is not limited to:
  - Strengthening and expanding federal appliance and equipment standards;
  - Enhancing efforts to deploy new technology (e.g., research and development, partnerships with industry, competitions, voluntary labeling, rebates and incentives for efficient appliances);
  - Strengthening existing state energy efficiency targets, and adopting targets in states without them;
  - Pursuing policies to better align utility incentive structures, such as: providing performance incentives for energy efficiency, requiring utilities to consider efficiency as part of their integrated resource planning, and decoupling, among other policies.

- New federal policies should be implemented to **promote the proliferation of ambitious state efficiency policies**, thus expanding the number of consumers that benefit from increased energy efficiency. This could include new **legislation**, such as a nationwide electric energy-efficiency resource standard, a clean-energy standard, and a greenhouse gas cap-and-trade program or carbon tax, including the option to recycle revenue into energy-efficiency measures. **EPA's proposed carbon pollution standards for existing power plants** could also be an important addition to the toolkit, since they allow states to make progress toward their carbon dioxide emissions reduction targets through efficiency programs.

- Federal, state, and local governments should ensure that consumers benefit from the latest cost-saving building technologies by **encouraging adoption and enforcement of the most up-to-date building codes**.

- Federal, state, and local governments should help unlock cost-saving opportunities available through **retrofits to existing buildings** by (1) expanding labeling and energy assessment tools; (2) implementing building energy auditing, disclosure, and benchmarking policies; (3) recognizing the benefits of energy efficiency in mortgages; and (4) incentivizing whole-building retrofits.

- Federal, state, and local governments should take steps to **improve access to low-cost financing** options to help address barriers that might otherwise be created by high up-front costs. Specifically, they should: (1) stimulate private funding; (2) improve access to property assessed clean energy (PACE) financing; and (3) pursue other innovative financing options (e.g., by establishing "green banks").

3. Develop and Deploy Cleaner and More Efficient Passenger Vehicles

- Corporate Average Fuel Economy (CAFE) standards and greenhouse gas emissions standards are poised to deliver significant benefits to consumers as a result of lower ownership costs and improved air quality. Depending on the progress of technology over the coming years, these **standards may warrant strengthening**.

- In the meantime, complementary policies by federal, state, and local governments can help promising technologies realize their potential:
  - **Increase the number of alternative fuel stations** (e.g., electricity and hydrogen) to help ease drivers' range anxiety and provide the certainty auto companies need to commit to manufacturing alternative-fuel vehicles.
  - Charging options should be improved by **eliminating barriers to access and adopting communication standards** for controlled charging by grid

operators. This would allow electric vehicle charging to better align with periods of high generation from variable renewable resources and provide low-cost grid stabilization as well as reduce charging costs for electric vehicle owners.

- **Research and development** for next-generation technologies should be expanded to help the United States take a leadership position in alternative vehicle manufacturing.
- Federal and state **mandates and incentives to promote sales of alternative vehicles** should be sustained and expanded to help accelerate the technology learning curve and bring lower-cost alternative vehicles to market faster.

4. Improve the Production, Processing, and Transmission of Natural Gas

- **Emissions standards for natural gas systems** should be implemented or strengthened to help correct the market failures that leave many cost-saving opportunities on the table. These standards could be achieved through section 111 of the Clean Air Act, through Congressional legislation, or through standards implemented at the state level.
- Agencies like the Federal Energy Regulatory Commission and EPA should work with industry to **revise contracts in such a way that service providers throughout the natural gas supply chain share in the benefits of reducing waste** and increasing the amount of natural gas brought to market.
- The Department of Energy (DOE) should work to improve emissions measurement and control technologies through **continued research and development**. Reducing the cost of this equipment will further encourage voluntary measures to reduce emissions, and lower the cost of complying with future standards from EPA.
- The Pipeline and Hazardous Materials Safety Administration could require **stricter inspection and maintenance standards** for gathering, transmission, and distribution systems, which would improve safety and increase industry revenues while reducing methane emissions from those sectors.

5. Reduce Emissions of Hydrofluorocarbons (HFCs)

- The United States should continue to work to achieve an international phase-down of the consumption of high-global-warming-potential (GWP) hydrofluorocarbons (HFC) through **amendments to the Montreal Protocol**.
- In the meantime, EPA and Congress can take the following steps to reduce domestic emissions of high-GWP HFCs:
  - EPA should use its authority under its Significant New Alternatives Policy program (SNAP) through section 612 of the Clean Air Act. This includes **finalizing proposed regulations to delist some uses of high-GWP HFCs** and continuing to phase down HFCs where safer, cost-effective alternatives exist. This will help harness win-win opportunities. EPA previously estimated that HFC emissions could be reduced by over 40 percent from what would otherwise be emitted in 2030 entirely through measures that come at a negative or break-even price today.
  - EPA should work toward **ensuring that the alternatives development process moves swiftly** and that new chemicals are quickly, yet thoroughly, tested for their safety and performance. EPA should also **finalize its proposed regulation to list new alternatives** and continue evaluating and approving appropriate low-GWP alternatives.
  - EPA should **extend the servicing and disposal of air conditioning and refrigeration equipment requirements** for HCFCs and CFCs to HFCs (under section 608 of the Clean Air Act) as well as increase initiatives for HFC reclamation and recycling to ensure that fewer virgin HFC compounds are used until they are phased down.[24]
  - Over time, it may also be appropriate to implement a **flexible program** to reduce emissions of high-GWP HFCs either by EPA under section 615 of the Clean Air Act or via Congressional legislation, as the flexibility provided by these programs could allow for deeper reductions in a cost-effective manner.

Box ES.1 | Nationwide Emissions Have Fallen, But More Work Remains

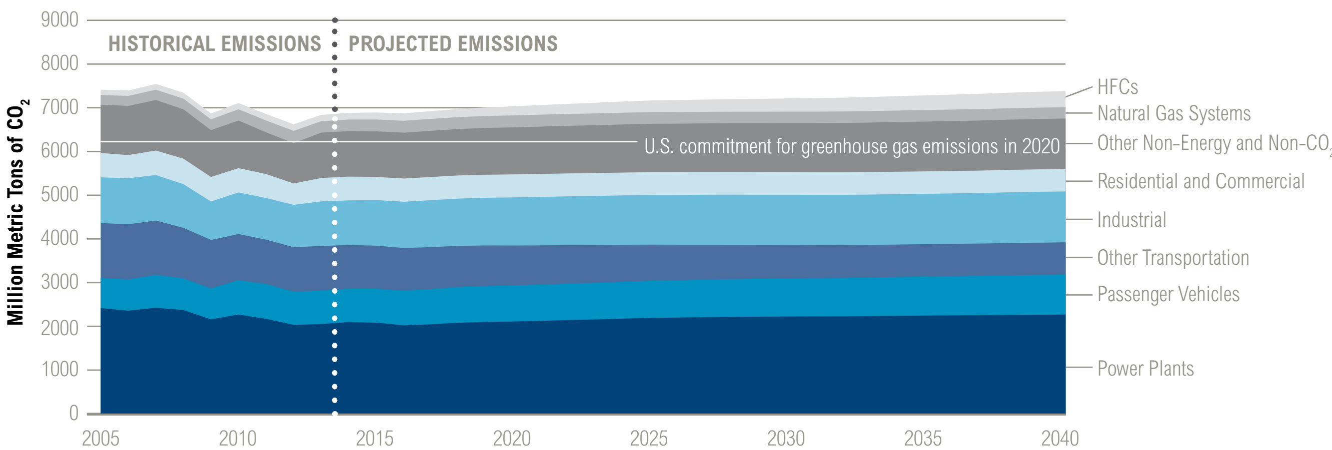
The United States has already begun to decouple its emissions from economic growth. From 2005 to 2013, energy-related CO_2 emissions fell 10 percent in absolute terms (Figure ES.1),[a] while real gross domestic product increased 11 percent.[b] These CO_2 reductions were the result of reduced residential electricity demand, a reduction in the carbon intensity of power generation, and reduced transportation emissions, among other factors.[c]

A number of state and federal policies contributed to these trends, and these policies have multiplied in recent years. However, as we conclude in the World Resources Institute report, "Can the U.S. Get There From Here?" the country is not expected to meet its international commitment to reducing emissions 17 percent below 2005 levels by 2020 unless significant new policies are adopted.[d]

The policies proposed by the Administration in 2013 and 2014 will help, but more will be necessary to reach the 2020 target and then to achieve the even more rapid emissions reductions needed thereafter to keep global temperature rise below 2°C. The current portfolio of standards and current market forces are not sufficient to drive a continued decline in CO_2 emissions from fossil fuel combustion, and other greenhouse gas emissions (both non-energy and non-CO_2 emissions) are expected to rise 15 percent above 2005 levels by 2020, largely because of increasing emissions of hydrofluorocarbons.[e,f,g]

However, that trajectory could shift considerably if the Administration adopts proposed policies, including greenhouse gas performance standards for existing power plants and new rules to reduce HFC emissions. The question is: Will these actions and others being considered go far enough to reach the 17 percent reduction target and achieve deep reductions in the years that follow?

Figure ES.1 | U.S. Actual and Projected Greenhouse Gas Emissions by Sector, 2005–40



Note: Projections only include policies finalized as of August 2014, and do not include recently proposed standards for existing power plants or HFCs.

Sources for energy emissions: U.S. Energy Information Administration, Annual Energy Review (Years 2005–13) and Annual Energy Outlook (Years 2014–40).
Sources for non-energy and non-CO_2 emissions: U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012" (Years 2005–12); U.S. Department of State, "U.S. Climate Action Report 2014" (Years 2013–14); World Resources Institute, 2013, "Clearing the Air: Reducing Upstream Greenhouse Gas Emissions from U.S. Natural Gas Systems."

Notes:

a. U.S. Energy Information Administration, "Table 12.1 Carbon Dioxide Emissions From Energy Consumption by Source," accessible at http://www.eia.gov/totalenergy/data/monthly/pdf/sec12_3.pdf.

b. U.S. Department of Commerce, Bureau of Economic Analysis, "Real Gross Domestic Product," Chained Dollars, accessed September 02, 2014, accessible at http://www.bea.gov/iTable/iTable.cfm?ReqID=9&step=1#reqid=9&step=3&isuri=1&910=x&911=0&903=6&904=2000&905=2013&906=a.

c. U.S. Energy Information Administration, "U.S. Energy-Related Carbon Dioxide Emissions," October 2013, accessible at: http://www.eia.gov/environment/emissions/carbon/.

d. N. Bianco, F. Litz, K. Meek, and R. Gasper, 2013, "Can the U.S. Get There from Here?" World Resources Institute, February, accessible at http://www.wri.org/publication/can-us-get-there-here.

e. Ibid.

f. As highlighted in this study, there are also emerging opportunities for cost-effective reductions in HFCs.

g. WRI estimates based on data from the following sources: U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012," and U.S. Department of State, "U.S. Climate Action Report 2014," (non-energy CO_2 and non-CO_2 emissions); U.S. Energy Information Administration, "Annual Energy Review," and U.S. Energy Information Administration, Annual Energy Outlook 2014 (most energy CO_2 emissions); World Resources Institute, 2013, "Clearing the Air: Reducing Upstream Greenhouse Gas Emissions from U.S. Natural Gas Systems," (methane emissions from natural gas systems).

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8. These ranges are based on lifetime net present value with 7 and 3 percent discount rates, respectively, using 2010 dollars. While more efficient vehicles are expected to cost more than their counterparts, EPA estimates that fuel savings from model year 2025 vehicles will offset the higher vehicle cost in less than 3.5 years when those vehicles are purchased outright by the consumer. However, consumers that purchase their new model year 2025 vehicle with a standard five-year loan will benefit right away as fuel savings offset loan repayment by $12 each month.
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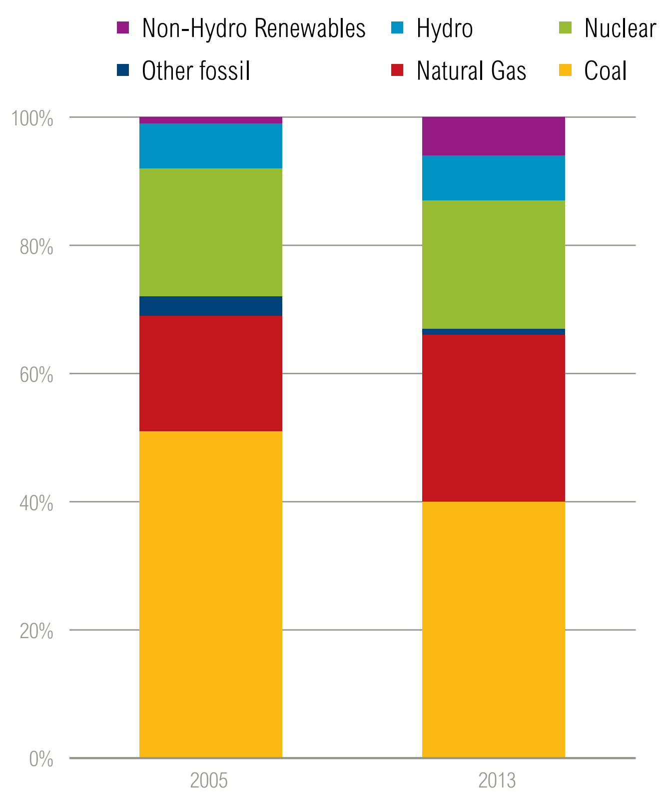
CHAPTER 1: PRODUCING CLEANER ENERGY

OVERVIEW

The U.S. power grid has already begun to decarbonize.[1] In 2013, carbon dioxide (CO_2) emissions were 15 percent below 2005 levels as a result of a reduction in the carbon intensity of power generation (Figure 1.1) and slowed demand growth.[2] Several emerging trends in the marketplace are driving these changes and could allow for a deep transition to a low-carbon future at a much lower cost than is commonly assumed, with net financial benefits for power companies and customers potentially accruing in some parts of the country. When layering in the public health benefits from replacing old, inefficient, and heavily polluting power generation with new, cleaner forms of generation (which also happen to be low-carbon), this transition could bring significant net benefits to society.

Figure 1.1 | **U.S. Electric Generation by Fuel Source**



Source: U.S. Energy Information Administration, Monthly Energy Review.

Here we profile recent and emerging trends in natural gas, coal, wind, solar, and nuclear power and examine policies that can unlock investments in a low-carbon power grid while delivering net economic benefits. In short, we found four main trends:

1. **Greater supply and lower prices for natural gas have helped reduce coal generation, leading to reductions in greenhouse gas emissions from the power sector.** In fact, coal, the dominant fuel used for power, accounts for only five percent of the new capacity built since 2000, whereas natural gas accounts for 74 percent of new capacity. The question is how much further the shift from coal to natural gas will go. Favorable natural gas prices and increasing standards to protect public health could lead to a wave of coal plant retirements in the coming years, likely with a corresponding increase in generation from natural gas. This would bring not only reductions in CO_2 emissions, but also reductions in a variety of pollutants, including sulfur dioxide (SO_2), nitrogen oxides (NO_x), and mercury. Natural gas combustion still emits CO_2, thus presenting long-term challenges for the fuel unless it employs carbon capture and storage; however, it still can play an important role in the decarbonization of the power sector. Replacing all existing coal generation with combined-cycle gas generation could reduce power-sector CO_2 emissions by 44 percent below 2012 levels. Importantly, as variable generation from resources such as wind and solar increases, grid operators will look to flexible resources like natural gas to help ensure grid reliability, suggesting that gas could play an important role even in an aggressive greenhouse gas abatement scenario.[a]

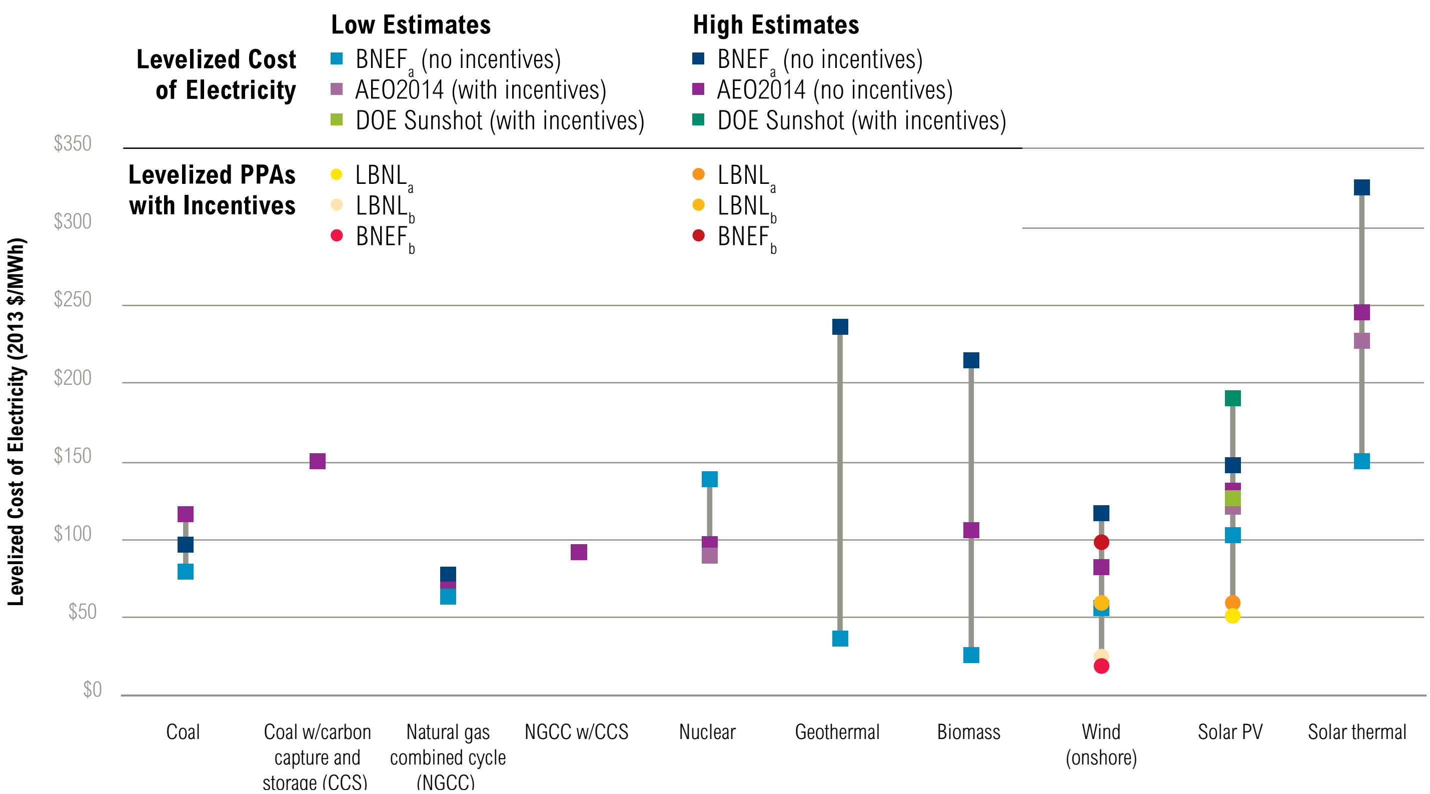
2. **Renewable generation has increased in recent years and could be more significant in the future.** Pollution-free electricity generation from renewable resources grew by almost 6 percent per year on average over the past five years (2009–13) and accounted for 12.5 percent of total generation in 2013—nearly half of which came from nonhydropower sources.[3] This increase has been spurred by widespread

a. Natural gas plants can cycle up or down more quickly, and more cheaply, than coal or nuclear plants, making them a more natural fit to serve as back-up generation for variable renewable resources.

implementation of state programs, federal tax incentives, voluntary renewable energy markets, new transmission, and rapidly declining prices for renewable resources, especially solar. As a result, new wind energy is cheaper than new coal generation in most markets (Figure 1.2),[4] and some new solar photovoltaic projects are being chosen over new coal generation because of lower costs or larger net benefits.

While the variability of renewable generation does create some challenges for grid balancing authorities, renewables have considerable room to expand on the

Figure 1.2 | **Levelized Cost of Electricity ($/MWh) for New Generation Sources and Levelized Power Purchase Agreement Prices for Recent Wind and Solar Projects**



Note: This figure depicts the estimated cost for new power plants (levelized cost of electricity) and recent actual costs for various renewable projects (levelized power purchase agreement). The line shows the full range of estimates, while the dots and boxes show specific data points from the U.S. Energy Information Administration (EIA), the Department of Energy (DOE), and Bloomberg New Energy Finance. These data suggest that new natural gas plants are typically cheaper to build than new coal plants, and new wind plants can be cheaper to build than new gas plants, even without incentives. Recently finalized wind and solar photovoltaic installations show that with incentives, certain projects could cost less than a new gas plant.

Levelized power purchase agreements (PPAs) represent an actual contract for future prices that has been "locked-in" and includes the value of any federal and state incentives. The **levelized cost of electricity (LCOE)** represents an estimate of the per-megawatt- hour cost of building and operating an electric generating plant, taking into account the project's capital costs, operating costs, and capacity factor, among other factors. Differences in levelized cost of electricity estimates can be explained by the underlying assumptions used in each analysis. For example, it has been suggested that EIA's assumptions related to renewable technologies are more conservative than recent governments and industry reports (see Union of Concerned Scientists, May 2014, "Climate Game Changer Methodology and Assumptions," accessible at: http://www.ucsusa.org/assets/documents/global_warming/UCS-Carbon-Standards-Analysis-Methodology-and-Assumptions.pdf). All cost and price estimates displayed here were converted to $2013.

Sources: **BNEF$_a$**: Bloomberg New Energy Finance, January 2014, "H1 2014 Levelised Cost of Electricity Update;" **EIA 2014**: U.S. Energy Information Administration, May 2014, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014," in *Annual Energy Outlook 2014*, accessible at http://www.eia.gov/forecasts/aeo/electricity_generation.cfm; U.S. Energy Information Administration, May 2014, "Table 8.2. Cost and Performance Characteristics of New Central Station Electricity Generating Technologies," in *Annual Energy Outlook 2014*, accessible at http://www.eia.gov/forecasts/aeo/assumptions/pdf/electricity.pdf; **DOE Sunshot**: U.S. Department of Energy, February 2012, "SunShot Vision Study," accessible at: http://energy.gov/sites/prod/files/2014/01/f7/47927_chapter5.pdf; **LBNL$_a$**: M. Bolinger and S. Weaver, Lawrence Berkeley National Laborator, September 2013, "Utility-Scale Solar 2012," accessible at: http://emp.lbl.gov/sites/all/files/lbnl-6408e_0.pdf; **LBNL$_b$**: R. Wiser and M. Bolinger, Lawrence Berkeley National Laboratory, August 2014, "2013 Wind Technologies Market Report," accessible at: http://emp.lbl.gov/sites/all/files/2013_Wind_Technologies_Market_Report_Final3.pdf; **BNEF$_b$**: Bloomberg New Energy Finance, 2014, "Sustainable Energy in America Factbook", accessible at http://www.bcse.org/factbook/pdfs/2014%20Sustainable%20Energy%20in%20America%20Factbook.pdf.

grid. Several studies have shown that grids across the country can handle up to 35 percent generation from variable renewable resources with minimal cost.[5] In part this is because of improvements in renewable energy forecasting and sub-hourly supply scheduling, as well as increases in transmission.[6,7] Over the longer term, however, as renewable penetration continues to increase with expected declines in equipment costs, the United States would benefit from expanded transmission[8] and increased system flexibility, for example through increased grid storage, distributed generation sources, and demand response.[9]

3. **Nuclear power has an uncertain future.** Nuclear power provides around-the-clock baseload generation that is free of CO_2 emissions. In 2013, it was responsible for 20 percent of total U.S. electric generation.[10] Industry-wide generation levels remained at or near historic levels while three new nuclear plants were under construction. However, several nuclear reactors closed in 2013.[11] Some analysis suggests that certain nuclear plants may be struggling to remain viable as a result of cheap natural gas; low renewable energy prices; lower demand for electricity; and rising costs for nuclear fuel, operations, and maintenance (particularly at smaller, older, standalone units).[12] If nuclear retirements continue, fossil baseload generation could increase, leading to an overall increase in CO_2 emissions from the power sector. Even if these pressures do not force nuclear plants to retire prematurely, the nation will eventually need to replace some of these units as they reach the end of their useful lives. Stringent regulations or other climate policies that value low-carbon generation could help improve the economics of the existing fleet, and could potentially spur the construction of new nuclear units, particularly if increasing international development of nuclear plants leads to reductions in construction costs. Any expansion, however, will likely depend on public concerns about nuclear safety and solving the challenges of long-term waste storage.

4. **Policies can encourage decarbonization.** With the confluence of the first two trends, and despite the challenges faced by nuclear generation, the nation appears to be trending toward a lower-carbon future. In some places this is happening through market forces alone, resulting in savings for consumers. However, even where incremental costs are associated with shifting generation, analysis suggests that net benefits are accruing to populations as a result of reductions in air pollution. With the right long-term policy push, the transition could accelerate, delivering even greater public health and environmental benefits. Conversely, a lack of policy could slow down this transition and lead to continued reliance on high-carbon electric generation.

The U.S. Environmental Protection Agency (EPA) is moving forward with greenhouse gas emissions standards for existing power plants under section 111(d) of the Clean Air Act, which they project would reduce power sector CO_2 emissions by 26 to 27 percent below 2005 levels by 2020 and by 30 percent by 2030[13] and lead to health benefits three to eight times the compliance costs. Given current technology trends, these estimates may be overly conservative, and deeper reductions may be possible.

Over time, Congress should consider implementing an economy-wide carbon price to capture the full costs of unchecked carbon emissions. Studies show that a carbon price can be implemented in ways that boost economic growth.[14] In the meantime, a number of additional discrete actions can help unlock investments in low-carbon technologies. Specifically:

- States and utilities should enhance access to long-term contracts by renewable energy providers.
- Congress should stabilize federal tax credits and eliminate inefficiency in their design.
- Financial regulators and lending institutions should work together to develop commercial investment vehicles.
- States and utilities should update regulations and business models to promote a flexible grid.
- EPA should finalize greenhouse gas performance standards for new and existing power plants.
- The United States should increase federal funding to spur the research, development, and commercialization of low-carbon and energy-saving technologies.

PROFILES OF CHANGE

Fueled by the declining costs of renewables and the increased supply and lower price of natural gas, the United States has made strides recently to reduce the carbon intensity of its electricity generation. Below we highlight a few of these developments, which together hint at the possibility for a deep transformation of the U.S. power sector.

Low Prices for Natural Gas Are Reducing Greenhouse Gas Emissions

- Power companies that once relied heavily on coal have recently turned to natural gas. For example, both Southern Power (and its affiliates) and Tennessee Valley Authority (TVA) generated over 60 percent of their electricity from coal in 2005. In 2013, coal provided about 40 percent of electricity for these utilities. Both utilities now rely more on natural gas; in 2013, Southern Power generated 34 percent of its electricity from natural gas (compared with 10 percent in 2005) and TVA generated 11 percent from natural gas (compared with 2 percent in 2005).[15]

- Nine Northeast and Mid-Atlantic states participating in the Regional Greenhouse Gas Initiative (RGGI) have already reduced power-sector emissions by more than 40 percent, and are committed to reducing them further, to 50 percent below 2005 emissions levels in 2020.[16] These reductions have been aided by the changing economics of coal and natural gas. Between 2005 and 2009, relatively low natural gas prices contributed to 31 percent of total reductions by driving a reduction in coal generation.[17] Because RGGI states invest much of the revenue from auctioning emissions allowances into energy efficiency programs, electricity bills in these states are projected to drop. Investments over the first three years alone are expected to reduce electricity bills by $1.1 billion (net present value).[b, 18]

Renewables Are Cost Competitive with Fossil-Based Generation in Several States

- A recent state survey of renewable and fossil contracts submitted to the Michigan Public Service Commission found that the most recent new utility-scale wind power contracts cost about half the price of new coal generation.[19] The same study found that a combination of renewable energy and energy efficiency is cheaper than any other new fossil fuel generator, including combined-cycle natural gas units.[20] DTE Energy in Michigan recently announced that it is lowering customers' electricity rates by 6.5 percent in 2014, citing low-cost wind energy (aided by technology improvements and tax credits) as a major factor.[21]

- Austin Energy in Texas finalized a power purchase agreement that will bring it 150 megawatts of solar energy at less than 5 cents per kilowatt hour.[22] By comparison, the company estimates that new natural-gas-fired generation would cost 7 cents per kilowatt hour, coal 10 cents, and nuclear 13 cents.[23] After subtracting federal tax incentives (according to company officials, the project is not receiving any local incentives), the rate for solar energy compares favorably to natural gas, at just over 7 cents per kilowatt hour.

- In early 2014, the Minnesota Public Utility Commission chose a 100-megawatt distributed solar project over natural gas projects because the solar project will deliver many economic and environmental benefits, including the elimination of transmission costs and a reduction in transmission line loss.[24] Specifically, it was found that "when one accounts for avoided energy costs, avoided capacity costs, avoided transmission costs, the impact of emissions, and the cost to Xcel Energy [the utility] from transmission line losses, the benefits of [the solar] proposal amounts to a savings of $46 million of net present value of societal costs."[25]

Renewable Energy Investments Are Driving Energy Bill Savings, Supporting New Jobs, and Providing Other Economic Benefits in Several States

- In Iowa, MidAmerican Energy just announced it will invest $1.9 billion in new wind power, bringing wind capacity up to 39 percent of its generation portfolio.[26] The company estimates that when all the turbines are completed, rates will go down by $10 million annually, while creating 460 construction jobs, 48 permanent jobs, and generating more than $360 million in new property tax revenue.[27]

- The Illinois Power Agency found that the state's renewable energy standard enabled significant job creation and economic development opportunities; moreover, in 2011, the growth of wind energy reduced electricity

b. In its analysis of the first three years of RGGI (2009–11), the Analysis Group found that RGGI customers experienced slightly higher (0.7 percent) electricity bills, but over the 2009–21 period, the investments made in energy efficiency led to net savings in electricity bills (See P.J. Hibbard et al, 2011).

rates by about 4 percent per megawatt hour of electricity generation, for total statewide savings of over $175 million.[28]

- Oregon's second largest utility, PacifiCorp, reported that the required investments in renewable energy actually helped lower their total costs by $6.6 million in 2011.[29]
- Studies by the New York Independent System Operator (NY ISO), Synapse Energy Economics, and the National Renewable Energy Laboratory suggest that increased renewable energy generation has the potential to save American ratepayers tens of billions of dollars a year over the current mix of electric power options.[30]

More Renewable Energy Is Integrating into the Grid at Minimal Cost

- Texas just completed a $6.8 billion transmission project that is expected to lead to 7.5 gigawatts of new wind generation over the next three years, and eventually up to 16 gigawatts of new wind generation (in addition to the 12 gigawatts of wind capacity installed by the end of 2012[31]).[32] In total, the state's grid balancing authority (ERCOT) is studying 25 gigawatts of new wind projects.[33] While many of these projects are in the planning process and may ultimately not be built,[34] these figures are significant when one considers that Texas' record peak summer generating capacity was about 68 gigawatts in August 2011.[35] Notably, Texas already generates more than twice as much electricity from wind as the next largest wind producing state (California), and has more installed wind capacity than all but five countries.[36]
- Several studies have shown that states can handle up to 35 percent of annual power from renewable sources with minimal cost. For example, PJM (a regional transmission organization covering the Mid-Atlantic, Virginia, and parts of the Midwest), the National Renewable Energy Laboratory (NREL) for the Western United States, and the state of Michigan have all found that 30–35 percent of electricity could be generated using variable renewable resources with minimal integration cost.[37]

The key question is whether these developments are indicative of a broader transition, or merely outliers. The underlying market and policy trends affecting these opportunities, as well as challenges, and emerging opportunities for natural gas, coal, renewables, and nuclear are explored below.

OPPORTUNITIES FOR NATURAL GAS

Recent low prices for natural gas have had a significant impact on the power sector, resulting in a surge in gas-fired generation and a corresponding decline in coal generation. The question is: How far and how fast will the shift from coal to gas be? That question will be determined largely by: (1) whether existing natural gas plants reach their full capacity; (2) how many coal plants retire; and (3) what is built in place of retiring coal plants.

The existing power generation fleet still has room for considerable change, as today's combined-cycle gas plants run well below their peak design capacity on average.[38] In the coming years, the combination of projected low gas prices and new public health standards could cause a number of the older and less efficient coal plants to retire, with natural gas as the likely beneficiary. These trends could be strengthened as new carbon pollution standards are implemented. Industry analysts do not expect retired coal plants to be replaced by new coal plants because new gas plants are currently much cheaper,[39] and because greenhouse gas emissions standards for the power sector could prevent new coal plants from being built unless they are able to reduce their emissions by 40 percent below the most efficient coal plant (which would likely entail partial carbon capture and storage).[40]

Natural gas-fired generation offers considerable near-term promise. Simply increasing generation at existing combined-cycle gas plants so that they run 75 percent of the time, displacing an equivalent amount of coal generation, could reduce greenhouse gas emissions from the power sector roughly 10 percent below 2012 levels, while replacing all existing coal generation with combined-cycle gas generation would reduce power-sector emissions by about 44 percent.[41] Importantly, coal remains a significant source of emissions of other pollutants, including SO_2, NO_x, $PM_{2.5}$, and mercury. Although recent public health standards will reduce the level of these emissions, they will not totally prevent them. Therefore, reducing coal generation can bring significant public health benefits.

Nevertheless, natural gas remains a source of greenhouse gas emissions, which has led some to raise questions about the nature of its long-term role in the U.S. power system. However, as variable generation from resources such as wind and solar increases, grid operators will likely look to flexible resources like natural gas to help ensure grid reliability, suggesting that gas could play an important role even in an aggressive greenhouse gas abatement scenario.

Box 1.1 | Government Support Accelerated the Shale Revolution

The U.S. government can play a key role in accelerating the evolution of the energy system, by ensuring research and development funding, tax credits, and other supportive policies for low- and zero-carbon sources of energy. The shale revolution provides a model for the role government can play in fostering change, as it followed decades of federal government support that facilitated natural gas production and promoted shale gas development along with other unconventional sources (e.g., coal bed methane, tight gas, shales, hydrates). This includes spending on research and development and tax credits (see Table 1.1).

Beginning in the 1930s, the United States built a highly integrated natural gas pipeline infrastructure that operated based on "common carriage," which ensured that producers had access to these pipelines. The presence of a mature pipeline network for natural gas was among the factors that facilitated the shale gas revolution because much of the fixed-cost natural gas infrastructure was already in place.

Regulatory support also played a significant role in the emergence of the shale gas industry. The Natural Gas Policy Act of 1978 encouraged the exploration and development of unconventional gas,[a] in large part by deregulating wellhead prices from "Devonian-age gas shales, coal seams and geo-pressured brines," and enabling producers to recover more of the costs from unconventional development.[b] Beginning in 1980, section 29 of the Crude Oil Windfall Profits Tax Act provided a production tax credit of $0.50 per thousand cubic feet of natural gas produced from shales and $1.00 per thousand cubic feet for coalbed methane. The tax credit provided immense support for the precommercial shale gas industry until it expired in 2002, just as commercial production was first achieved at the Barnett Shale in Texas. These economic incentives proved effective in driving the industry forward.

Notes:

a. Unconventional gas in this context includes shale gas, as well as coal bed methane.

b. V.A. Kuuskraa and H.D. Guthrie, 2001, "Translating Lessons from Unconventional Gas R&D To Geologic Sequestration Technology," accessible at http://seca.doe.gov/publications/proceedings/01/carbon_seq/1a3.pdf.

The Growing Use of Natural Gas

Natural gas generation in the United States increased by nearly 50 percent between 2005 and 2013, according to the U.S. Energy Information Administration (EIA).[42] This increase contributed to a reduction of just over 350 million metric tons of CO_2 (equating to a 15 percent reduction in greenhouse gas emissions) from the power sector over the same period.[43] EIA predicts that natural gas could play an even greater role in the years ahead as domestic production continues to grow.[44]

The power sector began to see a pronounced shift in new construction in the early 1990s, when new natural gas capacity exceeded new coal capacity by 4 to 1.[45] This trend intensified in the 2000s, when new gas capacity outpaced new coal capacity by 13 to 1 as a result of low natural gas prices and increased competition in electricity generation markets because of the deregulation of those markets in many states.[46] This rapid build out of natural gas capacity led to increased demand for natural gas, greatly increasing prices in the 2000s, which briefly muted further growth in natural gas generation.[47] By the mid-2000s, spurred in part by billions of dollars in federal research spending and subsidies, natural gas production surged. This increase in production caused natural gas prices to fall, which led to record amounts of natural gas generation and even more construction of natural gas plants (see Box 1.1 for more information on how the federal government accelerated gas production).[48]

The surge in natural-gas-fired generation has largely come at the expense of coal-fired generation, which fell from 53 percent of all generation in 2000 to 40 percent in 2013.[49] Because natural gas plants emit roughly half as much CO_2 as coal plants, overall greenhouse gas emissions from the electric sector have fallen as well.[50] Natural gas generation has the potential to increase further as gas plants remain underused across the United States.[51] The capacity factor[c, 52] of the combined-cycle natural gas fleet was about 51 percent in 2012, according to EIA data.[53] However, these units are designed to be operated at up to 85 percent capacity, suggesting that they can be run more frequently.[54] Increasing generation at these plants to just 75 percent of their capacity could reduce CO_2 emissions 10 percent below 2012 levels if it displaces coal-fired generation.[55]

c. A power generator's capacity factor indicates the ratio of the amount of electricity generated over a certain time period to the amount of electricity that generator could have produced if it was continuously generating electricity (See U.S. Energy Information Administration, May 2014).

Box 1.1 | Government Support Accelerated the Shale Revolution, continued

Table 1.1 | Federal Government Research and Development and Financial Support for Shale Gas Development

MECHANISM	DESCRIPTION	LEVEL OF SUPPORT	TIMEFRAME
Research and development: Public-private partnership	Eastern Gas Shales Project—A U.S. Department of Energy (DOE)-sponsored project that provided fundamental science and engineering research including geological characterization and development of drilling methods.[a]	$172.4 million total—$137.4 million from federal contributions and $35 million provided by industry as part of the cost-share; (1999 dollars)[b]	1976–92[c]
Research and development: Public-private partnership	Natural gas research and development funding provided by DOE for public-private partnerships	Annual natural gas budget of $12 million–$117 million[d]	1997–2007
Research and development led by an industry consortium	Gas Research Institute established and led by the gas industry	By surcharge (approval and oversight managed by the Federal Energy Regulatory Commission (FERC): 0.12 cents to 1.5 cents per thousand cubic feet (Mcf)[e, f]	1976–98
		After the surcharge expired, the research continued with voluntary donations from industry and federal funding allocated to Gas Research Institute[g]: Total contributions averaged $50 million to $100 million per year	1998–2005
Financial support: Incentive pricing	Natural Gas Policy Act of 1978, section 107	Deregulated the wellhead sales price for shale gas to enable producers to recover more of the costs from unconventional development by selling the gas at a higher price	1978–present
Financial support: Tax credit	Crude Oil Windfall Profits Tax Act section 29	Leveraged increased taxes on crude oil to provide tax credits for shale gas and coalbed methane of $0.50 per Mcf and $1.00 per Mcf, respectively	1980–2002

Notes:

a. Albert B. Yost II Morgantown Energy Technology Center, "Session 2A: Eastern Gas Shales Research," accessible at http://www.fischer-tropsch.org/DOE/_conf_proc/MISC/Conf-89_6103/doe_metc-89_6103-2A.pdf.

b. Committee on Benefits of DOE R&D et al., "Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000," accessible at http://www.nap.edu/catalog/10165.html.

c. The National Energy Technology Laboratory (NETL), DOE's unconventional gas research programs 1976-1995.

d. U.S. GAO, 2007, "Department of Energy: Oil and Natural Gas Research and Development Activities," accessible at http://www.gao.gov/products/GAO-08-190R.

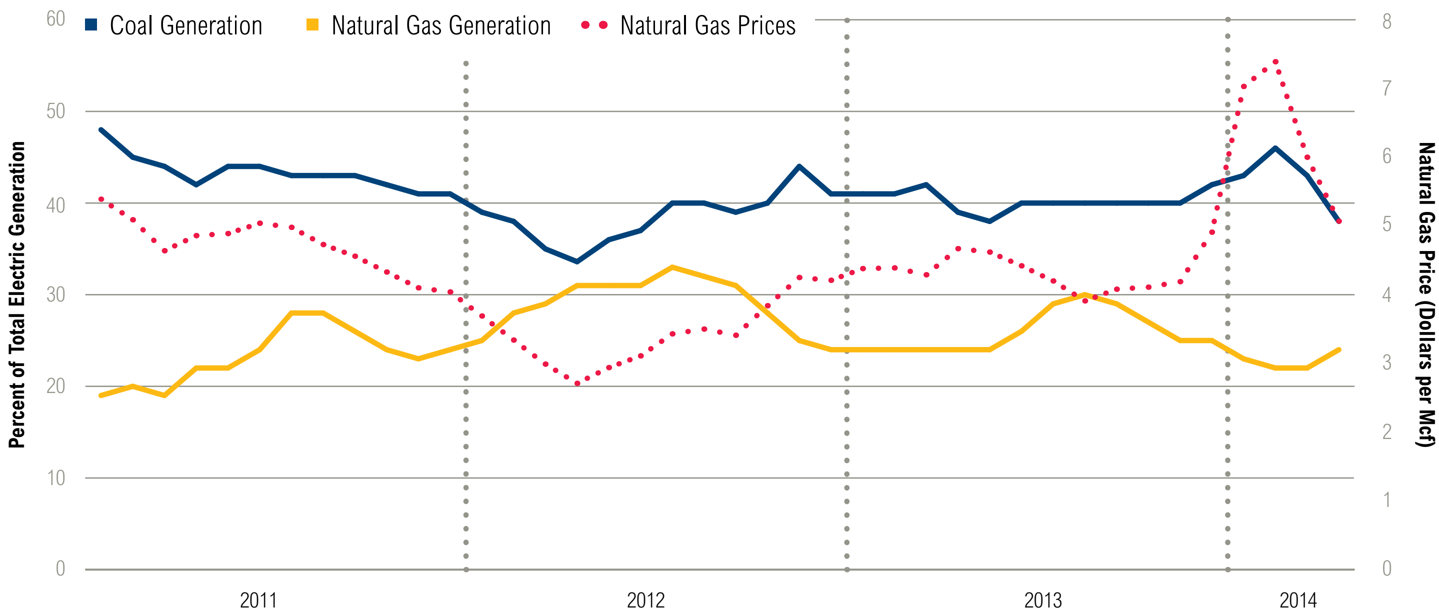
e. Only a portion of this went to unconventional gas research.

f. Henry R. Linden, 1996. "The Evolution of an Energy Contrarian," *Annual Review of Energy and the Environment* 21.1 (1996): 31–67.

g. In 1998 the Gas Research Institute's funding mechanism radically changed, leading to a phase out of the mandatory surcharge and a shift toward voluntary funding by industry and government.

Source: Based on research and analysis by WRI. First appeared in a working paper available online at http://www.brookings.edu/~/media/events/2014/2/06%20china%20clean%20energy/uschina%20moving%20toward%20responsible%20shale%20gas%20development_sforbes.pdf.

Figure 1.3 | **Average Annual Price for Delivered Natural Gas for Electric Power, 2011–14**



Note: Natural gas price is in constant 2012 dollars per thousand cubic feet of gas.

Source: U.S. Energy Information Administration, "Table 9.9 Cost of Fossil-Fuel Receipts at Electric Generating Plants," and "Table 7.2b Electricity Net Generation: Electric Power Sector," *Monthly Energy Review*, accessible at http://www.eia.gov/totalenergy/data/monthly/index.cfm.

Rising Natural Gas Prices Could Halt or Reverse Recent Gains

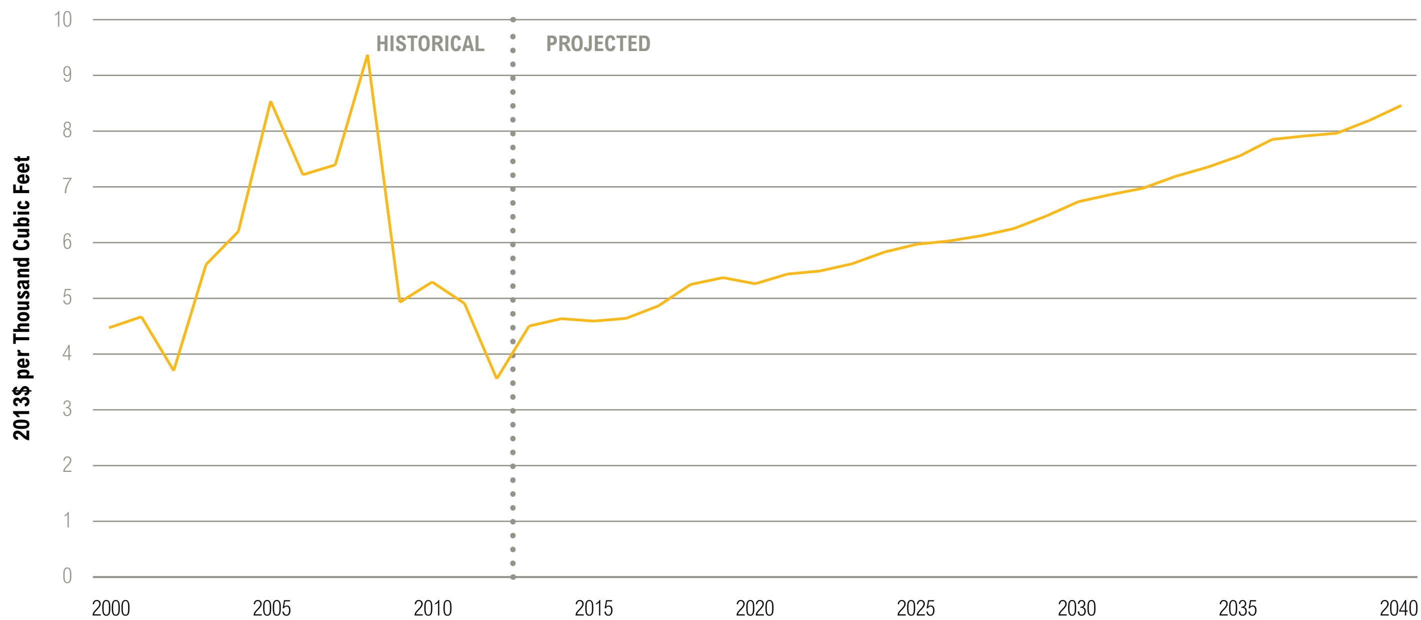
Market forces alone are not expected to drive this continued shift. The coal-to-gas-fuel price spread for existing fossil units is quite narrow, and recent analysis has suggested that gas prices may continue to rise.

As shown in Figure 1.3, when gas prices were at their low of $2.78 per thousand cubic feet in April 2012, gas and coal briefly provided an almost equal share of generation for the first time since 1973 (the earliest year for which EIA provides data).[56] Since then gas prices have risen, leading to a decrease in gas generation and corresponding increase in coal generation. EIA predicts that even with increases in production, natural gas prices will steadily increase over time, but that sustained prices will not reach the highs seen in 2008 until after 2040 (see Figure 1.4). Natural gas prices would rise more rapidly if carbon pricing or another program leads to a significant increase in gas generation.

Natural gas prices could also be driven up by increases in exports.[d, 57] Domestic natural gas prices are currently well below prices in much of the world. In 2013, prices in Europe were nearly three times higher than U.S. prices, while prices in Japan were over four times higher.[58] As of March 2014, 14 liquefied natural gas (LNG) export terminals had been proposed, with one having secured approval from DOE.[59] It will be years before these terminals are fully permitted and constructed, however, and because the liquefaction, transport, and regasification of LNG adds several dollars to the cost of each thousand cubic feet of natural gas, it is not yet clear how many terminals will actually be built and how much LNG the United States will ultimately export. While exports are generally expected to lead to price increases,[60] some studies have suggested that producers and consumers will react to mitigate price increases. Because the application process for a new LNG export terminal takes several years, producers and consumers can anticipate changes in the natural gas market and react accordingly—producers by increasing both storage and new supply, and consumers by anticipating potential price increases and reducing overall demand for gas, thus moderating those price increases.[61]

d. Currently, the U.S. imports and exports only a small fraction of the gas it consumes. In 2013, the United States consumed just over 26 trillion cubic feet of natural gas and produced 25.6 trillion cubic feet, importing 2.9 trillion cubic feet (almost entirely from Canada) and exporting 1.6 trillion cubic feet (mostly to Canada and Mexico) (See U.S. Energy Information Administration, 2014).

Figure 1.4 | **Historical and Projected Future Natural Gas Prices**



Source: Energy Information Administration, 2014, "Natural Gas Supply, Disposition, and Prices, Reference Case," *Annual Energy Outlook 2014*, accessible at http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2014&subject=8-AEO2014&table=13-AEO2014&region=0-0&cases=ref2014-d102413a; *EIA Monthly Energy Review*, July 2014, accessible at http://www.eia.gov/totalenergy/data/monthly/pdf/sec9_13.pdf

Further price increases for natural gas could increase generation at existing coal plants, slowing their retirement and curtailing the recent greenhouse gas emission reductions from the power sector unless programs are implemented that require generators to account for the impact of their greenhouse gas emissions.

A Changing Outlook for Coal Could Drive More Natural Gas Generation

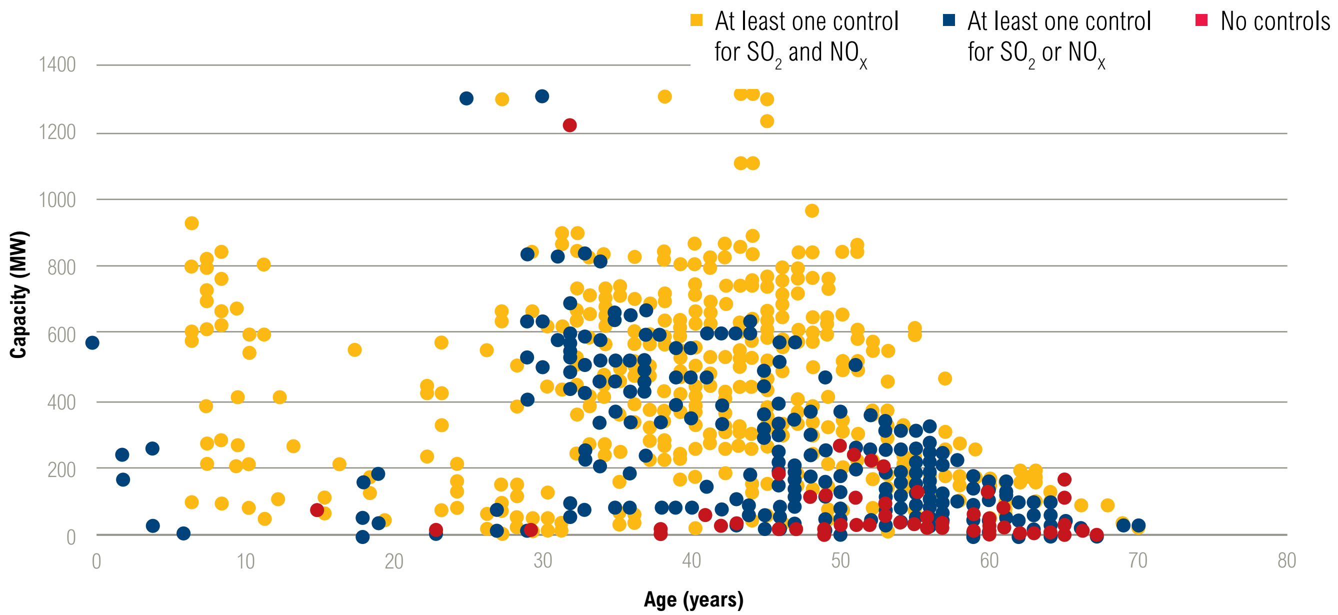
The transition from coal to gas could accelerate as the coal fleet ages and units become uneconomical. In fact, more than 18 gigawatts of coal plants retired between 2011 and 2013.[62] In the coming years, 50–117 gigawatts of coal generation could be "ripe for retirement" as a result of shifting fuel price economics, low electric demand growth, new pollution control requirements, declining prices for renewable generation, and their advanced age.[63] This accounts for 16–38 percent of existing coal generation capacity[64] (though likely a smaller percentage of total generation because the units most likely to retire tend to be smaller, less efficient, and have lower capacity factors).[65]

The existing coal fleet was largely built between 1950 and 1990. More than 30 percent of coal plants are more than 50 years old[66] and only 74 percent of these plants contain at least one control for SO_2 and NO_x (Figure 1.5),[67] air pollutants linked to respiratory diseases.[68] Several reports suggest that some plants without advanced mercury controls adequate to meet the new mercury and air toxics standards may opt for retirement before the rule begins to take effect in 2015, particularly those that are older, smaller, and have lower average annual capacity factors.[e, 69] For example:

- According to reports collected by EIA, 9.5 percent of the existing U.S. coal capacity in 2012 (roughly 30 gigawatts) is expected to retire before the Mercury and Air Toxics Standards (MATS) deadline rather than install advanced mercury controls. Owners and operators of another 20 percent of plants (roughly 60 gigawatts) reported they were unclear about whether they will retire or retrofit their plants to comply with MATS.[70, 71]

e. Under the Mercury and Air Toxics Standards, power plants will need to reduce mercury emissions 90 percent below what would otherwise be emitted from the combustion of coal without emissions controls. EPA has noted that most facilities will have up to four years to comply, with up to an additional year where necessary to ensure grid reliability (See U.S. Federal Register, April 2013).

Figure 1.5 | **Smaller, Older Coal Units are More Likely to Lack Controls for SO_2 or NO_x**



Note: "Pollution control" is defined as a wet or dry flue gas desulfurization "scrubber" (for controlling SO_2) or a pre- or post-combustion NO_x control technology. EPA notes that some units with reported SO_2 removal efficiencies of less than 50 percent are considered to have an injection technology and are classified as "unscrubbed." There may be some units with the same age and capacity, and thus data points may overlap.

Source: U.S. Environmental Protection Agency, National Electricity Energy Data System v. 5.13

- EIA modeling predicts that after 10 gigawatts of coal retire in 2012,[72] about 50 gigawatts of additional coal capacity will retire between the start of 2013 through 2020 (amounting to 16 percent of 2012 capacity). This is slightly less than all retirements in the power system between 1990 and 2012.[73, 74]

- However, some studies indicate that many more uneconomic units exist and could shut down in the coming years. For example, the Union of Concerned Scientists found that nearly 106 gigawatts of coal plants are either retiring or are uneconomic compared with existing natural gas plants and up to 117 gigawatts of coal plants are retiring or are uneconomic compared with new wind plants (with the federal production tax credit).[75]

Meanwhile, electricity regulators in the states that have oversight over capacity additions have started questioning the economics of their states' coal fleet. For example, the Oregon Public Utility Commission challenged PacifiCorp's analysis in which the company proposed billions of dollars of new pollution controls in their latest integrated resource plan.[76] One commissioner stated that the company "was headed 'for a trainwreck' on the rate approval process unless it fully accounted for the financial risks of spending hundreds of millions of dollars on its aging fleet of coal plants."[77, 78]

What Will Take the Place of Retired Coal Plants?

In the face of reduced generation from coal, the question is: What will generate electricity in its place? A big part of the answer has been, and will likely continue to be: more gas. It now costs roughly 19–44 percent more to generate electricity from a new coal plant than a new gas plant.[79] This is not just because of low natural gas prices, but also because of increases in coal prices from their recent lows in early 2000s, the higher fixed price of building new coal plants,[80] and increased pollution control requirements. Alone, these economics would likely spell an end to the construction of new coal-fired power plants, at least in the near term.[81] In addition, EPA proposed regulations in 2013 that require new coal generation to achieve CO_2 emission levels around 40 percent below the most efficient conventional plants, which presently is not possible without partial carbon capture and storage (see Box 1.2).[82] These regulations will reduce the risk of technological lock-in and stranded assets and encourage investment in low-carbon sources of generation, such as natural gas and renewables, which today are cheaper than new coal in most regions of the country.

Box 1.2 | Carbon Capture and Storage

Carbon capture and storage (CCS) technology has been demonstrated by a number of large-scale projects in operation or under construction around the world. Costs continue to fall, and the technology could play a significant role in the future as carbon regulations become increasingly ambitious.

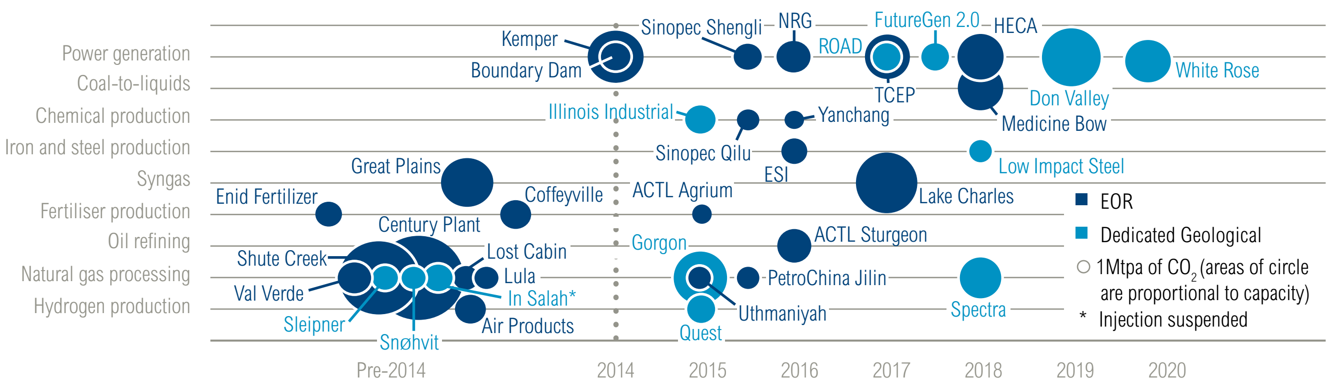
CCS demonstrations span a range of industrial facilities (natural gas processing; steel, cement, and power plants) and geological storage situations (using CO_2 to enhance oil recovery and storage in underground saline formations). According to the Global CCS Institute, as of February 2014, 21 large-scale CCS projects are in operation or under construction around the world. These projects have the collective capacity to capture 40 million metric tons of CO_2 per year (See Figure 1.2.1).

The cost for carbon capture and storage at a coal-fired power plant using enhanced oil recovery for storage is roughly equivalent to the cost of off-shore wind today, but costs are expected to come down with operational experience. For example, cost estimates for a 90 percent CO_2 capture were near $100 per metric ton of CO_2 for a first-of-a-kind plant around 2009, however more recent estimates put the cost of capture closer to $70 per metric ton, based on operation experience with post-combustion capture in demonstration projects.[a, b] If partial capture is employed, the cost on a per ton basis may be even less. In North America, much of the CO_2 captured in the initial demonstrations may be used for enhanced oil recovery, rather than stored for climate purposes. Such projects benefit from the existing CO_2 pipeline network and the incentive to boost domestic oil production and enhance energy security, but with marginal climate benefits.

Greenhouse gas emissions standards for new power plants under section 111(b) of the Clean Air Act, if finalized as proposed, will require new coal-fired power plants to reduce their emissions to a rate comparable to a natural gas combined-cycle power plant. In most cases this would require the installation of partial CO_2 capture on new coal plants. The comparatively low cost for low- and zero-carbon generation, such as natural gas and wind, make it unlikely that these regulations will spur many new CCS projects. Ambitious greenhouse gas reduction targets for the entire power sector, however, could drive power plants to deploy CCS technologies.

In the meantime, continued research and development support can continue to drive down technology costs, allowing for deep reductions at lower costs than might otherwise be possible.

Figure 1.2.1 | Twenty-One Large-Scale CCS Projects in Operation or Under Construction around the World Could Capture 40 Million Metric Tons of CO_2 Per Year



Note: CCS projects in the power and industrial sectors and projects utilising geologic storage options are expected to become operational over the coming years.

Source: Global CCS Institute, "The Global Status of CCS: February 2014," 2014, accessible at http://www.globalccsinstitute.com/publications/global-status-ccs-february-2014.

Notes:

a. For example, see this discussion paper estimating first of a kind plant costs: Mohammed Al-Juaied and Adam Whitmore, 2009, "Realistic Costs of Carbon Capture," July, Belfer Center for Science and International Affairs, accessible at http://belfercenter.ksg.harvard.edu/publication/19185/realistic_costs_of_carbon_capture.html; and this technical report: D. A. Jones, T. McVey, S. J. Friedmann, 2013, "Technoeconomic Evaluation of MEA versus Mixed Amines for CO_2 Removal at Near-Commercial Scale at Duke Energy Gibson 3 Plant," August, Lawrence Livermore National Laboratory, accessible at http://library.llnl.gov/uhtbin/cgisirsi/cAiqgVY6nD/MAIN/269660007/2/1000 (search LLNL-TR-642494) that estimates the costs based on data from research projects. Costs for carbon capture and storage are usually given in dollars per ton of CO_2 avoided rather than a cost per MWh because the cost per MWh varies depending on the type of plant and is equivalent to a plant of that type without CO_2 capture and storage. The other way to look at the cost of CCS is the percentage increase in price. Coal is at the high end with an estimated 60–80 percent increase, while ethelyene, ethanol, and gas processing plants may experience less than a 5 percent increase in costs because they emit CO_2 in much higher concentrations. See R. Middleton, J. Levine, J. Bielicki, M. Rice, H. Viswanathan, J. Carey, P. Stauffer. "Jump-Starting Commercial-Scale CO_2 Capture and Storage Using High-Value Chemicals and Products," Los Alamos National Laboratory.

b. D. A. Jones, T. McVey, and S. J. Friedmann, 2013, "Technoeconomic Evaluation of MEA versus Mixed Amines for CO_2 Removal at Near-Commercial Scale at Duke Energy Gibson 3 Plant," August 19, Lawrence Livermore National Laboratory, accessible at https://e-reports-ext.llnl.gov/pdf/761994.pdf.

How Good Is Gas?

The recent surge in gas generation has helped reduce U.S. CO_2 emissions. Natural gas is sometimes considered a "clean" fuel because of its lower emissions profile than coal. However, some question its long-term role in the transition to a low-carbon economy because of its greenhouse gas emissions and local environmental concerns associated with its extraction, processing, transmission, and distribution (see Chapter 4). While overinvestment in natural gas plants could result in stranded assets[f, 83] under

Box 1.3 | Major Public Health and Environmental Impacts from Fossil Fuel Combustion

Some of the major impacts on public health and the environment from fossil fuel combustion are described here. For a more comprehensive overview of the impacts associated with fossil and non-fossil-based electric generation, see Hamilton et al., *Multiple Benefits from Climate Mitigation: Assessing the Evidence*.[a]

Particulate Matter (PM): Particulate matter is a general term for a combination of solid particles and liquids (including acids and other pollutants) in the air. Particles less than 10 micrometers in diameter (PM_{10})—roughly one-fifth the diameter of a human hair—can pass through the throat and nose and lodge deep in the lungs.[b] They can lead to serious health effects, including "premature death in people with heart or lung disease, nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, and increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing."[c] The smallest particulates—smaller than 2.5 micrometers ($PM_{2.5}$)— are particularly harmful. In addition, they are the main cause of haze in parts of the United States, which reduces visibility. When nitrogen oxides and sulfur dioxide react with other compounds in the atmosphere they can form particulate matter.[d]

Sulfur Dioxide: Once emitted, sulfur dioxide (SO_2) cools in the atmosphere to form ultrafine particulate matter ($PM_{2.5}$). It can then fall to the ground as acid rain, which can damage structures and plants, and can make bodies of water uninhabitable to fish. In addition, high concentrations of SO_2 can lead to adverse respiratory impacts, especially for vulnerable groups such as children, the elderly, and asthmatics. SO_2 is formed when sulfur in fuels is combined with oxygen during the combustion process. While coal can be a significant source of sulfur, there is typically very little sulfur in natural gas.[e]

Nitrogen Oxides: Nitrogen oxides (NO_x) are a group of pollutants that includes nitrogen dioxide (NO_2), nitric oxide (NO), nitrous acid (HNO_2) and nitric acid (HNO_3). In high concentrations, they can also exacerbate respiratory issues such as asthma. These pollutants also contribute to the formation of ground-level ozone (or smog), $PM_{2.5}$, and acid rain. Ozone can also lead to respiratory issues and harmful effects on sensitive vegetation and ecosystems.[f] The combustion process itself forms NO_x as the high temperatures cause nitrogen (N_2) and oxygen (O_2) in the atmosphere to react. In addition, certain fuels, such as coal and biomass, contain nitrogen, which reacts with oxygen to form NO_x during the combustion process. While fuel-based nitrogen accounts for a significant amount of the NO_x formed from coal combustion, it is not a significant contributor to the NO_x emitted by natural-gas-fired power plants.[g,h]

Mercury: When coal or other mercury-containing compounds (e.g., certain waste products) are burned, mercury is released into the atmosphere and eventually gets deposited on land or into water. Aquatic microorganisms convert mercury in water into methyl mercury, its most common organic compound. This pollutant then bioaccumulates, or builds up, in fish and shellfish and in the humans and other animals that consume them.[i] Methyl mercury is particularly damaging to the developing nervous system of unborn children and young children.

Water: A typical 500 megawatt power plant produces enough heat to boil millions of gallons of water each day. Once used, this steam must be cooled so that it can recycle through the plant. The cooling process frequently employs either once-through cooling systems or closed-loop systems, which use nearby water sources, such as rivers, lakes, aquifers, or the ocean. According to the U.S. Geological Society, 41 percent of all freshwater withdrawals in the United States in 2005 were for thermoelectric power operations, nearly all of which was used for cooling.[j] Power plants impact marine ecosystems when withdrawing water because fish, shellfish, and their eggs may be drawn into or trapped against intake pipes.[k] In addition, the discharge of hot wastewater (or "thermal pollution") can adversely affect wildlife unaccustomed to sudden temperature spikes. The wastewater often contains high levels of pollutants: in fact, steam electric power plants are responsible for more than one-half of all toxic pollutants discharged to surface waters by all industrial categories regulated under the Clean Water Act.[l]

Extraction: Mining coal and drilling for natural gas can have significant impacts on the local environment. Natural gas extraction is associated with emissions of volatile organic compounds that are precursors to the formation of smog, and hazardous air pollutants that are often toxic or carcinogenic. Millions of gallons of water are also used to hydraulically fracture each well,[m] and the resulting wastewater is often stored in above-ground ponds before being treated and discharged to waterways, posing risks to the local environment and potentially creating hazards downstream.[n] In addition, some have raised questions about groundwater impacts from the process of natural gas extraction itself. Coal mining is also a significant source of both air and water pollution,[o] and the process of mountaintop removal—whereby the tops of mountains are dynamited off to expose coal seams underneath—has major environmental impacts on local land and water.

f. An asset is "stranded" if "a reduction in its value (that is, value to investors) is clearly attributable to a policy change that was not foreseeable by investors at the time of investment." See endnote 83, Karen Laughlin, June 2014.

certain scenarios, the role of natural gas could be significantly extended by its ability to help back variable renewable generation. In addition, natural gas plants could also employ carbon capture and storage in the future.

Natural gas emits less CO_2 than coal or oil, and negligible amounts of SO_2 and mercury.[84] While burning coal produces toxic coal ash, burning gas produces almost no solid waste, which reduces threats to drinking water. Both coal and natural gas, however, can be significant sources of NO_x emissions and can impact ecosystems in a variety of ways (see Box 1.3). Thus policies that reduce power generation by either source can provide additional public health and environmental co-benefits.

Hamilton et al. estimated that the co-benefits of reducing greenhouse gas emissions from coal plants could be in the range of $5 to $130 per metric ton of CO_2 depending on the nature of the controls installed in the plant and its physical location, among other factors. Meanwhile, they found that the co-benefits of reducing greenhouse gas emissions from natural gas plants could range from $0.10 to $42 per metric ton of CO_2.[85] On average, the monetized health and other damages not related to climate change from each megawatt hour of coal generation is 20 times the amount of damage from natural gas generation.[86] This suggests that under most circumstances, switching from coal to gas will produce significant public health benefits.

Another challenge associated with the expansion of natural gas generation is that the production, processing, transmission, and distribution of natural gas are also significant sources of greenhouse gas emissions. The primary component of natural gas—methane—is a powerful greenhouse gas, which exerts 34 times the impact of CO_2 over a 100-year timeframe.[87] Therefore, any leaks in the supply chain will undercut the climate advantage of natural gas over other fossil fuels.[88] However, as described in Chapter 4, cost-effective opportunities exist to reduce methane emissions from natural gas systems to 1 percent or lower, at which point natural gas presents clear advantages over coal, even when the global warming impacts are evaluated over a 20-year timeframe (see Figure 1.6).

Box 1.3 | Major Public Health and Environmental Impacts from Fossil Fuel Combustion, continued

Notes:

a. K. Hamilton, M. Brahmbhatt, N. Bianco, and J. Liu, “Multiple Benefits from Climate Mitigation: Assessing the Evidence,” New Climate Economy, *forthcoming*.

b. U.S. Environmental Protection Agency, 2012, “What are the Six Common Air Pollutants?” accessible at: http://www.epa.gov/airquality/urbanair/ and http://www.epa.gov/pm/.

c. U.S. Environmental Protection Agency, “Particulate Matter: Health,” 2014, accessible at: http://www.epa.gov/pm/health.html.

d. U.S. Environmental Protection Agency, 2012, “What are the Six Common Air Pollutants?” accessible at: http://www.epa.gov/airquality/urbanair/.

e. U.S. Environmental Protection Agency, 2014, “Six Common Pollutants: Sulfur Dioxide,” accessible at: http://www.epa.gov/airquality/sulfurdioxide/index.html.

f. U.S. Environmental Protection Agency, 2013 “Ground Level Ozone,” accessible at: http://www.epa.gov/airquality/ozonepollution/.

g. National Energy Technology Laboratory, “Syngas Processing Systems,” accessed August 28, 2014, accessible at http://www.netl.doe.gov/research/coal/energy-systems/gasification/syngas-processing.

h. U.S. Environmental Protection Agency, 2014, “Six Common Pollutants: Nitrogen Dioxide,” accessible at http://www.epa.gov/airquality/nitrogenoxides/.

i. U.S. Environmental Protection Agency, 2014, “Mercury: Basic Information,” accessible at: http://www.epa.gov/mercury/about.htm.

j. J. Kenny et al., 2009, “Estimated Use of Water in the United States in 2005,” U.S. Department of the Interior, U.S. Geological Survey, accessible at http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf.

k. http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/.

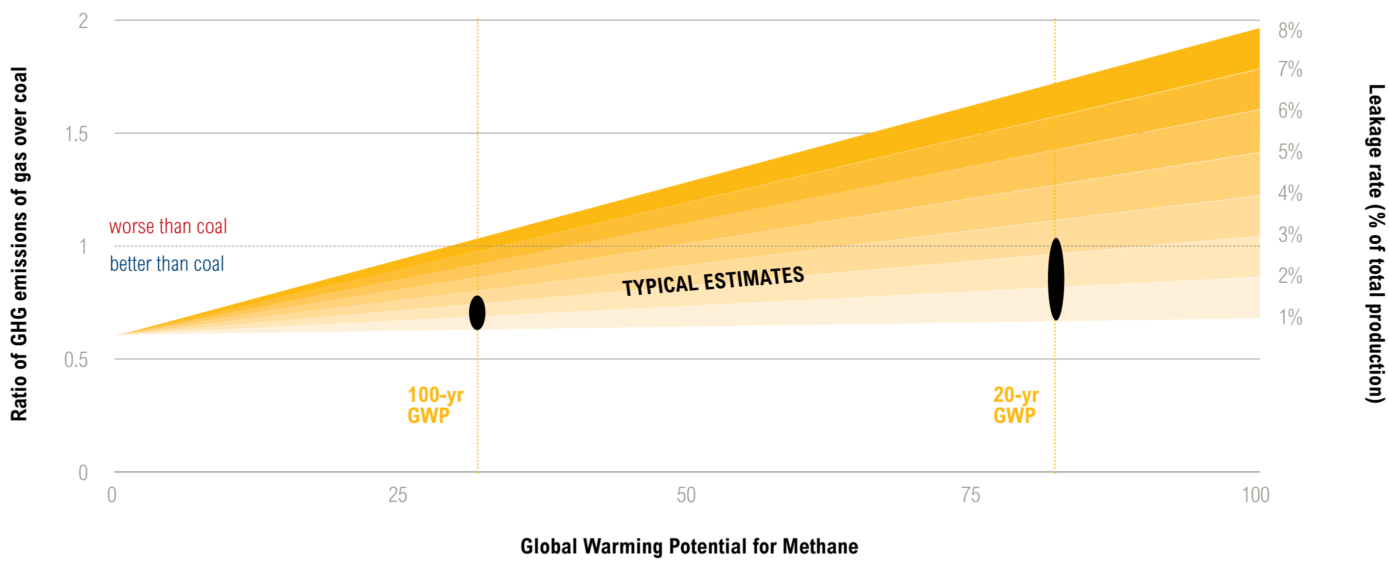
l. http://water.epa.gov/scitech/wastetech/guide/steam-electric/upload/proposed_factsheet.pdf

m. Frac Focus, 2014, “Hyraulic Fracturing Water Usage,” accessible at http://fracfocus.org/water-protection/hydraulic-fracturing-usage.

n. Nathaniel R. Warner, Cidney A. Christie, Robert B. Jackson, and Avner Vengosh, 2013, “Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania,” *Environmental Science & Technology*, accessible at http://pubs.acs.org/doi/abs/10.1021/es402165b?journalCode=esthag&.

o. U.S. Environmental Protection Agency, 2013, “Coal,” accessible at http://www.epa.gov/cleanenergy/energy-and-you/affect/coal.html.

Figure 1.6 | **Gas vs. Coal—A Climate Perspective**



Note: Considerable uncertainty remains surrounding the amount of natural gas emitted to the atmosphere during the production, processing, transmission, distribution, and end-use of natural gas (for more information, see Chapter 4). Yet even at the high end of leakage estimates (as depicted by the black ovals), natural gas has a smaller climate footprint than coal over 100 years. For policymakers concerned with comparative climate impacts over 20 years, however, the picture is much less clear.

Source: Adapted from IEA (International Energy Agency), "Golden Rules for a Golden Age of Gas," 2012, World Energy Outlook Special Report on Unconventional Gas, adapted from IEA (2012), figure 1.5.

While considerably lower than the greenhouse gas emissions from coal combustion (without carbon capture and storage), the combustion process itself at natural gas-fired power plants is still a significant source of CO_2 emissions. As a result, analysis by Michael Levi at the Council on Foreign Relations suggests that natural gas could play a significant role in reducing emissions through 2030. After that point, he found that natural gas' overall contribution to the U.S. energy supply must either decline, or plants must be accompanied by carbon capture and storage if the United States is going to help the world stabilize CO_2 emissions at 450 parts per million and keep warming to 2° Celsius above pre-industrial levels.[89] This raises questions about whether natural gas plants and the broader scope of natural gas infrastructure could become stranded assets in a low-carbon world. The scale of the risk will largely depend on how much new generation is built, the pace of commercialization of carbon capture and storage, and the ability of those plants to integrate with increasing solar and wind resources.

As variable generation from renewables increases in the coming years, natural gas will play an increasingly important role as back-up generation to ensure grid reliability. This is because natural gas plants can easily be ramped up or down to meet changing demand.[90] Analysis by the Climate Policy Initiative concluded that natural gas plants "will increasingly be valued more for their flexibility than for their actual energy output."[91]

Thus, natural gas could play an important role even in an aggressive greenhouse gas abatement scenario. However, for natural gas to realize its full potential, the environmental concerns surrounding its use need to be met. They include: methane leakage associated with natural gas production and processing; air and water quality impacts associated with natural gas development; and volatile organic compounds, sulfur dioxide, and hazardous air pollutants associated with natural gas production.

EMERGING OPPORTUNITIES FOR RENEWABLES

Renewable generation has been on the rise in recent years, and evidence suggests that it could play an even more significant role in the future. Electricity generation from non-hydro renewable resources increased by almost fourfold between 2005 and 2013, accounting for 6 percent of generation in 2013 (all renewables, including hydro, accounted for 12.5 percent of total generation).[92, 93] This increase has been driven by widespread implementation of state programs, federal tax incentives, voluntary renewable energy markets, new transmission, and declining prices for renewable resources. Twenty-nine states and the District of Columbia have renewable portfolio standards, which require a portion of electricity generated to come from renewable sources. According to analysis by the National Renewable Energy Laboratory, existing state renewable portfolio standards are expected to drive 140 terawatt hours of new renewable generation by 2015.[94] Lawrence Berkeley National Laboratories project that up to 3–5 gigawatts of new renewable capacity per year will be needed through 2025 to comply with existing targets.[95] However, falling costs for renewable projects—particularly when coupled with voluntary renewable power markets, EPA's carbon pollution standards, and uncertainty around future fossil-based electricity prices—could drive new wind and solar construction above and beyond those state mandates, while delivering benefits for consumers in the form of lower electricity rates and better air quality.[96]

In this section we profile emerging trends in wind, solar photovoltaic, and concentrating solar power. We also reflect on how grid operators have been addressing the challenges of integrating these variable resources in recent years, and how they might manage an increasing amount of renewables going forward. In short we have four main findings:

1. **Wind development costs have fallen in recent years because of improved turbine technology and more favorable terms for turbine technology purchasers.**[97] Many states are generating more of their electricity using wind resources, and are finding numerous economic benefits by doing so. This is partly because of the 64 percent decline in levelized power purchase agreements for wind generation between 2009 and the end of 2013, to about $24 per megawatt hour on average across the country (with incentives).[98] New wind energy is now routinely cheaper than new coal generation, and is cheaper than new gas in many parts of the country. If gas prices continue to rise or wind prices continue to fall, wind will become increasingly competitive with natural-gas-fired generation in more regions of the country.

2. **Prices for solar photovoltaic modules have declined 80 percent since 2008.**[99] When combined with the federal investment tax credit, this rapid decline has helped make power purchase agreements for electricity generated from utility-scale projects competitive with conventional sources in some regions. Power purchase agreements for utility-scale photovoltaic projects have reported prices below $50 per megawatt hour.[100] However, prices for residential systems are typically higher because of their smaller size and larger non-module (soft) costs, such as mounting hardware, labor, permitting, and fees.[101]

3. **Concentrating solar power (CSP) is also on the rise in the United States.** One major benefit of CSP is its ability to be deployed with thermal energy storage so it can produce electricity on demand.[102] CSP is a relatively new technology with only 1.4 gigawatts deployed as of early 2014. While its costs are currently high, the DOE SunShot Initiative aims to reduce the cost of generation to $60 per megawatt hour by 2020.

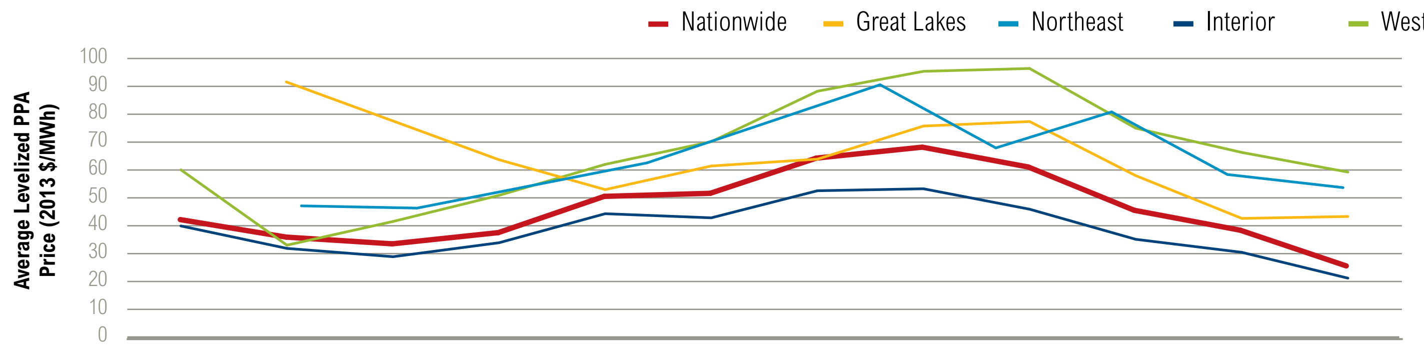
4. **While the variable nature of wind and solar generation creates some challenges for grid operators, there is considerable room to expand the amount of renewables on the grid.** Several studies have shown that grids across the country can handle up to 35 percent or more variable renewable resources with minimal integration costs.[103] This is partly because of improvements made in forecasting the availability of renewable energy and sub-hourly supply scheduling, as well as increases in transmission.[104, 105] As renewable generation continues to increase, however, the United States may need to expand transmission and increase system flexibility, for example through demand response and energy storage.[106]

Wind Generation

Wind development costs have fallen in recent years as a result of improved turbine technology, turbine price reductions, and more favorable terms for turbine technology purchasers.[107] Wind power is now cost competitive in many states with new coal-fired generation, and in some instances, it is even cost competitive with *new* gas-fired generation, even without federal tax credits. If gas prices continue to rise or wind prices continue to fall, wind will become increasingly competitive with natural-gas-fired generation in more regions of the country.[108]

Because of falling costs and state programs, many states are generating more of their electricity using wind resources, and are finding economic benefits by doing so. In 2013, eight states generated more than 15 percent of their electricity with non-hydro renewables, mostly wind.[109] Iowa is among the leaders, with wind accounting

Figure 1.7 | **Wind Power Purchase Agreement Prices by Region, 1996–2013**



PPA Year:	1996–99	2000–01	2002–03	2004–05	2006	2007	2008	2009	2010	2011	2012	2013
Contracts:	**10**	**17**	**24**	**30**	**30**	**26**	**39**	**49**	**48**	**38**	**13**	**18**
MW:	**553**	**1,249**	**1,382**	**2,190**	**2,311**	**1,781**	**3,465**	**4,048**	**4,642**	**3,980**	**970**	**2,761**

Note: Prices are generation-weighted average levelized wind power purchase agreement prices.

Source: Wiser and Bolinger, Lawrence Berkeley National Laboratory, August 2014, "2013 Wind Technologies Market Report," accessible at http://emp.lbl.gov/sites/all/files/2013_Wind_Technologies_Market_Report_Final3.pdf

for more than 27 percent of generation in 2013 as a result of more than 5,000 megawatts of installed capacity.[110] The state had another 1,000 megawatts under construction in early 2014. Wind development of this scale has had a positive impact on the Iowa economy. MidAmerican Generation estimates that its anticipated $1.9 billion investment in new wind power will cause rates for Iowa customers to go down by $10 million annually when all the turbines are completed, while generating 460 construction jobs, 48 permanent jobs, and more than $360 million in new property tax revenue.[111] These results are not unique. Studies by the Midcontinent Independent System Operator (MISO) and the Illinois and Ohio Public Utility Commissions, among others, have also found that increasing wind resources in the Midwest region will drive electricity prices down for customers.[112]

New wind generation is competitive with new coal in many parts of the country. These positive economic results are partly because of the 64 percent decline in levelized power purchase agreements for wind generation between 2009 and the end of 2013, from $70 per megawatt hour to around $24 per megawatt hour on average across the country.[g, 113] This brings them down below prior lows for wind in the early 2000s.[h, 114] These agreements incorporate the federal production tax credit, which can provide a wind project with up to $23 per megawatt hour.[i, 115, 116] However, as discussed further in the section "Bringing Opportunities to Scale," project developers typically only capture about $16 per megawatt hour because of inefficiencies in the structure of the tax credit.[117]

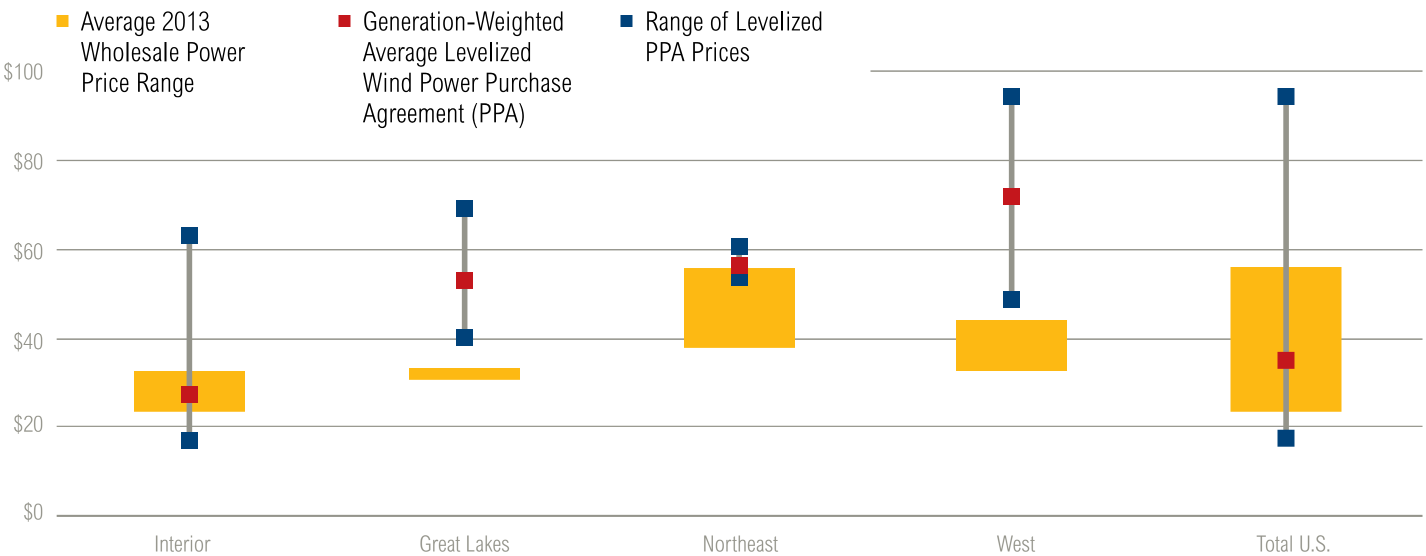
The price of wind varies by location, in large part because of geographic differences in wind resource quality. Bloomberg New Energy Finance and Lawrence Berkeley National Laboratory report that power companies in the interior region of the country recently signed power purchase agreements for wind projects in the $20–$35 per megawatt hour range, the lowest in the country.[118] At these prices, new wind turbines beat out new coal and new natural gas plants even without the production tax credit. Meanwhile, prices currently range between $50 and $60 per megawatt hour in the Mid-Atlantic, the Pacific Northwest, and California and between $55 and $90 per megawatt hour in New England (Figure 1.7 illustrates how regional prices have changed over time).[119] At these prices,

g. Prices vary geographically across the country. Part of the reason wind prices fell in 2013 is that the sample was dominated by projects in the interior portion of the country, where wind prices are lowest. For example, projects in the interior of the United States saw power purchase agreement prices of around $22 per megawatt hour (See Wiser and Bolinger, August 2014).

h. Note, wind turbine prices more than doubled from 2002 through 2008 as a result of "a decline in the value of the U.S. dollar relative to the Euro; increased materials, energy, and labor input prices; a general increase in turbine manufacturer profitability due in part to strong demand growth and turbine and component supply shortages; increased costs for turbine warranty provisions; and an up-scaling of turbine size, including hub height and rotor diameter." Before this increase in turbine prices, wind power purchase agreement prices were in the mid-$30 per megawatt hour range. In 2009, national average power purchase agreement prices jumped to a high of around $90 per megawatt hour (generation-weighted average levelized cost) (See Wiser and Bolinger, August 2014).

i. The American Recovery and Reinvestment Act of 2009 allowed project developers to receive 30 percent of a project's capital cost in the form of a cash payment in lieu of the tax credits. However, qualifying projects needed to begin construction by December 31, 2011 (See U.S. Department of Treasury, May 2014).

Figure 1.8 | **Wind Power Struggles to Compete with Current Wholesale Power Prices in Some Regions**



Source: Ryan Wiser and Mark Bolinger. Lawrence Berkeley National Laboratory. August 2014. "2013 Wind Technologies Market Report."

wind can still compete with new coal plants (estimated at $79–$118 per megawatt hour) in many circumstances even without the production tax credit.[120] Their competitiveness with new natural gas generation, however, depends on natural gas prices.

Predicting future gas prices for the electricity sector is difficult because the price has changed significantly in recent years—from $12.30 per thousand cubic feet in June 2008, to $2.78 in April 2012, to $5.03 at the end of 2013.[j, 121, 122] A natural gas price of $4 per thousand cubic feet corresponds to generation costs about $52 per megawatt hour, and a natural gas price of $7 per thousand cubic feet corresponds to a generation cost around $76 per megawatt hour, according to EIA data.[123] This means that some wind projects in the Mid-Atlantic, Pacific Northwest, and California that receive tax credits can potentially beat out new gas plants as long as natural gas prices do not fall below $4 per thousand cubic feet and the wind plants continue to receive tax credits. If the credits are not extended, wind projects in these areas would struggle to out-compete new natural gas generation at natural gas prices under $7 per thousand cubic feet. EIA projects that natural gas prices begin to approach the $7 per thousand cubic feet range by 2030. However, higher prices could be seen sooner if natural gas production is lower than expected, or if natural gas exports increase significantly.[124]

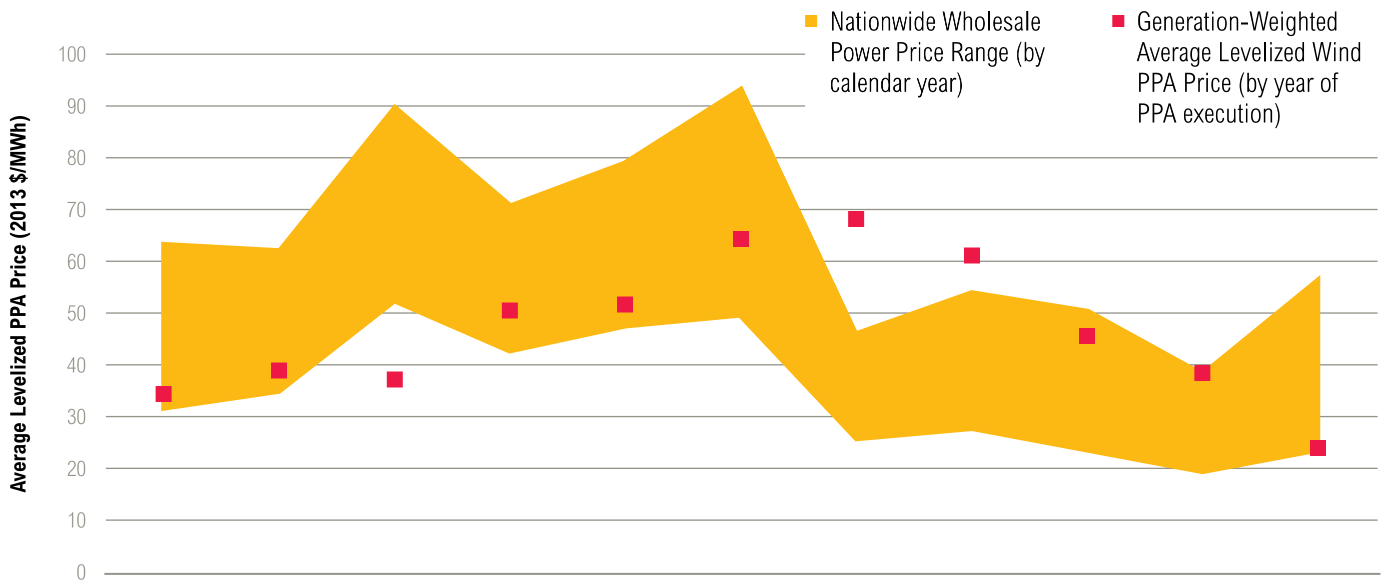
Likewise, technological advances could also continue driving wind prices downward in these regions, making wind more competitive with new natural gas projects.

Because of this interplay between natural gas fuel prices and the competitiveness of wind, some have suggested that wind could provide a valuable hedge against unknown future natural gas prices. This is particularly true when one considers the possibility of continued volatility in natural gas prices, which is not captured by the projected average annual prices shown in Figure 1.4.

The challenge of existing generation. For wind to rise to a significant portion of the nation's generation mix in the near term, it will need to not just outcompete new fossil generation, but also existing fossil generation. According to analysis by Lawrence Berkeley National Laboratory, with the production tax credit, the lowest priced wind contracts for 2011–13 (for which data were available) were below average wholesale electric prices in the interior region of the United States, while wind contracts in the rest of the country were mostly higher than wholesale electric prices (Figure 1.8).[125] In addition, competing coal and gas units will frequently capture ancillary service revenues from ensuring grid reliability,[126] for which wind generation frequently does not qualify.

j. While new supplies of natural gas from shale formations should mitigate some of this volatility, there is no guarantee that the end of sudden price spikes has been reached—indeed, the cold winter of 2013–14 and infrastructure constraints in the Northeast caused natural gas prices for electric power to increase by over 50 percent between December 2013 and February 2014, before falling back to previous levels three months later.

Figure 1.9 | **Wind Power Purchase Agreement Prices Fell Below Yearly Wholesale Electricity Prices in 2013**



PPA Year:	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Contracts:	**9**	**13**	**17**	**30**	**26**	**39**	**49**	**48**	**38**	**13**	**18**
MW:	**570**	**547**	**1,643**	**2,311**	**1,781**	**3,465**	**4,048**	**4,642**	**3,980**	**970**	**2,761**

Source: Ryan Wiser and Mark Bolinger. Lawrence Berkeley National Laboratory. August 2014. "2013 Wind Technologies Market Report."

However, this analysis yields too static an understanding of the interplay between wind prices and electricity wholesale prices.[127] As shown in Figure 1.9, wholesale power prices are not constant, and in fact have fallen considerably in recent years largely because of low natural gas prices.[k, 128] If gas prices increase and wind prices continue to decrease, these relationships will continue to shift in a manner that is more favorable to wind development. According to analysis by Lawrence Berkeley National Laboratory, the average wind power purchase agreement price (included in their sample) fell to $24 per megawatt hour (with the production tax credit) in 2013, which was at the low end of the range of nationwide electricity prices. Part of the reason for this, however, is that the sample was dominated by projects in the interior portion of the country, where wind prices are lowest.[129]

Location is no longer a barrier for wind. A key development for wind energy has been the continued increase in turbine height—from a hub height of 30 meters in 1990–95 to about 140 meters in 2011.[130] Turbine technology improvements, including the ability to install larger turbines on taller towers (which can have a hub height of 140 meters and a rotor diameter of 160 meters), have expanded the areas suitable for onshore wind energy development. Nearly 1,000 gigawatts of additional wind capacity could be possible throughout the country if these new, taller turbines are installed (which is about as much as the total amount of wind capacity current installed).[131] The majority of this new potential is in the eastern United States, which was previously thought to have lower onshore wind potential than other parts of the country. Capitalizing on low-speed wind resources (6 meters per second) these state-of-the-art turbines could result in levelized costs of $35–$55 per megawatt hour (this includes the federal production tax credit), according to a National Renewable Energy Laboratory analysis.[132] Without additional financial support, the price range would be $58–$78 per megawatt hour (assuming the full level of the production tax credit can be realized by the developer, which, as previously discussed, is usually not the case). This price is well below the levelized cost of

k. Note, wholesale power prices are one part of retail electricity prices, which also include costs associated with transmission, distribution, stranded assets, and other services. While wholesale power prices were lower in 2013 compared with 2008, retail electricity prices actually increased by 3.4 percent over the same period (See U.S. Energy Information Administration, July 2014).

electricity from coal technologies ($79–$118 per megawatt hour) and is similar to the levelized cost of new natural gas generation ($63–$78 per megawatt hour).[l, 133]

However, hurdles in developing these state-of-the-art wind turbines remain, including transportation and regulatory issues. For example, it can be difficult to transport these large towers and blades around turns, narrow roads, or through tunnels or on railways.[134] The weight limit of side roads can also be restrictive. DOE is currently exploring innovative solutions, such as segmented blades and on-site tower manufacturing. Continued or expanded funding can help drive commercialization of these technologies.

Additionally, as of April 2012, the Federal Aviation Administration (FAA) stated it is not approving structures over 152 meters until it establishes new rules, policies, and procedures for marking and lighting. In late 2012, two wind turbine manufacturers and developers indicated that they received "no hazard" determinations from the FAA for turbine installations which were slightly taller than 152 meters. However, because of this perceived limitation, some manufacturers and developers have been hesitant to engage in projects that exceed 152 meters. According to the National Renewable Energy Laboratory, finalizing FAA guidelines will help ensure that project developers have the certainty they need. This can help open up the country to the development of these cost-effective higher altitude resources.[135]

Solar Power

Solar photovoltaic power is also on the rise in the United States as a result of falling prices and new state solar mandates. Residential and commercial systems made up the bulk of new photovoltaic capacity additions from 2001 to 2009, at which time utility-scale photovoltaic systems started increasing their market share.[136] In 2013, 4.8 gigawatts of photovoltaic capacity was added in the United States—60 percent from utility-scale installations. At the beginning of 2014, the United States had 13.4 gigawatts of installed photovoltaic capacity.[137] However, other countries have led in new solar photovoltaic capacity—in 2013 alone, China added 12.9 gigawatts while Japan added 6.9 gigawatts.[138] According to EIA, there are proposals for another 6.5 gigawatts of proposed U.S. utility-scale photovoltaic projects, suggesting strong near-term growth prospects.[139]

Concentrating solar power (CSP) is also on the rise in the United States as 517 megawatts of CSP was installed during the first quarter of 2014; which is more than the total capacity installed through 2013. With these additions, total CSP capacity has reached 1.4 gigawatts. While CSP prices remain high, the DOE SunShot Initiative aims to reduce the levelized cost of CSP technology to $60 per megawatt hour by 2020.

Solar photovoltaic prices are rapidly falling. According to Bloomberg New Energy Finance, prices of solar modules have declined by 99 percent since 1976 and by about 80 percent since 2008.[140] Project costs vary depending on project size, configuration, and the solar resources at the project location. Solar projects in the United States are supported by a federal investment tax credit through 2016, which is valued at 30 percent of the total project capital cost.

Decreasing solar module prices, combined with the federal investment tax credit, have helped make power purchase agreements for electricity generated from utility-scale projects competitive with conventional sources. In their February 2014 *Sustainable Energy in America Factbook*, Bloomberg reported that the typical utility-scale photovoltaic project in the 2015–16 timeframe will be in the mid-to-high $60 per megawatt hour range.[141] However, in the summer of 2014, Austin Energy finalized a new solar photovoltaic power purchase agreement below $50 per megawatt hour. This is cheaper than company estimates for new natural gas generation ($70 per megawatt hour), coal ($100 per megawatt hour) or nuclear ($130 per megawatt hour).[142] Even without the estimated full value of the federal investment tax credit (30 percent of the total project capital cost), the rate for solar energy still compares favorably to natural gas, at just over $70 per megawatt hour (according to company officials the project is not receiving local incentives). However, as mentioned earlier, because of inefficiencies associated with the investment tax credit, its value to a project (in terms of how much it reduces long-term power purchase agreement prices) is frequently less than its full value.

Prices for residential systems are typically higher than utility-scale systems because of their smaller size and larger non-module costs (or "soft costs," such as mounting hardware, labor, permitting, and fees).[143] Declines in installed prices for residential and commercial photovoltaic

l. However, as mentioned previously, fossil generation can also capture ancillary service revenues, such as forward capacity payments.

systems historically have been aided by reductions in soft costs, but these costs have remained relatively flat in recent years. As a result, soft costs have grown to become a large portion of total system costs.[144] Lowering these costs could help drive further solar photovoltaic price reductions—households in the United States typically pay $2.70 per watt more in soft costs for residential photovoltaic systems than households in Germany (which has about the same solar photovoltaic resource as Alaska).[145] Soft costs make up over half of total residential photovoltaic costs in the United States (compared with 21 percent in Germany).[146] Many factors contribute to these higher soft costs, including U.S. installers having a longer installation process, higher marketing and advertising costs, higher sales taxes on photovoltaic systems, higher labor costs, and higher permitting and interconnection fees.[147] Reducing these costs to levels more consistent with those in Europe could help further increase deployment.

Soft costs are 45–50 percent lower for utility-scale photovoltaics,[148] yet potential remains to further lower these costs and reduce overall utility-scale photovoltaic system prices. For example, total system costs for global, best-in-class utility-scale solar installations are now $1.55 per watt and are expected to continue falling.[149] DOE reports that while soft costs for utility-scale photovoltaic systems (including permitting, inspection, and installation) have dropped by almost one-third between 2010 and 2013, these costs still make up around 40 percent of utility-scale photovoltaic system costs.[150]

While some soft costs for all sectors (residential, commercial, utility) will likely fall over time with more experience and economics of scale, policies could help address other costs by simplifying interconnection, permitting, and inspection requirements, among others.[151] Government funding can also help spur investment and innovation. In May 2014, the U.S. Department of Energy (DOE) announced its SunShot Catalyst contest, which offers a reward of up to $1 million for help in reducing the soft costs of solar by identifying relevant problems and developing innovative business solutions as well as prototyping these ideas and incubating the final product.[152]

Location is not a barrier for photovoltaics

Solar resource potential varies across the United States, with the Southwest having the highest resource potential. For example, Arizona has 50 percent more solar resource potential than Maine, and Maine has 50 percent more solar resource potential than Germany.[153] However, Germany has over 2.5 times more installed photovoltaic capacity (35.7 gigawatts at the end of 2013)[154] than the entire United States (13.4 gigawatts through the first quarter of 2014).[155] In fact, solar photovoltaic accounted for 5.7 percent of Germany's net generation in 2013,[156] while it accounted for only 0.2 percent of U.S. generation in the same year.[157]

Distributed photovoltaics bring unique benefits and costs

Distributed generation (i.e., small scale generation[m, 158]) solar photovoltaic resources offer unique benefits and costs to both power companies and customers.[159] For example, as mentioned earlier, Minnesota's Public Utility Commission ruled in favor of a 100-megawatt solar project over natural gas projects because the solar project will deliver many benefits, including the elimination of transmission costs and a reduction in line losses by interconnecting with multiple substations across the state.[160] However, distributed solar projects also have costs associated with program administration and the interconnection and integration with the grid.[161] Some states and utilities (such as Minnesota and Austin Energy in Texas) are looking at other models to encourage distributed generation by fully compensating solar owners for the value produced by solar distributed generation, but in a way that does not penalize consumers that do not have distributed generation themselves.[162]

Concentrating solar power is emerging

Concentrating solar power (CSP) is also on the rise in the United States—517 megawatts of CSP was installed during the first quarter of 2014; which is more than the total capacity installed through the end of 2013 (total CSP capacity is now 1.4 gigawatts).[163] CSP produces electricity by concentrating solar energy to produce heat, which is used to heat fluids and move a steam turbine. A major benefit of CSP is its ability to be deployed with thermal

m. According to the Department of Energy, distributed generation energy "consists of a range of smaller-scale and modular devices designed to provide electricity, and sometimes also thermal energy, in locations close to consumers," (See U.S. Department of Energy, 2014).

energy storage so that it can store energy and produce electricity on demand.[164] With this attribute, CSP plants can be used to balance the grid over a variety of timescales—from minutes to days.[165] Currently, CSP plants have 4–8 hours of thermal energy storage but experts expect that this can eventually increase to 24 hours.[166] It can also be integrated with fossil-based generation to produce "hybrid" configurations.[167]

CSP cost and performance vary by technology type, project location, and incentives, although total costs remain high. For locations in the Southwest (which has the best resource potential in the country), DOE has estimated its levelized cost in the $130–$190 per megawatt hour range (including a 30 percent investment tax credit); note, EIA estimates higher levelized costs at $224 per megawatt hour with incentives and $243 per megawatt hour without incentives.[168, 169] DOE expects prices to decrease by lowering the upfront investment cost (through scaling up manufacturing and installation as well as technology advancements aimed at reducing costs) and improving technological performance.[170] The DOE SunShot Initiative aims to reduce the levelized cost of CSP to $60 per megawatt hour by 2020.[171]

CSP technologies have benefited from government funding and industry partnerships; DOE reports that long-term investments by DOE and industry partners drove the installation of "some of the most innovative CSP plants in the world" in 2013, including the Solana parabolic trough plant (280 megawatts) that includes six hours of storage so the plant can dispatch electricity to customers in cloudy weather or after the sun sets.[172] Four additional plants are expected to become fully operational in the United States during 2014, including the largest CSP plant in the world.[173] In fact, DOE has called 2014 "the year of concentrating solar power," with these new plants nearly quadrupling the preexisting U.S. CSP capacity. Continued support from federal and state loan programs and incentives, as well as industry partnerships could help drive CSP costs down even further.

Integrating Variable Renewable Generation

Solar and wind generation are unique among sources of electricity, in that their output varies based on when the sun shines and the wind blows. As a result, generating capacity factors typically fall between 18 and 53 percent for wind power[174] and between 14 and 30 percent for photovoltaics.[175] Solar photovoltaic and wind sources are also unable to dispatch on command in response to hourly changes in electricity demand (unlike other forms of generation such as coal, gas, nuclear, and hydro). These limitations create challenges for grid balancing authorities who are responsible for ensuring that electric supply matches demand, and preventing outages that result when there is a mismatch. However, several studies have shown that existing grids across the country can handle up to 35 percent variable renewable resources with minimal integration costs.[176] This is because of improvements in forecasting, grid management, and transmission. Achieving deeper penetration of renewables, however, will likely require sustained investment to expand transmission and increase system flexibility, for example through demand response and energy storage.

Today's grid can handle considerably more renewable electricity

Several studies have shown that states can handle up to 35 percent annual variable renewable generation penetration with minimal integration costs. For example, PJM (covering the Mid-Atlantic, Virginia, and parts of the Midwest), National Renewable Energy Laboratory (for the Western United States), and the state of Michigan have all found that 30–35 percent of electricity could be generated using variable renewable resources with minimal integration costs.[177] Analysis by Synapse concluded that bringing more renewables online would provide a net benefit of up to $9.4 billion a year in the Midwest ($241 per year per person in the Midcontinent Independent System Operator region) and $6.9 billion a year in the PJM region ($113 per year per person) after taking into account the infrastructure costs and lower wholesale power prices.[178]

The move to integrate increased amounts of wind and solar photovoltaic power into the existing power grid has benefited from improvements in renewable energy forecasting and sub-hourly supply scheduling.[179] Studies have shown that integration costs are lower in areas with faster dispatch; sub-hourly dispatch can reduce costs by at least 50 percent.[180] These integration improvements have also led to economic benefits.[181] For example, Xcel Energy was able to reduce its average wind forecast errors from 15.7 percent to 12.2 percent between 2009 and 2010, resulting in a savings of $2.5 million.[182] DOE is working to further improve renewable integration by optimizing the design and performance of electrical, thermal, and fuel systems at multiple scales (from end user to regional) that will further increase reliability and performance, reduce costs, and minimize environmental impacts.[183] This approach could also help increase the efficiency of the U.S. power system.

Increased renewable generation has also been assisted by significant investments in transmission. As renewable penetration increases, investments in transmission expansion will need to continue, but likely at a rate comparable to levels seen about five years ago. According to Lawrence Berkeley National Laboratory, "during the last five years, more than 2,300 circuit miles of new transmission additions were constructed per year, with an additional 18,700 circuit miles planned over the next 5 years. By comparison, transmission was only being constructed at a rate of about 1,000 circuit miles per year as recently as 5 years ago."[184] Over the long term, the National Renewable Energy Laboratory found that the increase in transmission necessary to generate 80 percent of U.S. electricity demand from variable renewable electricity technologies in 2050 is within the recent historical range for annual investor-owned utility transmission expenditures in the United States (i.e., $2 billion per year to $9 billion per year from 1995 through 2008).[185] Meanwhile, the Edison Electric Institute reported that transmission investments through 2024 are likely to average roughly $6 billion per year, more than three-quarters of which is expected to help with renewable integration.[186]

A grid where renewables account for the majority of generation, however, may require further changes

Sustained expansion of renewable generation will eventually require expansion of storage technologies that provide grid stabilization services such as backup power, load leveling, and frequency regulation as well as other services that help increase the overall flexibility of the electric grid.[187] For example, the California ISO identified energy storage, among other measures, as being able to help address real-time system conditions as the state ramps up to 33 percent renewable generation by 2020, such as short, steep ramps of generation startups or shut downs, increased risk of over-generation, and decreased frequency response throughout the day.[188] As a result, in October 2013, the California Public Utilities Commission unanimously approved a mandate requiring the state's big three investor-owned utilities to add 1.3 gigawatts of energy storage by 2020.[189] Many types of energy storage technologies are available and can provide for multiple applications, such as pumped hydro, compressed-air energy storage, or various types of batteries and flywheels. However, according to DOE, four main challenges related to the widespread deployment of storage technologies remain: cost, validated reliability and safety, equitable regulatory environment, and industry acceptance.[190] Continued research and development as well as establishing industrial standards for energy storage and regulations that define how storage technology should be used and monetized could help alleviate some of these issues.[191]

The Regulatory Assistance Project (RAP) analyzed how best to balance a system that had between 50 and nearly 100 percent of its load (in megawatts) met by solar and wind resources at different times during the day. They identified strategies that can not only help create a more uniform load, but also "enable greater renewable integration, enhance system reliability, and reduce generation and transmission capital and fuel costs." These strategies include those described earlier coupled with:[192]

- Pursuing targeted energy efficiency measures to reduce peak demand;
- Implementing aggressive demand-response programs;
- Implementing variable electricity pricing that increases electricity rates during the "ramping hours" of the utility's load to enable price-induced changes in demand;
- Deploying energy storage in targeted locations (including the use of electric vehicles that are connected to the grid);
- Adopting service standards that allow grid operators to manage electric water heating loads and thermal storage capacity associated with new large air conditioners;
- Retiring inflexible generating plants with high off-peak must-run requirements;
- Using more solar thermal with storage instead of solar photovoltaic generation (where appropriate given local solar resources); and,
- Taking advantage of the diversity in neighboring region's resources by using inter-regional power transactions.

RAP concluded that "the combination of renewables and [these] strategies is an easier system to manage than a system without the addition of renewables."[193]

The Future of Renewables

While electricity generation from non-hydro renewable resources increased by almost fourfold between 2005 and 2013, it remains around 6 percent of total generation in the United States (12.5 percent including hydro sources).[194] This is well below renewable energy's contribution to the grid in many other developed countries.[195] For example, the European Union (EU-28) generated an average of 20 percent of its electricity from renewable sources (including hydro) in 2013, with 17 countries achieving at least 20 percent and 5 countries achieving at least 50 percent. For wind and solar generation to play a significant role in the decarbonization of the U.S. electric grid, a step-change in investment will be required. Whether or not this happens will depend on a number of factors including:

- The rate at which existing power plants reach the end of their economic lives;
- Future natural gas prices;
- The extent to which state mandates, voluntary markets, and other programs (such as GHG standards for existing power plants) drive renewable energy adoption;
- How states recognize and take advantage of policies that help the grid accommodate large amounts of these variable resources via complementary grid services like energy storage, demand response, and flexible back-up generation;
- The ability to reduce inefficiencies in the system that increase project development costs, such as the inability to secure long-term contracts and the limitations with the design of federal tax credits (see "Bringing Opportunities to Scale");
- Technological progress; and,
- Whether climate and public health externalities are fully factored into generation decisions.

REMAINING CHALLENGES AND OPPORTUNITIES FOR NUCLEAR

Nuclear power provides around-the-clock baseload generation that is free of CO_2 emissions. In 2013, it was responsible for 20 percent of total U.S. electric generation and for over 60 percent of U.S. zero-carbon generation.[196] At the time of publication, three new nuclear plants were under construction, the first new plants since 1996.[197] However, several nuclear reactors closed in 2013[198] and analysis suggests that some nuclear plants are struggling to remain viable as a result of cheap natural gas, low renewable energy prices, lower demand for electricity, and rising costs for nuclear fuel and operations and maintenance (particularly at smaller, older, standalone units).[199] Continued retirements could prompt an increase in fossil baseload generation and lead to an overall increase in CO_2 emissions from the power sector. Even if these pressures do not force nuclear plants to retire prematurely, the nation will eventually need to replace some of these units as they reach the end of their useful lives. Stringent regulations that value low-carbon generation could help improve the economics for the existing fleet, and could potentially spur the construction of new nuclear units, particularly if increasing international development of nuclear plants leads to reductions in construction costs. Any expansion, however, will likely depend on solving the challenge of public concerns about nuclear safety and long-term waste storage.

Fleet Capacity Is High, But Some Units May be Struggling

Generation from nuclear plants has been relatively constant over the past 15 years at about 20 percent of U.S. electric generation, but some units have struggled as of late. According to EIA, total nuclear generation in 2012 and 2013 was within 2 percent of its 2000–10 average. Meanwhile, the average capacity factor for nuclear plants in 2012 (86 percent) and 2013 (90 percent) was comparable to the 2000–10 average (90 percent), and well above the typical capacity factors achieved from 1980 to 1995.[200]

However, this apparent constancy could be masking some difficulties at the plant level, as some analysis has suggested that certain units are struggling. According to analysis by Credit Suisse, 10 units were offline for more than 100 days in 2012, versus an average of four units per year over the previous four years.[201] In addition, four nuclear plants retired in 2013, and a fifth is slotted to retire by the end of 2014.[202] Together these retired and soon-to-retire units accounted for 4.2 gigawatts of capacity[203] (4 percent of 2012 nuclear capacity).[204] This will be offset, however, by the three new nuclear plants under construction, which will have a combined capacity of 6.6 gigawatts.[205] The question is whether the new or the retiring units are outliers or portend a greater shift in the economics of nuclear generation.

A recent study by Credit Suisse found that some nuclear units may be experiencing a $6 per megawatt hour shortfall between their operating costs and electricity sales revenue because electricity prices have not kept up with the increased costs of nuclear generation.[206] The study found that nuclear fuel prices rose 9 percent per year from 2007 to 2011, while total operation and maintenance costs increased 5 percent per year. Meanwhile, power prices have not escalated at the same rate. While rates vary by region and customer class, U.S. electricity rates overall increased only 2 percent per year from 2007 to 2011, and 3 percent from 2004 to 2013.[207] Analysis by Exelon, the nation's largest nuclear operator,[208] suggests a more dire outlook for some nuclear units. They found that small single-unit nuclear plants have projected shortfalls of $2 to $18 per megawatt hour in the Mid-Atlantic and New England regions, and up to $38 per megawatt hour in the Midwest. They also found that under current market conditions, even larger plants could face shortfalls in certain regions.[209]

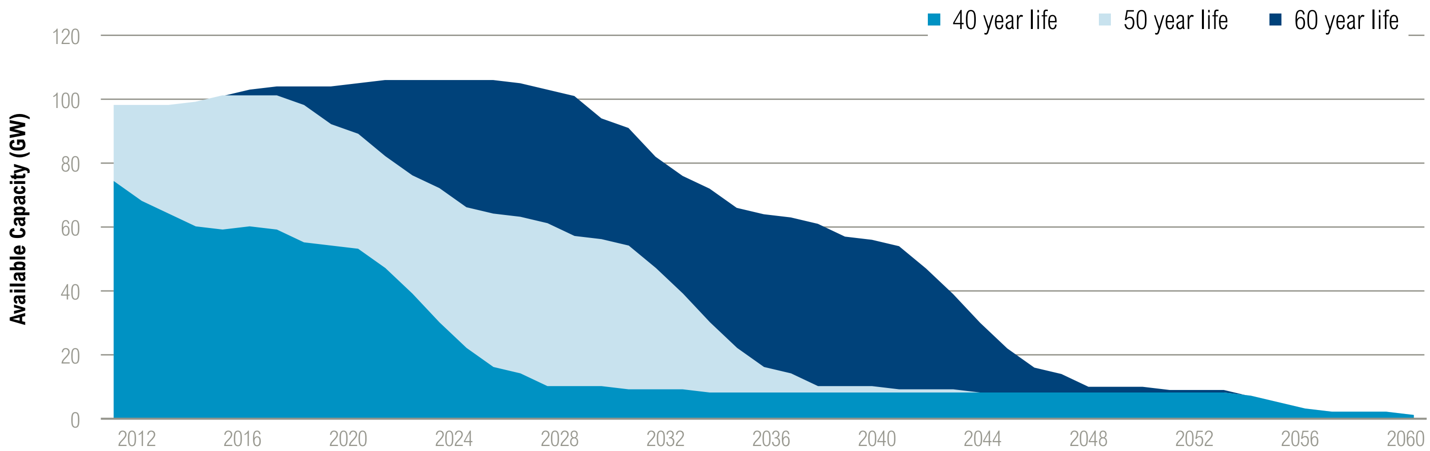
In some regions, increasing renewable generation (aided by federal tax incentives) can cause market electricity prices to become very low, or even negative, during periods of low demand and high renewable generation.[210] This is primarily because renewable energy sources have no fuel costs, and will typically be price takers in competitive markets, often bidding at or near $0 per megawatt hour.[211] When renewable generation is particularly high in a region that is transmission constrained, negative pricing may result because of the renewable electricity credit and/or production tax credit benefits renewable generation receives in addition to the payments for supplying the grid with electricity.[212] To compete, a nuclear unit may actually pay a system operator to take its power rather than shutting down and restarting, which can be costly.[213] However, this is a rare phenomenon, and new transmission is expected to help alleviate this issue in most regions.[214, 215] For example, the new competitive renewable energy zone (CREZ) transmission lines in Texas were built to carry the electricity generated by wind in remote areas of the state to areas of higher demand, which has helped reduce instances of negative pricing.[216] In fact, EIA recently reported that the instances of negative pricing have not only been lowered dramatically, but have also dropped in magnitude from the -$20 to -$50 or more per megawatt hour range in 2011 and 2012 to just slightly less than $0 per megawatt hour in 2014.[217]

Some industry analysts have concluded that the larger challenge for nuclear generation is low natural gas prices. In May 2014, Commissioner John Norris of the Federal Energy Regulatory Commission stated that "the current low gas prices and increased reliance on our gas fleet pose the biggest economic challenge to our nuclear fleet."[218] As previously noted, natural gas prices have nearly doubled since their lows in 2012. While these trends are not expected to continue, EIA projects that natural gas prices will slowly increase over time and that higher natural gas prices after 2020 would support the continued operation of the nuclear fleet, with limited retirements between 2020 and 2040.[219]

What Will The Future Hold For An Aging Fleet? The Role of New Construction and Public Safety Concerns

Even if market pressures do not force nuclear capacity to prematurely retire, the nation will eventually need to replace some of these units as they reach the end of their useful lives. The question is when. The average age of the nuclear fleet is 33 years. Reactors are licensed for 40 years, and can apply for a 20-year extension.[220] Forty-three[221] of the nation's 100[222] nuclear reactors are up for relicensing in the next 20 years. If all are relicensed and run for a full 60 years, the current and proposed fleet will

Figure 1.10 | **Most Nuclear Plants Could Retire Between 2030 and 2060**



Note: Figure includes the seven proposed nuclear units (7.7 GW summer capacity) listed in Form EIA-860 that are estimated to come online between 2015 and 2022.
Source: U.S. Energy Information Administration. "Form EIA-860 2012."

gradually shut down between 2030 and 2060 (Figure 1.10). Credit Suisse speculates that if margins remain thin for the industry, fewer owners of nuclear plants will invest the capital typically required for extending plant life and relicensing, particularly for smaller nuclear plants. Regulations that value low-carbon generation could help improve the economics for the existing nuclear fleet. According to EPA, the $6-per-megawatt-hour shortfall identified by Credit Suisse can be overcome when CO_2 is valued at $12–$17 per metric ton.[223] EIA analysis found that implementing a carbon pricing program that started at $25 per metric ton in 2015, increasing by 5 percent per year, could actually drive a nearly 50 percent increase in nuclear generation in 2030 compared with 2012 generation.[224]

It remains to be seen whether the three new nuclear plants are the start of a trend in the United States. Nuclear plants are typically more expensive to build ($98–$138 per megawatt hour) than new coal plants ($79–$118 per megawatt hour without carbon capture and storage; $150 per megawatt hour with it) and natural gas units ($63–$78 per megawatt hour).[225] However, China, India, and Russia are scaling up nuclear generation: all have "maintained ambitious development programs" according to the International Energy Agency.[226] As of 2013, China had about 17 gigawatts of operational nuclear capacity,[227] and as of March 2013 more than 60 reactors were reportedly under construction,[228] with targets of building 40 gigawatts of nuclear capacity by 2015 and 58 gigawatts by 2020.[229] IEA notes that because non-OECD countries are shifting toward nuclear power, the transition to more advanced reactors is accelerating.[230] If this expansion moves forward as planned, it could lead to a reduction in the cost of new nuclear generation, which could increase the likelihood that new nuclear plants would be built in the United States.

However, the high cost of new construction is only one of the factors that have slowed the advance of nuclear. Safety concerns, heightened by Japan's Fukushima disaster, have led some countries to reevaluate the role of nuclear. Germany, for example, has announced its intention to phase out its entire nuclear fleet.[231] Another challenge is waste disposal, which would likely need to be solved before a sizable expansion of the nuclear fleet could happen. However, barriers to taking action to address nuclear waste include: the lack of a permanent storage facility for spent fuel; public fears related to the transport of spent nuclear fuel from nuclear plants to potential storage sites; and concerns that any reprocessing of spent fuel could lead to the proliferation of weapons-grade materials.

BRINGING OPPORTUNITIES TO SCALE

Long-term policy signals, such as carbon pricing or a greenhouse gas emission standard, are needed so that power companies can make good long-term decisions that minimize stranded assets and maximize return on investment. In addition, a number of actions can help promote development of low-carbon generation. These actions can help unlock investments in low-carbon technologies in the absence of any long-term policy signal, and can help deliver even greater change and/or increase the net benefits when combined with a long-term policy signal. They are outlined below.

Long-term policy signals—such as carbon pricing or a greenhouse gas emissions standard—are needed.

While the economics of new electricity generation are now clearly in favor of building lower-carbon generation like natural gas or renewable energy, continuing uncertainty still exists about how much new generation will be built. In the coming years, power plant owners will need to decide whether to reinvest in their existing fleet of old coal-fired power plants to bring them into compliance with national standards for mercury and other air toxics—a decision made in the context of low-cost natural gas, declining prices of renewables, and pending carbon pollution standards for new and existing power plants. As mentioned earlier, studies have shown that a significant portion of the existing coal fleet is becoming uneconomic compared with natural gas and wind power.[232] This provides a critical window of time to signal power companies and investors through a long-term regulatory and policy environment. Failing to do so could increase the risk of stranded assets, which would increase electricity rates for consumers.

Extracting and burning fossil fuels to generate electricity produces many negative externalities—including greenhouse gas emissions and adverse health effects from air and water pollution—that are not fully reflected in the price we pay for power. Internalizing those externalities is among the most economically efficient ways to reduce the side effects associated with an overreliance on polluting sources of energy. By putting a discrete price on carbon emissions, through either a nationwide carbon tax or cap-and-trade program, the United States would send a long-term price signal to change consumer behavior and spur power companies to make investments in cleaner sources of energy. Studies show that these policies can promote economic growth if revenues are used to offset distortionary taxes elsewhere in the economy, or put to other beneficial uses such as energy efficiency.[233]

Other approaches can achieve similar results. For example, EPA is moving forward with greenhouse gas emissions standards for existing power plants under section 111(d) of the Clean Air Act. The recent proposal sets state-specific rate-based standards (in pounds of CO_2 per megawatt hour) that must be met by 2030, with an interim goal between 2020 and 2029.[234] EPA did not prescribe how each state must meet these standards; instead, a flexible approach was proposed that allows states to use a combination of measures to decarbonize their power fleets. This includes making existing coal plants more efficient, re-dispatching natural gas in place of existing coal generation, using carbon-free generation (such as nuclear and renewables), and increasing demand-side energy efficiency, among other measures. EPA projects that these proposed standards would reduce power-sector CO_2 emissions by 26 to 27 percent below 2005 levels by 2020 and 30 percent by 2030[235] and lead to $55 billion to $93 billion in climate and health benefits by 2030 at a cost of $7.3 billion to $8.8 billion.[236] Notably, the health benefits alone are projected to be 3 to 8 times the compliance costs.

Compliance costs are kept down, in part, because energy efficiency programs can be used as a compliance option, which, as we profile in Chapter 2, frequently provides $2 or more in savings for every $1 invested. As a result, electricity bills are projected to be about 8 percent lower in 2030.[237] According to EPA analysis, the standards are expected to increase generation from non-hydro renewables only 7–8 percent above business-as-usual projections in 2020 and 2 percent in 2030. Given the current trends in renewable technologies, more renewable generation (and thus more CO_2 abatement) seems achievable.

The benefits of integrating energy efficiency and climate programs have been well demonstrated by the Northeast and Mid-Atlantic Regional Greenhouse Gas Initiative. The Analysis Group found that because of the energy efficiency investment states made during the program's first three years (2009–11), 16,000 job years were created. In addition, electricity bills in these states are projected to drop by $1.3 billion and economic growth is expected to grow by $1.6 billion.[238]

States and utilities should enhance access to long-term contracts by renewable energy providers.

This can be accomplished by: (1) requiring utilities to enter into long-term power purchase agreements when meeting state renewable targets; and (2) by allowing consumers the option to voluntarily enter into long-term fixed-price purchase agreements for renewables.

Long-term contracts for energy, through power purchase agreements for example, can ensure long-term revenue support and eliminate electricity market price risks at the same time.[239] In fact, the Climate Policy Initiative found that under current financing arrangements, extending the duration of a power purchase agreement by 10 years (say from 10 to 20 years), alone could reduce the average electricity costs over the lifetime of typical wind and solar projects by 10–15 percent.[240] Thus, market reforms that make it easier (or possible) for project developers to obtain these contracts can help reduce financing costs. For example, Massachusetts enacted legislation that directs its utilities to meet part of the state renewable portfolio standard through procuring long-term power purchase agreements—approximately 3 percent of the utilities' retail load between 2009 and 2014 and 7 percent by 2016—"to facilitate the financing of renewable energy generation."[241] This means that almost two-thirds of the state's renewable portfolio standard requirement for 2016 (11 percent) will be met through long-term contracts.[242]

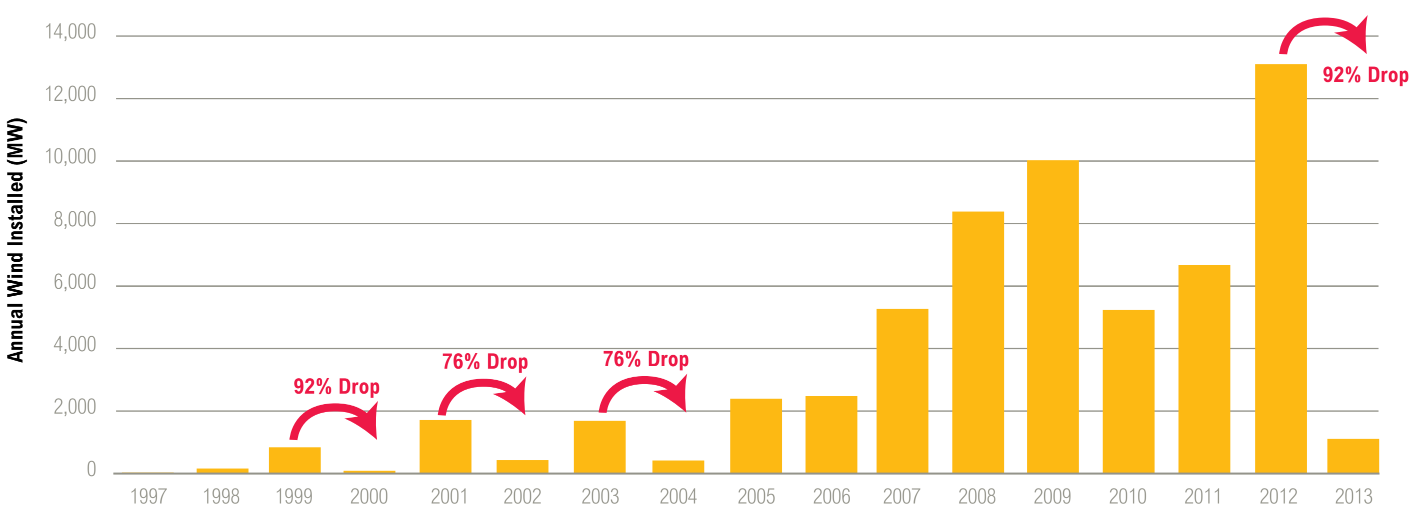
Companies[243] and government agencies can play a role as well by directly entering into long-term renewable contracts for their renewable purchases, potentially delivering benefits to shareholders and taxpayers alike. States and utilities should support these voluntary purchases by ensuring that contracting processes are simple and meet the customers' unique needs.

Congress should stabilize federal tax credits and eliminate inefficiency in their design.

Renewable power projects have been supported through tax credits, helping the technology reach maturity more rapidly and thus reducing production costs. However, application of the credits is uneven and inefficient. Addressing these barriers could reduce volatility in the marketplace and ensure that more of the value flows to project developers, which together would help lower the cost of new renewable generation.

As discussed earlier, renewable projects in many parts of the country can now outcompete new coal plants, and sometimes outcompete new gas plants. But, this is not yet true for all technologies in all regions. Over time it may be appropriate to sunset these tax credits, but in the meantime, the marketplace would benefit from enhancing stability in the incentive structure. The production tax credit has been allowed to expire several times before being re-extended. This has increased the volatility in the market for new wind power as projects scramble to take advantage of expiring federal tax incentives and then pause while waiting to see if the incentives are extended (Figure 1.11).

Figure 1.11 | **Impact of Production Tax Credit Expirations on Annual Wind Capacity Installation, 1997–2013**



Note: The production tax credit expired and was extended in 2000, 2002, and 2004. In 2013, the tax credit expired.

Source: American Wind Energy Association (AWEA), "Federal Production Tax Credit for Wind Energy," accessible at http://www.awea.org/Advocacy/Content.aspx?ItemNumber=797.

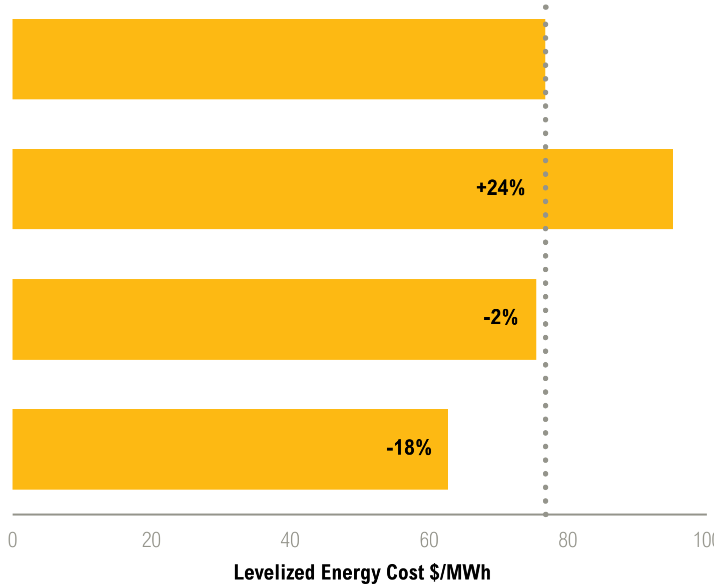
Figure 1.12 | **Levelized Cost of Energy Under Different Financial Structures in the United States (Projected Wind Project in the Absence of Tax Credits)**

Projected situation: Wind plants being built today have construction safe harbor PTCs. Looking forward, in the absence of tax incentives, most wind power would be project financed with 12–20 year bank debt at interest rates 2% or more higher than corporate bonds.

Impact of the financial crisis: Some banks are reducing the time period over which they lend to reduce their own risk, limiting debt to 7 years raises lifetime energy cost 15%.

Utility corporate finance: Utilities can reduce financing costs by financing projects using corporate debt and equity, but leverage falls slightly and the resulting investment is fairly unattractive to utilities.

New investment models: Properly structured, a portfolio of renewable energy projects traded on financial markets could attract corporate bond type investors for a large share of the investment, lowering debt and equity costs, increasing leverage, and accessing large pools of capital.



Source: David Nelson, 2014, "Roadmap to a Low Carbon Electricity System in the U.S. and Europe," Climate Policy Initiative.

Analysis by the Lawrence Berkeley National Laboratory and the Climate Policy Initiative found that the current structure of the production tax credit and investment tax credit could reduce their value to project developers by up to 36 and 64 percent, respectively.[244] Renewable project developers frequently do not have sufficient tax liabilities to use the full value of the tax credit. As a result, developers often bring in a third party "tax equity" investor who invests in the project in exchange for being able to use most or all of the production tax credit benefits.[245] However, according to Lawrence Berkeley National Laboratory, tax equity is the second most expensive form of capital that renewable projects often use.[246] Reauthorizing the 1603 American Recovery and Reinvestment Tax Act grant program (which offered developers a cash payment of 30 percent of the project's cost),[247] or making tax incentives "refundable" (where the recipient applies as much of the credit to the tax liability as possible and is then refunded the balance in cash) could help ensure that more of the value of the credit flows to project developers and not financial intermediaries without increasing the cost to U.S. taxpayers.[248]

Financial regulators and lending institutions should develop commercial investment vehicles that provide investors direct access to low-carbon renewable investments.

Wind projects being built in the United States today are able to take advantage of the production tax credit. However, with this tax credit expired, most wind projects going forward will likely rely on project finance with interest rates 2 percent or more higher than corporate bonds.[249] Switching those projects to new investment models (such as YieldCos or more traditional municipal finance) could reduce the annual investment return requirement by 1–2 percent and thus reduce the cost of renewable energy by up to 18 percent (Figure 1.12). Such a switch is possible because, according to *Better Growth, Better Climate*, renewable projects are "relatively simple investments. There are no fuel costs to manage, operating costs are relatively low, output is fixed by wind or solar conditions, and revenues are also fixed, assuming a fixed, long-term price contract or feed-in tariff. As simple investments, these projects remain attractive investments even when returns are low, and with the right structural changes they can remain attractive at lower returns still."[250] Under the right circumstances, this can allow them to attract bond investors.

YieldCos, which own portfolios of low-risk long-term projects, are equity vehicles that can go a step further than infrastructure bonds by effectively bundling equity and debt in one package. By bundling projects, the project finance premium for single projects can be avoided, while for a portfolio of projects with risks comparable to corporate bonds, the result for investors can be a higher-yielding bond-like instrument that reduces the overall financing cost for the projects in question. YieldCos such as NRG Yield, TransAlta Corporation, and Pattern Energy Group and NextEra have begun to enter the marketplace. However, the full potential of this investment vehicle will likely remain constrained as long as the production tax credit and the investment tax credit remain nonrefundable.[251]

Municipal bonds are debt securities issued by governments commonly used to finance capital expenditures, such as roads and school buildings. Municipalities have "low borrowing costs and a long history of financing infrastructure for municipal needs, giving them the ability to finance renewable energy at low costs."[252] Additionally, some municipal bonds are tax exempt.[253] However, this requires the municipal government to bear the equity risk and role itself. Therefore, this vehicle may only be appropriate in certain types of circumstances.

States and utilities should update regulations and business models to promote a flexible grid.

Utilities and regulators may find it advantageous to work together to update regulations and business models to better align with the transition to a low-carbon power system. This includes properly valuing and encouraging demand response and storage; fully harnessing smart grid technologies, seamlessly integrating and properly valuing distributed generation; and ensuring that transmission expansion continues and is accompanied by appropriate pricing mechanisms; among other steps.

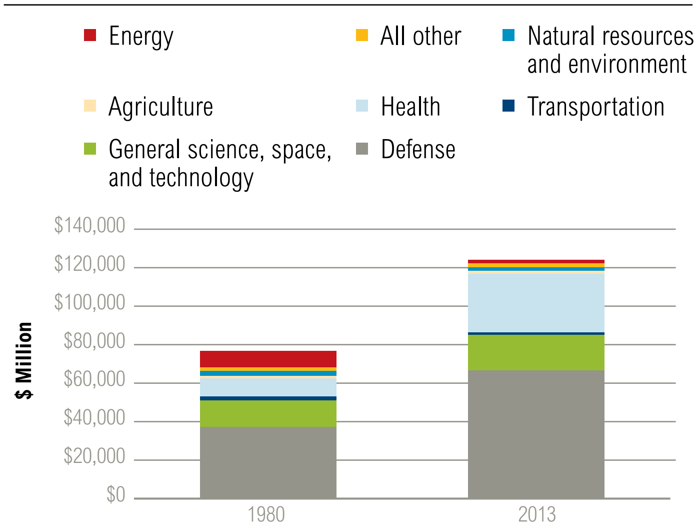
EPA should finalize greenhouse gas performance standards for new and existing power plants.

Together these actions will: (1) help with the nation's efforts to reduce greenhouse gas emissions; (2) deliver public health benefits through improved air quality; (3) reduce the risk of technological lock-in and stranded assets; and (4) encourage investment in low-carbon sources of generation, such as natural gas and renewables, which today are cheaper than new coal in most regions of the country.

The United States should increase federal funding to spur the research, development, and commercialization of low-carbon and energy-saving technologies.

Financing for research and development in the power sector does not match the scale of the challenge. Power company funds spent on research and development were only $280 million in 2011, or approximately 0.05 percent of power sector sales.[254] By comparison, company funds spent on research and development were 11 percent of sales for pharmaceuticals, 8 percent for computers and electronics, 5 percent for professional services, and 3 percent for general manufacturing.[255] Compounding the challenge is the fact that federal spending on research and development in the power sector has fallen 77 percent in inflation adjusted dollars from 1980 to 2013 (from $8.3 billion to $1.9 billion), declining from 11 percent to 2 percent of total federal research and development spending (Figure 1.13).[256] Increasing federal funding to match the scale of the challenge could help the nation develop the next generation of low-carbon technology, and in so doing foster opportunities for American businesses and manufacturing by helping the country remain a world leader of innovation.

Figure 1.13 | **Federal Spending on Research and Development, 1980 and 2013**



Source: U.S. Office of Management and Budget, Historical Tables, Table 9.8. This was adjusted to constant 2009 dollars using GDP deflators in U.S. Office of Management and Budget, Historical Tables, Table 10.1.

ENDNOTES

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4. While new natural gas generation is almost always cheaper to build than new coal generation, the cost of building new wind or solar generation is now becoming cheaper than coal in many areas of the country. For example, see U.S. Energy Information Administration, 2014, "Annual Energy Outlook 2014 Early Release Overview," accessible at http://www.eia.gov/forecasts/aeo/electricity_generation.cfm>; Bloomberg New Energy Finance, 2014, *Sustainable Energy in America Factbook*, accessible at http://www.bcse.org/factbook/pdfs/2014%20Sustainable%20Energy%20in%20America%20Factbook.pdf; T. Randall, "U.S. Wind Power Blows New Records. Again. And Again," Bloomberg, Sustainability, April 2014, accessible at http://www.bloomberg.com/news/2014-04-07/u-s-wind-power-blows-new-records-again-and-again-.html; Michigan Environmental Council, "MEC Priorities," accessible at http://www.environmentalcouncil.org/priorities/article.php?x=326>; N. Ankrum, "AE's Solar Deal: 'Game Changer,' " *Austin Chronicle*, July 4 2014, accessible at http://www.austinchronicle.com/news/2014-07-04/aes-solar-deal-game-changer/.
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242. Ibid.
243. World Resources Institute and World Wildlife Fund, 2014, "Corporate Renewable Energy Buyers' Principles: Increasing Access to Renewable Energy," July, accessible at http://www.wri.org/sites/default/files/Corporate_Renewable_Energy_Buyers_Principles.pdf.

244. Specifically, Lawrence Berkeley National Laboratory found that wind developers can typically lose 36 percent of the production tax credit's value while solar developers can typically lose 64 percent of the investment tax credit's value. CPI found similar results, with wind developers typically losing 33 percent of the PTC's value while solar developers can typically lose 50 percent of the ITC's value. Mark Bolinger, 2014, "An Analysis of the Costs, Benefits, and Implications of Different Approaches to Capturing the Value of Renewable Energy Tax Incentives," May, Lawrence Berkeley National Laboratory, accessible at http://emp.lbl.gov/sites/all/files/lbnl-6610e.pdf; Uday Varadarajan, Brendan Pierpont, Andrew Hobbs, and Kath Rowley, 2012, "Supporting Renewables while Saving Taxpayers Money," Climate Policy Initiative, accessible at http://climatepolicyinitiative.org/wp-content/uploads/2012/09/Supporting-Renewables-while-Saving-Taxpayers-Money.pdf.
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249. The Global Commission on the Economy and Climate, September 2014, "Better Growth, Better Climate: The New Climate Economy Report," accessible at: http://newclimateeconomy.report/.
250. Ibid.
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252. David Nelson, 2014, "Roadmap to a Low Carbon Electricity System in the U.S. and Europe," Climate Policy Initiative, accessible at http://climatepolicyinitiative.org/wp-content/uploads/2014/06/Roadmap-to-a-Low-Carbon-Electricity-System-Parts-1-and-2.pdf.
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254. Investment data reflects research and development performed by utilities, according to data from the National Science Foundation (Appendix table 4-20, Domestic R&D Paid for by the Company and Others and Performed by the Company, by Business Activity: 2011," accessible at http://www.nsf.gov/statistics/seind14/content/chapter-4/at04-20.pdf) and estimated utility revenue data from the United States Census Bureau (http://www.census.gov/services/). This does not include venture capital or private financing, nor does it include investment in demonstration of clean energy technologies.
255. National Science Foundation, "Business R&D Performance in the United States Increased in 2011," 2013, accessible at http://www.nsf.gov/statistics/infbrief/nsf13335/#tab1.
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CHAPTER 2: REDUCING ELECTRICITY CONSUMPTION

OVERVIEW

The United States has implemented a robust and growing portfolio of both regulatory and voluntary energy efficiency initiatives aimed at reducing electricity use. Together, these initiatives have helped offset total electricity demand growth, which has fallen from over 6 percent per year in the early 1970s to around 1 percent per year today as major household appliances—including refrigerators, dishwashers, and clothes washers—have become 50 to 80 percent more energy efficient. New federal appliance standards implemented since 2009 alone are expected to save consumers nearly $450 billion in lower electricity bills between now and 2030. State efficiency programs regularly save customers over $2 for every $1 invested, and in some cases up to $5.

Yet, a growing body of literature suggests electricity demand could be reduced further, and that additional actions could reduce demand 14 to 30 percent below projected levels over the next two decades while creating hundreds of billions of dollars in net savings for consumers, and significantly reducing U.S. greenhouse gas (GHG) emissions. Promising next-generation technologies under development—for example, high-efficiency rooftop air conditioning units, wide bandgap semiconductors, and data-enabled intelligent technologies—could lead to even greater savings.

In large part, the presence of cost-saving efficiency opportunities is due to the persistence of market barriers, such as lack of information about potential energy savings, limited capital for upfront investments, and split incentives that occur when the actors with the ability to make investment decisions differ from those who are affected by those decisions. Targeted policy interventions can help overcome these barriers and encourage improvements in efficiency, driving cost savings for consumers while reducing greenhouse gas emissions.

In this chapter, we focus on opportunities in the residential and commercial sectors, which together account for 74 percent of electricity sales nationwide.[1] These sectors have experienced significant reductions in their energy intensity as a result of the successful implementation of a number of policies, including appliance and equipment standards, energy efficiency savings targets, building codes, voluntary labeling programs, financial incentives for customers, and federally supported research and development.

The United States can continue to reduce electricity demand growth and save money for consumers and businesses in the near to medium term by scaling up existing initiatives, increasing investment in research and development, and adopting new policies. The U.S. Environmental Protection Agency's (EPA) greenhouse gas standards for existing power plants, proposed in June 2014,[2] could be an important addition to the toolkit. By including state efficiency programs as a compliance option, ambitious standards could encourage widespread adoption of strong efficiency policies, such as energy efficiency targets. These standards should be complemented by a portfolio of other state, federal, and local actions including: (1) updating building codes and improving their enforcement; (2) measures to promote retrofits of existing buildings; and (3) improving access to low-cost finance for efficiency projects.

PROFILES OF CHANGE

The energy efficiency of the American economy continues to improve as a result of innovations in technology, business models, and finance, coupled with sustained pushes from new state and federal policies. This success can be attributed largely to the simple fact that smart efficiency investments save consumers and businesses money. Consider:

- Over the past decade, efficiency has remained the least-cost option for utilities, with levelized costs to utilities ranging from 2 to 5 cents per kilowatt hour,[3] about one-half to one-third the cost of new electricity generation options.[4]
- Major household appliances—including refrigerators, dishwashers, and clothes washers—have become 50 to 80 percent more energy efficient over the last two decades as a result of technological innovation driven by

stricter federal and state efficiency standards, ENERGY STAR labeling,[5] federal research and development, and state energy efficiency programs.[6] For example, refrigerators sold today use only one-quarter of the energy they did in 1975—this will drop to one-fifth following the latest round of standards that will take effect in 2014—while providing 20 percent more storage capacity at less than half the price per unit.[7, 8, 9] Meanwhile, new clothes washers, dishwashers, and air conditioners use 70, 40, and 50 percent less energy, respectively, than they did in 1990.[10]

- Since 2009, the U.S. Department of Energy (DOE) has issued new or updated standards covering more than 30 products.[11] These standards could save consumers nearly $450 billion in lower electricity bills between now and 2030,[12] and reduce total electricity consumption by 400 terawatt hours in 2030, 9 percent below projected demand in the absence of standards.[13]

- The price for light emitting diodes (LEDs) is falling rapidly and may soon begin to transform the lighting market. Prices have fallen by about 80 percent since 2012, from over $50 per bulb to models that cost less than $10 today.[14] Today, LEDs use only one seventh the amount of electricity of conventional incandescent light bulbs[15] and save consumers up to $140 for every bulb they replace.[16] This rapid advancement has been driven in part through federal light bulb efficiency standards,[17] voluntary appliance labeling through the ENERGY STAR program, and federal research and development efforts.

- A diverse group of over 100 businesses and other entities—including Macy's, PNC Financial Services Group, Walgreens, Ascension Health, USAA Real Estate Company, and others—have pledged to reduce the energy intensity of their building portfolios 20 percent over 10 years through DOE's Better Buildings Challenge. Partners in the program have found that annual energy intensity improvements upwards of 2.5 percent per year are possible with cost-effective measures, giving them an average total energy savings (electricity and heating fuel) of about $60 million per year.[18] The Administration is expanding the program as part of President Obama's Climate Action Plan to include multifamily housing, which could save $7 billion in total energy costs (electricity and heating fuel) nationwide each year for families living in these units.[19, 20]

- Demonstrations of whole-building retrofits and next-generation systems-level building technologies are showing that even greater energy savings in buildings are possible, as high as 30 to 50 percent per building. For example, DOE is currently working with private and academic partners to develop advanced, integrated control systems for cooling and heating, lighting, ventilation, and windows with the goal of reducing total building energy use (electricity and heating fuel) by 40 percent.[21] DOE has also implemented programs to target major efficiency improvements in specific technologies for which no federal standards exist, such as its Rooftop Challenge that focuses on 10- to 20-ton-capacity rooftop air conditioners.[22]

- Twenty-four states have implemented electric efficiency savings targets, and most have proven cost effective. The portfolios of programs states use to meet their targets regularly save customers over $2 for every $1 invested, and in some cases up to $5.[a, 23] As a result of these programs, EPA predicts that some states could approach zero or even negative electricity demand growth even as their economies continue to grow.[24]

- Efficiency is beginning to feature in forward capacity markets in regions where it is permitted to directly compete for the right to meet the capacity needs of the electric grid. In the Independent System Operator (ISO) New England grid region,[25] the electric efficiency resources clearing the forward capacity market more than doubled between the first auction held in 2008 and 2013, accounting for nearly 30 percent of new capacity in the 2013 auction (to be provided in the 2016–17 timeframe).[26] Electric energy efficiency resources clearing the market also nearly doubled in the PJM interconnection grid region[27] during auctions held between 2009 and 2013, accounting for 20 percent of new capacity in the 2013 auction (also for the 2016–17 timeframe).[28, 29]

- Companies are capitalizing on growing demand for building energy management services, an industry now worth over $2 billion.[30] For instance, the green tech company OPower developed home energy assessments that show homeowners how their energy use compares

a. Estimate based on a review of 23 state programs for which cost and savings data were available. These data were available in all but one state with an energy savings target (North Carolina) at the time of publication. Note that we did not calculate the cost and benefit data, but relied on information reported by each state, utility, or independent organization. Methodologies and assumptions underlying the calculations of costs and benefits may differ across reports and we did not standardize these estimates.

to their neighbors. OPower provides services to 93 utilities—including National Grid, PG&E, Exelon, and others—and reaches approximately 32 million households and businesses worldwide, with most activity focused in the United States. Opower increased its revenue over eightfold between 2010 and 2013 and had a strong initial public offering in April 2014, selling over 6 million shares and raising over $115 million in revenue.[31]

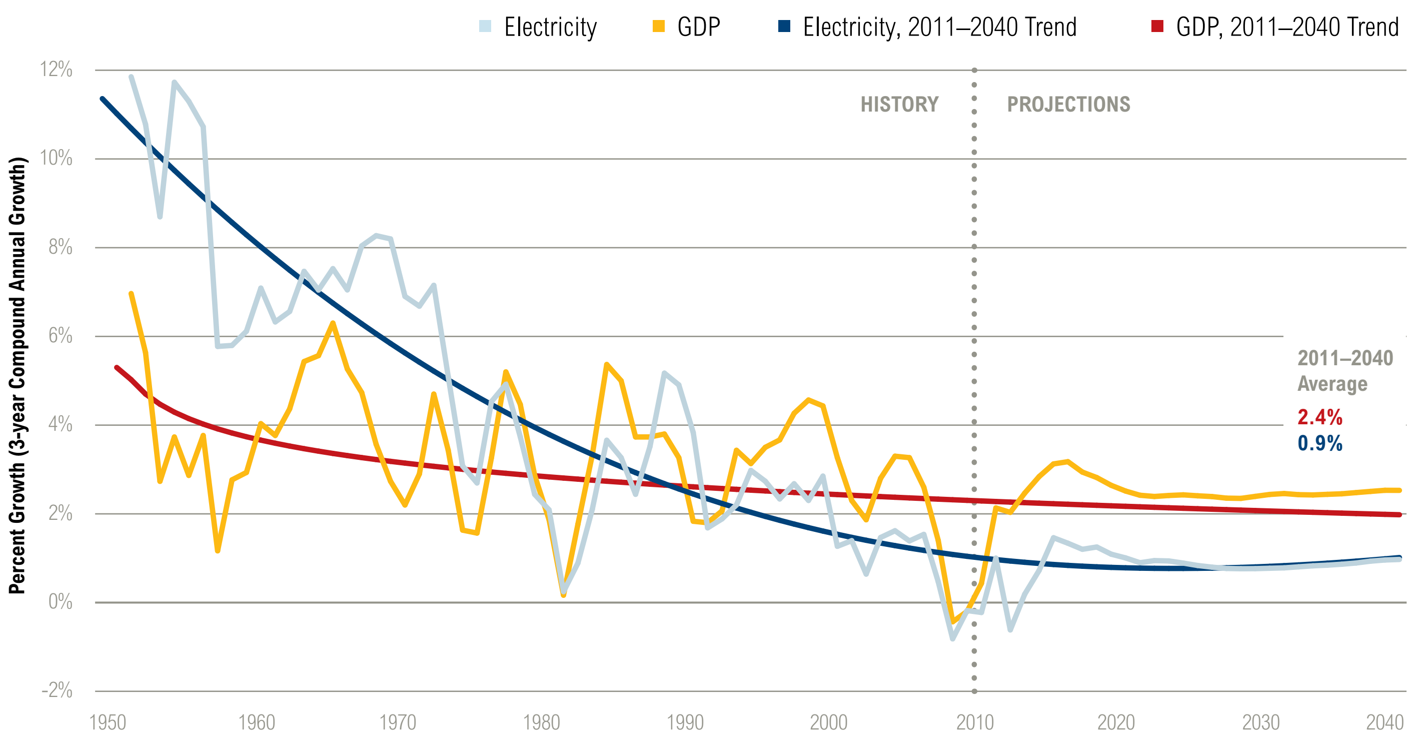
These profiles illustrate just a handful of the success stories around the United States—opportunities that could be scaled up with the right initiatives.

OPPORTUNITIES FOR SCALE

Despite steady growth in new construction, home size, and use of home appliances and electronics, total electricity demand growth has been declining, from over 6 percent per year in the early 1970s to only 1 percent per year from 2004 through 2013.[32, 33] This decline has occurred even as gross domestic product (GDP) has continued to grow, outpacing electricity demand growth since the 1990s (Figure 2.1).[34, 35] Falling electricity demand growth is the result of a number of factors, including slowing population growth, widespread use of more energy-efficient appliances and equipment, and a shift toward less energy intensive industry. The U.S. Energy Information Administration expects that, even without new policies to promote efficiency improvements, electricity demand growth will remain steady at an average of 0.9 percent per year through 2040, while GDP and population grow at 2.5 percent and 0.7 percent annually.[36, 37]

Nevertheless, research suggests that much greater efficiency potential and economic savings are available. While economists debate the size of this potential,[38] a growing body of literature concludes that electricity

Figure 2.1 | **GDP Has Outpaced Electricity Demand Growth Since the 1990s**



Note: U.S. electricity use and economic growth, 1950–2040. Percent growth (3-year compound annual growth rate) and trend lines.

Source: Energy Information Administration, "U.S. Economy and Electricity Demand Growth are Linked, but Relationship is Changing, March 2013, accessible at http://www.eia.gov/todayinenergy/detail.cfm?id=10491#.

demand could be reduced 14 to 30 percent below future projections in the 2020–30 timeframe while saving consumers money. For example:

- A 2010 study by the National Academy of Sciences found that it is possible to reduce electricity consumption in buildings 30 percent below projections in 2030 while saving consumers $130 billion each year as a result of reduced electricity costs.[39]
- In 2009, McKinsey & Company found that unlocking cost-effective efficiency potential in the residential and commercial sectors could reduce electricity use by about 30 percent below projections in 2020 and yield $330 billion in net savings.[40]
- The Institute for Electric Innovation, an industry association of investor-owned utilities, found that even modest growth in current energy efficiency policies could reduce total electricity consumption by 14 percent in 2035, offsetting the majority of future demand growth. They also found that if policy action is more ambitious, overall decreases in electricity consumption could be possible, with reductions up to 20 percent below projected levels in 2035.[41]
- The Rockefeller Foundation identified investment opportunities of nearly $280 billion across the residential, commercial, and industrial sectors that could return $1 trillion in total energy bill savings (electricity and heating fuel) over 10 years and create 3.3 million cumulative job years of employment.[42]

Box 2.1 | Overview of Market Barriers to Investing in Energy Efficiency

Split incentives (or principal-agent problems) occur when the actors with the ability to make investment decisions differ from those who are affected by those decisions. This is a significant barrier to efficiency measures in commercial and residential rental properties, where building owners typically do not pay the energy bills and thus lack incentive to invest in efficiency. Split incentives can also arise between different actors in the same organization. For example, in large companies, energy efficiency investment decisions are typically made by financial officers in charge of capital budgets, but the energy savings accrue to the division responsible for operations.[a]

Ownership transfer issues arise when residents do not expect to capture the lifetime benefits of an investment. This can be a significant issue for homeowners: energy efficiency measures have a payback period of around 7 years, yet 40 percent of homeowners will have moved by that time. Homeowners may not implement long-lived efficiency measures if they think they will not own the home long enough to reap the savings.[b]

Capital constraints may be a particular problem in the residential sector, where core spending accounts for about 90 percent of the average household budget.[c] Efficiency improvements compete with more visible home improvements including remodeling and entertainment.[d]

Lack of knowledge or uncertainty about the longer-term benefits of more efficient product choices affects purchases in both the residential and commercial sectors. Consumers may simply be unaware of the lifetime energy savings associated with different products, or they may not have confidence in the long-term benefits.[e]

Consumer decisionmaking does not always center on a simple assessment of costs and benefits. Other factors influence consumer choices of products (e.g., appearance, features) or choices to undertake retrofit projects (e.g., convenience). Energy efficiency tends not to be the highest priority for consumers, who may stick with the status quo rather than implement new efficiency projects even though they are cost effective. Consumers also tend to value short-term savings more than long-term savings and desire relatively short payback periods on their investments, creating a hurdle for deeper retrofits.[f]

Notes:

a. National Academy of Sciences, National Academy of Engineering, and National Research Council, 2010, "Real Prospects for Energy Efficiency in the United States," 2010, National Academies Press (NAP), Washington, DC, accessible at http://www.nap.edu/openbook.php?record_id=12621.

b. H. C. Granade, J. Creyts, A. Derkach, P. Farese, S. Nyquist, and K. Ostrowski, 2009, "Unlocking Energy Efficiency in the U.S. Economy," July 2009, McKinsey Global Energy and Materials, accessible at http://www.greenbuildinglawblog.com/uploads/file/mckinseyUS_energy_efficiency_full_report.pdf.

c. Ibid.

d. C. Rich, B. Sisson, A. Dasinger, M. Chenard, G. Atwood, M. Eckhart, C. Eicher, J. Presswood, P. Smith, M. Hughes, A. Gerney, S. Buettner, and L. Ungar, 2013, "Residential & Commercial Buildings," January, Alliance Commission on National Energy Efficiency Policy, Residential & Commercial Buildings Research Team, accessible at https://www.ase.org/sites/ase.org/files/ee_commission_building_report_2-1-13.pdf.

e. H. C. Granade, J. Creyts, A. Derkach, P. Farese, S. Nyquist, and K. Ostrowski, 2009. "Unlocking Energy Efficiency in the U.S. Economy," July, McKinsey Global Energy and Materials, accessible at http://www.greenbuildinglawblog.com/uploads/file/mckinseyUS_energy_efficiency_full_report.pdf.

f. Ibid.

- The Rocky Mountain Institute estimated that total building-sector energy consumption (electricity and heating fuel) could be reduced by 40 to 70 percent by 2050 through cost-effective strategies.[43, 44]

Barriers to Savings

This body of research raises the question of why efficiency would be left on the table if it is truly an economic win-win opportunity. Studies suggest that these cost-saving efficiency opportunities exist because of the persistence of several well-studied market barriers. For example, energy efficiency projects require upfront investments that return savings over a number of years, yet building owners or homeowners may lack the incentive (e.g., because of split incentives and ownership transfer issues) or capital to make upfront investments. Even if capital is available, consumers may not place a high priority on efficiency, preferring to invest in other building improvements or projects, in part because consumer decisionmaking does not always center on a simple assessment of costs and benefits. These and other prevalent barriers are described in Box 2.1.[45, 46, 47]

Overcoming Barriers

Experience over the past several decades has shown that well-implemented policy interventions can help overcome or reduce the impact of market barriers by: (1) driving more-efficient new products to market and culling the shelves of inefficient products; (2) encouraging uptake of the most efficient products and equipment; and (3) improving the efficiency of new and existing buildings.

A number of efficiency programs are already in place and delivering considerable savings. Below we profile three sets of policies, including: (1) appliance and equipment efficiency standards, labeling, and research and development; (2) state energy efficiency savings targets; and (3) building codes. Scaling them up could help drive significant improvements in efficiency, saving customers money while reducing GHG emissions.

Appliance and equipment standards, labeling, and research and development

Federal appliance and equipment standards set minimum energy efficiency levels for more than 50 products commonly used in homes and businesses, covering 90 percent of the energy used by homes, 60 percent by commercial buildings, and 29 percent by industry.[48] According to the Lawrence Berkeley National Laboratory (LBNL), standards adopted since 1987 generated $370 billion in cumulative utility bill savings (electricity and heating fuel) for consumers in 2012.[49] Without these standards, total electricity demand would have been 8 percent higher in 2012.[50] Looking forward, LBNL estimates that existing standards will save over 3,200 terawatt hours of electricity and $570 billion on utility bills (electricity and heating fuel) between 2012 and 2020.[51] Over 20 new standards under development by DOE are poised to deliver even greater savings.[52, 53]

Appliance and equipment standards are complemented by other programs, including research and development, partnerships with industry, competitions (e.g., L-prize and ENERGY STAR awards), voluntary labeling programs (e.g., ENERGY STAR and the Federal Trade Commission's EnergyGuide), and rebates and incentives for efficient appliances. Together, these programs can drive innovation and commercialization of products that are even more efficient than the minimum required by standards. This can pave the way for increased stringency of standards over time.

For example, until recently, residential clothes dryers had seen virtually no technological improvements since they entered the market 50 years ago. The Super-Efficient Dryer Initiative, a partnership between state and federal efficiency programs that began in 2009, engaged with manufacturers, and supported an ENERGY STAR competition for clothes dryers and development of an ENERGY STAR label. In 2012, Samsung Electronics became the first manufacturer to receive EPA's ENERGY STAR Emerging Technology Award for Advanced Dryers for a model that used 25 percent less energy than conventional models.[54] Shortly thereafter, in early 2014, LG announced that they would soon release the first heat-pump clothes dryer for the U.S. market, which the company claims is 50 percent more efficient than a standard model.[55] The United States has seen similar success stories for other products including LEDs, water heaters, and refrigerators.

State energy efficiency savings targets

Over the past decade, states have increasingly adopted energy efficiency savings targets that require utilities to achieve a specific amount of electricity savings either annually or over a specified time. To meet these standards, utilities or third-party program administrators offer energy-saving programs to electricity customers, helping them overcome capital constraints or other market barriers. In the process, these programs regularly save customers over $2 for every $1 invested, and in some cases up to $5.[56] Beyond benefitting direct participants through lower electricity bills, utility programs frequently benefit other consumers because reducing electricity demand allows power companies to avoid investments in new capacity for generation, transmission, and distribution.

As of May 2014, 24 states had fully funded, mandatory electric savings targets, including energy efficiency resource standards, combined renewable standards and efficiency standards, or policies requiring the capture of all cost-effective electric efficiency.[57] These programs are typically run by utilities or third-party administrators and financed through a charge on electric bills or a public benefit fund. Programs often include financial incentives (e.g., rebates and loans), technical services (e.g., audits and retrofits), and educational campaigns.[58]

The majority of states with savings targets aim to save over 1 percent of annual electricity sales once programs are fully ramped up, and several states have pushed further, with a few requiring savings in excess of 2 percent of sales. Many states with the most robust programs are expected to see electricity growth rates well below the national average over the next six years, and several states are actually expected to experience negative demand growth in the 2015–20 timeframe.[59]

State experiences show that energy efficiency programs are cost-effective, win-win opportunities that can save money for customers and provide broader benefits including economic growth, job creation, and improved local air quality. For instance, Minnesota's largest utility, Xcel energy, reported that the direct savings of their electric efficiency programs exceeded its expenditures over fourfold in 2012, netting customers over $300 million in savings.[60] According to the Wisconsin Public Service Commission, the state's efficiency program will inject over $900 million into the state's economy and net over 6,000 new jobs over the next 10 years. After taking into account benefits from reduced electricity and natural gas bills as well as avoided air pollution, total benefits are estimated to be three times greater than program costs.[61] Many other states are experiencing similar results. The Pacific Northwest National Laboratory found that every $1 million of consumer energy bill savings leads to a net gain of 8 jobs because the money saved is spent on other goods and services, and that an additional 11 net jobs are created for every $1 million of upfront investment in energy efficiency projects.[62]

The proliferation of state efficiency policies has contributed to a doubling in electric efficiency budgets over the past six years. Although not universal, this trend is expected to continue, with electric efficiency budgets reaching $10 to $14 billion by 2025.[63, 64, 65, 66] Lawrence Berkeley National Laboratory projects that state spending on electric efficiency could scale up from $6 billion to $12 billion in 2025, even in the absence of new policy developments like standards for existing power plants. This would lead to national annual incremental electricity savings of 0.5–1.2 percent of sales, potentially offsetting the demand growth otherwise projected by the Energy Information Administration.[67, 68]

However, there appears to be room for improvement as more than half the states do not have any energy efficiency targets, and some states with targets could do more. The American Council for an Energy-Efficient Economy (ACEEE) recently estimated that the United States could increase GDP by over $17 billion by 2030 while creating over 600,000 new jobs if every state ramped up its electricity savings to 1.5 percent of electricity sales per year.[69] Scaling up state energy efficiency savings targets so that each state achieves savings of 2 percent annually would reduce electricity consumption in the range of 400–500 terawatt hours in 2035 (9–11 percent of total projected electricity sales),[70] and save customers tens of billions of dollars in the process (see Box 2.2).

Box 2.2 | State Efficiency Programs: Who Pays and Who Benefits?

Funding sources for state efficiency programs vary throughout the country. Some states provide funds for energy efficiency investments by selling air pollution allowances at auction (e.g., the Regional Greenhouse Gas Initiative) or by allowing efficiency resources to bid into forward capacity markets (e.g., ISO-New England). Other states use surcharges on electricity bills to collect revenue for public benefits funds or allow utilities to recover costs for efficiency programs they pay for directly.[a]

Regardless of the specific mechanism, the funding ultimately comes from the customers themselves. Therefore, states often design their programs to ensure that the benefits of efficiency upgrades and the corresponding reduction in utility bills are shared among consumers.[b] This is done by allocating program funding among both residential and commercial consumers. Some states also target a portion of their funds to small businesses and low-income customers.

For instance, in Massachusetts, about 60 percent of its 2012 efficiency program budget was dedicated to residential customers. About half of the residential funding was targeted specifically toward low-income homes through incentives for ENERGY STAR appliances, zero-interest loans on home heating and air conditioning systems, weatherization assistance, and subsidized lighting and refrigeration retrofits for multi-family homes, among other strategies. Over half of program spending for commercial and industrial customers was dedicated to programs for small businesses, including zero-interest financing and technical assistance for retrofits.[c]

Inevitably, not every electricity customer will receive efficiency upgrades through state programs. However, all consumers do benefit when reduced demand caused by the program allows the region to avoid certain types of infrastructure investments, such as transmission expansion and building new power plants. All state residents also enjoy health benefits when reduced power consumption leads to lower air pollution. In Massachusetts, program administrators estimate that these shared benefits could reach $4 billion in net lifetime savings for residents after accounting for program costs.[d]

Notes:

a. American Council for an Energy-Efficient Economy, November 2013, "The 2013 State Energy Efficiency Scorecard," available at http://www.aceee.org/state-policy/scorecard.

b. Analysis Group, 2014, "EPA's Clean Power Plan: States' Tools for Reducing Costs and Increasing Benefits to Consumers," accessible at http://www.analysisgroup.com/uploadedFiles/Publishing/Articles/Analysis_Group_EPA_Clean_Power_Plan_Report.pdf.

c. Massachusetts Energy Efficiency Advisory Council, 2012, "Staying on Top: Energy Efficiency Continues to Deliver Benefits to Massachusetts Residents and Businesses," November 2013, Massachusetts Department of Energy Resources, Boston, MA, accessible at http://www.mass.gov/eea/docs/doer/energy-efficiency/ma-advisory-council-2012-report.pdf.

d. Net savings estimate includes lifetime energy and nonenergy benefits from efficiency programs implemented in the state from 2010 to 2012. The evaluation defines energy benefits as "the value of avoided energy purchases, reductions in operations and maintenance costs, and other resource savings (e.g., water or raw materials)" and nonenergy benefits as "reduced pollutant emissions and increased comfort or worker productivity." For more details, see http://www.mass.gov/eea/energy-utilities-clean-tech/energy-efficiency/eeac-2011-report-ee-advisory-council.pdf.

Building energy codes

Building codes help ensure that new construction and existing buildings that undergo major renovations or repairs meet minimum efficiency requirements. This helps overcome split incentives in the marketplace between builders and occupants and between landlords and tenants that can otherwise prevent investment in cost-effective energy efficiency opportunities. Building codes adopted between 1992 and 2012 have resulted in approximately 2 quads[b] in cumulative total energy savings and are expected to save more than $40 billion over the lifetime of buildings constructed during this time period.[71] Lawrence Berkeley National Laboratory estimates that future energy code adoption could result in cumulative energy savings of 20 quads and cumulative cost savings of approximately $190 billion from 2013 through 2040.[72, 73]

Because states and localities adopt and enforce building codes, the stringency of standards can vary. The 2009 American Recovery and Reinvestment Act (a.k.a. the stimulus bill) helped drive a modernization of state building codes by making new state energy funding conditional on each state's pledge to adopt ASHRAE 90.1-2007[74] standards for commercial buildings and the 2009 International Energy Conservation Code for residential buildings.[c, 75] Many states have adopted

b. A quad is a unit of energy equal to 1 quadrillion (10^{15}) British thermal units (BTUs).

c. DOE establishes model codes, but these are not legally binding. However, the agency does have the obligation and authority to support the adoption, implementation, and enforcement of new building codes within states through technical assistance and incentives. For more information, see O.V. Livingston, D.B. Elliott, P.O. Cole, R. Bartlett, 2013, "Building Energy Codes Program: National Benefits Assessment, 1992-2040," U.S. Department of Energy, October, accessible at http://www.energycodes.gov/about/statutory-requirements.

these standards, which can reduce energy use by new buildings 10 percent below what was required by older codes.[d]

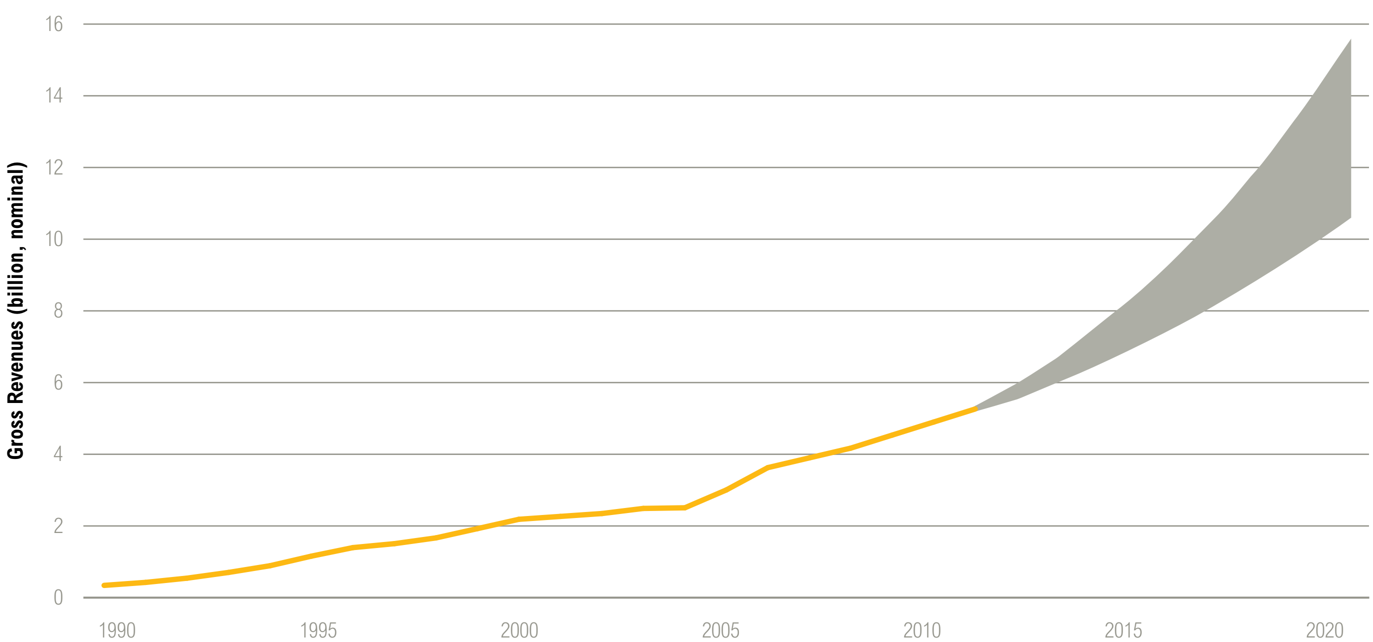
However, only about one-quarter of states have adopted the most up-to-date codes for residential and commercial buildings—which reduce building energy use by 20 and 25 percent, respectively, compared with the 2007–09 standards—leaving the door open for greater savings by other states.[e, 76] In *Factors Affecting Electricity Consumption in the United States*, the Institute for Electric Innovation estimates that updating state building codes could lead to electricity savings of 123–205 terawatt hours in 2035, 3–4 percent below total electricity demand projections (assuming they are enforced).[77]

Opportunities for the Private Sector

Demand for energy efficiency services has been on the rise in part because of the programs described above, providing a growing opportunity for private energy service companies. Major companies include Johnson Controls, Ameresco, Honeywell, Noresco, Chevron Energy Solutions, among others. Energy service company (ESCO) revenues have risen steadily since the 1990s, more than doubling between 2000 and 2012 to over $5 billion, and are expected to reach $11 to $15 billion by 2020 (Figure 2.2).[78] Thus far, state and local government facilities, schools, and hospitals have accounted for about 90 percent of the ESCO market. However, this may change as ESCOs have been looking to expand into other commercial and residential markets as well.[79]

Over the past five years, demand has particularly grown for intelligent building energy management systems. These systems allow users to collect information and make adjustments to energy use, enabling identification of retrofit opportunities, real-time load reduction, optimization of energy use, as well as monitoring and verification of new approaches or technologies. Commercial

Figure 2.2 | **Energy Service Company Revenues Rose Steadily Since 1990 and Are Projected to Climb Higher by 2020**



Source: Lawrence Berkeley National Laboratory, http://emp.lbl.gov/sites/all/files/lbnl-6300e_0.pdf.

d. As of July 2014, 38 states had adopted IECC 2009 or more efficient codes for residential buildings, and 42 states had adopted ASHRAE 2007 or more efficient codes for commercial buildings. For more information, see U.S. Department of Energy Building Energy Codes Program, accessible at https://www.energycodes.gov/.

e. According to DOE, 10 states have adopted IECC 2012, which can achieve over 20 percent site energy savings compared to IECC2009 and 12 states have adopted ASHRAE 90.1-2010, which can achieve 25 percent site energy savings relative to 90.1-2007.

building energy management is now a $2 billion industry. In addition to well-established ESCOs, a number of new software and technology companies are emerging in the field, including Retroficiency, FirstFuel, Lucid, Agilis, KGS Buildings, and Building IQ. Companies such as Tendril, C3, and OPower have also moved into the residential market, providing services to utilities to meet energy efficiency savings targets.[80]

EMERGING OPPORTUNITIES

DOE and EPA are promoting the development and commercialization of innovative technologies and approaches that could be game-changers for building efficiency in the next 5 to 10 years. Three of these opportunities—high-efficiency rooftop air conditioners, wide bandgap semiconductors, and data-enabled intelligent efficiency—are profiled below.

High-efficiency Rooftop Air Conditioners

DOE is working with industry partners to catalyze the market introduction of new high-efficiency 10-ton-capacity commercial air conditioners (i.e., rooftop units) that use 50 percent less energy than typical equipment through its High Performance Rooftop Unit Challenge. In 2011, DOE released a specification detailing how to build units that could meet the challenge.[81, 82] Since then, two manufacturers have met the challenge—Daikin McQuay in 2012 and Carrier in 2013—and three others are still participating.[83, 84] DOE estimates that replacing equipment 10 years and older with new models could save 80 trillion British thermal units of energy per year, over 60 percent of the typical annual energy use (the typical lifespan of a commercial rooftop unit is 10–20 years).[85, 86] And if all existing rooftop units were replaced with units built to DOE's latest specification, businesses would save about $1 billion each year in energy costs.[87] Based on pilot testing, DOE expects that these units likely will have less than a three-year payback period for businesses before taking into account any incentives offered by utilities. As part of the Commercial Building Energy Alliance, major companies—including Costco, Macy's, Target, and Lowe's—have signed a pledge indicating their support of DOE's efforts and interest in purchasing high-efficiency units as they become commercially available.[88]

Wide Bandgap Semiconductors and In-building DC Power

The balance between alternating current (AC) and direct current (DC) power consumption in U.S. buildings is shifting toward DC as consumers use more electronics (e.g., computers, TVs, LED lighting) and as motor loads (e.g., dishwashers, refrigerators) become more efficient because of appliance standards, labeling, and innovation. The problem is that a significant amount of energy is lost when converting from wall current, which is typically AC, to DC for these products. For instance, one-quarter of the power from the wall is wasted when powering a typical laptop.[89]

If successful, wide bandgap semiconductors could change the landscape of electronics in the near term by eliminating up to 90 percent of the power losses that occur in electricity conversion from AC to DC with current technology.[90] This is because they can handle higher temperatures, frequencies, and voltages than their silicon counterparts, thereby wasting less energy. In addition, their higher-temperature operation allows for smaller, lighter product designs, which could reduce production costs and thus prices of technologies including LEDs and consumer electronics. Wide bandgap semiconductors could have a broad range of applications throughout the economy, including industrial motors, grid integration, utility applications, and electric vehicles. DOE is working with partners across industry, academia, and state and federal organizations to bring down the cost and promote domestic manufacturing of this technology.[91, 92]

Data-enabled Intelligent Efficiency

Efficient technology is moving toward a systems-level approach, as opposed to an individual end-use product-based approach. Technologies under development for lighting, windows, ventilation, and heating and cooling collect data from individual equipment and use enabling technologies (e.g., sensors, control panels, data storage) to optimize performance of the integrated system as its components respond to real-time demands and environmental factors.[93] Energy information systems that provide whole-building, web-accessible data can allow facility managers to identify waste, cutting building electricity use by as much as 30 percent.[94] As previously mentioned, DOE is partnering with private and academic partners to develop and deploy these systems.

Retailers, particularly grocery stores, are increasingly using networked sensors to monitor their building energy consumption by devices such as refrigerators and air conditioners. The motivation is partly to save energy by identifying poor operation (e.g., air conditioners left running after business hours, aging and failing refrigerator compressors, unnecessary lighting) and partly to reduce operational waste (e.g., repairing refrigerators before they fail and food is spoiled). Companies such as OPower, Innovari, Enernoc, and Verisae are beginning to offer these services for retailers.

REMAINING CHALLENGES

The extent to which greater efficiency opportunities can be harnessed depends in part on reducing the impacts of the market barriers discussed previously. Additional challenges to be addressed include conflict with traditional regulatory models, building code compliance, and access to financing for energy efficiency. Below we explore these three challenges in more detail.

Conflict with Traditional Regulatory Models

Under traditional regulatory models, utilities are rewarded based on the volume of their electricity sales. Therefore, revenue from sales declines as efficiency programs expand. This creates natural disincentives for them to pursue all cost-effective opportunities to improve efficiency. A shift in their financial model could unlock pathways to deep electricity savings.

Over the past several years, states have begun taking steps to retool regulatory frameworks to support energy efficiency. Sixteen states have a form of decoupling in place, whereby utility profits are to some extent "decoupled" from sales.[95] Twenty eight states provide performance incentives for energy efficiency.[96] States have also enacted policies to require or encourage utilities to pursue electric efficiency as a resource: 20 states require efficiency planning or consideration of efficiency under utility integrated resource planning and 7 states require distribution utilities to invest in all cost-effective efficiency before adding more expensive new supply (i.e., least-cost procurement).[97, 98, 99, 100, 101]

Lack of Compliance with Building Energy Codes

Building codes can only deliver savings to consumers if they are properly enforced. Unfortunately, efforts to monitor and enforce compliance are weak or lacking in many jurisdictions around the country, sacrificing billions of dollars in potential energy savings. This is because of a number of challenges including lack of resources, limited educational efforts, and absence of political will, among others. The Institute for Market Transformation estimates that weak compliance currently costs consumers $63 to $189 million in energy (electricity and heating fuel) per year. They found that enhanced code compliance for new construction from 2013 through 2017 could yield lifetime savings of $37 billion.[102, 103]

Financing Challenges for Energy Efficiency Projects

The widespread deployment of existing and emerging technologies that can achieve deep reductions in energy use is an ongoing challenge, particularly in existing buildings. Because buildings are long-lived assets, retrofits to increase their efficiency are necessary to achieve deep energy demand savings on a national scale.[104] Retrofits that reduce building energy use in the range of 30 to 50 percent—or even greater, in some cases—are possible through cost-effective whole-building approaches.[105] Too frequently, however, building owners are discouraged from undertaking these projects because of factors such as high upfront investment, lengthy completion times, limited access to (or knowledge about) attractive financing options, and limited data on financing and returns on efficiency projects.

Energy efficiency projects are a challenging area for traditional lending. They generally offer poor collateral because many investments (e.g., improvements to building walls, windows, and ducts) cannot be repossessed and resold if the lessee defaults. Lenders typically have low confidence in the success of financial products for energy efficiency because of the lack of comprehensive historical data about their performance. Some have suggested that standardization (i.e., making loans and leases similar regardless of where they originated) could allow financial products to be offered in high volume, aggregated, and re-sold on secondary markets, which is where the profit lies for many financial institutions. This could attract more investors, allowing for better financing terms.[106, 107] However, standardization requires strong historical data so that lenders can properly assess risk. Without that data, lenders will typically assume high risk and thus require more security, restrict underwriting, and offer high interest rates and short financing terms,[108] leading to less favorable terms compared with loans for other projects.[109]

In the late 2000s, property-assessed clean energy (PACE) programs emerged as an innovative mechanism to fund energy efficiency or renewable energy projects. State PACE legislation enables a city or county to offer funds for clean energy projects—usually by issuing bonds—which homeowners or business owners repay through an annual assessment on their tax bills.[110, 111, 112] From 2008 to 2011, state legislation enabling PACE financing was rapidly adopted, and is now in place in 31 states and the District of Columbia, 25 of which have active PACE programs in place or under development.[113] As of May 2014, over 250 PACE projects worth more than $75 million had been completed, and more than $250 million in PACE project applications were in the pipeline nationwide.[114] However, residential PACE programs have stalled since 2010, when the Federal Housing Finance Agency advised major lenders not to back PACE-assessed mortgages.[f, 115] While PACE financing is continuing to scale up in the commercial sector, it is not clear what role it will play in the residential market.

BRINGING OPPORTUNITIES TO SCALE

The United States can continue to reduce electricity demand growth and deliver savings to consumers by scaling up existing initiatives and adopting new programs to fill gaps in efforts. Although it is not a comprehensive list, we explore several opportunities that can be implemented in the near term to overcome market barriers and harness more electric efficiency potential. No single measure will be sufficient to achieve deep electricity savings; rather, an integrated approach will be necessary. Through a comprehensive efficiency portfolio including elements discussed below, the United States can continue to reduce electricity demand growth in the near term and, if ambitious, potentially flatten or reduce overall electricity use in the longer term.

The United States should scale up existing initiatives.

Existing efficiency programs help overcome market barriers to investment in cost-effective energy efficiency measures. Strengthening and deepening these initiatives would further offset electricity demand growth while saving millions of dollars for consumers. Specifically, we recommend:

Box 2.3 | Rebounds in Electricity Consumption Caused by Efficiency Policies

As homes and appliances become more efficient, their operating costs decrease and consumers may increase their use of electricity, a phenomenon broadly referred to as the "rebound effect." Direct rebound effects occur when cost-savings from an energy-efficient product lead to increased used of that product. Indirect rebound effects occur when consumers spend their utility bill savings on other energy-consuming products (e.g., savings from a more efficient refrigerator allow them to purchase a new mobile phone). Both direct and indirect rebound effects increase public welfare. However, they offset some of the electricity savings from efficiency programs.

The magnitude of rebound effects is uncertain, as there has been limited empirical research and studies show wide variation across end uses and within and among countries. Recent studies have broadly estimated that direct rebound effects for appliances in the United States may erode as much as 10 to 12 percent of the energy savings from efficient appliances.[a] The magnitude of indirect rebound effects is also uncertain, although recent estimates suggest this effect is not greater than 15 percent.[b, c] A few case studies from the United States and other developed countries showed greater rebound effects, in some instances 30 percent for indirect effects and up to 60 percent for direct and indirect effects combined, but many of these studies were published over two decades ago and have not been supported by more recent research.[d]

Notes:

a. For example, see S. Nadel, 2012, "The Rebound Effect: Large or Small?" August, White Paper, American Council for an Energy-Efficient Economy (ACEEE). Washington, DC, accessible at http://aceee.org/files/pdf/white-paper/rebound-large-and-small.pdf; K. Gillingham, M. J. Kotchen, D. S. Rapson, and G. Wagner, 2013, "Energy Policy: The Rebound Effect Is Overplayed," January 23, *Nature* 493, 475-476, accessible at http://www.nature.com/nature/journal/v493/n7433/full/493475a.html; and Gilligham et al., 2014, "The Rebound Effect and Energy Efficiency Policy," accessible at http://www.econ.ucdavis.edu/faculty/dsrapson/Rebound_Effect_GRW.pdf.

b. S. Nadel, 2012, "The Rebound Effect: Large or Small?"

c. K. Gillingham et al., "Energy Policy: The Rebound Effect Is Overplayed."

d. D. Chakravarty, S. Dasgupta, and J. Roy, 2013, "Rebound Effect: How Much to Worry?" *Current Opinion in Environmental Sustainability* 5 (2): 216-28, accessible at http://www.sciencedirect.com/science/article/pii/S1877343513000134.

f. FHFA stated that first liens established by PACE loans represent a "key alteration of traditional mortgage lending practice" and that they "present significant risk to lenders and secondary market entities."

- The federal government should continue to set efficiency standards for new appliances and strengthen existing standards.
- These standards should continue to be supported through efforts to deploy and commercialize new technologies, such as: sustained and enhanced research and development, partnerships with industry, competitions (e.g., L-prize and ENERGY STAR awards), voluntary labeling programs (e.g., ENERGY STAR and the Federal Trade Commission's EnergyGuide), and rebates and incentives for efficient appliances.
- States without energy efficiency targets should adopt them, and those with targets should consider increasing them.
- States should pursue policies to address conflicts with regulatory models, such as: providing performance incentives for energy efficiency, requiring utilities to consider efficiency as part of their integrated resource planning, and decoupling, among other policies.

New federal policy signals should promote ambitious state action.

Federal policies should be enacted that promote more widespread adoption of ambitious state policies thus expanding the number of consumers who benefit from increased energy efficiency. This could be accomplished through a variety of legislative approaches, such as a nationwide electric energy efficiency resource standard, a clean energy standard, and a greenhouse gas cap-and-trade program or carbon tax that recycles revenue into energy efficiency measures.

However, a similar effect could also be achieved in the near term by EPA's greenhouse gas emissions standards for existing power plants under section 111(d) of the Clean Air Act. The rule EPA proposed in June 2014 allows states to make progress toward their carbon dioxide reduction targets through electric efficiency programs.[116] Because energy efficiency is typically the lowest cost compliance option, this rule could encourage states to increase the ambition of their efficiency targets and other efficiency programs, and spur some of the 26 states that do not currently have robust, binding efficiency programs to adopt them. Doing so can help reduce the costs of implementing the standards and produce net benefits for electricity customers over time, as well as inject more revenue into the economy and create new jobs.[117, 118]

The question for many states will be how far to go. In establishing state-specific standards, EPA assumed that all states will eventually achieve annual electricity savings of 1.5 percent per year, a rate 12 states have already achieved or plan to achieve.[119] They estimate that this would reduce electricity use and electricity bills nationwide by 11 and 8 percent, respectively, below 2030 projections. However, there is reason to believe that states could go even further since there is no limit to the amount of efficiency they can apply toward the standard, and several states are already achieving annual savings of 2 to 2.5 percent of sales.

The Regional Greenhouse Gas Initiative (RGGI) has several years of practical experience linking emissions standards and energy efficiency. RGGI is a cap-and-trade program for power-sector carbon dioxide emissions among nine states in the Northeast and mid-Atlantic regions, which could serve as a model for compliance with EPA's new standards. The program auctions approximately 90 percent of its emission allowances and invests a significant portion of the proceeds in energy efficiency programs. This approach has been successful and cost effective in the region: over $440 million in efficiency investments from 2009 to 2011 (about half of total auction revenue generated) are projected to save electricity customers nearly $1.1 billion through 2021, while generating 16,000 new job-years and injecting over $1.5 billion in value added to the economy.[120]

Federal, state, and local governments should take action to encourage adoption and enforcement of the most up-to-date building codes.

About three-quarters of states do not have the most up-to-date building energy codes, and weak enforcement of codes in states and jurisdictions around the country is leaving billions of dollars in savings on the table.

According to the American Council for an Energy-Efficient Economy, enforcement can be improved through education and training of contractors, building inspections, streamlining review processes for building plans and permit applications, and in some cases third-party enforcement.[121] While building code enforcement typically occurs at the local level, the federal government can encourage more widespread adoption of the most recent codes and best practices for compliance by continuing outreach to states and jurisdictions through measures such as: DOE's Building Energy Codes Program; providing contingent energy funding to states; and potentially through EPA's carbon pollution standards for existing power plants.

Federal, state, and local governments should help unlock cost saving opportunities available through retrofits to existing buildings.

Federal, state, and local authorities should take actions to help capture the win-win opportunities available in existing buildings, including: (1) improving labeling, (2) recognizing the benefits of energy efficiency in mortgages, (3) incentivizing whole-building retrofits, and (4) implementing building energy auditing, disclosure, and benchmarking policies.

1. Expanding federal voluntary building labeling programs (e.g., ENERGY STAR, Home Energy Rating System [HERS], LEED, and others) and energy assessment tools (e.g., DOE's Home Energy Score) could help overcome lack of knowledge or uncertainty by informing consumers about money-saving opportunities and providing incentives for building owners to invest in energy efficiency even if they will not benefit directly from utility bill savings. Expansion of partnerships like the Better Buildings Challenge—which provides technical assistance, grants, and publicity for projects—could help building owners find financing for upfront costs.

2. Local, state, and federal governments should promote building energy auditing, disclosure, and benchmarking policies. These policies typically make building energy-use information available to its owners, occupants, interested buyers or tenants, and potential financiers. In some cases, the information is also made available to the public. Disclosure of information can encourage energy efficiency upgrades by making owners aware of money-saving opportunities and by helping prospective buyers or investors factor efficiency into their purchasing decisions. This information can also help city or state policymakers target incentives, grants, and other efficiency programs to the segments of the building sector that would yield the greatest impact.[122, 123] Seventeen cities currently have such policies in place or under consideration for commercial or residential buildings.[124] A handful of cities—including Austin (Texas), Boston, and New York—require owners to complete upgrades based on the results of the audit.[125] But there is room to go further; as of 2013, energy auditing, disclosure, and benchmarking policies covered only about 7 percent of commercial floor space nationwide.[126]

3. State and federal authorities should consider implementing policies to incorporate the benefits of energy efficiency investments in mortgages. For example, the Sensible Accounting to Value Energy (SAVE) Act of 2013 would have required all federal-agency-issued, insured, or purchased mortgages—covering more than 90 percent of all new loans[127]—to account for energy efficiency. This could allow buyers to receive better loan terms when factoring in energy savings from efficient equipment over time, which would have encouraged buyers and sellers to consider the costs and benefits of efficiency upgrades at the time of sale. In the absence of new legislation, the federal government has a number of ways to promote consideration of energy efficiency in mortgages using existing authorities, for instance by revising appraisal and underwriting procedures at Fannie Mae and Freddie Mac.[128]

4. State utility efficiency programs should be expanded beyond a focus on single measures to include whole-building retrofits. The current emphasis on single measures misses a major portion of the efficiency opportunities in existing buildings. Several states, including California and Connecticut, are pioneering new models that encourage deeper retrofits by offering incentives for whole-building approaches and limiting benefits for small or individualized measures.[129]

Federal, state, and local governments should take steps to improve access to financing options.

Federal, state, and local jurisdictions should take steps to improve access to low-cost financing for energy-efficiency projects by: (1) stimulating private funding; (2) improving access to PACE financing; and (3) pursuing other innovative financing options. These measures can reduce barriers imposed by upfront costs and provide business and homeowners with confidence in the performance of energy efficiency measures.

1. Working with states and financial institutions, the federal government should stimulate private financing by helping facilitate the standardization of loan terms. Specific actions could include:

- Collecting and maintaining a centralized database of financed projects to allow lenders to develop accurate risk profiles, increase lending, and ultimately lower financing costs;[130, 131]
- Developing common data definitions and reporting guidelines for energy efficiency financing programs; and,
- Developing best practices for measuring energy savings, for instance through DOE's Uniform Methods Project.[132]

2. Federal, state, and local jurisdictions should improve access to PACE financing. Although PACE has faced challenges, states and local jurisdictions continue to pursue this model, particularly in the commercial sector. A handful of states have recently developed strategies to continue operating their residential PACE programs, for instance by insuring mortgage holders against losses they may incur because of PACE financing, subordinating the status of residential PACE liens, or maintaining the senior status of PACE liens and providing disclaimers to homeowners interested in enrolling.[133] The federal government should work with states to remove impediments to residential PACE programs.

3. State and federal authorities should also examine other innovative financing mechanisms.[134] In 2013, New York became the first state to use the Clean Water State Revolving Fund to support over $24 million in bonds to finance energy efficiency projects, an approach that could serve as a model to other states.[135] Several states have established "green banks," which provide low-cost, long-term financing by leveraging public funds to attract private investment. This model is relatively new, but has attracted clean energy investments in Connecticut, New York, Hawaii, and California, with a number of other states expressing interest.[136, 137]

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CHAPTER 3: CLEANER AND MORE FUEL EFFICIENT VEHICLES

Passenger cars and light trucks (also known as light-duty vehicles)[1] account for about 16.5 percent of total U.S. greenhouse gas emissions.[2] New greenhouse gas and fuel economy standards established by the U.S. Environmental Protection Agency (EPA) and U.S. Department of Transportation (DOT) require new vehicles sold in 2025 to be roughly twice as fuel efficient as those sold today. Owners of those vehicles will benefit directly from the standards—they will save on average a net $3,400 to $5,000 over the life of their 2025 vehicle compared with a vehicle meeting the model year 2016 standards.[3]

Next-generation technologies, such as electric and plug-in hybrid vehicles, have begun entering the marketplace at a significant rate. In turn, increased sales, along with technological improvements, have helped drive a rapid decline in the price for advanced battery systems. Some industry analysts predict that long-range electric vehicles will become cost competitive with internal-combustion-engine vehicles by the early 2020s, even without federal tax incentives. In addition, several manufacturers are expected to offer fuel-cell vehicles in the 2015–17 timeframe.

For these next-generation technologies to fully take hold, however, they will need to overcome a variety of barriers, including a lack of fueling/charging infrastructure, drivers' "range anxiety," and higher upfront costs (even if lifetime costs of these alternative vehicles are lower).

Continued innovation and initiatives to address these barriers could make it easier and more cost effective to meet the model year (MY) 2025 standards, and possibly achieve deeper reductions after 2025. Particularly rapid advancements could even allow DOT and EPA to make the standards more ambitious during the midterm Corporate Average Fuel Economy (CAFE) standards review for MY 2022–25.[4] In the meantime, new technologies could benefit from continued research and development, vehicle incentives and mandates, expansion of fueling and charging stations, and technology standardization. Taking these actions will allow the United States to continue to decrease its dependence on oil imports, reduce emissions of harmful air pollutants, and take a global leadership position in alternative vehicle manufacturing.

PROFILES OF CHANGE

New vehicle technologies have taken a significant step forward in recent years. Consider that:

- The number of sport utility vehicles with a fuel economy of at least 25 miles per gallon (mpg) has doubled over the last five years, while the number of car models with a fuel economy of at least 40 mpg has increased sevenfold.[5] Looking forward, car manufacturers are making improvements to increase engine efficiency, reduce vehicle weight, and other measures to drive even more increases in vehicle efficiency.

- Hybrid vehicles accounted for over 6 percent of total passenger car sales in 2013.[6]

- Sales of electric and plug-in hybrid electric vehicles are on the rise. At the end of 2013, these vehicles accounted for about 1.2 percent of total passenger car sales—almost double the number sold in 2012.[7] Although they only account for a modest percentage of total vehicle sales, the uptake of plug-in vehicles has been far faster than the initial uptake of hybrid vehicles in the United States.

- Battery prices have fallen by more than 40 percent since 2010.[8] This trend is likely to continue; Tesla Motors plans to build facilities by 2017 that produce batteries 30 percent cheaper than today's batteries.[9]

- Several large automakers continue to pursue hydrogen fuel-cells systems for light-duty vehicles, with early commercialization expected in the 2015–17 timeframe.[10] The U.S. Department of Energy (DOE) reports that fuel-cell prices for technologies under development have dropped from $275 per kilowatt in 2002[11] to $55–$67 per kilowatt in 2013,[12] a reduction of 76–80 percent. This is notable because fuel cell systems could reach price parity with internal combustion engines at

$30 per kilowatt.[13] The National Academy of Sciences projects that the cost of a fuel-cell passenger car could reach price parity with an advanced gasoline car as early as 2030.[14]

- In October 2013, eight states announced an initiative to support implementation of their zero-emissions vehicle mandates. This initiative calls for the states to coordinate actions to develop the necessary infrastructure and incentives needed to meet their mandates to have 15 percent of new cars sold within their borders be zero-emission vehicles by 2025. The multistate effort includes California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont, which represent 23 percent of the U.S car market.[15] This effort is expected to put at least 3.3 million of these vehicles on the road by 2025.[16]

OPPORTUNITIES FOR SCALE

New vehicle standards will roughly double the fuel economy of vehicles sold in 2025 while delivering lower costs to consumers, increased energy security, and improved air quality. This rapid change in vehicle performance is not new to the automobile industry. The key difference will be that improvements will be channeled into energy efficiency rather than making vehicles larger, faster, and more powerful. In fact, the number of car models achieving more than 40 miles per gallon has already jumped sevenfold since MY 2008, to 22 models in MY 2013.

Reducing Greenhouse Gases (GHG) while Saving Customers Money

Recent EPA and DOT greenhouse gas and fuel economy standards for light-duty vehicles demonstrate that it is possible to reduce GHG emissions while saving customers money. These standards will result in cars and light trucks that emit roughly one-half as many greenhouse gases as those sold in the United States today, and are expected to save their owners an average $3,400 to $5,000 net over the life of the vehicle (compared with vehicles built in 2016) as a result of lower fuel costs.[a, 17] The entire MY 2017–2025 program is estimated to save car owners $326 billion to $451 billion on a net basis[18] and reduce greenhouse gas emissions by 2 billion metric tons. This translates into net savings of $186 to $291 per metric ton of CO_2 reduced in 2030 and 2050, respectively.[19] In addition, these standards will deliver $3.1 billion to $9.2 billion in benefits to the public over the lifetime of MY 2017–25 vehicles (net present value) because of reduced non-greenhouse gas air pollutants, according to EPA.[20] The combined standards from MY 2012–16 and MY 2017–25 will help reduce America's dependence on oil by more than 2 million barrels per day in 2025,[21] which equates to just over half the daily U.S. oil imports from the Organization of Petroleum Exporting Countries (OPEC) in 2013.[22]

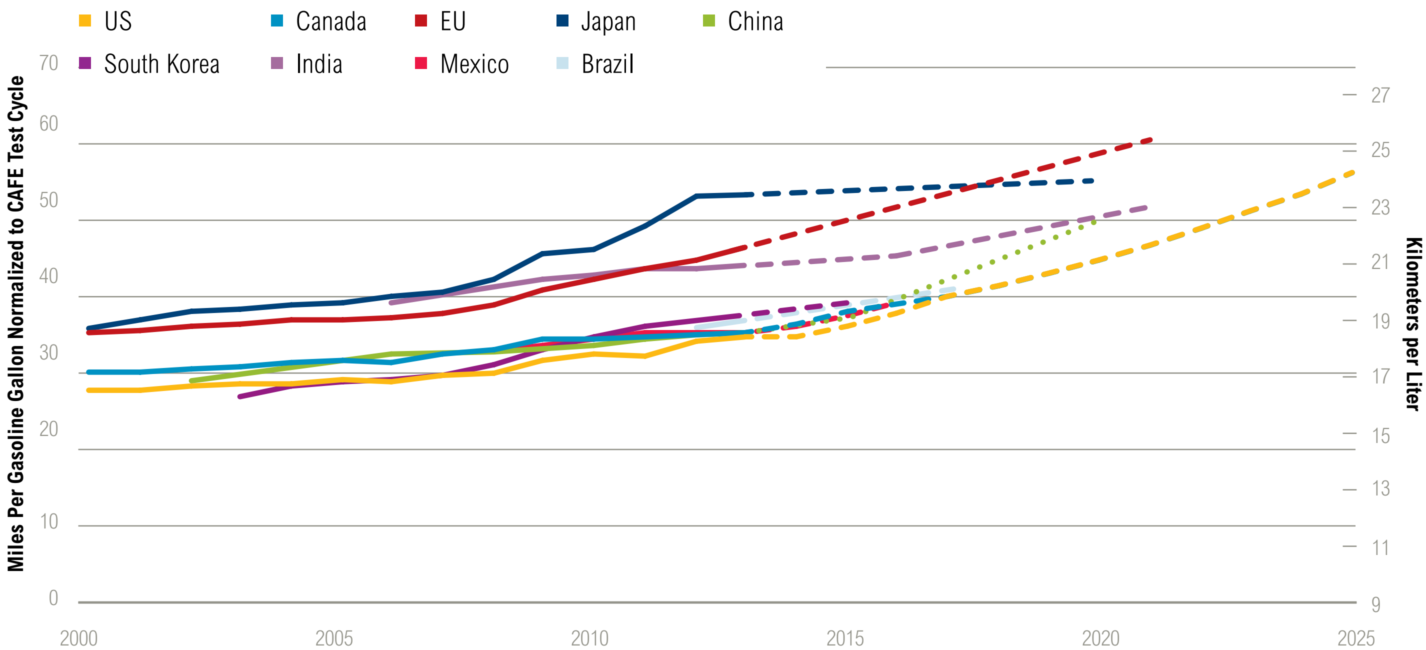
The EPA and DOT standards will leverage technical progress abroad as other countries require improvements in vehicle fuel efficiency (see Figure 3.1). In 2020, the European Union will require vehicles to meet a standard equivalent to 60.6 mpg and Japan will require vehicles to meet a standard equivalent to 55.1 mpg. If China's efficiency targets are finalized as proposed, vehicles will meet a standard equivalent to 50.1 mpg in 2020. Thus, they would require more efficient vehicles in 2020 than required in the United States. However, on average, vehicles in most of these other countries are smaller, lighter, and have lower performance compared with vehicles sold in the United States.

Vehicle Innovation Shifts to Fuel Efficiency

This rapid change in vehicle performance is not new to the automobile industry. Over the past 40 years, vehicle performance has improved considerably.[23] However, since 1985, most improvements to light-duty vehicles have made them larger, faster, and more rapidly accelerating rather than more fuel efficient (Figure 3.2).[24] If technology improvements had been solely applied to improving fuel economy during these years, it is estimated that light-duty vehicle fuel economy could have been 33 to 50 percent higher in the 2000s compared with the 1980s.[25]

a. The standards require a continuous improvement in vehicle performance, so that on average new 2025 model year vehicles emit 163 grams of carbon dioxide equivalent per mile (CO_2e/mile), which is equivalent to 54.5 miles per gallon (mpg) if the improvements are achieved exclusively through fuel economy. This results in an equivalent fuel economy standard of 49.7 mpg because DOT considers only drivetrain improvements and does not consider improvements in air conditioning leakage of hydrofluorocarbons (HFCs—See Chapter 5).

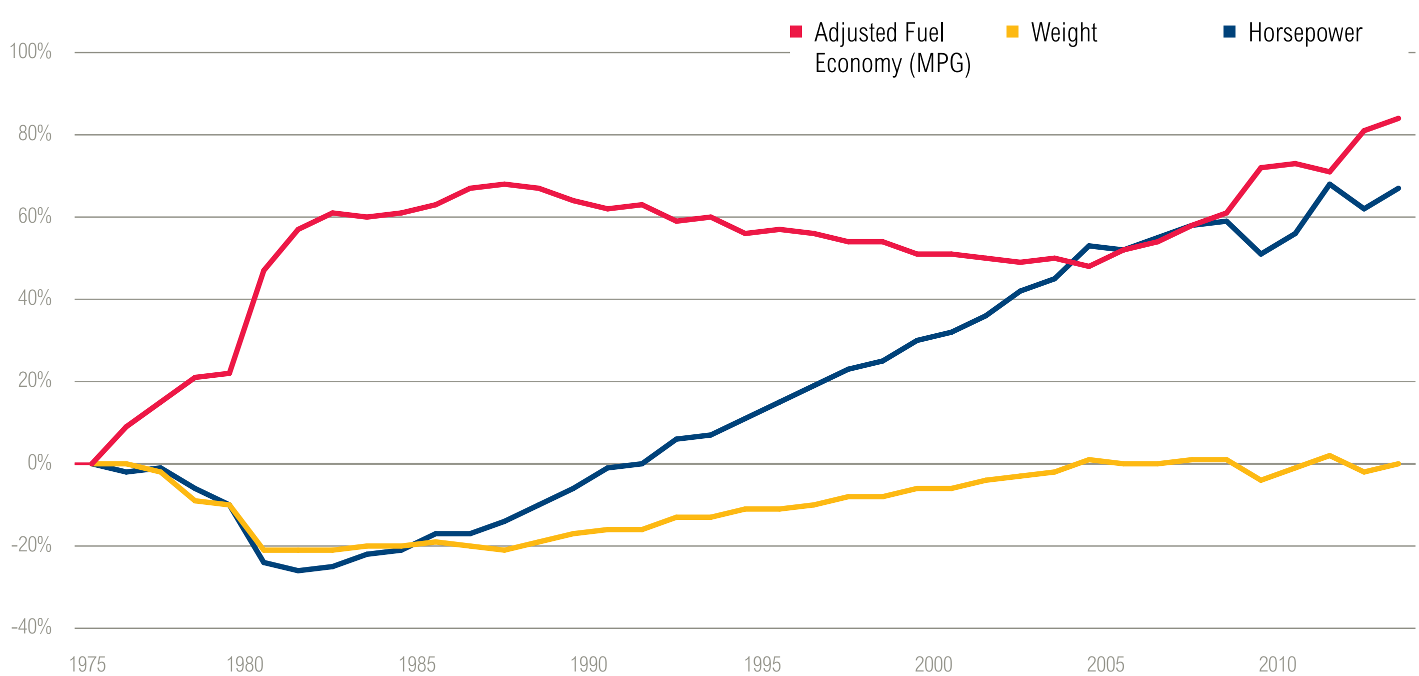
Figure 3.1 | **Fuel Economy Standards Are Rising Around the World, 2000–25**



Notes: (1) Solid lines: historical passenger car performance; (2) Dashed lines: enacted targets; (3) Dotted lines: proposed targets or targets under study; (4) China's target reflects gasoline vehicles only. The target may be higher after new energy vehicles are considered; (5) The U.S. standards are fuel economy standards set by NHTSA, which is slightly different from GHG standards due to A/C credits; (6) Gasoline in Brazil contains 22% of ethanol (E22), all data in the chart have been converted to gasoline (E00) equivalent; (7) Supporting data can be found at: http://www.theicct.org/info-tools/global/passenger-vehicle-standards.

Source: The International Council on Clean Transportation.

Figure 3.2 | **Adjusted Fuel Economy, Weight, and Horsepower for MY 1975-2013**



Source: U.S. Environmental Protection Agency, December 2013, "Light-Duty Automotive Technology, Carbon Dioxide Emissions and Fuel Economy Trends: 1975 through 2013," accessible at: http://www.epa.gov/fueleconomy/fetrends/1975-2013/420r13011.pdf.

Since the new vehicle standards went into effect, improvements have taken place across vehicle types. The number of sport utility vehicles (SUVs) with a fuel economy of at least 25 mpg has doubled, while the number of car models with a fuel economy of at least 40 mpg has increased sevenfold (Figure 3.3).[26] Five percent of the MY 2013 vehicles already meet the MY 2025 standards.[b, 27]

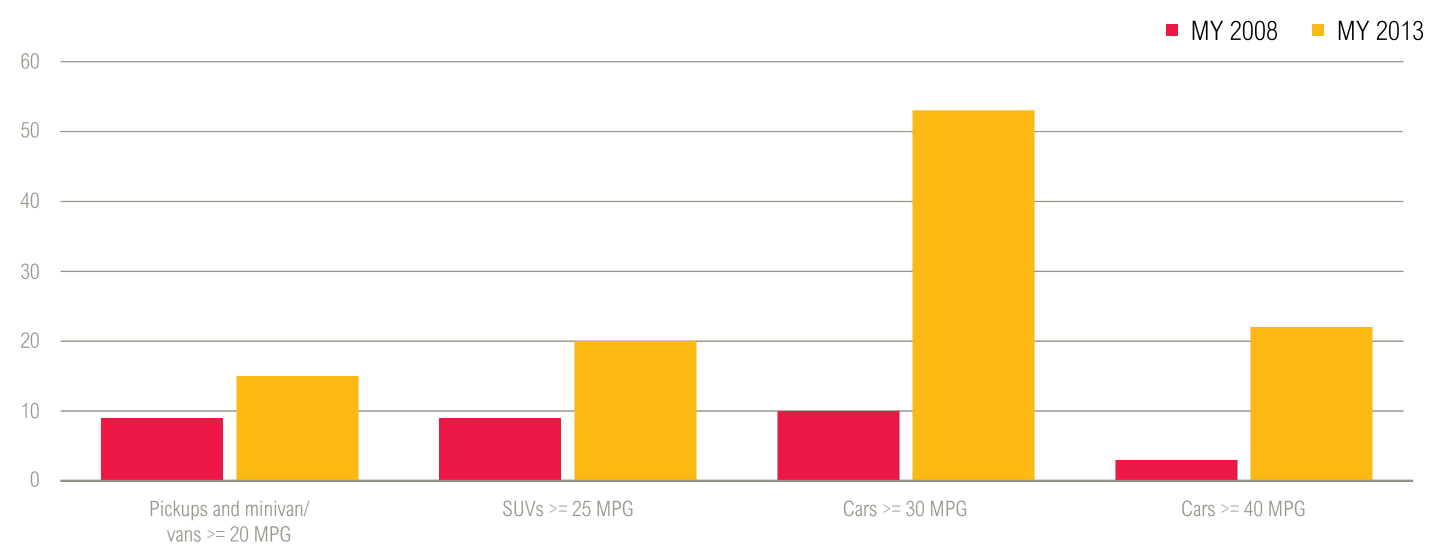
Ways to Improve Fuel Efficiency

Fuel efficiency can be gained in many areas. Only a small fraction (14–30 percent) of the energy used by today's cars actually moves the car forward. The rest of the energy is consumed by engine heat losses (68–72 percent), wind resistance (9–12 percent), braking (5–7 percent), rolling resistance (5–7 percent), drivetrain losses (5–6 percent), and parasitic losses (4–6 percent).[28]

Recent progress in fuel efficiency has been assisted by improvements in engine efficiency and reductions in losses due to braking, resulting from the increasing number of vehicles with variable valve timing, gasoline direct injection, turbochargers, gasoline direct injection, hybrid engines, and six- and seven-speed transmissions, among other technologies.[29] Manufacturers are continuing to innovate. For example, Toyota recently developed a new gasoline engine with 38 percent thermal efficiency, which should deliver at least 10 percent better fuel efficiency than other models.[30]

Additional improvements in fuel efficiency can be achieved through better aerodynamic designs and making cars lighter. A 21–28 percent decline in aerodynamic drag resistance could occur by 2030, resulting in a 4–7 percent reduction in fuel consumption, according to analysis by the National Academy of Sciences.[31] Nearly every car manufacturer is expected to employ mass reduction strategies going forward.[32] Ford recently reduced the mass of the popular four-door F150 truck by 12–13 percent.[33] Because of these improvements, as well as other increases in efficiency, reports suggest that the MY2015 F150 could achieve nearly 30 mpg in highway driving,[34] compared with the current model's 23 mpg.[35] Several recent studies suggest that car and truck weights could be reduced even further—"by up to 15 to 30 percent, with no impact on safety and at low, if not zero, extra cost."[36] Several manufacturers have actually set weight reduction targets in this range by 2015–20.[37] The National Academy of Sciences concluded, "Advanced designs that emphasize dispersing crash forces and optimizing crush stroke and energy management can allow weight reduction while maintaining or even improving safety."[38]

Figure 3.3 | **Number of Models Meeting Fuel Economy Thresholds in MY 2008 and MY 2013**



Note: Calculations are based on city/highway combined label miles-per-gallon estimates for gasoline, diesel, and hybrid vehicles, and miles-per-gallon-equivalent estimates for electric vehicles and plug-in hybrids.

Source: U.S. Environmental Protection Agency, December 2013, "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2013," accessible at http://www.epa.gov/fueleconomy/fetrends/1975-2013/420r13011.pdf.

b. Note, this includes air conditioning credits aimed to phase out the use of high-global-warming-potential HFCs—see Chapter 5.

Box 3.1 | The Role of Reducing Vehicle Miles Travelled in Lowering Light-Duty Vehicle Emissions

Greenhouse gas emissions from passenger cars have fallen 11 percent between 2005 and 2012,[a] largely because of fewer miles travelled by drivers. Following steady average growth of 1.8 percent per year from the 1970s to mid-2000s, the per capita vehicle miles travelled decreased nearly 8 percent between 2004 and 2012.[b] Growth in total vehicle miles traveled (VMT), which had been rising at 3 percent per year on average since 1970, fell to 0.7 percent per year from 2005 to 2012.[c, d] And for the first time since the 1970s, light-duty vehicle travel has not been closely aligned with the growth of economic indicators including income and employment.[e]

Although the economic recession is one reason people have driven less in recent years, it is not the sole determinant as the decline began prior to the recession and has continued since. Other factors include changing demographics, rising fuel prices, and changing consumer preferences. In addition, the factors that contributed to a rising number of vehicle miles travelled in the late 20th Century—such as more women entering the workforce, the spread of low-density suburban areas and highways, increases in household income, and improvements in vehicle technology—are beginning to approach saturation according to the State Smart Transportation Initiative, U.S. Public Interest Research Group, and the Frontier Group.[f, g]

Since 1990, driving licensing rates generally have been declining among younger age brackets, falling 5 percent over the past decade for the population under 35 years old.[h] Driver's license rates among young people peaked in 1979, then declined 5 percent among 20- to 24-year-olds and 20 percent among those 19 and younger. This decline was partly caused by increased restrictions on licenses and driving for young adults, as well as preferences for urban, low-travel lifestyles among individuals ages 16 to 30.[i] Adults aged 65 and over are also driving less; they increased their use of public transit by 40 percent between 2001 and 2009.[j]

It is uncertain whether these trends will continue or whether driving will increase as the country continues to recover from the recession, as population grows, or as new technology develops that lowers the costs of driving (e.g., more efficient or electric vehicles). The U.S. Energy Information Administration's *Annual Energy Outlook 2014* assumes growth in total vehicle miles travelled will rebound slightly to 0.9 percent per year from 2012 to 2040, but will remain below the 2007 peak through 2040.[k] Other research indicates growth could slow further, potentially even flattening through 2030, as demographics and preferences continue to shift.[l]

Fully addressing transportation emissions will require smart policies that provide alternative transportation options and incentives to pursue them. A handful of states—including Maryland, California, New York, Washington, and Massachusetts—are implementing smart growth and travel demand strategies to do just that, including compact development, infill, improved and expanded public transportation, and others.[m] A detailed analysis of such policies, however, is beyond the scope of this analysis.

Notes:

a. U.S. Environmental Protection Agency (EPA), 2014, "Table 2-15: Transportation-Related Greenhouse Gas Emissions (Tg CO_2 Eq.)," *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012*, April, EPA, Washington, DC, accessible at http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Chapter-2-Trends.pdf.

b. B. Davis and P. Baxandall, 2013, "Transportation in Transition: A Look at Changing Travel Patterns in America's Biggest Cities," December, U.S. PIRG Education Fund and Frontier Group, accessible at http://www.uspirg.org/sites/pirg/files/reports/US_Transp_trans_scrn.pdf.

c. Ibid.

d. U.S. Energy Information Administration (EIA), 2014, "Annual Energy Outlook 2014 – with Projections to 2040," May 7, EIA Office of Integrated and International Energy Analysis, Washington, DC, accessible at http://www.eia.gov/forecasts/aeo/.

e. Ibid.

f. Davis, B. and P. Baxandall, 2013, "Transportation in Transition: A Look at Changing Travel Patterns in America's Biggest Cities," December, U.S. PIRG Education Fund and Frontier Group, accessible at http://www.uspirg.org/sites/pirg/files/reports/US_Transp_trans_scrn.pdf.

g. C. McCahill and C. Spahr, 2013, "VMT Inflection Point: Factors Affecting 21st Century Travel," September, State Smart Transportation Initiative (SSTI), accessible at http://www.ssti.us/wp/wp-content/uploads/2013/10/VMT_white_paper-final.pdf.

h. U.S. Energy Information Administration (EIA), 2014, "Annual Energy Outlook 2014 – with Projections to 2040," May 7, EIA Office of Integrated and International Energy Analysis. Washington, DC, accessible at http://www.eia.gov/forecasts/aeo/.

i. Fehr & Peers, Transportation Consultants, 2014, "Demographic Trends & the Future of Mobility," Insight from Fehr & Peers Think, accessible at http://www.fehrandpeers.com/fpthink/demographictrends/.

j. U.S. Energy Information Administration (EIA), 2014, "Annual Energy Outlook 2014 – with Projections to 2040," May 7, EIA Office of Integrated and International Energy Analysis. Washington, DC, accessible at http://www.eia.gov/forecasts/aeo/.

k. Ibid.

l. Ibid.

m. For example: Cambridge Systematics, Inc, and Michael Baker Jr., Inc., 2011, "Maryland Climate Action Plan - MDOT Draft 2012 Implementation Plan," April 11, accessible at http://climatechange.maryland.gov/site/assets/files/1392/appendix_d-1-_mdot_draft_2012_implementation_plan_draft_final.pdf>; California Environmental Protection Agency, Air Resources Board (ARB), "Sustainable Communities," SB 375 Implementation, last reviewed June 30, 2014, accessible at http://www.arb.ca.gov/cc/sb375/sb375.htm.

EMERGING OPPORTUNITIES

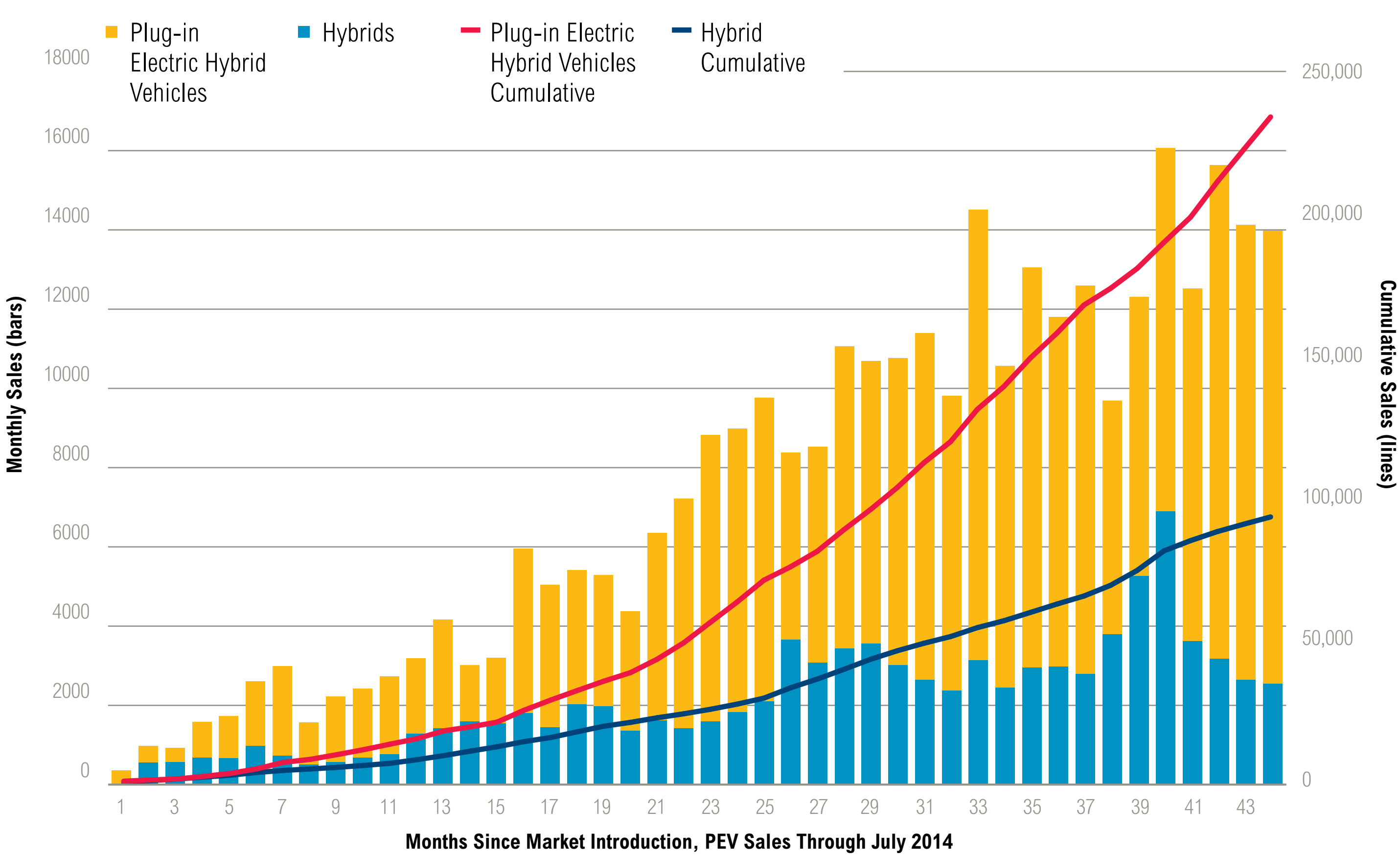
Steady advances in electric vehicle battery technology and the anticipated roll-out of hydrogen fuel-cell vehicles in the 2015–17 timeframe hints that the automobile industry may be on the brink of an even greater transition.

Plug-in Vehicles (Electric Vehicles and Plug-In Hybrids)

Sales of electric vehicles and plug-in hybrids are on the rise. This is due in large part to a combination of federal incentives, state mandates, and rapidly declining battery prices. If electric vehicle battery prices continue their rapid decline, electric vehicles may become cheaper than conventional gasoline or diesel vehicles when considering fuel savings over the life of the vehicle. In addition, optimizing vehicle charging to match times when electricity is cheapest could further reduce the cost of these vehicles while facilitating expansion of renewables on the electric grid.

Plug-in hybrids allow consumers to stretch a gallon of gasoline further than conventional combustion engines or standard hybrids by charging the battery directly from the electric grid. Whereas hybrids still have a conventional engine, electric vehicles are powered solely by electricity and do not have an internal combustion engine. Electric vehicles and plug-in hybrids both averaged just over 4,000 vehicle sales a month in 2013. Combined, they accounted for 1.2 percent of total car sales in 2013, which was almost double their sales percentage in 2012 (0.7 percent).[39] Together with hybrid vehicles, these vehicles accounted for 7 percent of total car sales in 2013. While modest compared with the size of the U.S. fleet, the uptake of electric vehicles has been faster than the initial uptake of hybrid vehicles in the United States (See Figure 3.4).

Figure 3.4 | **The Uptake of Electric Vehicles Has Been Faster than the Uptake of Hybrid Vehicles**



Notes: Insight was first released in the U.S. market in December 1999. Prius HEV was first released in the U.S. market in January 2000. Volt and Leaf were first released in the U.S. market in December 2010.

Source: Argonne National Laboratory Transportation Technology R&D Center, 2014, "Light Duty Electric Drive Vehicles Monthly Sales Update," Technology Analysis, U.S. Department of Energy (DOE), accessible at http://www.transportation.anl.gov/technology_analysis/edrive_vehicle_monthly_sales.html.

The rapid deployment of electric vehicles has been aided by state and federal tax incentives, zero-emission vehicle mandates, and high-occupancy vehicle (HOV) lane access incentives. The federal government offers up to a $7,500 tax credit for electric vehicles and plug-in hybrids purchased in or after 2010, based on the capacity of the battery used to fuel the vehicle.[40] These credits will be phased out for each manufacturer's line of plug-in vehicles once 200,000 are produced.[41] A multi-state zero-emission vehicle mandate and memorandum of understanding between California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont (accounting for 23 percent of the U.S car market) is projected to put at least 3.3 million zero-emission vehicles on the road by 2025.[42] To ensure this target is met, the states will coordinate on key actions, such as educating consumers, providing driver incentives, increasing the number of zero-emission vehicles in state, municipal, and other public fleets, and promoting workplace charging, among other actions.[43] In addition, some states are granting electric vehicles and plug-in hybrids access to HOV lanes to help encourage uptake.

Battery Prices are Falling

The increase in electric vehicle production has been supported by, and has helped lead to, a rapid decline in the cost of vehicle batteries.[44, 45] While the price car producers pay for battery packs is proprietary, it has been reported that battery costs for electric vehicles have fallen by more than 40 percent since 2010,[46] and the decline seems likely to continue. Several sources have estimated that current battery pack costs are in the $400 to $500 per kilowatt hour range.[c, 47, 48] However, the cost of Tesla's cylindrical battery packs is reportedly much lower, around $270 per kilowatt hour.[49, 50] Tesla recently announced plans to build facilities by 2017 that will produce large electric vehicle batteries that are 30 percent cheaper than today's batteries (around $190 per kilowatt hour, assuming the current reported prices).[51] This would be a significant milestone as batteries for long-distance electric vehicles (280 mile range) are expected to become cost competitive with internal combustion engines at $125 per kilowatt hour, according to the U.S. Department of Energy (DOE).[d, 52, 53]

Plug-in hybrid batteries are more expensive than electric vehicle batteries because of their smaller size and higher power demand, but they have seen similar trends in recent years. Although the price that car manufacturers pay for these batteries is not well known, DOE estimates that the costs of plug-in hybrid electric vehicle batteries have fallen 50 percent over the last four years, with batteries expected to cost around $325 per kilowatt hour in the next two to four years if manufactured at a high scale.[54] DOE's target is to drive costs down to $300 per kilowatt hour by 2015, which would become cost competitive with internal combustion engines without federal vehicle subsidies.[e, 55, 56]

As a result of federal subsidies and falling battery prices, some models, such as the Mitsubishi iMiEV and the Nissan Leaf SE, have an upfront price lower than comparable conventional vehicles (see Figure 3.5).[57] Even more vehicles are cost competitive when considering the total cost of ownership because they offer considerable fuel and maintenance savings. The lower upfront and lifetime cost savings, however, depend on federal incentives of $7,500 per vehicle.

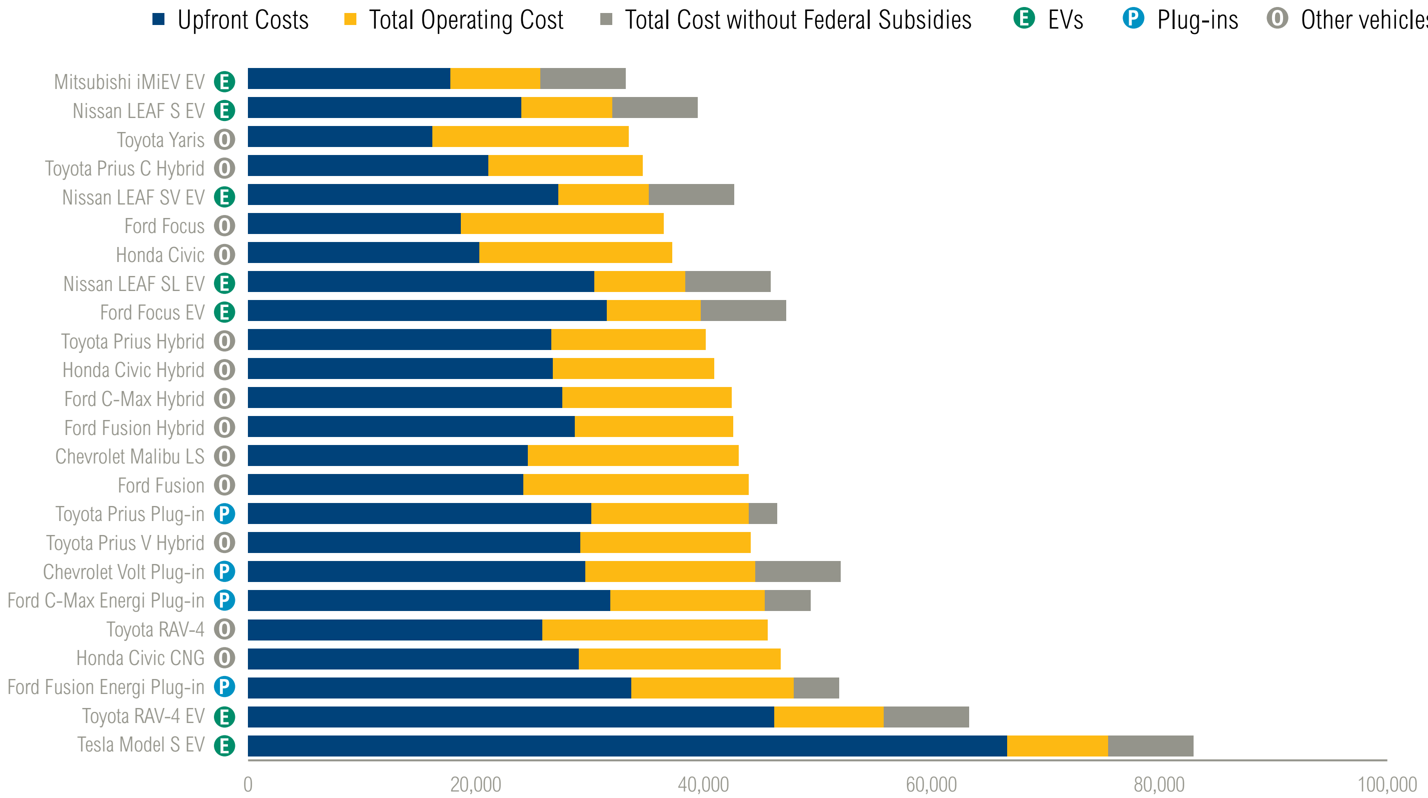
Because battery prices make up a large portion of total upfront costs for electric vehicles and plug-in hybrids, these costs could fall dramatically as battery prices decrease. The operating costs of a conventional car are about one-half of its upfront costs, while the operating (powering) costs for electric vehicles are roughly one-third of their upfront costs. If battery prices come down another 30 to 50 percent, the total upfront costs of the Volt could decrease by $2,400 to $4,000; the LEAF by $3,600 to $6,000, and the Tesla Model S by $10,500 to $17,500.[58] Tesla projects it will release a third-generation model in three to four years that will be 20 percent smaller than the Model S and cost half the price at $35,000 after federal subsidies, if Tesla's new manufacturing plant

c. Battery pack costs vary depending on the scale at which they are produced as well as the type of vehicle for which they are designed (e.g., smaller batteries produced for hybrid or plug-in hybrid vehicles have a higher cost in dollars per kilowatt hour than larger batteries produced for long-distance electric vehicles). For example, batteries for hybrid vehicles (high power-to-energy ratio) are required to store a small amount of energy since it is constantly recharging, while batteries for electric vehicles (low power-to-energy ratio) need more energy capacity to drive longer ranges (See M. Lowe et al., 2010).

d. According to DOE, "In developing the battery cost target for the EV Everywhere Grand Challenge, DOE assumed a gasoline price of $3.49 per gallon (based on the U.S. Energy Information Administration's Annual Energy Outlook 2013 Reference Case projection for 2020). Taken together with other concomitant advancements (cost reductions in electric motors and power electronics, vehicle weight reduction of 30 percent, and reduction in EV auxiliary loads), a battery cost of $125 per kilowatt hour would provide an electric vehicle with a 280-mile range the same levelized total cost of ownership over a five-year period as an internal combustion engine vehicle of similar size," (See J. Miller, August 2014).

e. This is higher than the electric vehicle battery price target partly because the plug-in battery is smaller, according to Argonne National Laboratory. Battery cells for electric vehicles are also able to use thicker electrodes, which offer additional cost savings compared with a plug-in battery (See Gallagher and Nelson, 2014).

Figure 3.5 | **Total Cost of Ownership of Select Vehicles in the United States**



Notes: Upfront costs calculated using manufacturer's suggested retail price and delivery charges[a] as well as taxes and registration from Edmunds,[b] adjusted for applicable federal credits.[c] Upfront costs do not include costs for home-charging equipment beyond what is provided at purchase. Fuel costs based on manufacturers' reported fuel economy,[d] DOE's Alternative Fuels Data Center's (AFDC) annual driving distance and fuel escalation cost assumptions, and DOE's current fuel price estimates.[e] Maintenance costs are based on estimates from AFDC.[f] Note, according to DOE, annual maintenance costs are typically less for electric vehicles than conventional cars because the battery, motor, and associated electronics require little to no regular maintenance, there are fewer fluids to change, regenerative braking significantly reduces brake wear, and there are fewer moving parts.[g] Annual operating costs were discounted 5 percent and a 12-year lifetime was assumed for all cars.[h] Note, these estimates do not include the potential need to replace the battery pack, although it is unclear how soon battery packs being used today will degrade.

Sources:

a. Obtained from each vehicle's official website. Unless otherwise noted (e.g., the Nissan Leaf), the base model was assumed for each vehicle model.
b. For vehicle makes and models not available from the Edmund's total cost of ownership tool, taxes and registration fees were assumed to be 6 percent of the vehicle's manufacturer's stated retail price.
c. U.S. Department of Energy, "Federal Tax Credits for Plug-in Hybrids."
d. Obtained from each vehicle's official website.
e. U.S. Department of Energy (DOE) Alternative Fuels Data Center, "Vehicle Cost Calculator Assumptions and Methodology," last updated February 19, 2013, DOE Office of Energy Efficiency & Renewable Energy, accessible at http://www.afdc.energy.gov/calc/cost_calculator_methodology.html; U.S. Department of Energy (DOE), 2014, Alternative Fuels Data Center, "Fuel Prices," last updated June 4, 2014, DOE Office of Energy Efficiency & Renewable Energy, accessible at http://www.afdc.energy.gov/fuels/prices.html.
f. U.S. Department of Energy, Alternative Fuels Data Center, "Vehicle Cost Calculator Assumptions and Methodology."
g. U.S. Department of Energy (DOE), Alternative Fuels Data Center, "Maintenance and Safety of Hybrid and Plug-In Electric Vehicles," last updated September 24, 2013, DOE Office of Energy Efficiency & Renewable Energy, accessible at http://www.afdc.energy.gov/vehicles/electric_maintenance.html.
h. In a similar analysis, Bloomberg New Energy Finance assumed a 5 percent discount rate and a 12-year lifespan for all vehicles analyzed. See Bloomberg New Energy Finance, 2014, "Sustainable Energy in America 2014 Factbook."

delivers the projected battery cost savings.[59] Until these price decreases happen, federal subsidies can reduce the upfront costs and total cost of ownership of electric vehicles, which in turn, could help drive more electric vehicle purchases and promote technology development as manufacturers benefit through learning-by-doing.

Further reductions in electric vehicle operating costs could occur if electricity markets become structured to incentivize charging during times when marginal generation costs are lowest. Electric vehicles are a large potential source of flexibility for grid operators. Timing electric vehicle charging to align with periods of high generation from renewable resources could provide low-cost grid stabilization and reduce charging costs for owners of electric vehicles.[60] A recent study found that optimally varying electric vehicle charging time would not only give utilities additional support for wind integration, but also cut the cost of integrating plug-in hybrids charging into the electric system by half.[61] The study also found that electric vehicle owners could see additional savings up to $70 each year above the fuel savings already achieved when comparing electricity over gas.[62] To maximize this benefit, vehicle charging standards would need to incorporate communication standards that enable controlled charging.[63]

Electric Vehicle Profitability

A few recent reports question the profitability of electric vehicles, and speculate whether some manufacturers are limiting their sales to the mandated state minimums.[64] However, Tesla started reporting profits in 2013[65] and Chevrolet expects the next generation of the Volt plug-in to be profitable, unlike the current version.[66] As vehicle demand increases (via state zero-emission vehicle mandates or federal greenhouse gas and fuel economy standards), increased production scale, as well as continued technological learning and declining battery costs will help increase these vehicles' profitability.[67]

Hydrogen Vehicles

Hydrogen fuel-cell vehicles are also beginning to show potential. Automakers have developed and leased demonstration hydrogen fuel-cell automobiles to real-world customers for the last five years and have stated their intention to introduce these vehicles in commercial volumes of 1,000s or more in the 2014 to 2017 timeframe.[68] More specifically:

- Honda and Hyundai already lease a limited number of fuel-cell vehicles with ranges of 240 and 270 miles, respectively.[f]
- Toyota has announced that they will release a fuel-cell vehicle in 2015 with an expected range of 300 miles.[69]
- Mercedes expects to release their B-Class F-Cell in 2017 with an expected range of 190 miles.[70]

Hydrogen fuel-cell systems can achieve greater energy density than lithium ion batteries, allowing them to achieve greater ranges than electric vehicles and making them a better fit for certain types of light-duty vehicles, as well as medium- and heavy-duty vehicles (like tractor trailers) that require more power. In addition, their use of a gaseous fuel allows for a short fueling time like conventional gasoline and diesel vehicles. While prices for these vehicles have yet to be released, the cost for fuel cells continues to decline. DOE estimates that fuel-cell prices dropped from $275 per kilowatt in 2002[71] to $55–$67 per kilowatt in 2013,[g, 72] a reduction of 76–80 percent.[73] DOE expects prices to hit $40 per kilowatt by 2020 with an ultimate goal of $30 per kilowatt,[74] at which point DOE expects fuel cells to reach price parity with internal combustion engines.[75] A recent report by the National Academy of Sciences projects that the cost of a fuel-cell passenger car could reach price parity with an advanced gasoline car as early as 2030.[76]

REMAINING CHALLENGES

Here we explore challenges with deploying electric vehicles, hydrogen powered vehicles, natural gas powered vehicles, as well as the implications of autonomous vehicles and changes in consumer behavior associated with the advancement of more efficient vehicles (also known as rebound effects). We find that in each case the newness of the technology coupled with their reliance on network effects[h] create some barriers to further uptake. However, a number of programs and entrepreneurs are working to address these challenges.

Electric Vehicles

Without federal subsidies, the upfront and lifetime costs of most electric vehicles are more expensive than traditional internal combustion engine powered vehicles. This could change if battery prices continue to fall and more electric vehicles hit the market. In the meantime, other issues related to range, infrastructure, and longer charging times compared with petroleum-fueled vehicles remain.

f. Honda has been leasing a small number of their FCX Clarity vehicles (with an expected range of about 240 miles and a 59 mpg fuel economy) in southern California since 2008. A redesigned version of this vehicle is expected to be introduced in 2015 that will offer more power and a longer driving range (about 300 miles) for a lower price. Hyundai is also leasing a Tuscon fuel-cell sport utility vehicle for $499 per month, which has a range of up to 270 miles and a 49 mpg fuel economy. This price includes all fuel and maintenance costs, with valet car pickup and delivery whenever service is needed.

g. The range of prices in 2013 is a result of manufacturing volume with the lower cost estimate based on a higher production volume assumption (See U.S. Department of Energy, June 2014).

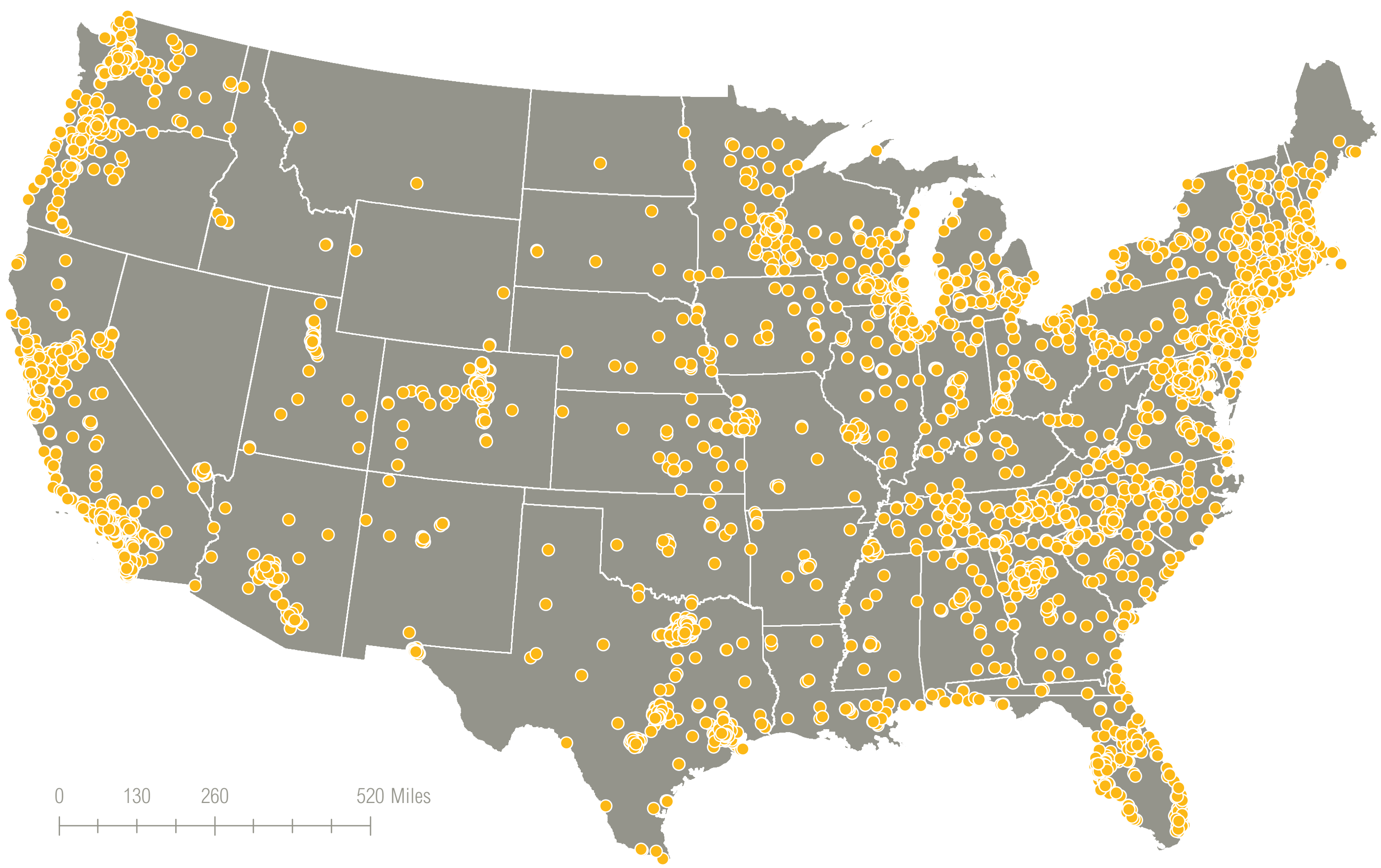
h. Network effects occur when the value of a product or activity to a consumer depends on the number of others who also undertake that product or activity. For example, widespread penetration of electric cars depends on the development of a robust network of charging stations. However, it is less profitable to build new charging stations when there are only a few drivers of electric vehicles.

Electric vehicles currently on the market have a range of 84 to 265 miles.[77] The Volt can drive 38 miles on electricity only, but can go 380 miles with a full charge and full tank of gas.[78] However, factors like driving style, cargo load, and weather conditions can affect the potential driving range. Cold weather limits battery performance and drains the battery, especially if the heater is also used.[79] For example, Tesla reported that driving in 0°F to 32°F degree weather could reduce vehicle range by 8–18 percent when driving without using the heating system, and 18–30 percent when using the heating system. Other reports noted even larger decreases (30–50 percent) in freezing weather across a variety of electric vehicle models.[80] However, some owners reported that their electric vehicles were able to start in cold weather when their gasoline-powered cars would not.[81]

With typically lower driving ranges than conventional vehicles, providing the necessary charging infrastructure to prevent "range anxiety" is important. While charging stations for electric vehicles have been popping up across the country—there were over 8,500 public electric charging stations as of July 2014[82]—charging stations are still only a fraction of the roughly 160,000 conventional refueling stations in the United States (see Figure 3.6).[83] This challenge may be less of an issue, however, in urban areas where drivers have short commutes or rely on car-sharing programs.

In the long run, electric vehicles may be more appealing to urban and suburban drivers with small-to-midsize vehicles who primarily travel short distances, such as their daily commute.[84] This is especially true if other next-

Figure 3.6 | **Electric Vehicle Charging Stations, mid-2014**



Note: Includes all public electric vehicle charging stations open as of mid-2014.

Source: U.S. Department of Energy (DOE), 2014, Alternative Fuels Data Center: Alternate Fueling Station Locator, DOE Office of Energy Efficiency & Renewable Energy, accessible at http://www.afdc.energy.gov/locator/stations/results?utf8= percentE2 percent9C percent93&location=&filtered=true&fuel=ELEC&owner=all&payment=all&ev_level1=true&ev_level2=true&ev_dc_fast=true&radius_miles=5.

generation vehicle technologies, like hydrogen fuel-cell vehicles with a typical range and refueling time similar to conventional vehicles, are able to enter the market at high volumes.

Although electric vehicles that use electricity from a low-carbon grid typically have lower lifecycle greenhouse gas emissions than similar conventional vehicles, this advantage is not as strong in areas where coal is used heavily to generate electricity.[85] However, EPA is starting to incentivize the production of clean electricity for use by electric vehicles under its recently updated renewable fuel standard (RFS).[86] Specifically, electricity used to power electric vehicles produced from a wide range of bio-based sources, such as biogas from landfills, municipal wastewater treatment facility digesters, and agricultural digesters, now qualify to be used for compliance under the updated RFS. According to the Vermont Energy Investment Corporation, this new rule could create new revenue streams for utilities and farmers (that generate biogas from methane digesters) and encourage utilities to support electric vehicles.[87] EPA is also working toward decarbonizing the electric grid over time; their recently proposed Clean Power Plan would reduce the carbon intensity of the U.S. power system by roughly 15 percent in 2020 compared with business-as-usual projections for the same year.[88]

Hydrogen Vehicles

Like electric vehicles, hydrogen vehicles face challenges from lack of infrastructure and the carbon intensity of fuel production.

Compared with charging stations for electric vehicles, the network for hydrogen filling stations is far less developed—only 12 public hydrogen filling stations exist in the United States, 10 in California and 1 each in South Carolina and Connecticut.[89] California is clustering stations where the first fuel-cell vehicle drivers are likely to live to give both manufacturers and consumers greater confidence that stations will be available. If all stations are developed as planned, California will have about 51 public hydrogen stations in 2015.[90] Other states are making progress; for example, the Texas Emission Reduction Program recently awarded partial funding to build the state's first public hydrogen fueling station.[91] However, for fuel-cell vehicles to become widespread, major developments in hydrogen fueling infrastructure need to occur nationwide. Federal, state, or city mandates, in combination with funding that continues to support stations during the initial ramp up of hydrogen vehicle penetration, could help spur this development.

Most hydrogen fuel produced in the United States (95 percent) is made by a process called natural gas reforming in large central plants. The process emits greenhouse gases;[92] however, over its lifecycle, the hydrogen fuel produced has climate benefits over petroleum-based fuels.[93] Researchers are also developing cleaner methods to produce hydrogen, such as using excess renewable energy for electrolysis, which could not only create fuel for vehicles but also store energy from the grid, a combination that could help the economics of renewable energy.[94] California requires all proposed stations to supply hydrogen produced with at least 33 percent renewable energy and provides incentives for fueling stations that supply hydrogen produced with 100 percent renewable energy.[95] The initial price for hydrogen fuel at the pump will likely be high; current estimates fall around $10 per gallon of gasoline equivalent (untaxed).[96] Even at these prices, a fuel-cell vehicle's fuel operating cost will only be about 20 percent higher than a comparable current gasoline vehicle because the fuel-cell vehicle is expected to travel more than twice as far per gallon of gasoline equivalent because of its superior efficiency (for example, the Honda Clarity gets 60 mpg of gasoline equivalent compared with a current typical midsize car's fuel economy of 28 mpg).[97] As hydrogen production for transportation grows in scale and maturity, the cost to dispense hydrogen at a station is expected to decrease. A recent analysis by University of California Davis' Institute for Transportation Studies concluded that hydrogen fuel-cell vehicles could have fuel operating costs less than or equal to hybrid gasoline electric vehicles over the long term.[98]

Natural Gas Vehicles

While natural gas vehicles currently cost more than gasoline and diesel powered vehicles, the current low price of natural gas provides an enticing incentive for the development and deployment of natural gas vehicles. However, a few key challenges for natural gas cars and light trucks remain, including a limited fueling infrastructure and the size of in-vehicle natural gas storage tanks. In addition, the current methane leakage rate for natural gas systems could cause these vehicles to actually increase overall greenhouse gas emissions. Even if the rate is reduced considerably (see Chapter 4), the benefits of switching from gasoline to natural gas will remain much more limited than the benefits of switching electric generation from coal to gas.

Until recently, the only dedicated compressed natural gas (CNG) light-duty vehicle in the United States was the Honda Civic Natural Gas vehicle,[99] but several manufacturers are now offering additional dedicated or bi-fuel trucks and vans that can run on either gasoline or CNG.[100] The sale price for these vehicles is higher than comparable gasoline models; for example, the Civic CNG costs $26,640 whereas a gasoline Civic Sedan costs $19,190.[101] However, CNG vehicles can offer savings at the pump, as long as natural gas prices stay low. As of April 2014, CNG is more than a dollar cheaper than an equivalent gallon of gasoline.[102]

The large size of the compressed gas storage tank presents some challenges for CNG vehicles. These tanks can compromise the interior vehicle space and utility.[103] Higher pressure tanks can reduce the amount of space required, but come with higher costs and energy requirements to compress the gas.

As with other alternative vehicles, the refueling infrastructure for natural gas vehicles is not well developed; as of mid-2014 there were only 732 CNG fueling stations across the country.[104] The methane leakage from the refueling infrastructure is not well known, but ongoing studies are examining this issue.[105]

Natural gas vehicles could help reduce petroleum consumption, but their greenhouse gas emissions, including upstream methane emissions, cast doubt on their long-term climate benefit. Many studies have found that methane leakage associated with the production and transport of natural gas can undermine the greenhouse gas benefits of its use as a transportation fuel.[106] For natural gas vehicles to present relative climate advantages over gasoline-fueled vehicles, the leakage rate would need to be kept below roughly 1.6 percent.[107] Most recent studies, however, have found that current natural gas systems have a higher leakage rate (for more discussion on this topic, see Chapter 4). Notably, the 1.6 percent leakage rate is merely the breakeven point between natural gas and gasoline. Meanwhile, natural-gas-powered electric generation emits about one-half as many greenhouse gases as a coal-fired plant. This suggests that the better climate investment is using natural gas to fuel power plants as opposed to vehicles.

Autonomous Vehicles

Some analysts have suggested that autonomous (or self-driving) cars have the potential to revolutionize the transportation system, but doubts still remain on the net fuel savings benefit these vehicles could achieve.[108] While such vehicles may sound impossibly futuristic, some of these technologies, such as lane-keeping and warning systems, adaptive cruise control, parking assistance, are available now.[109] Google has already started testing autonomous vehicles on public roads.[110] Because these vehicles can be programed to optimize traffic flows, some believe autonomous vehicles could lead to safer and more efficient driving.[111, 112] However, great uncertainty remains about the net benefit of autonomous vehicles; the National Academy of Sciences noted that while potential for efficiency and safety benefits exists, new mobility opportunities available through autonomous driving could dramatically increase overall vehicle miles travelled.[113] The National Renewable Energy Laboratory found that, depending on market penetration and other factors, autonomous vehicles could reduce fuel consumption by 90 percent or increase it by more than 250 percent.[114] Legal, liability, privacy, insurance, and cost concerns also remain.[115] For example, new regulations would be needed for auto insurance as well as new federal and state guidelines for use of autonomous vehicles on public roads (beyond testing purposes).[116]

Changes in Driving Preferences Caused by More Efficient Vehicles

Reducing per-mile transportation costs by increasing vehicle efficiency or by moving to cheaper fuels, such as electricity, could lead to an increase in vehicle miles travelled (and thus fuel consumption). However, studies have demonstrated this rebound effect is generally small for personal transportation, in the range of 10 percent.[117] The rebound effect could be more noticeable as more drivers trade in conventional vehicles for electric vehicles, which have per-mile fuel costs that are about 70 percent lower.[118] In theory, this could lead to a 7 percent increase in vehicle miles travelled. Even if that occurs, however, electric vehicles will still have greenhouse gas benefits over conventional cars (based on the national average emissions intensity of the electricity grid in 2013).[119] Since most electric vehicles today have limited ranges, the rebound effect may be more limited or nonexistent. Looking ahead, improved battery technology allowing for longer ranges, changes in the greenhouse gas intensity of the electric grid, and changes in fuel costs could all affect driving patterns of electric vehicle owners.

BRINGING THESE OPPORTUNITIES TO SCALE

Current standards (finalized in 2012) will roughly double the fuel economy of new cars by 2025 while saving customers money. However, if technological progress continues, it should be easier and more cost effective to meet the 2025 standards, and might even be possible to achieve deeper reductions after 2025. It is also possible that particularly rapid advancements could even allow DOT and EPA to make the standards more ambitious during the mid-term CAFE review for MY 2022–25.[i, 120]

Continued fuel economy improvements will also help enhance U.S. energy security and help improve air quality. Reducing light-duty vehicle CO_2 emissions by 80 percent below 2005 levels by 2050 could lead to $670 billion to $2.3 trillion in net savings because of reduced fuel costs (net present value), according to the National Academy of Sciences.[j, 121] Realizing these goals depends heavily on the rate of technological progress. The Academy of Sciences concludes that this will require "strong and effective policies emphasizing research and development, subsidies, energy taxes, or regulations will be necessary to overcome cost and consumer choice factors." In addition, it will require policies and programs to help lay the infrastructure to support these new technologies, making it easier for early movers. Four of the key policies are profiled below.

Increase the number of alternative fuel stations, such as electricity and hydrogen.

As previously mentioned, electric vehicle and hydrogen charging stations still represent only a fraction of the number of fueling stations in the United States. Federal, state, or city funding or mandates, in combination with private funding, could help spur the construction of more stations to help ease range anxiety. For example, California's AB8, signed into law in September 2013 includes a provision to fund at least 100 hydrogen stations with a commitment of up to $20 million a year from its Alternative and Renewable Fuel and Vehicle Technology Program.[122] This commitment to fund infrastructure provides certainty for companies as they make their own commitments to vehicle manufacturing.[123] Several automakers expect to bring hydrogen vehicles to the California market in the next few years.

As the number of electric vehicles increases, private investment, from utilities for example, may gradually take over financing charging stations. For example, electric utilities could install and inspect home charging stations as well as develop public charging stations. This would not only help expand the alternative vehicle fueling infrastructure, but also open up additional revenue streams for utilities. The Georgetown Climate Center concluded that many additional benefits could be derived from this business model—the utility could ensure that the charging equipment operates efficiently on the grid without disruption, charge a fee based on the amount of electricity consumed (which non-utilities are not typically allowed to do in most states), and expand service to less profitable areas that might be ignored by other private companies, among others.[124] Analysis by Silver Spring Networks, a smart grid company, found a benefit-to-cost ratio of 1.83 (net present value) for utilities that owned, installed, and operated their own electric vehicle charging equipment.[125]

Improve charging options by eliminating barriers to access and adopting communication standards that provide for controlled charging.

Public charging stations can cost between $15,000 and $25,000, plus the cost of installation.[126, 127] Unlike gasoline stations, which serve any driver, many charging stations are run as networks of private stations. Drivers who want to charge at a station outside their network may be refused access or asked to pay a higher cost.[128] New federal regulations or mandates that ensure open access to all electric vehicle charging stations would help address the fractured nature of these networks.

Vehicle charging standards should also incorporate communication standards that enable controlled charging. Because drivers are typically in their cars for a short amount of time during the day, electric vehicles are usually parked and could be connected to charging infrastructure for more hours than needed to receive a full charge.

i. Because of the long timeframe of the MY2017–25 standards and because the National Highway Traffic Safety Administration (NHTSA) is required to conduct a separate rulemaking to establish final standards for vehicles for MY2022–25, EPA and NHTSA will conduct a comprehensive midterm evaluation and agency decision making process. This should occur by April 1, 2018 (See U.S. Environmental Protection Agency, 2012).

j. Note, this analysis defines net present value (NPV) as "the sum of all costs and benefits from 2010 to 2050, plus the fuel, GHG, and petroleum costs and benefits of vehicles sold through 2050 that will still be in use beyond that date." A 2.3 percent rate for all years was used, which is consistent with the most recent guidance of the U.S. government (See National Research Council, 2013).

Enabling grid operators to align electric vehicle charging with periods of high generation from variable renewable resources could help them cost effectively balance supply and demand. This would save grid operators money, a portion of which could be passed along in the form of savings for electric vehicle owners.[129]

Expand research and development for new technologies.

Sustained research and development by federal or state governments and private investors should drive advancement of next-generation technologies and help the United States take a leadership position in alternative vehicle manufacturing. As of 2009, Asia accounted for over 90 percent of the global production of batteries,[130] which can account for up to 50 percent of the cost of a new electric vehicle.[131] Expanding battery manufacturing in the United States could help American manufacturers capture more value in the battery supply chain. As mentioned, Tesla is planning to do just that and their upcoming "gigafactory" is expected to produce large electric vehicle batteries that are 30 percent cheaper than today's batteries by 2017.[132]

Sustain and expand federal and state mandates and incentives to promote sales of alternative vehicles.

Sustained technological progress will require continued deployment of new vehicles, and the learning-by-doing that comes with it. State and federal mandates and incentives can help ensure that these early-stage vehicles make it to market. The multi-state zero emission vehicle initiative discussed previously is expected to put 400,000 zero emission vehicles on the road by 2015 and about 1.4 million by 2020, potentially accelerating the learning curve.[133] This initiative has developed several key actions that if implemented would help promote zero emission vehicle leases or purchases, including: providing financial incentives, promoting infrastructure development, and increasing the number of zero emission vehicles in state and municipal fleets.[134] Expanding this target to include more states or establishing an equivalent federal program could further help increase the penetration of these vehicles.

States may also wish to consider providing alternative vehicles access to high-occupancy vehicle lanes. For example, California allows drivers of CNG, hydrogen, and electric cars to travel in HOV lanes regardless of the number of occupants.[135] The first 40,000 applicants that purchased or leased a plug-in hybrid vehicle also qualified for this benefit, and the cap was hit on May 9, 2014.[136]

ENDNOTES

1. Light-duty cars and trucks are those that have a gross vehicle weight rating of 8,500 pounds or less.
2. U.S. Environmental Protection Agency (EPA), Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012. Chapter 2: "Trends in Greenhouse Gas Emissions," April 2014, EPA, Washington, DC, accessible at http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Chapter-2-Trends.pdf; U.S. Environmental Protection Agency (EPA), 2014, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012, Chapter 3: "Energy," April, U.S. EPA, Washington, DC, accessible at http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.
3. The standards require a continuous improvement in vehicle performance, so that on average new 2025 model year vehicles emit 163 grams of carbon dioxide equivalent per mile (CO_2e/mile), which is equivalent to 54.5 miles per gallon (mpg) if the improvements are achieved exclusively through fuel economy improvements. This results in an equivalent fuel economy standard of 49.7 mpg because DOT considers only drivetrain improvements and does not consider improvements in air conditioning leakage of HFCs.
4. Because of the long time frame of the MY2017–25 standards and because National Highway Traffic Safety Administration (NHTSA) is required to conduct a separate rulemaking to establish final standards for vehicles for MY2022–25, EPA and NHTSA will conduct a comprehensive midterm evaluation and agency decision making process. This should occur by April 1, 2018. See U.S. Environmental Protection Agency (U.S. EPA), 2012, "EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017–2025 Cars and Light Trucks," accessible at http://www.epa.gov/otaq/climate/documents/420f12051.pdf; and A.J. Krupnick, J. Linn, V. D. McConnell, 2014, " Research Questions for the Midterm CAFE Review," March, Resources for the Future, accessible at http://common-resources.org/2014/research-questions-for-the-midterm-cafe-review/.
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10. Bloomberg New Energy Finance, 2014, "Sustainable Energy in America 2014 Factbook," February, The Business Council for Sustainable Energy (BCSE), accessible at http://www.bcse.org/factbook/pdfs/2014%20Sustainable%20Energy%20in%20America%20Factbook.pdf.
11. U.S. Department of Energy (DOE), About the Fuel Cell Technologies Office: "Accomplishments and Progress," accessible at http://energy.gov/eere/fuelcells/accomplishments-and-progress.
12. The range of prices in 2013 is a result of manufacturing volume with the lower cost estimate based on a higher production volume assumption. See U.S. Department of Energy, June 2014, "Fuel Cell System Cost—2013," accessible at http://www.hydrogen.energy.gov/pdfs/13012_fuel_cell_system_cost_2013.pdf.
13. Jacob S. Spendelow, Ph.D. Fuel Cell Technologies, U.S. Department of Energy, personal communication, April 17, 2014.
14. Note, this result was obtained under the "optimistic" scenario. Under the "midrange" scenario, the cost of a fuel-cell passenger car will be within $2,000 of a gasoline car by 2030 and reach price parity by 2045. See National Research Council, 2013, "Transitions to Alternative Vehicles and Fuels," National Academies Press, Washington, DC, accessible at http://www.nap.edu/catalog.php?record_id=18264.
15. Governor's Interagency Working Group on Zero-Emission Vehicles, 2013, "2013 ZEV Action Plan: A Roadmap toward 1.5 Million Zero-Emission Vehicles on California Roadways by 2025," February, Office of Governor Edmund G. Brown Jr. Sacramento, CA, accessible at http://opr.ca.gov/docs/Governor's_Office_ZEV_Action_Plan_(02-13).pdf; D. Clegern, 2013, "Governors Announce Bold Initiative to Put 3.3 Million Zero-Emission Vehicles on the Road by 2025," October 24, California Environmental Protection Agency, Air Resources Board, Sacramento, CA, accessible at http://www.arb.ca.gov/newsrel/newsrelease.php?id=520.
16. As noted in EPA's Regulatory Impact Analysis, EPA expects electric vehicles to make up 2 percent of the new light-duty fleet in 2025, on average. This equates to just over 316,000 electric vehicles, if 2025 sales are consistent with EIA's Annual Energy Outlook 2014 Reference Case projections (1.58 million light duty vehicle sales in 2025). See U.S. Environmental Protection Agency, 2012, Regulatory Impact Analysis: "Final Rulemaking for 2017–2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards," Table 3.5–25 Final Rule Fleet Technology Penetration in MY 2025, August, accessible at http://www.epa.gov/otaq/climate/documents/420r12016.pdf; and U.S. Energy Information Administration, "Light Duty Vehicle Sales by Technology Type," in *Annual Energy Outlook 2014*, accessible at http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2014&subject=15-AEO2014&table=48-AEO2014&region=1-0&cases=ref2014-d102413a.
17. U.S. Environmental Protection Agency (EPA), 2012, "EPA and NHTSA Set Standards to Reduce Greenhouse Gases."
18. Lifetime net present value with 7 and 3 percent discount rates, respectively, in 2010 dollars. See U.S. Environmental Protection Agency (EPA), 2012, "EPA and NHTSA Set Standards to Reduce Greenhouse Gases."
19. Note, in calculating these savings, EPA assumes a 10 percent fuel economy rebound effect from the efficiency gains resulting from these standards. In other words, if the per-mile fuel cost was reduced by 30 percent, then EPA takes into account an estimated 3 percent increase in vehicle miles travelled. See U.S. Environmental Protection Agency, 2012, "Final Rulemaking for 2017–2025 Light-Duty Vehicle Greenhouse Gas Emission Standards," Table 3.5–25 "Final Rule Fleet Technology Penetration in MY 2025," accessible at: http://www.epa.gov/otaq/climate/documents/420r12016.pdf.
20. According to EPA's Regulatory Assessment Report, "The final rule reduces the net human health risk posed by non-GHG related pollutants. In monetized terms, the present value of particulate matter and ozone-related impacts associated with the Calendar Year analysis equals between $3.1 and $9.2 billion in benefits, depending on the assumed

discount rate (7 percent and 3 percent, respectively).” See U.S. Environmental Protection Agency, 2012, “Final Rulemaking for 2017–2025 Light-Duty Vehicle Greenhouse Gas Emission Standards.”
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119. Our calculations show that a typical Ford Focus would consume 375 gallons of gasoline annually while a typical Ford Focus EV would consume around 3,700 kilowatt hours of electricity without a rebound effect and nearly 4,000 kilowatt hours with a rebound effect, assuming the national average electric grid CO_2 emissions intensity from 2013 (0.53 kilograms per kilowatt hour; U.S. Energy Information Administration, *Monthly Energy Review* "Table 12.6: Carbon Dioxide Emissions From Energy Consumption: Electric Power Sector," accessible at http://www.eia.gov/totalenergy/data/monthly/pdf/sec12_9.pdf, and "Table 7.2b: Electricity Net Generation: Electric Power Sector," accessible at http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_6.pdf; and the CO_2 intensity of gasoline (8.91 kilograms of CO_2 per gallon; U.S. Energy Information Administration, "Voluntary Reporting of Greenhouse Gases Program Fuel Emission Coefficients," accessible at http://www.eia.gov/oiaf/1605/coefficients.html#tbl2). The Ford Focus would emit 40 metric tons of CO_2 over the life of the vehicle while the Ford Focus EV would only emit 25 metric tons of CO_2 over the life of the vehicle.
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126. J. Pyper, "Charger Standards Fight Confuses Electric Vehicle Buyers, Puts Car Company Investments at Risk," July 24, 2013, *ClimateWire*, accessible at http://www.eenews.net/climatewire/stories/1059984950. Note, home charging equipment typically costs much less. Most manufacturers provide a charger that can be used in any outlet with the purchase of an electric or plug-in hybrid vehicle. Drivers can also purchase faster charging equipment. For example, equipment that can charge the Nissan Leaf in five hours starts at $999 for the charger only or $1,999 for the charger, installation fees, and a three-year warranty. See Nissan, "Home Charger Installation and Cost," accessible at http://www.nissanusa.com/electric-cars/leaf/charging-range/charging/.
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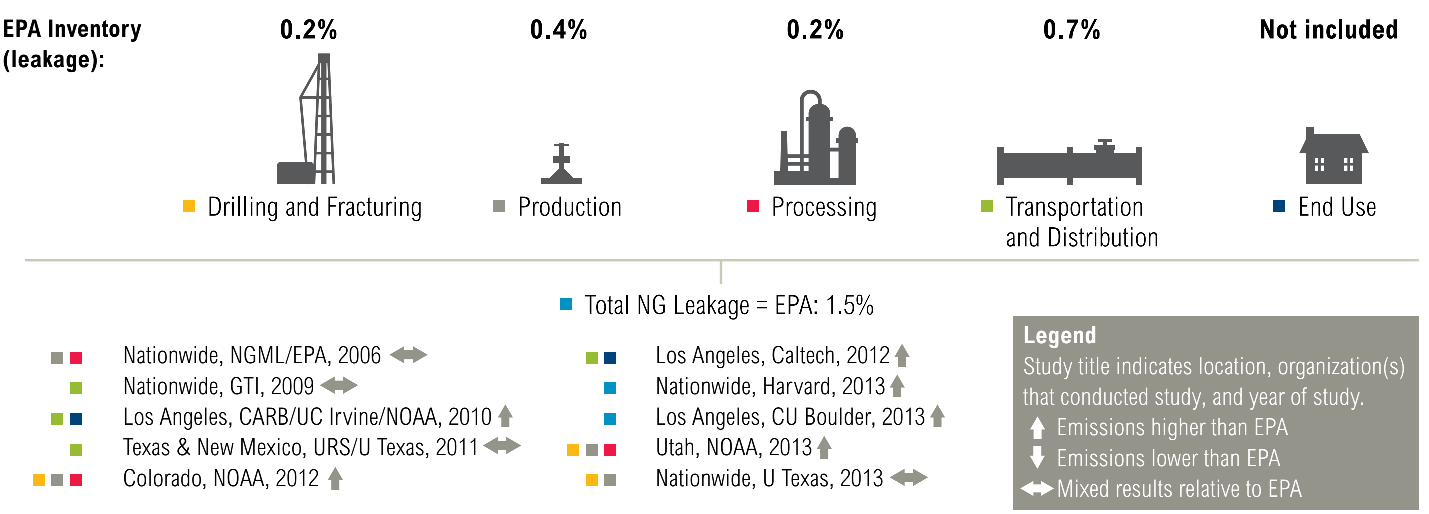
CHAPTER 4: IMPROVED PRODUCTION, PROCESSING, AND TRANSMISSION OF NATURAL GAS

OVERVIEW

Methane, the primary component of natural gas, is a potent greenhouse gas, with at least 34 times the global warming potential of carbon dioxide.[a, 1] Leaks and vents of natural gas occur throughout the natural gas supply chain, from drilling through production, processing, transmission, distribution, and end use. These emissions reduce the greenhouse gas advantage that natural gas provides over coal, and can reduce or eliminate the benefits it might provide over gasoline and diesel as a fuel for cars and trucks. In addition, toxic gases co-emitted with methane cause smog and air pollution that harms human health and the environment.

The exact scale of methane leakage is not known; the U.S. Environmental Protection Agency's (EPA) 2014 Greenhouse Gas Inventory estimates that the natural gas system's methane leakage rate was about 1.2 percent in 2012, but many recent studies suggest that it may be much greater, perhaps in the range of 3 percent to as high as 10 percent.[b, 2] The points of methane leakage in the natural gas production process and a comparison of the leakage rates estimated by several studies with EPA's estimates are shown in Figure 4.1. Even at a leakage rate of 1.2 percent, natural gas companies would be emitting the equivalent of the annual greenhouse gas emissions of 32 million cars or 40 coal-fired power plants.[3]

Figure 4.1 | **Methane Leakage Sites and Rates from the Natural Gas System**



Notes: This figure relies on data from the 2013 Environmental Protection Agency Inventory, Annex 3, available at http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-Annexes.pdf.
Source: M. Lavelle, 2014, "Methane Emissions Far Worse than U.S. Estimates, but Study Concludes Natural Gas Still Better than Coal," The Great Energy Challenge, February 13, National Geographic Society, accessible at http://energyblog.nationalgeographic.com/2014/02/13/methane-emissions-far-worse-than-u-s-estimates-but-study-concludes-natural-gas-still-better-than-coal/.

a. According to the latest estimates from the Intergovernmental Panel on Climate Change, because it is a powerful but short-lived greenhouse gas, methane traps 34 times as much heat in the atmosphere as CO_2 over 100 years, and 86 times as much over 20 years. (See Gunnar Myhre, 2013.)

b. Because EPA does not report an average nationwide leakage rate, WRI calculated a figure of 1.2 percent using methane emissions data from the 2014 EPA Greenhouse Gas Inventory, and natural gas production data from the U.S. Energy Information Administration. To convert volumes of methane to volumes of natural gas, we assumed an average methane content of natural gas of 90 percent across all life cycle stages. (See U.S. Environmental Protection Agency, 2014, and U.S. Energy Information Administration, August 2014.)

Fortunately, reducing methane emissions is often good for business because companies are able to sell more natural gas rather than let it escape into the air. Voluntary measures to reduce emissions have already led to an increase of over $264 million in revenue from natural gas sales, according to EPA.[4] However, their use remains uneven largely because of market barriers, such as opportunity costs, imperfect information, and principal-agent problems, which impair the ability of drillers and other service providers to capture the increased revenue from changes in equipment and practices. Analysis has shown the natural gas industry could make over $1 billion per year by capturing additional wasted gas.[5]

New legislation or standards, such as greenhouse gas emissions standards under section 111(d) of the Clean Air Act, could overcome these market barriers and help realize this lost opportunity. Other federal agencies can take steps to help reduce emissions in ways that would complement such regulations. For example, the Federal Energy Regulatory Commission (FERC) can pursue tariff adjustments, the Department of Energy (DOE) can help improve emissions measurement and control technologies, and the Pipeline and Hazardous Materials Safety Administration (PHMSA) could require stricter inspection and maintenance standards for gathering, transmission, and distribution systems.[6]

PROFILES OF CHANGE

Recent studies support the notion that there is a "fat-tail distribution" of methane emissions, meaning that a small percentage of sources are responsible for a large percentage of the emissions.[7] Through good practices or voluntary emissions reduction measures, many companies throughout the natural gas supply chain—from well drilling through distribution—are already taking steps to reduce methane emissions. Voluntary measures, like the ones below, already reduce about 20 percent of methane emissions from natural gas systems, according to EPA.[8] These measures include:[9]

- Using artificial lifts to increase well pressure to stimulate the flow of natural gas while liquids are removed from the well reduced emissions by 12 billion cubic feet in 2012.[c]
- Using pipeline blowdown techniques to lower pressure in transmission pipelines while venting natural gas during planned maintenance or emergency shutdowns reduced emissions by over 4 billion cubic feet in 2012.
- Performing reduced emissions completions (also called green completions) at the wellhead reduced methane emissions by over 12 billion cubic feet across the country in 2012, earning companies nearly $50 million in additional revenue from selling this gas. Performing reduced emissions completions at natural gas wells will soon be required under EPA rules.[d, 10]

These and other actions are being taken by a number of companies throughout the natural gas industry, such as El Paso (now part of Kinder Morgan) and Southwestern Energy, which have recognized the advantages of going beyond regulations to voluntarily implement emissions reduction technologies and techniques.[11] Among the additional measures Southwestern adopted are: using automated compressors to reduce venting, installing no-bleed pneumatic controls, and using infrared cameras to identify leaks to be repaired. In addition, the company performed reduced emissions completions at many of its wells for years before EPA's 2012 New Source Performance Standards (NSPS).[12] State or federal standards could lead to increased deployment of these measures and other best practices across the industry.

OPPORTUNITIES FOR SCALE

New Air Pollution Rules Will Reduce Leaks and Vents

Reducing or eliminating the leaking, venting, and flaring of natural gas can also provide significant health and air quality benefits. Hazardous air pollutants and volatile organic compounds (VOCs) like benzene are released into the atmosphere along with methane, especially at the wellhead (natural gas processing removes many such impurities). Natural gas development is a major source of smog in many areas: rural areas in Wyoming with high concentrations of natural gas operations have experienced worse smog than the city of Los Angeles.[13] While monetizing the impact of reducing emissions of methane and conventional air pollutants from natural gas systems can be challenging, studies have suggested that the health benefits

c. Assuming a natural gas composition of 85 percent methane and a 100-year global warming potential for methane of 34.

d. Beginning in October of 2012, companies have had to flare or capture natural gas emitted during well completions, the process by which a well is made ready for production. By 2015, all of this gas must be captured. WRI estimates that these rules will reduce methane emissions by 13 percent in 2015 and 25 percent in 2035 below a business-as-usual trajectory. Revenue estimate based on gas price of $4 per thousand cubic feet. (See James Bradbury, 2013.)

due to improved air quality could be as high as $2,640 per metric ton of volatile organic compounds nationwide, with even higher benefits in some localities.[14]

EPA rules to reduce emissions of hazardous air pollutants, sulfur dioxide (SO_2) and volatile organic compounds[15] are projected to reduce emissions of volatile organic compounds by 172,000 metric tons in 2015 alone.[16] Meanwhile, they are expected to save the natural gas industry approximately $10 million per year once fully implemented in 2015 because the value of the natural gas saved is greater than the cost of equipment to capture it (annual savings are estimated at $330 million versus $320 million in compliance costs).[17] The rules will have the co-benefit of reducing total greenhouse gas emissions from natural gas systems by 10 to 15 percent, or roughly 19–33 million metric tons of CO_2 equivalent.[18] By 2035, methane emissions could be reduced 25 percent below annual business-as-usual projections, as old equipment is replaced over time and new equipment becomes subject to the new standards.[19, 20]

Some states, notably Wyoming, Colorado, and Pennsylvania, have implemented rules that go beyond EPA's new air quality standards.[21] But analysis suggests that even these states have left considerable opportunities on the table. By building on the example set by these states and going even further to require the use of many or all of the technologies that have proven to be cost-effective means of reducing emissions, the United States could make deep, lasting cuts in methane emissions.

Studies Confirm Profitability of Reducing Emissions

A significant fraction of methane emissions not currently addressed by state or federal policies could be cost-effectively reduced with existing technologies, according to two recent studies. Over 20 percent of the remaining methane emissions from onshore gas development after the implementation of EPA's new standards can be reduced at net *negative* cost (that is, they generate net savings), and 40 percent of emissions can be reduced at an average cost of just $0.01 per thousand cubic feet of natural gas produced,[e] according to a 2014 study by ICF International.[22] These estimates are based on conservative assumptions, including the high end of the range of equipment costs and the low end of the range for emissions reductions from that equipment, ICF notes. They also do not include the ancillary benefits of cleaner air and reduced greenhouse gas emissions. A 2012 study by the Natural Resources Defense Council suggested even greater levels of negative cost opportunity, and that legislation or standards to move the entire industry to use best practices would generate revenue of $1.5 billion annually (at gas prices of $4 per thousand cubic feet) and reduce U.S. greenhouse gas emissions by approximately 150 million metric tons of CO_2 equivalent in 2020,[23] while reducing emissions of harmful air pollutants.

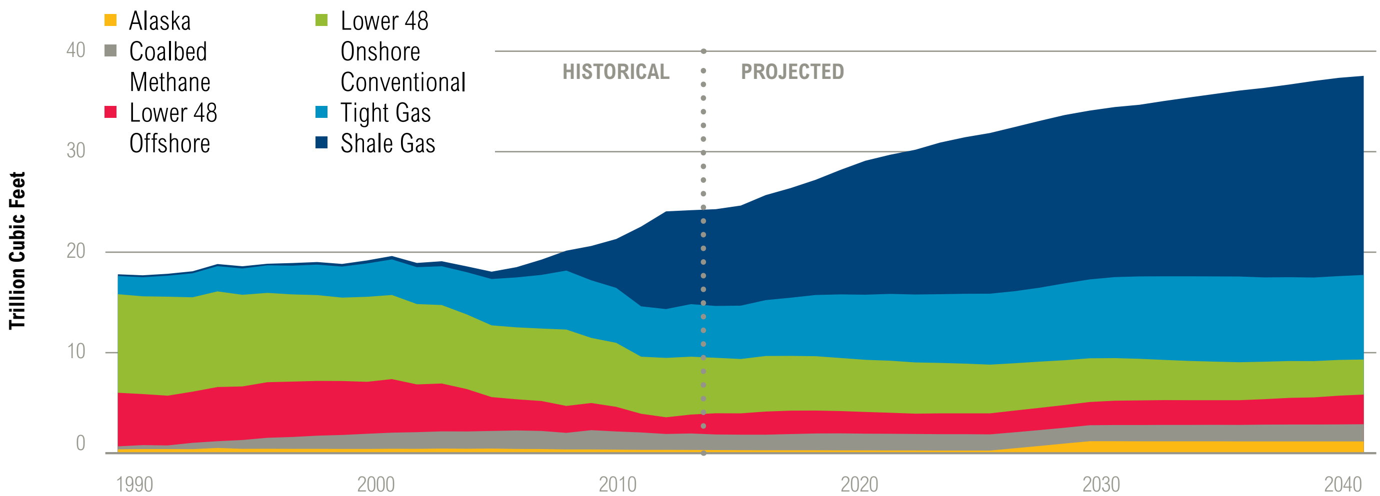
As natural gas prices rise, the savings generated through the deployment of many of these technologies and practices will increase (see Box 4.1 for examples of cost-effective emissions reduction strategies). These studies examined the cost savings available at spot prices of $4 per thousand cubic feet, which is roughly equal to average spot prices for 2013 through the first half of 2014. However, prices are expected to increase about 20 percent by 2020,[24] especially if the United States begins exporting liquefied natural gas (see Chapter 1 for more details).[f, 25] This suggests that it may be possible to achieve deeper levels of reductions while generating financial savings for industry.

However, higher prices also make more gas production economically viable, leading to increased production and the possibility of greater greenhouse gas emissions—unless additional steps are taken to reduce methane emissions. Nevertheless, deploying the technologies and practices examined in the ICF and NRDC reports could significantly reduce industry-wide methane emissions below a business-as-usual trajectory, even as technological advances open up new gas reserves.[26] (Note, the projected increase in natural gas production is shown in Figure 4.2.)

e. For reference, in the first six months of 2014, natural gas spot prices largely fluctuated between $4 and $5 per thousand cubic feet (Mcf). However, for a few weeks at the start of 2014, natural gas prices jumped to nearly $7 per Mcf due to the intensely cold winter experienced across the United States, which led to large withdrawals of natural gas from storage. Prices then quickly retreated to between $4 and $5 per Mcf.

f. In recent years, increased supply drove down the monthly average spot price of natural gas in the United States from $13 per thousand cubic feet in June 2008 to a low of $2 per thousand cubic feet in April 2012. As demand for natural gas has risen for both electricity production and as an industrial feedstock, prices have rebounded to between $4 and $5 per thousand cubic feet, as of this writing. (See U.S. Energy Information Administration, August 2014.)

Figure 4.2 | Natural Gas Production by Source, 1990–2040



Source: U.S. Energy Information Administration, "Market Trends: Natural Gas," accessible at http://www.eia.gov/forecasts/aeo/MT_naturalgas.cfm.

Box 4.1 | Examples of Emissions Reductions Technologies and Techniques

Dry seal centrifugal compressors: Centrifugal compressors are used at processing plants and compressor stations to keep gas moving through the pipeline. Seals around the compressor prevent gas from escaping, but some seals work better than others. "Wet" seals use oil to prevent natural gas from escaping, while dry seals do not. Dry seals have proven more effective at reducing methane leaks, and are more reliable as well.[a] Ensuring that all new centrifugal compressors use dry seals, and retrofitting wet seal compressors where appropriate, would lead to significant emissions reductions—on the order of 17 million metric tons of CO_2 equivalent from the processing and transmission stages[b]—with a payback period of under three years. In July 2014, the Department of Energy proposed energy efficiency standards for natural gas compressors,[c] a positive step that may indirectly reduce methane emissions, but will not be as effective as—and should be considered a complement to, not a substitute for—directly regulating methane emissions from compressors and other sources.

Low-bleed pneumatic devices: Pneumatic devices are used throughout the natural gas industry, to control and regulate temperature, pressure, and liquid levels, among other functions. These devices, powered by pressurized natural gas, are designed to release natural gas into the atmosphere. Replacing high-bleed pneumatics with low-bleed equivalents is frequently mentioned as one of the most cost-effective emissions reduction options available to the natural gas industry. The U.S. Environmental Protection Agency estimates that pneumatic controllers are responsible for 13 percent of all methane emissions from natural gas systems,[d] and that investments to replace high-bleed devices with their low-bleed equivalents can reduce emissions by up to 90 percent and pay for themselves in less than one year.

Leak detection and repair: Leaks from pumps, valves, compressors, and other equipment throughout the natural gas supply chain, can be detected in many ways, from infrared cameras to a simple soap-bubble test. Identifying and fixing leaks wherever they occur reduces waste while also improving safety at natural gas facilities and improving air quality in the surrounding areas. Depending on the cost of the technology used to identify leaks, the frequency of the leak surveys, and the quantity of gas escaping into the atmosphere, leak detection and repair programs are often one of the most cost-effective means for reducing methane emissions.

Notes:

a. See U.S. Environmental Protection Agency, 2006, "Replacing Wet Seals with Dry Seals in Centrifugal Compressors," EPA, Washington, DC, October, accessible at http://www.epa.gov/gasstar/documents/ll_wetseals.pdf.

b. Assumes a 100-year global warming potential for methane of 34. See Environmental Protection Agency, 2014, "Annex 3- Methodological Descriptions for Additional Source or Sink Categories," EPA, Washington, DC, April, accessible at http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Annex-3-Additional-Source-or-Sink-Categories.pdf.

c. See Energy Efficiency and Renewable Energy Office, 2014, "Energy Conservation Program for Certain Commercial and Industrial Equipment: Gas Compressors; Request for Information," Federal Register Pre-Publication, July 28, accessible at http://www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0040-0022.

d. U.S. Environmental Protection Agency, 2014, "Oil and Natural Gas Sector Pneumatic Devices," EPA Office of Air Quality Planning and Standards, April, accessible at http://www.epa.gov/airquality/oilandgas/2014papers/20140415pneumatic.pdf.

REMAINING CHALLENGES

Currently, only about 20 percent of methane emissions from natural gas systems are eliminated through voluntary measures, according to EPA, leaving considerable cost-effective emissions reduction opportunity on the table. If so much valuable product is going to waste, why aren't companies doing more to eliminate methane emissions?

Several market barriers prevent investment in otherwise attractive opportunities. These barriers include principal-agent problems, imperfect information, and opportunity costs.

Thousands of companies are active in the U.S. natural gas industry, from service providers that drill wells to pipeline operators to the local utilities that operate the million-plus miles of small distribution pipelines, creating **principal-agent problems**. With so little vertical integration across the industry, the incentives for investment in emissions control technologies are not well aligned; too often, the company making the investment to reduce leakage of natural gas is different from the company that will reap the benefits by having more gas to sell. Contractors and service providers in the production, processing, transmission, and distribution stages often do not own the gas flowing through their equipment, in much the same way that landlords do not often have the proper incentive to make energy efficiency investments that would benefit only their tenants.

In addition, because emissions measurement and monitoring technology is still expensive and not widely used, companies have **imperfect information** on how much methane they are emitting, and from which sources. More and better information would give these companies a better picture of how much money they could save by investing in technologies that reduce methane emissions.

For some, it is a matter of competing priorities. The **opportunity cost** of investing in equipment to reduce or eliminate natural gas leaks is less money to invest elsewhere. Although most emissions control technologies pay for themselves in three years or less, that period may not compare favorably to other investment opportunities.[27] Indeed, a 2007 industry publication states that "companies and investors operate under capital constraints and the estimated financial returns of such GHG reduction projects may not justify diverting capital from other higher-return or more strategic initiatives."[28]

Because of these barriers—principal-agent problems, imperfect information, and opportunity costs—policy intervention is required to ensure reduced methane emissions. Although new state and federal regulations will help curtail emissions while delivering savings to owners and operators of natural gas systems, additional standards are needed to realize the full scope of cost-saving opportunities that have been identified.

BRINGING THESE OPPORTUNITIES TO SCALE

New legislation or standards, such as greenhouse gas emissions standards under section 111(d) of the Clean Air Act, could overcome these market barriers and help realize this lost opportunity. Other federal agencies, such as the Federal Energy Regulatory Commission, the Department of Energy, and the Pipeline and Hazardous Materials Safety Administration, can also take steps to increase industry's investment in cost-effective mitigation options.

Establish performance standards for industry.

The most effective way to overcome market barriers and drive investment in cost-effective mitigation options is to establish performance standards for both new and existing sources. WRI analysis has found that such policies could save producers money while driving system-wide leakage to less than 1 percent of production.[29] Some progress has been made on reducing methane emissions from new sources: with its 2012 standards, EPA has issued rules that will lead to cost-effective reductions in local air pollution while simultaneously reducing methane emissions and turning a profit for industry. Yet, 90 percent of natural-gas-related methane emissions in 2018 will come from infrastructure that was already in place in 2011, according to ICF International's analysis.[30] Driving investment in the full range of opportunities identified here will likely also require EPA to go beyond local air pollution standards and to target greenhouse gases (methane) specifically.[g, 31] Such standards could be in the works as the Administration

g. Upstream of the processing plant, natural gas is comprised of roughly 70–95 percent methane, and has high concentrations of volatile organic compounds (VOCs). Regulations targeting VOCs at wells and in gathering lines will therefore have large methane cobenefits. After processing strips away many of the impurities in the natural gas, however, and depending on the quality of the natural gas when it comes out of the ground, natural gas is typically between 87 and 96 percent methane. This means that even large leaks of natural gas may not emit significant quantities of VOCs, making regulations that target methane the best way to ensure emissions reductions. (See R.C. Burruss, 2004, and U.S. Department of Interior U.S. Geological Survey, 2004.)

has announced an economy-wide methane strategy that requires EPA to study opportunities to reduce greenhouse gas emissions from additional stages of the natural gas life cycle, and potentially to propose new standards that build on the success of EPA's New Source Performance Standards.[32]

Of course, many other options are available to reduce methane emissions, including the use of subsidized loans or tax credits to incentivize the use of emissions control technologies, or penalties to discourage unnecessary leaks, vents, or flares of methane.[33] However, the nature of natural gas systems would seem to limit the effectiveness of policies that attempt to drive change by imposing a price signal, limiting them to a complementary role to performance standards. One challenge is that significantly shifting the actions taken by owners and operators of natural gas infrastructure could require a price signal that rivals the price of gas itself. In addition, leaks are spread out across over 700,000 wells and over 300,000 miles of transmission pipelines, making the types of monitoring and verification required for market-based programs particularly challenging.

Other federal agencies can help.

The Federal Energy Regulatory Commission, the Department of Energy, and the Pipeline and Hazardous Materials Safety Administration can take steps to reduce GHG emissions from natural gas systems in ways that would complement emissions standards.

The Federal Energy Regulatory Commission could work with industry to overcome principal-agent problems by revising contracts so that service providers throughout the natural gas supply chain have the correct incentives for making investments in emissions reduction technologies under the Natural Gas Act of 1938 and the Energy Policy Act of 2005.[34, 35, 36] As WRI noted in "Clearing the Air,"

"Tariffs and contracts between pipeline companies and their shippers are subject to oversight and approval by the Federal Energy Regulatory Commission (FERC). Pipeline companies often require shippers to make in-kind payments (tariffs) for natural gas used by pipeline companies and for lost and unaccounted for fuel (LAUF), both of which contribute to upstream CO_2 and methane emissions from natural gas pipeline systems. While a competitive market for natural gas transmission creates an incentive for pipeline companies to keep their tariff rates down, some tariff structures guarantee cost recovery for fuel usage and LAUF regardless of the services rendered."[37]

Indeed, in July 2014, DOE announced that it would recommend that FERC explore opportunities for establishing such mechanisms.[38] Moreover, FERC could use its regulatory authority to ensure that all natural gas operations under its jurisdiction reduce leaks and vents of natural gas to the extent technologically and economically feasible (with provisions for transmission companies to recoup their expenses), both to safeguard the safety of workers and the system, and to ensure that the interstate natural gas market is functioning with as few distortions as possible.[39]

The Department of Energy can also help improve emissions measurement and control technologies by promoting continued research and development. This could help bring down the cost of emissions measurement technologies and increase their usage across the industry. This, in turn, could drive greater investment in cost-effective greenhouse gas mitigation activities by improving the industry's ability to target leaks across the million-plus miles of pipelines.

In addition, the Pipeline and Hazardous Materials Safety Administration could require stricter inspection and maintenance standards for gathering, transmission, and distribution systems, which would likely help reduce methane emissions from those sectors.

ENDNOTES

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3. At the average 2012 Henry Hub price of $2.82 per thousand cubic feet of natural gas, this represents $1.03 billion in lost revenue. It would be $1.36 billion at average 2013 prices of $3.82 per thousand cubic feet. See U.S. Energy Information Administration, "Natural Gas Data," accessible at http://www.eia.gov/dnav/ng/hist/rngwhhdA.htm. For greenhouse gas equivalencies, see U.S. Environmental Protection Agency, "Greenhouse Gas Equivalencies Calculator," accessible at http://www.epa.gov/cleanenergy/energy-resources/calculator.html. Note that EPA uses an outdated 100-year global warming potential (GWP) for methane of 25.
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15. More specifically, this rulemaking revised existing National Emissions Standards for Hazardous Air Pollutants (NESHAPS) and New Source Performance Standards (NSPS) applicable to the oil and gas sector, and established a new standard (NSPS Subpart OOOO) applicable to crude oil and natural gas production, transmission, and distribution. The revisions to NESHAPS and NSPS target reduction of hazardous air pollutants, volatile organic compounds, and sulfur dioxide emissions. The new rule (NSPS OOOO) targets volatile organic compound emissions reductions (and indirectly methane and hazardous air pollutants) from leaking and vented emissions such as those associated with well completions by requiring implementation of reduced emissions completions or green completions technology.
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17. As EPA notes in its final rule for natural gas systems, "With the data available, we are not able to provide credible health benefit estimates for the reduction in exposure to HAP [hazardous air pollutants], ozone and PM2.5 [particulate matter] for these rules, due to the differences in the locations of oil and natural gas emission points relative to existing information and the highly localized nature of air quality responses associated with HAP and VOC [volatile organic compounds] reductions. This is not to imply that there are no benefits of the rules; rather, it is a reflection of the difficulties in modeling the direct and indirect impacts of the reductions in emissions for this industrial sector with the data currently available…" See U.S. Environmental Protection Agency, "Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews," Final Rule, 40 CF Parts 60 and 63, *Federal Register*, August 2012, accessible at http://www.gpo.gov/fdsys/pkg/FR-2012-08-16/pdf/2012-16806.pdf.
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25. U.S. Energy Information Administration, August 2014, "Henry Hub Natural Gas Spot Price," available at http://www.eia.gov/dnav/ng/hist/rngwhhdM.htm.
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29. For more information, see Bradbury et al., 2013, "Clearing the Air." WRI analysis found that federal standards requiring the use of ten cost-effective technologies that address the largest sources of methane emissions would likely bring the system-wide leakage rate below 1 percent. Many technologies and techniques pay for themselves in three years or less simply through the sale of additional gas that would have otherwise been emitted into the atmosphere. If we include the environmental and health cobenefits of reducing emissions of a powerful greenhouse gas as well as conventional air toxics and other pollutants, even more technologies could be classified as "cost effective."
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34. Under Section 7 of the Natural Gas Act, the Federal Energy Regulatory Commission (FERC) reviews applications for natural gas pipelines, and works with other agencies to ensure safety standards are met. And under the Energy Policy Act, FERC has broad jurisdiction to regulate the sale of natural gas in interstate commerce. For more information, see Federal Energy Regulatory Commission, "Gas Pipelines," July 2014, accessible at https://www.ferc.gov/industries/gas/indus-act/pipelines.asp, and U.S. Energy Policy Act of 2005, Public Law 109-58, August 8, 2005, accessible at http://www.gpo.gov/fdsys/pkg/PLAW-109publ58/pdf/PLAW-109publ58.pdf.
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38. For more information, see U.S. Department of Energy, "Factsheet," July 29, 2014, accessible at http://www.energy.gov/articles/factsheet-initiative-help-modernize-natural-gas-transmission-and-distribution.
39. For more recommendations, see Bradbury et al., 2013, "Clearing the Air."

CHAPTER 5: REDUCING EMISSIONS OF HIGH GLOBAL WARMING POTENTIAL GASES

OVERVIEW

Hydrofluorocarbons (HFCs) are a small but rapidly growing component of U.S. (and global) greenhouse gas (GHG) emissions. These gases, which are commercially produced for use as refrigerants, foam blowing agents, and aerosols, can have very high global warming potentials (GWPs). Those with the highest GWPs trap thousands of times more heat than carbon dioxide (CO_2). Their use is on the rise as a result of the phase-out of their ozone-depleting predecessors, hydrochlorofluorocarbons (HCFCs).[a]

Direct emissions occur when HFCs leak from the equipment they are servicing. In addition, depending on the particular HFC's thermodynamic efficiency, their use can affect the equipment's electricity consumption (and CO_2 emissions associated with that electricity). However, alternatives with low and even near-zero global warming potential are increasingly available. They include "natural refrigerants" such as CO_2 and hydrocarbons (HCs) as well as hydrofluoroolefins (HFOs), which contain hydrogen, fluorine, and carbon like HFCs, but have much lower GWPs.[1] Some of these alternatives also offer performance benefits (via superior thermodynamic efficiency) compared with the higher-GWP HFCs they replace, lowering the amount of electricity consumed and thereby reducing electricity bills and GHG emissions.

The Environmental Protection Agency (EPA) estimated that the United States can reduce HFC emissions by over 40 percent from what would otherwise be emitted in 2030 entirely through measures that have a negative or break-even price today. This includes the retrofit of existing equipment with lower-GWP refrigerants, using new equipment, and improving equipment servicing practices. Several companies have begun using these alternatives, and many are saving money and energy while they reduce GHG emissions.

However, adoption remains uneven for a variety of reasons. Although converting to some low-GWP alternatives may offer net cost savings, some have high upfront costs or require the replacement of equipment, or even the redesign of a facility or vehicle.[2] Additionally, there is insufficient pull on the demand side: customers who purchase refrigeration or air conditioning equipment may not know about or ask for low-GWP alternatives. Thus, there is little reason to believe that the U.S. market will rapidly move to these alternatives without new rules or other incentives. A number of U.S. chemical manufacturers and equipment manufacturers have advocated for a global phase-down of high-GWP HFCs through amendments to the Montreal Protocol.[3] International momentum appears to be gradually building for these amendments. Policy measures have already begun to promote the adoption of lower GWP alternatives in some regions, including the European Union and Japan.[4]

In the meantime, EPA can drive the adoption of negative and zero-cost technologies, as well as other low-cost technologies, using its authority under the Clean Air Act. EPA has already started offering incentives to phase out high-GWP HFC use in personal vehicles[5] and adopted standards to control HFC leakage from air conditioning systems in pickups, vans, and combination tractors.[6] Additionally, in July 2014, EPA proposed rules under section 612 of the Clean Air Act (implemented through the Significant New Alternatives Policy [SNAP] program) to approve low-GWP alternatives and move some higher-GWP HFCs out of the market for various applications.[7] EPA should finalize these proposed rules as well as continue evaluating and approving low-GWP alternatives and delisting high-GWP HFC uses as alternatives become commercially available. Over time, it may also be appropriate to implement a flexible program either by EPA under section 615 of the Clean Air Act or via Congressional legislation.

a. HCFCs have been used as a replacement for CFCs, another group of ozone-depleting substances with high global warming potentials that were phased out under the Montreal Protocol (except for allowed exemptions). Because of the success of this phase-out, the Montreal Protocol has already spurred large greenhouse gas benefits. However, the rise of HFCs is causing GHG emissions from the sector to increase.

PROFILES OF CHANGE

HFC manufacturers, like Honeywell, Arkema, and DuPont, already produce a variety of low-GWP alternatives, including HFOs and HFO blends, for use in automobiles, supermarkets, home air conditioning, commercial chillers, refrigerators, coolers, and other appliances and equipment. Several companies have begun using these and other alternatives, finding them as effective as high-GWP HFCs, and, in some cases finding that they provide benefits such as improved energy efficiency and net financial savings over the lifetime of the equipment. No single solution works across all end-use applications, but innovation is occurring in many end uses. For example:

- HFO technologies or HFO-HFC blends are being used in place of HFCs in automobile air conditioning, the production of insulating foams, residential and light commercial air conditioning, domestic and commercial refrigeration, and industrial waste heat recovery. These products have GWPs 50 to 99.9 percent lower than the HFCs they replace.[8] Because HFOs are a relatively recent innovation, new products are steadily coming into the market from various producers. Fifteen car companies, including General Motors, Ford, and Chrysler, are moving forward with HFO-1234yf,[9] a new low-GWP refrigerant for personal vehicle air conditioners that has a GWP 99.9 percent lower than the HFC it replaces.[10] An estimated 1 million cars on the road worldwide already use this low-GWP refrigerant.[11] This number is expected to grow to nearly 3 million by the end of 2014.[12]

- CO_2 transcritical technology[b, 13] is creating new cost saving alternatives for some refrigeration applications. Sobeys, a Canadian supermarket chain, found that using CO_2 transcritical technology in cold to moderate climates has multiple benefits, including greater cooling capacity, lower energy use (via a more efficient heat rejection process to heat the store), lower materials and installation costs, and lower operating, maintenance, and electricity costs.[14] While CO_2 transcritical systems cost around 11 percent more than conventional systems, the added cost is estimated to be repaid within three years. In 2012, Sobeys made CO_2 transcritical technology a national standard for all its new stores in Canada.[15] Convenience stores using the technology in Japan have achieved 10–26 percent energy savings.[16]

- Coca-Cola uses CO_2 in 1 million HFC-free coolers and aims to purchase only CO_2-based equipment by 2015.[17] Because of its transition to CO_2-based technology for new equipment, Coca-Cola has improved its cooling equipment energy efficiency by 40 percent since 2000, and reduced their direct greenhouse gas emissions by 75 percent.[c,18]

- Supermarkets in Europe are increasingly adopting “cascade” systems, in which a small HFC- or HFO-charged loop cools a CO_2 loop, combining high energy efficiency and smaller HFC charge size (i.e., the amount of chemical the system uses).[19] Supervalu started using this type of system in 2012 at one of its supermarkets in California and found that its total greenhouse gas impact, including recovery, losses, leakage, and energy consumption, was 84 percent lower than a comparable HFC-based system.[20]

- Coolers introduced by PepsiCo, Red Bull, Heineken, and Ben & Jerry’s are based on hydrocarbons including propane (R-290) or isobutane (R-600a). These companies combined have more than 600,000 units in use today and have seen energy efficiency improvements from 10 to 20 percent or even greater.[21]

- Centrifugal chillers (used to cool buildings like hotels, schools, healthcare facilities, and other commercial buildings)[22] employing low-GWP refrigerants HFO-1234ze and HFO-1233zd are available and extensive studies have validated their high performance in these applications.[23] For example, Trane just announced a line of new HFO chillers that have 10 percent higher efficiency than the “next best chiller available.”[24]

- The Consumer Goods Forum, a CEO-level organization formed in 2009 of 400 global consumer goods manufacturers and retailers with combined revenue in excess of $2.8 trillion, has agreed to begin phasing out HFC refrigerants in 2015 and replacing them with non-HFC refrigerants.[25]

b. The United Nations Environment Programme defines transcritical CO_2 systems as: “Refrigeration systems that use CO_2 as a primary refrigerant...In transcritical CO_2 refrigeration systems, CO_2 is the sole refrigerant, evaporating in the subcritical region and rejecting heat at temperatures above the critical point in a gas cooler instead of a condenser.” (See United Nations Environment Programme and Climate and Clean Air Coalition, 2014).

c. Note, CO_2 transcritical technology has temperature limitations and works most efficiently in cold to moderate climates.

OPPORTUNITIES FOR SCALE

According to EPA, these cases are not unusual. In a recent analysis, it found that the nation could reduce annual consumption of HFCs by 20 percent below business-as-usual estimates in 2020, and 42 percent in 2030 through alternatives that pay for themselves over the life of the equipment.[26] This is largely the result of considerable technological progress over the past several years to make low-GWP alternatives available. Examples of these cost-effective opportunities for refrigeration and air conditioning (the largest consumers of HFCs) are shown in Table 5.1.

Table 5.1 | **Examples of the Abatement Options for Refrigeration and Air Conditioning Applications in the United States**

ABATEMENT OPTION	COMMENT
More efficient HFC-134a systems for light-duty motor vehicle air conditioners	Leak reductions and greater efficiency decrease direct emissions and lead to lower fuel consumption.
HFO-1234yf in light-duty motor vehicle air conditioners	HFOs (including HFO-1234yf) have begun to replace the higher-GWP HFC-134a in the United States and the European Union, and are now found in more than 1 million vehicles worldwide. The European Union banned HFC-134a beginning in 2017. A U.S. ban of HFC-134a for passenger vehicles is proposed for 2021 models.
More efficient HFO-1234yf systems in light-duty motor vehicle air conditioners	Leak reductions and greater efficiency decrease direct emissions and lead to lower fuel consumption.
Distributed systems in large retail food refrigeration systems	Reduced refrigerant charge size and lower leak rates with comparable performance and costs. Significant reduction in climate impact. Further reductions can be achieved by using lower-GWP HFO blends.
HFC secondary loop and/or cascade systems in new large retail food refrigeration systems	Technology is proven: reduced refrigerant charge and lower leak rates at comparable performance and cost. Further reductions can be achieved by using HFOs and lower-GWP HFO blends.
Ammonia (NH_3) or hydrocarbon secondary loop and/or cascade systems in large retail food refrigeration systems	Flammability and toxicity concerns have limited adoption. Comparable performance but up-front costs may be higher.
CO_2 transcritical systems in large retail food refrigeration systems	Good performance in cool climates, but lower efficiencies in moderate to warmer climates. Up-front costs and maintenance may be higher.
Reduced GWP refrigerants in large new retail food refrigeration systems	Use of lower-GWP HFCs or HFO blends can reduce GWP by more than 50 percent while reducing energy consumption.
Retrofits of R-404A systems in large retail refrigeration food systems	Potential to reduce direct GWP by about 50 percent while reducing energy consumption. Proven technology. Several commercial products available.
Low-GWP refrigerants in small retail food refrigeration systems	CO_2, HCs, and HFOs are being introduced in vending and small retail units. Flammability regulations limit charge size.
Hydrocarbons in window units and dehumidifiers	Small charge sizes and equipment modifications may allow safe use.

Table 5.1 | **Examples of the Abatement Options for Refrigeration and Air Conditioning Applications in the United States (continued)**

ABATEMENT OPTION	COMMENT
R-32 (difluoromethane) or HFOs in unitary air conditioners and packaged terminal air conditioners/packaged thermal heat pumps	R-32 is being introduced in small mini-split air conditioning systems. Safety evaluations are underway for larger systems. HFO-based blends are also being evaluated.
Microchannel heat exchangers in small or medium air conditioning systems	Potential for charge-size reduction. Some adoption currently underway.
Low-GWP refrigerants in chillers	Multiple HFO options available for direct expansion chillers, centrifugal and screw chillers. HCs and ammonia use are also possible for certain industrial applications.
Ammonia or CO_2 in large refrigeration systems	Ammonia is commonly used in certain segments such as cold storage warehouses and food processing plants. Toxicity, safety, and cost may limit applications.
Refrigerant recovery at disposal	Rising cost of refrigerants may drive increased recovery.
Refrigerant recovery at servicing	Rising cost of refrigerants may drive increased recovery.
Leak repair in all systems	Increased cost and awareness driving focus on leak reduction.

Source: U.S. Environmental Protection Agency, September 2013, "Global Mitigation of Non-CO_2 Greenhouse Gases: 2010 – 2030, Section IV: Industrial Processes," accessible at http://www.epa.gov/climatechange/Downloads/EPAactivities/MAC_Report_2013-IV_Industrial.pdf; Thomas Morris, director of commercial development, Honeywell, personal communication, July 23, 2014.

EMERGING OPPORTUNITIES

While options are available to reduce the majority of HFC emissions across most major source categories today, more technologies are in the pipeline and are expected to be available within the next five years.[27] For example, Honeywell recently announced plans to expand manufacturing of HFO refrigerants, blowing agents, and aerosol propellants in the United States,[28] and Arkema has announced it will construct HFO production facilities.[29] DuPont is producing HFOs and is working on a new foam expansion agent based on HFO technology, as well as various HFO products for refrigeration and air conditioning applications.[30] As HFO production scales up, costs for these low-GWP alternatives are anticipated to decline. This would likely result in more widespread use of these alternatives as well as development of more new technology, which could drive prices even lower. For example, once Heineken started purchasing HFC-free coolers at a large scale, their cost dropped by 15 percent. Now the main barriers they face to more widespread use of the new technology are legal barriers, such as the need for approval of HFC alternatives, rather than cost barriers.[31]

This would not be the first time that the industry innovated to reduce its environmental impact. With the signing and subsequent implementation of the Montreal Protocol in 1989, industry began phasing out ozone-depleting CFCs. The Protocol drove technological development and investment in a new generation of air conditioning and refrigeration equipment, leading to significant benefits to public health and the environment while producing lifetime savings for consumers.

ARC Research Consultants estimates savings of $1.8 trillion in global health benefits and $459 billion in avoided damages to agriculture, fisheries, and materials that would have otherwise resulted from increased depletion of the ozone layer (both cumulative estimates from 1987 to 2060).[32] Meanwhile, the phase-out of ozone depleting substances also reduced greenhouse gas emissions by a net 135 billion metric tons of CO_2 equivalent from 1990 to 2010 (or about 11 billion metric tons of CO_2 equivalent per year), according to a United Nations Environment Programme (UNEP) study. This net annual greenhouse gas savings is about five times higher than the Kyoto Protocol's annual global emissions reduction target for 2008–12 for all greenhouse gases.[33] Note that this figure is likely even higher, as it does not include the energy and greenhouse gas savings from using more efficient equipment.[34]

EPA reports that the phase-out led to substantial lifetime savings through reduced energy use and reduced operation and maintenance costs, as well as improved consumer comfort.[35] Consumers globally were not faced with higher prices for new products, and some of the new products were cheaper to maintain than the conventional equipment because of higher efficiencies, product quality, and reliability.[36] One study noted that by the mid-1990s "virtually all of the global reductions in CFC use had come at little or no cost to consumers."[37] In addition, by 2000, CFCs were phased out of 45 percent of existing chillers (large air conditioning units for buildings), which reduced energy use by almost 7 billion kilowatt hours per year, amounting to $480 million annual savings from new equipment by 2000, according to the Air-Conditioning, Heating, and Refrigeration Institute.[38]

REMAINING CHALLENGES

While alternatives are available today, with more expected to become available in the near future, achieving continued deep reductions of high-GWP HFCs will require continued technological progress and regulatory responsiveness, and may require transitioning to alternatives that will not pay for themselves in the short term.

Continued technological progress is needed to develop alternatives for a variety of applications—such as household refrigerators and room air conditioning units—while continuing to meet strict standards for safety and performance, including efficiency and durability.[d, 39]

Hydrocarbon alternatives offer the appeal of very low global warming potentials (e.g., propane has a GWP of 3). The main challenge is that their flammability risk may make them unsuitable for certain uses. However, after extensive testing, EPA has found that some hydrocarbons can be effective and safe in certain household applications, provided the charge size remains small.[40]

In the meantime, other alternatives can reduce the GWP of the refrigerants used in these products by about a factor of 10—from the thousands to the hundreds. For example, Honeywell is working on low-GWP HFO alternatives for stationary air conditioning units that provide energy efficiency benefits, reduce costs, and meet industry standards for safety and performance.[41] In addition, alternatives for commercial refrigeration are being evaluated. Oak Ridge National Laboratory found that N-40 (a highly efficient low-GWP refrigerant in supermarket refrigeration) shows considerable increases in energy efficiency and reductions in environmental impact.[42] Honeywell notes N-40 comes without flammability issues.[43]

It can take several years before new refrigerants are included in commercial products. New chemicals may have different properties than their high-GWP counterparts, and may require development of new equipment. In addition, new chemicals must be tested for safety, health, and environmental impacts under EPA's Significant New Alternatives Policy (SNAP) program, and some may require revisions to building codes.[e, 44] The more quickly EPA can fulfill its mission of properly testing new chemicals, the more quickly these alternatives can make it to market, reduce GHG emissions, and allow product developers to turn a profit on their innovations.

Ultimately, achieving deep GHG reductions related to HFC use may require the United States (and likely other developed countries) to go beyond applications that already save costs over the life of the equipment unless new chemicals enable cost saving reductions in GHG emissions for additional product categories. The upside is that using more expensive chemicals could encourage

d. Previous reports indicated that the preferred low-GWP refrigerant alternative for personal vehicles, R1234yf, may have flammability issues. However, EPA and scientists have worked to further understand and address these issues. In fact, EPA found that R1234yf ignited only when significant modifications to vehicle hardware and controls were made. In another case, it was found that the air conditioning systems on some vehicles ruptured during impact, increasing the risk of refrigerant flammability; however, some manufacturers already design these systems to avoid leakage after impact (See Andrew Marsh, February 2013, and Fred Sciance, October 2013). In March 2014, scientists found that R1234yf does not pose any serious safety risks, and nine vehicles are already using this new refrigerant in North America. (See EurActiv.com and Reuters, March 2013, and Elliot Maras, January 2014).

e. Note, in investigating the mitigation potential of HFC use, EPA examined technologies available today and noted that its analysis "does not explore new equipment abatement options for all refrigeration and AC equipment types, although such options may exist." Therefore, EPA's estimate that the United States can lower HFC emissions over 40 percent from what would otherwise be emitted in 2030 entirely through measures that come at a negative or break-even price today presumably includes only those technologies that have addressed the remaining issues discussed in this section (See U.S. Environmental Protection Agency, September 2013).

equipment owners to reduce leakage rates, and to employ chemical capture and recycling that would help improve the overall costs and climate benefits.

BRINGING THESE OPPORTUNITIES TO SCALE

Although a number of companies already use low-GWP technologies, in many cases realizing cost and/or energy savings, uptake of these alternatives has been slow. If left unchecked, consumption of high-GWP gases is expected to continue to grow considerably. This suggests that new standards are ultimately required to realize the economy-wide cost savings possible from phasing out certain uses of high-GWP HFCs, and to drive continued technological process.

International momentum toward phasing down high-GWP HFCs appears to be building. The proposed North American amendment to the Montreal Protocol, which would reduce HFC consumption 85 percent by 2035 compared with 2008–10 levels,[45] is supported by more than 100 nations.[46] Several key countries that had opposed the amendment started to change course in 2013. For example, China, which was previously opposed, released a joint statement with the United States in June 2013 in which the two countries agreed to "work together and with other countries through multilateral approaches that include using the expertise and institutions of the Montreal Protocol to phase down the production and consumption of HFCs."[47] As part of a September 2013 agreement, leaders from 26 nations—including countries like India and Brazil, which have historically been hesitant to commit to phasing down the use of HFCs— expressed their support for similar action,[48] though India has since continued to criticize the proposal.

A number of producers and consumers of HFCs have come out in support of a global phase-down. For example, the Alliance for Responsible Atmospheric Policy, an industry coalition of about 100 manufacturers and businesses that rely on HCFCs and HFCs, supports a planned, orderly global phase-down of high-GWP substances, as well as action to improve energy efficiency, leakage reduction, and recovery/reuse or destruction at end-of-life.[49] DuPont, which manufactures HFCs and also develops their replacements, is also actively supporting the North American proposal to build on the outstanding success of the Montreal Protocol.[50]

Despite this progress, the Montreal Protocol has yet to be amended. Therefore, countries are beginning to take action at the national level. For example, the European Union's mobile air conditioning and F-gas directives are creating transitions to low-GWP refrigerants in various end use sectors[51] and Japan is also developing HFC regulations.[52] In the United States, EPA has started offering incentives under its light-duty vehicle greenhouse gas regulations that encourage the adoption of lower-GWP automobile air conditioning refrigerants as well as air conditioning systems with lower leakage.[53] In addition, EPA has adopted standards to control HFC leakage from air conditioning systems in pickups, vans, and combination tractors under its medium- and heavy-duty GHG regulations.[54]

While the necessary international consensus has not yet emerged, the United States should continue to work to achieve an international phase-down of HFC consumption through amendments to the Montreal Protocol. In the meantime, there are options to drive GHG emissions reductions through win-win opportunities in the United States. Specifically, we find that:

- EPA should continue to take action domestically under its Significant New Alternatives Policy program (SNAP) through Section 612 of the Clean Air Act. EPA should finalize its proposed rule to delist some uses of high-GWP HFCs and continue to phase down HFCs where safer, cost-effective alternatives exist, including vehicle air conditioning, commercial refrigeration like supermarkets and vending machines, plastic foam products, and consumer aerosols. EPA estimates that the SNAP phase-down rule will reduce emissions by 31 to 42 million metric tons of CO_2e in 2020 (a 15 to 20 percent reduction in projected business-as-usual HFC emissions).[55] This rule could capture nearly all (99 percent) of the negative or net-zero cost opportunities identified.[f, 56]

f. EPA's marginal abatement cost (MAC) curves, when applied to the most recent HFC emissions projections from the U.S. Department of State's Climate Action (CAR6) report, identified roughly 50 million metric tons CO_2e and 156 million metric tons CO_2e of potential abatement in 2020 and 2030 from these four main HFC uses, respectively, at a negative or break-even price. This amounts to 99 percent of the total negative or zero-net cost HFC abatement identified for both years (See U.S. Environmental Protection Agency (EPA), September 2013, and U.S. Department of State, 2014).

- Ultimately, new chemicals will be needed to continue driving deep reductions in the use of high-GWP HFCs. EPA should work toward ensuring that the alternatives development process moves swiftly, and that new chemicals are quickly, yet thoroughly, tested for their safety and performance. EPA should also finalize its proposed rule to list new alternatives and continue evaluating and approving appropriate low-GWP alternatives.

- EPA should also extend the servicing and disposal of air conditioning and refrigeration equipment requirements for HCFCs and CFCs (under section 608 of the Clean Air Act) to HFCs as well as increase initiatives for HFC reclamation and recycling to ensure that fewer virgin HFC compounds are used until they are able to be phased down.[g, 57]

- Over time it may also be appropriate to implement a flexible program to reduce emissions of high-GWP HFCs either by EPA under Section 615 of the Clean Air Act or via Congressional legislation, as the flexibility provided by these programs could allow for deeper reductions in a cost-effective manner.

g. The Alliance for Responsible Atmospheric Policy recently petitioned the U.S. EPA to extend the rules on air conditioning and refrigerant management in section 608 of the Clean Air Act to HFCs (See Alliance for Responsible Atmospheric Policy, January 2014). This action is also included in the proposed Senate bill, the Super Pollutants Act of 2014 (See "Super Pollutants Act of 2014").

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ABOUT WRI

WRI is a global research organization that spans more than 50 countries, with offices in the United States, China, India, Brazil, and more. Our more than 450 experts and staff work closely with leaders to turn big ideas into action to sustain our natural resources—the foundation of economic opportunity and human well-being.

Our Challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision
We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

ABOUT THE NEW CLIMATE ECONOMY

The Global Commission on the Economy and Climate is a major new international initiative to examine the economic benefits and costs of acting on climate change. Chaired by former President of Mexico Felipe Calderón, the Commission comprises former heads of government and finance ministers, and leaders in the fields of economics, business and finance. It was commissioned in 2013 by the governments of seven countries: Colombia, Ethiopia, Indonesia, Norway, South Korea, Sweden and the United Kingdom. The Commission has operated as an independent body and, while benefiting from the support of the seven governments, has been given full freedom to reach its own conclusions.

The New Climate Economy (NCE) is the Commission's flagship project. It provides independent and authoritative evidence on the relationship between actions which can strengthen economic performance and those which reduce the risk of climate change. It aims to influence global debate about the future of economic growth and climate action.

More information is available at www.newclimateeconomy.net.