Energy Efficiency in the United States: 35 Years and Counting

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Neal Elliott coordinates ACEEE's overall research efforts. He is an internationally recognized expert and author on energy efficiency, energy efficiency programs and policies, electric motor systems, combined heat and power (CHP) and clean distributed energy, and analysis of energy efficiency and energy markets. A frequent speaker at domestic and international conferences, he joined ACEEE in 1993.

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Executive Summary

INTRODUCTION

In 1973, the Arab members of the Organization of Petroleum Exporting Countries (OPEC) imposed an oil embargo that increased energy prices and spurred efforts to conserve energy and improve energy efficiency in the United States and worldwide. In 1980, energy efficiency researchers formed the American Council for an Energy-Efficient Economy (ACEEE), whose mission is to act as a catalyst to advance energy efficiency policies, programs, technologies, investments, and behaviors in order to help achieve greater economic prosperity, energy security, and environmental protection. From our vantage point as we turn 35 this year, we believe that energy efficiency has been a major success story, providing net benefits for households, businesses, the US economy, our security, and the environment. Over those 35 years we have learned many lessons and accomplished many goals, which this paper highlights. But just as important, we look ahead at possible and recommended pathways for the next 35 years, through 2050.

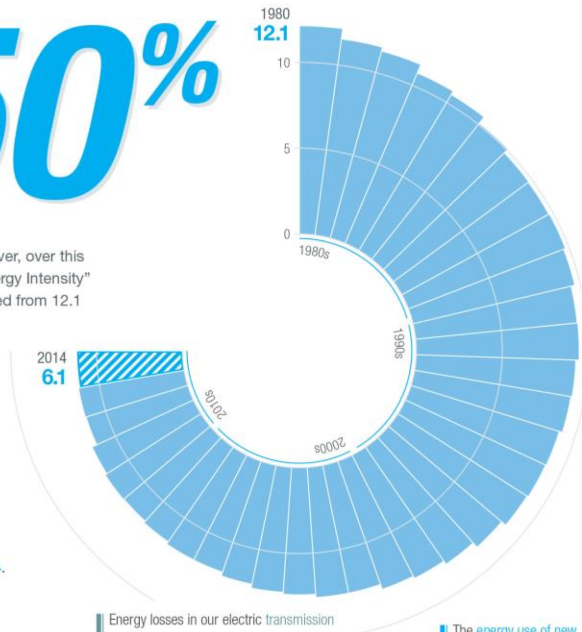
THE PAST 35 YEARS

From 1980 to 2014, US energy use increased by 26%. However, over this same period, US gross domestic product (GDP) increased by 149%. A common approach for looking at these two variables together is to examine energy intensity, defined as energy use per real dollar of GDP. Energy intensity declined from 12.1 thousand Btus per dollar in 1980 to 6.1 in 2014, a 50% improvement. The improvement in energy intensity averaged 2.0% per year over this period. Energy efficiency was an important contributor to this improvement. However efficiency gains were also partly due to shifts in the US economy away from some energy-intensive segments (e.g., heavy manufacturing). Based on available data, we conservatively estimate that about 40% of the improvement in energy intensity was due to structural shifts, and 60% was due to efficiency improvements. Energy efficiency savings in 2014 were about 58 quadrillion Btus (a quadrillion is 10 to the 15th power), saving US consumers and businesses about $800 billion in 2014 (based on the average 2014 energy price). This comes to about $2,500 per capita.

Efficiency investments and savings also generate jobs, including direct jobs installing efficiency measures, indirect jobs upstream in the supply chain, and jobs induced as energy bill savings are spent elsewhere and multiply through the economy. Energy savings can also help to drive modest overall growth in the US economy.

Further, energy efficiency savings over the past 35 years have contributed to our nation's security and improved our environment. For example, looking specifically at petroleum, imports accounted for 33% of US crude oil use in 1983 (the recent low point), increasing to 67% in 2006 before declining to 44% in 2014. Contributors to this drop included the Great Recession of 2007–2010, growing domestic energy production, and improvements in energy efficiency, particularly vehicle fuel economy. Reductions in energy consumption also mean reduced emissions of fuel-combustion by-products, including sulfur dioxide and nitrogen oxides (contributors to acid rain and smog), mercury and other toxic metals (contributors to health problems), and carbon dioxide (the predominant greenhouse gas).

Energy Intensity Has **Decreased** by 50% Since 1980

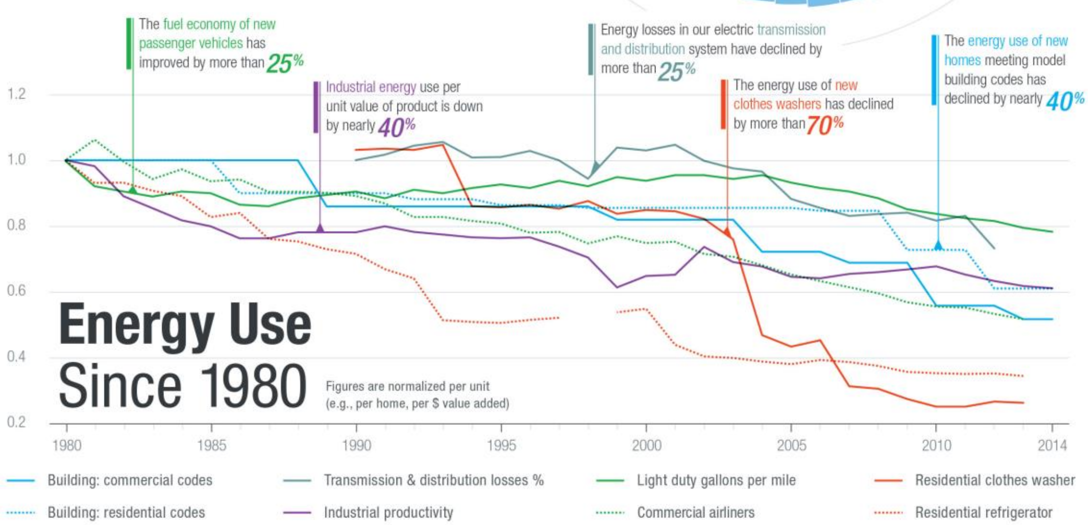


What is Energy Intensity?

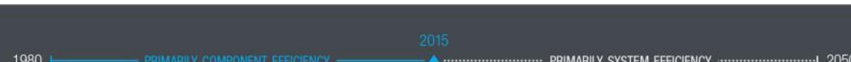
From 1980 to 2014, US energy consumption increased by 26%. However, over this same period, US gross domestic product (GDP) increased 149%. "Energy Intensity" is defined as energy use per real dollar of GDP. Energy intensity declined from 12.1 thousand Btu per dollar in 1980 to 6.1 in 2014.

What does this savings mean for the US economy?

US consumers and businesses conservatively saved $800 billion in 2014 (based on the average 2014 energy price). Dividing by the US population, **energy efficiency saved about $2,500 per capita in 2014**.



ACEEE
American Council for an Energy-Efficient Economy



Founded in 1980 in the aftermath of a major oil crisis, ACEEE has advanced energy efficiency policies, programs, and investments for 35 years. In that time, we have affected change in appliance and equipment standards, building codes, utility- and government-run programs, vehicle fuel efficiency, and other areas, improving energy efficiency in every sector of the economy.

As a nation, we've made great progress on improving component energy efficiency, saving energy in appliances, equipment, and vehicles. While that work must continue, technology is evolving that will allow us more control over systems. Systems efficiency will be more than the sum of its parts, as networked components in buildings' environmental controls, factory assembly lines, and transportation networks will all work together to save more energy than would be possible by themselves alone. The result will be a stronger economy, more control over our energy future, and a cleaner environment.

In 2014 US carbon dioxide emissions totaled 5,404 million metric tons (MMT), 10% below 2005 levels. Energy efficiency plays a large and critical role in US government plans to reduce 2020 emissions by 17% below 2005 levels.

These overall improvements are a result of many small and large gains throughout our economy, including improvements to equipment, new and existing buildings, industrial processes, vehicles, airplanes, and the electric grid. Some of these are illustrated in figure ES1. To note just a few examples, since 1980:

- The energy use of new clothes washers has declined by more than 70%.
- The energy use of new homes per square foot has declined by nearly 20%.
- Industrial energy use per unit value of product is down by nearly 40%.
- The fuel economy of passenger vehicles has improved by more than 25%.
- Energy losses in our electric transmission and distribution system have declined by more than 25%.

Many factors have driven these efficiency gains, including market forces, policy impacts, and the interplay between the two. For example, utility energy efficiency programs have grown in popularity since efficiency investments generally cost less than new generating plants per unit of electricity. Appliances have improved dramatically due to the combined effects of federal and state appliance efficiency standards, the voluntary ENERGY STAR® labeling program recognizing products of above-average efficiency, utility energy efficiency programs, and tax incentives that encourage manufacturers to develop more efficient products. Stricter building codes, along with ENERGY STAR home certification, utility programs, and growing interest in green buildings in some market segments have driven improvements in new buildings. Industrial efficiency gains have been spurred by new technical developments, better energy management practices, and a desire to reduce costs so as to increase profits. Other major efficiency drivers have included vehicle efficiency standards, federal research and development (R&D) efforts (resulting in some important new products), and growth in private energy service companies that invest in and guarantee savings in exchange for a share of the financial benefits. On the other hand, energy prices have not been a major driver; after accounting for inflation, energy prices today are similar to or less than those of 35 years ago.

THE NEXT 35 YEARS

While much progress has been made, there are large and cost-effective energy efficiency opportunities that, by 2050, can collectively reduce energy use by 40–60% relative to current forecasts. Major areas of opportunity include:

- Better systems integration, including through "intelligent efficiency," i.e., the use of sensors, controls, big data, and computer chips to monitor and control energy use in real time
- Improvements to the many types of equipment (such as computers, televisions, and elevators) that collectively account for growing miscellaneous energy loads
- Evolution of building design to yield zero net energy and ultra-low-energy buildings
- Industrial process improvements

- Increased use of advanced vehicles, including electric, hybrid, and self-driving vehicles
- Taking building energy retrofits to a much higher level, including more widespread and deeper retrofits for larger savings per building
- Better efficiency of the electric grid through expanded use of combined heat and power systems, greater power plant efficiency, reduced transmission and distribution losses, expanded use of other distributed generation resources, and improved grid control and integration
- Promotion of sustainable development and transportation patterns
- Initiatives to change wasteful energy-using behaviors among consumers and businesses

PATHWAY TO AN ENERGY-EFFICIENT FUTURE

If we aggressively pursue these efficiency opportunities, we can roughly double the rate of efficiency improvement in the next 35 years relative to the past 35 and reduce 2050 energy use to half of current forecasts. To do this we need to take our efforts to promote energy efficiency to a new level, which means both doing it better and doing it smarter. Our efforts should:

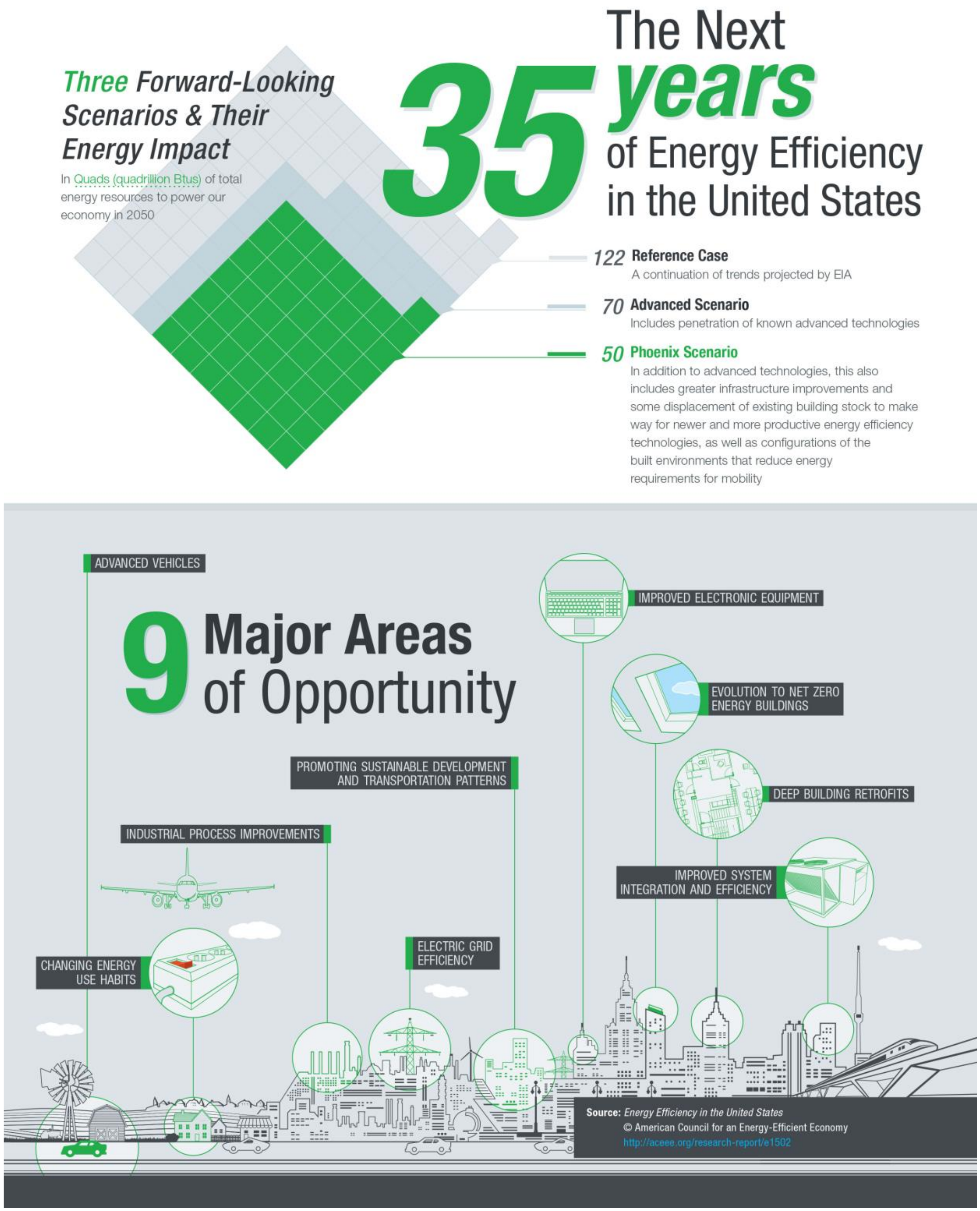
- Harness and transform markets
- Make efficiency a key strategy for the utility of the future
- Expand federal, state, and local policy efforts

Markets

Large savings can often be achieved by understanding, harnessing, and transforming important markets. The market is a powerful force and can often be used to encourage efficiency actions and investments. We need to increase demand for efficient goods and services, develop and implement market transformation strategies, and expand the availability of financing.

Educated consumers (including industrial customers) will choose to save energy and money and to enjoy the many other benefits of energy efficiency. Many consumers do not understand that there often are large differences in operating costs among different homes, buildings, and pieces of equipment. Providing consumer information on what is possible, including the relative energy use of different options, can sometimes lead to more efficient choices. For example, appliances and other types of equipment can be rated and labeled in an easy-to-understand way that facilitates energy-saving comparisons. Similarly, a growing number of cities and states have adopted ordinances requiring that the energy use of commercial buildings and/or homes be disclosed to potential purchasers or renters so they can make informed decisions. Consumers can also be motivated by the many co-benefits of energy efficiency in addition to energy savings. For example, good, efficient lighting in schools can improve student scores; in stores it can improve sales.

For each major area of opportunity in the next 35 years, we must develop multipronged initiatives to address barriers in specific markets and eventually make efficient products and services normal practice.


The Next 35 years of Energy Efficiency in the United States
Three Forward-Looking Scenarios & Their Energy Impact
In Quads (quadrillion Btus) of total energy resources to power our economy in 2050
122 Reference Case
A continuation of trends projected by EIA
70 Advanced Scenario
Includes penetration of known advanced technologies
50 Phoenix Scenario
In addition to advanced technologies, this also includes greater infrastructure improvements and some displacement of existing building stock to make way for newer and more productive energy efficiency technologies, as well as configurations of the built environments that reduce energy requirements for mobility
9 Major Areas of Opportunity
ADVANCED VEHICLES
IMPROVED ELECTRONIC EQUIPMENT
EVOLUTION TO NET ZERO ENERGY BUILDINGS
PROMOTING SUSTAINABLE DEVELOPMENT AND TRANSPORTATION PATTERNS
DEEP BUILDING RETROFITS
INDUSTRIAL PROCESS IMPROVEMENTS
IMPROVED SYSTEM INTEGRATION AND EFFICIENCY
ELECTRIC GRID EFFICIENCY
CHANGING ENERGY USE HABITS
Source: Energy Efficiency in the United States
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Market transformation efforts will need to engage in each stage of market development and include:

- Research, development, and demonstrations (RD&D) in order to advance new energy-saving technologies and practices and address the limitations of existing technologies and practices
- Market diffusion activities to grow market share
- Execution of a transition strategy to move through the latter stages of the market diffusion curve.

Building codes or equipment efficiency standards are common transition strategies. Or the market benefits may be substantial enough, once these benefits are demonstrated, that the technology or practice takes off on its own. Once a transition strategy is executed, the process often begins again, with new, even more efficient technologies and practices being developed and helped up the market diffusion curve.

Easy-to-access financing can enable energy efficiency investments among consumers and businesses that are capital constrained. Thus an important step on the pathway to an energy-efficient future is to improve the availability and usefulness of financing. In recent years, a variety of creative loan products have been receiving significant interest, including on-bill financing and property-assessed clean energy financing. States are establishing "green banks" to spearhead these and other strategies. And firms and organizations are looking at ways to standardize financing packages so that secondary markets can be established for energy efficiency financing, helping capital to flow to these loans. These mechanisms should be refined and promoted and additional creative new mechanisms developed.

Utilities

Energy efficiency programs operated by and under contract to utilities have saved substantial energy, and these savings are growing. But the utility industry is going through profound changes as sales growth slows and as distributed generation gains in importance. Utilities and utility regulators will need to reexamine utility business models, including the role of energy efficiency. In our opinion, new business models should support robust energy efficiency programs, as such programs provide valued services to consumers and help to minimize ratepayer costs. In some cases, utilities will embrace energy efficiency services on their own; in other cases, regulators will need to encourage efficiency efforts, for example by making energy efficiency results a factor in performance-based ratemaking. Rate design will also play a role; in the future, time-of-use rates are likely to predominate, and if structured well they can fairly allocate costs and encourage efficiency improvements.

Policies

Government has played a substantial role in promoting energy efficiency improvements. Successful policies—such as appliance, equipment, and vehicle standards; building codes; and policies promoting utility energy efficiency investments—should continue. These set an efficiency floor but also encourage equipment manufacturers and energy service providers to innovate so they can offer value-added goods and services, increase sales, and take advantage of the opportunities created by energy efficiency programs and policies. In addition, creative new policies should be developed, piloted, and, where successful, expanded. Much of the innovation is likely to come at state and municipal levels, where a variety of approaches can be tested before successful policies are moved to higher levels of government. States traditionally lead on utility regulation and building codes. In recent years, municipalities have also begun to step out, spurred by energy efficiency block grants provided under the American Recovery and Reinvestment Act of 2009 and by growing interest in sustainable and resilient cities. Decisions about the location and scale of development are primarily local, so municipalities and regional consortiums of municipalities need to lead on such issues as transportation and land use planning. Municipalities have been leading on some new policy areas, such as increasing transparency in building energy use and making communities more resilient so they can better weather natural and economic challenges.

The federal government plays a critical role in energy efficiency R&D, ENERGY STAR, and appliance and vehicle efficiency standards. It also supports updates to model building codes and provides funding and technical assistance to states and municipalities on code adoption and implementation. These activities should continue. The federal government can also identify the best state and local policies and help extend them around the country. In addition, the government generally leads on tax policy, and substantial opportunities exist to remove barriers and provide ramps to energy efficiency as part of tax reform.

Governments at all levels can also help in a few other areas such as data and analysis and greenhouse gas policy, both of which will help advance energy efficiency.

More broadly, there is a need to build political support for energy efficiency policies. Traditionally energy efficiency policies and programs have enjoyed broad, bipartisan support. But in recent years some policymakers have bristled at any suggestion of significant government involvement or expenditure, and the efficiency-related items the two parties can agree on have become more limited. Voters of all stripes still support energy efficiency, but more effort is needed to bolster the bipartisan support that energy efficiency has historically enjoyed. Continued research on the need for, and the effectiveness of, energy efficiency policies—and the substantial benefits, financial and otherwise, that accrue—is essential to this effort.

Conclusion

Energy efficiency has made great strides in the past 35 years, and we have learned many important lessons on how markets and policies can work together to advance it. Looking forward, we find opportunities to reduce 2050 energy use by half relative to a business-as-usual reference case. In order to harvest these large efficiency opportunities, we need to take our efforts to a higher level, improving overall energy productivity by more than 3% per year, up from the 2% annual average of the past 35 years. To do this we need to understand market barriers and transform markets by addressing each stage of the market diffusion curve. We need a broad set of specific strategies that build on the knowledge gained over the past 35 years. The challenges are many, but so are the benefits in terms of lower energy bills, a stronger economy, improved energy security, and a cleaner environment. The past has shown us what efficiency can do and it can guide us to even greater success in the future.

Introduction

In 1973, the Arab members of the Organization of Petroleum Exporting Countries (OPEC) imposed an oil embargo that increased energy prices and spurred efforts to conserve energy and improve energy efficiency in the United States and worldwide. In 1980, energy efficiency researchers formed the American Council for an Energy-Efficient Economy (ACEEE), whose mission is to act as a catalyst to advance energy efficiency policies, programs, technologies, investments, and behaviors in order to help achieve greater economic prosperity, energy security, and environmental protection. From our vantage point as we turn 35 this year, we believe that energy efficiency has been a major success story, providing net benefits for households, businesses, the US economy, our security, and the environment. Over those 35 years we have learned many lessons and accomplished many goals, which this paper highlights. But just as important, we look ahead at possible and recommended pathways for the next 35 years, through 2050.

This paper has three sections: a review of national energy efficiency trends over the past 35 years, an examination of the major factors that have driven these trends, and a look ahead at what we can do over the next 35 years. We emphasize energy efficiency, meaning a reduction in the amount of energy needed to deliver the same or more services, but at times we also include energy conservation (i.e., doing with less). The first section is data intensive, so readers more interested in explanations than data may want to skip to the summary of the first section, which begins on page 18.

The Past 35 Years

In this section we review data on energy use and energy efficiency trends over the 1980–2014 period. We begin with data on total national energy consumption and then discuss trends in the buildings, industrial, transportation, and utility sectors.

ENERGY INTENSITY

From 1980 to 2014, US energy use increased from 78 quadrillion Btus (quads) to 98 quads, an increase of 26%.[1] However, over this same period, US gross domestic product (GDP) increased by 149%. A common approach for looking at these two variables together is to examine energy intensity, defined as energy use per real dollar of GDP. Energy intensity declined from 12.1 in 1980 to 6.1 in 2014, a 50% improvement (units are thousand Btus per 2009 dollar) (EIA 2015a). This improvement in energy intensity averaged 2.0% per year over this period.

Energy efficiency was an important contributor to this trend. However the improvement was also partly due to shifts in the US economy away from some energy-intensive segments (e.g., heavy manufacturing). For example, Huntington (2009) examined energy productivity gains over the 1997–2006 period and estimated that 39% of the improvement during this period was due to structural shifts in the economy and 61% was due to intensity improvements within each of 65 sectors he examined. This implies that energy efficiency

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[1] A quadrillion is 10 to the 15th power.

improvements might have averaged about 1.2% per year (60% of the 2% per year discussed above).

Looked at another way, if energy intensity remained unchanged, in 2014 the United States would have used 195 quads. If we estimate that 40% of the improvement arose from structural change (rounding from Huntington's 39%, since these estimates are inexact), use would have been 156 quads with structural change alone.[2] Actual use was only 98 quads, implying efficiency-related savings of about 58 quads (see figure 1).

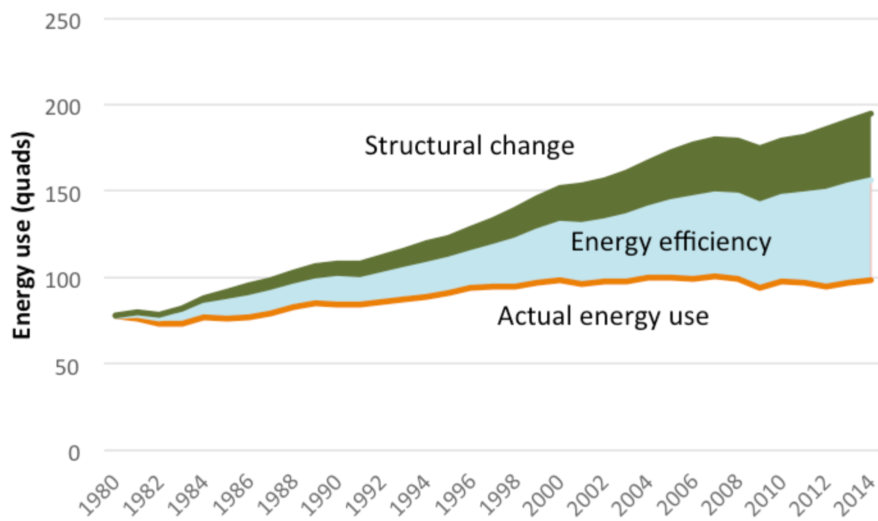

Figure 1. Energy use, 1980–2014: actual use and estimates of structural and efficiency impacts. *Source:* ACEEE analysis based on data in EIA 2015a and Huntington 2009.

BENEFITS TO THE US ECONOMY, OUR SECURITY, AND THE ENVIRONMENT

The large energy savings achieved have provided substantial economic, security, and environmental benefits.

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[2] Other researchers have also examined this issue. For example, as Huntington notes, Metcalf (2008) estimates that about one-quarter of the intensity improvement is due to structural shifts, while the US DOE, using a much broader definition of structural shift in its analysis of the 1985–2011 period (available at http://www1.eere.energy.gov/analysis/eii_total_energy.html), finds that about 60% of the improvement in energy per dollar GDP is due to structural shifts. Huntington also provides data indicating that since 1997, the share of intensity improvement attributable to structural change has grown larger. Based on these data points, our conservative estimate is that about 40% of the improvement is due to structural shifts. We use this figure to paint an overall picture, recognizing that it is approximate.

Economic Impacts

As discussed above, energy efficiency savings in 2014 were about 58 quads. Using the average 2014 energy price, this means that without energy efficiency we would have spent about $800 billion more on our energy bills in 2014—about $2,500 per capita.[3] Efficiency investments and savings also generate jobs, including direct jobs installing efficiency measures, indirect jobs upstream in the supply chain, and jobs induced as energy bill savings are spent elsewhere and multiply throughout the economy (ACEEE 2012). These energy savings can also help to drive overall growth in the economy, typically measured by GDP. We could find no good studies that retrospectively examine the impact of energy efficiency on GDP. However there have been many prospective studies (see Laitner and McKinney 2008 for a summary of many of these). In general these studies find that energy efficiency has a small but positive impact on GDP. The impact is small because the benefits of energy efficiency are partially offset by the fact that when less energy is used, the contribution of traditional energy supplies to GDP is reduced.

Security

US energy imports hit a low of 12 quads in 1983 and then climbed to a 2007 peak of 35 quads. Since then, imports have declined to 23 quads. Looking specifically at petroleum, imports accounted for 33% of US crude oil use in 1983, increasing to 67% in 2006 before declining to 44% in 2014 (EIA 2015a).[4] Contributors to this drop include the Great Recession of 2007–2010, growing domestic energy production, and improvements in energy efficiency, particularly vehicle fuel economy. Declining imports from unstable regions of the world improve our security.

Environment

Reductions in energy consumption mean reduced emissions of fuel combustion by-products, including sulfur dioxide and nitrogen oxides (contributors to acid rain and smog), mercury and other toxic metals (contributors to health problems), and carbon dioxide (the most prevalent greenhouse gas). In 2014 US carbon dioxide emissions totaled 5,404 million metric tons (MMT), 10% below 2005 levels (EIA 2015a). President Obama has established a target for 2020 emissions to be 17% below 2005 levels. Energy efficiency plays a large and critical role in the plan to meet this goal (Executive Office of the President 2013).

So far we have taken a very high-level view. In the following sections we examine trends in the residential, commercial, industrial, transportation, and utility sectors in more detail. The data generally show efficiency improvements throughout the 1980–2014 period, but for many of the variables the improvements have accelerated in recent years. Unless specifically noted, all data are for source energy use, meaning that energy losses at power plants associated with electricity consumption in each sector are incorporated into the consumption data for that sector.

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[3] $13.87 per million Btus; derived from EIA 2015d.

[4] These percentages are calculated by taking total petroleum imports and dividing by the sum of imports plus US field production.

BUILDINGS AND EQUIPMENT

The US Energy Information Administration (EIA) estimates that the buildings sector accounted for about 41% of total US energy consumption in 2014 (EIA 2015a). We use energy in buildings for heating, cooling, hot water, lighting, and many different types of appliances and equipment. Over the past 35 years there have been substantial improvements in building energy efficiency. We summarize key trends separately for the residential and commercial sectors.

Residential

Residential sector total energy use increased from 15.8 quads in 1980 to 21.5 quads in 2014, a rise of 37% (EIA 2015a). The increase in consumption has been driven partly by growth in the number of households, up 53% through 2014.[5] It has also been driven by growing house size: average living space per household in single-family detached homes rose from less than 2,200 square feet in 1980 to nearly 2,700 square feet in 2009 (the last year for which data are available), an increase of 23% (EIA 2015b). On the other hand, energy efficiency has helped reduce the consumption increase.

One useful metric for looking at overall trends is to examine energy consumption per household, as illustrated in figure 2. Energy use fluctuates from year to year due to weather, the state of the economy, and other factors. Still, broad trends emerge. Consumption per household declined in the 1978–1983 period, was roughly level through 2010 (with expected fluctuations), declined in 2011–2012, but rose somewhat in 2013 and 2014 as the effects of the Great Recession wore off.

[5] Total households rose from 80.8 million in 1980 to 123.2 million in 2014, according to the US Census Bureau. Data for 1980–2012 from http://www.census.gov/compendia/statab/2012/tables/12s0059.pdf; data for 2013–2014 from https://www.census.gov/hhes/families/data/households.html.

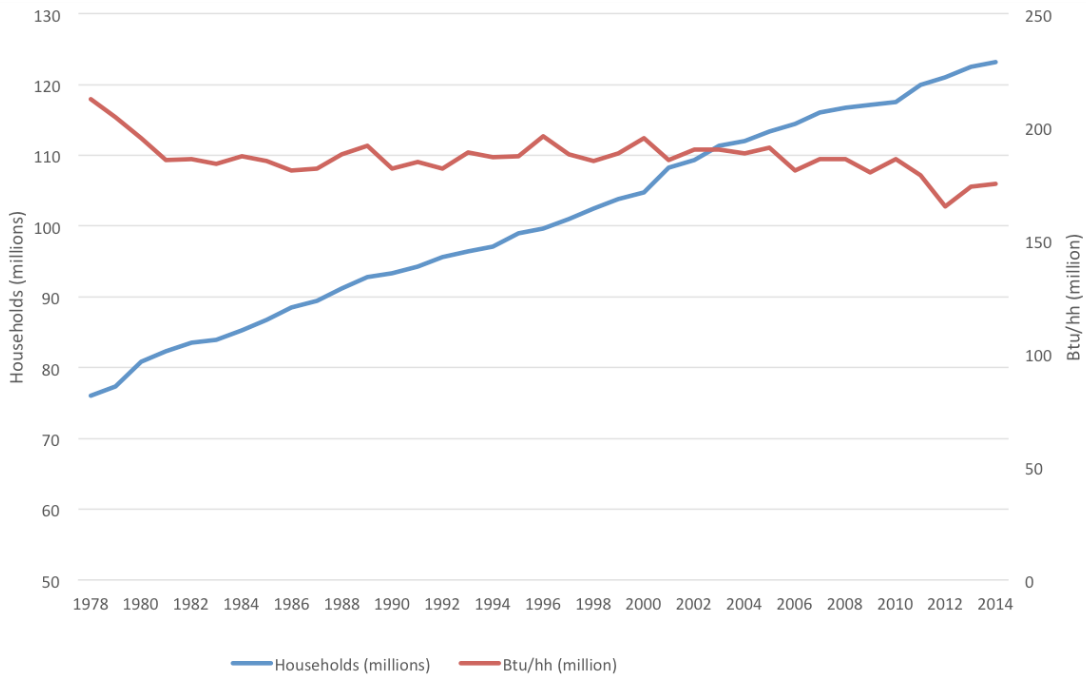

Figure 2. Average source energy consumption per household and number of households, 1978–2014. These figures include commercial energy sources such as electricity, natural gas, heating oil, propane, and wood. From 1989 on, they also include residential use of solar and geothermal energy. *Source:* ACEEE analysis based on data from EIA 2015a and US Census Bureau.

EIA (2015b) has conducted a more sophisticated analysis to tease out the impact of energy efficiency on household energy use relative to other factors such as the number of households, increasing home size, population shifts to the South and West, and changes in weather. The results are summarized in figure 3 and cover the period from 1980-2009. Energy efficiency is the primary contributor to the 37% decline in energy intensity shown in the figure. Much smaller contributions to declining energy use per household are regional population shifts (–2.7%), changes in the mix of housing types (–1.7%), and weather (–2.4%). These factors are offset by the growing number of homes (+33%, shown as "housing effect" in the figure) and the increase in home size (+20%). This analysis is based on site energy use (energy actually used in homes) and, unlike the other data we are summarizing in this section, does not include energy losses at power plants associated with the electricity used in homes. As a result, the EIA analysis does not show the full impact of growing electricity use for air-conditioning and household electronics.

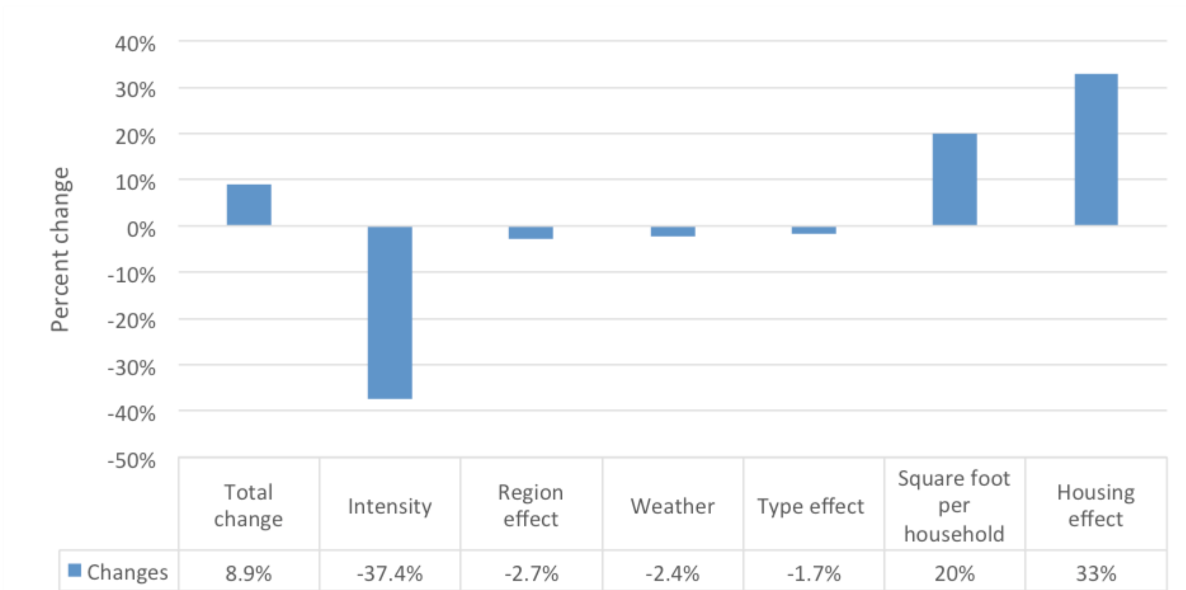

Figure 3. Deconstruction of change in total residential site energy consumption, 1980–2009. Unlike other data in this section, this analysis uses site energy and not source energy. Site energy use increased 9% over this period, while source energy use grew more than 30%. *Source:* EIA 2015b.

It is also helpful to look at household energy use as a function of when a home was built. Figure 4 summarizes these data for 2009. As can be seen, homes built in recent decades use less energy, with homes built in the first decade of the 21st century using 19% less energy per square foot than homes built in the 1970s. As discussed later, stricter building energy codes are likely a significant contributor to this improvement.

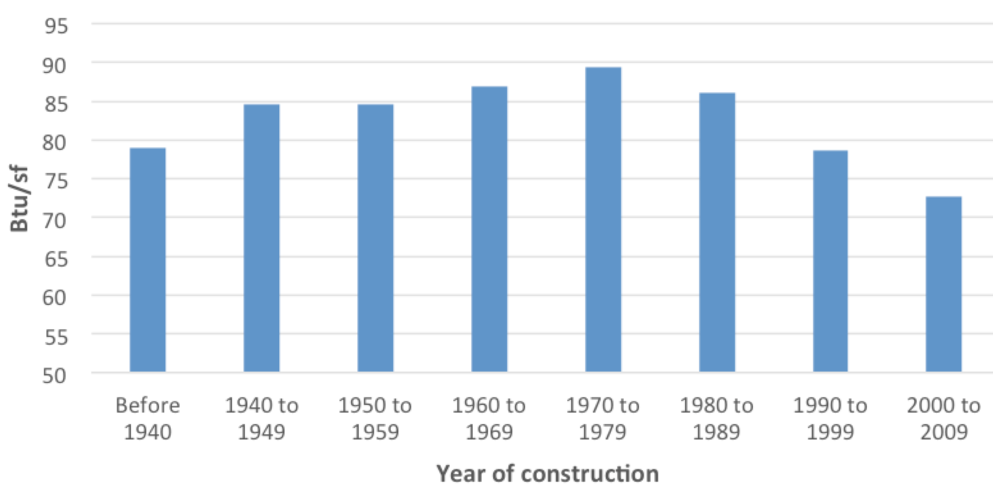

Figure 4. Energy intensity (source energy) in 2009 by housing vintage. *Source:* ACEEE analysis using data from EIA 2013a.

Finally, to complete our picture of efficiency improvements in the residential sector, it is useful to look at data on the energy efficiency of various major pieces of household equipment. Figure 5 shows the sales-weighted average energy efficiency of products sold each year as a fraction of the average efficiency of products sold in 1980. As can be seen, energy use reductions were about 18% for furnaces, nearly 50% for central air conditioners, about 65% for refrigerators, and nearly 75% for clothes washers.

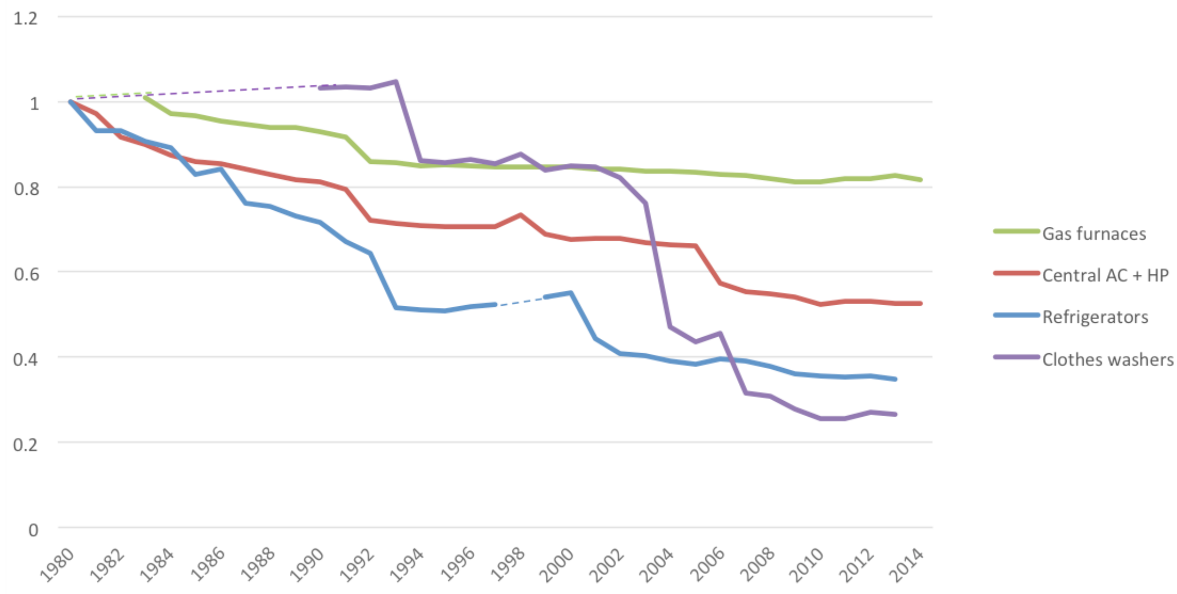

Figure 5. Relative average energy consumption of new appliances sold over the 1980–2014 period (2014 refrigerator and clothes washer data not yet available). ***Source:*** **ACEEE analysis of data from Air-Conditioning and Refrigeration Institute, Association of Home Appliance Manufacturers, Lawrence Berkeley National Laboratory, and confidential industry sources.**

Overall, many factors have affected residential energy use over the past 35 years, but energy use per household is down about 10%, despite the fact that homes are larger and contain many more energy-using devices. Energy efficiency—in new construction, lighting, heating and cooling equipment, and many major appliances—has been a major driver of this improvement.

Commercial

Commercial-sector energy use climbed substantially from 1980 to 2013, increasing from 10.6 to 18.0 quads on a source energy basis, a rise of 73%. This appears to have been driven primarily by an increase in commercial building floor area—up 70% from 1979 to 2012 (EIA 2015c). However, as shown in figure 6, while floor area has trended upward over time, energy use per square foot has gone up and down, peaking in the 1999–2003 period but declining since then.

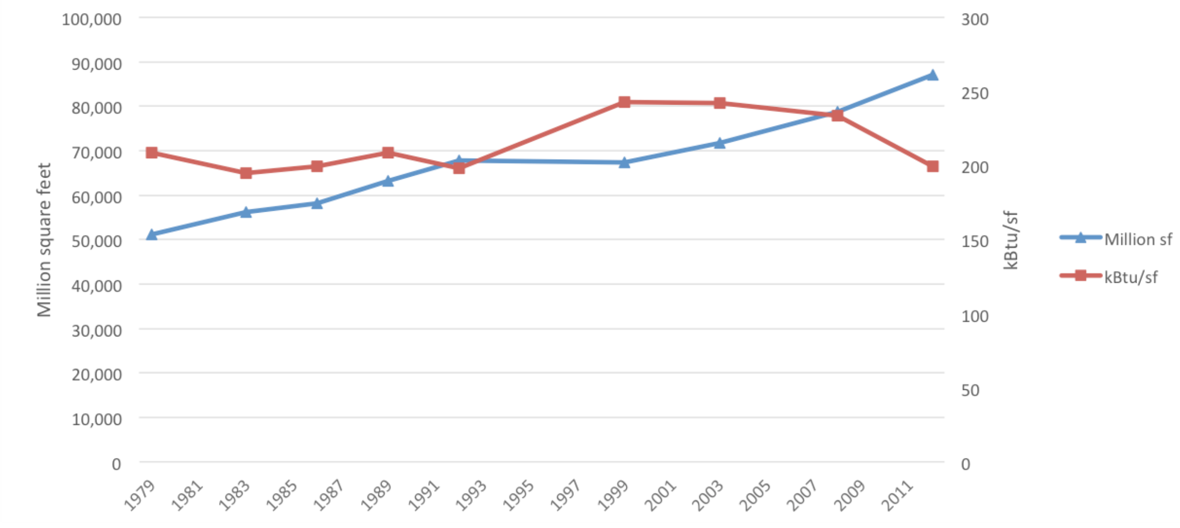

Figure 6. Commercial building floor area and energy consumption per square foot, 1979–2012. There are separate data points for 1999, 2003, and 2008, so the increase over this period cannot be due to a single data error. The recent decline is based on a single data point, for 2012; the next set of data will help us determine whether this 2012 data point is reasonable. Additional information about this issue, which relates to estimates of the total floor area of commercial buildings, can be found at http://www.eia.gov/consumption/commercial/data/archive/cbecs/cbecs2003/statistical_detail.html. *Source:* ACEEE analysis using data from EIA 2015a and EIA 2015c.

A somewhat similar trend took place for new commercial buildings, but more than a decade earlier. Energy use per square foot in 2003 was highest for buildings built during the 1980s and declined for ones that were built since then (figure 7). As discussed later, progressively tighter building codes for new construction and efficiency regulations on lighting and other equipment have likely been major drivers of these changes.[6]

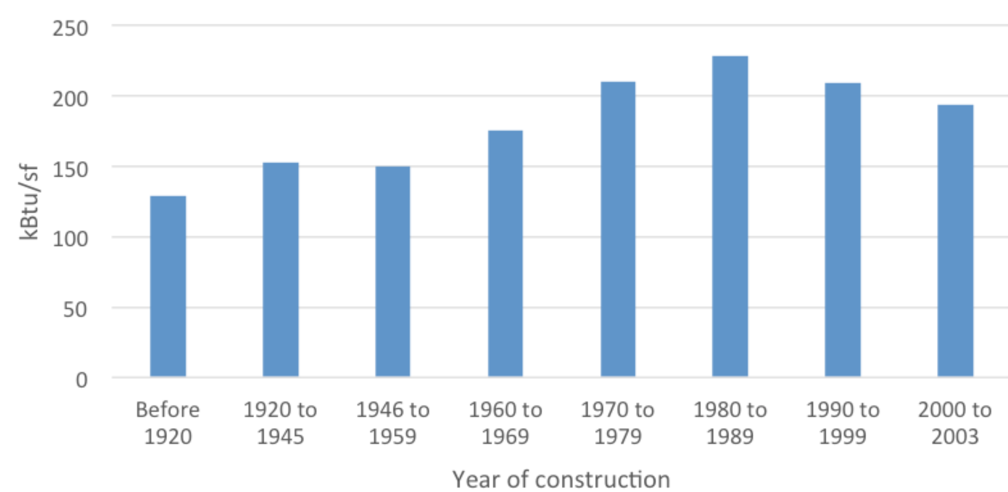

Figure 7. Energy use (source) per square foot in 2003 as a function of date of construction. *Source:* ACEEE analysis using data from EIA 2006.

[6] Unfortunately, data on construction since 2003 are not currently available, although data from the 2012 Commercial Building Energy Consumption Survey (CBECS) are scheduled to be released in late 2015.

Lighting and heating, ventilation, and air-conditioning (HVAC) are the two biggest energy uses in commercial buildings, accounting for about 60% of commercial building energy use in 2010 (DOE 2012). These end uses have seen substantial energy efficiency improvements in the past 35 years. For example, fluorescent tubes account for about 85% of commercial-sector lighting energy use (DOE 2012). In 1980 the most common fixture used 180 watts to power four tubes (40 W per tube plus an additional 20 W for an inefficient ballast). Today an efficient new fluorescent fixture uses around 52 W to light the same surface area, and more-efficient LED fixtures use around 32 W. These changes were made possible by improved lamps and ballasts, improved fixtures that direct a higher proportion of light to the work surface, and changes in work practices where lighting is now optimized for computer use and not, as was the case decades ago, for reading printed material that was often of poor quality.

Likewise, the energy efficiency of major types of HVAC equipment has also increased. Table 1 compares minimum heating and cooling efficiency requirements in the 1980 national model building code for commercial buildings with those in the 2015 version.[7] Many states have incorporated this model into their codes. Energy savings over this period range from about 15 to 40%, depending on the type of equipment.

Table 1. Efficiency of commercial heating and cooling equipment in ASHRAE standards, 1980 and 2015.

Appliance	Example	1980 efficiency	2015 efficiency	Savings
Rooftop packaged AC	10 ton	7.5 EER	12.9 IEER	~40%
Furnace		75% Ec	80% Ec++	~15%
Water-cooled chiller	300 ton	0.88 kW/ton	~0.58 kW/ton	34%

IEER is a seasonal measure of efficiency, EER a peak measure. Given differences in these metrics, the savings percentage is approximate. Ec is combustion efficiency. The 2015 furnace standard also requires electronic ignition, low jacket losses, and power venting or a vent damper. The 2015 chiller standard includes two metrics and two options. The figure reported here is a simple average of these four values. *Source:* ACEEE analysis based on the 1980 version of ASHRAE Standard 90 and the 2015 version of ASHRAE Standard 90.1.

Many factors have affected commercial energy use over the past 35 years, but energy use per square foot is down about 18% from its peak in 1999. This decline has occurred despite growing saturations of computers and office equipment in buildings. Improvements in lighting and HVAC system efficiency have been substantial and have helped drive this overall decline.

INDUSTRY

The industrial sector includes manufacturing, mining, construction, and agriculture. It is unique among the end-use sectors in that its energy intensity has declined consistently over the past 35 years, while energy use has fluctuated within a range as the sector output has

[7] Standard 90, published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

varied with economic activity (see figure 8). Overall, industrial energy intensity declined 38% over the 1980–2013 period.

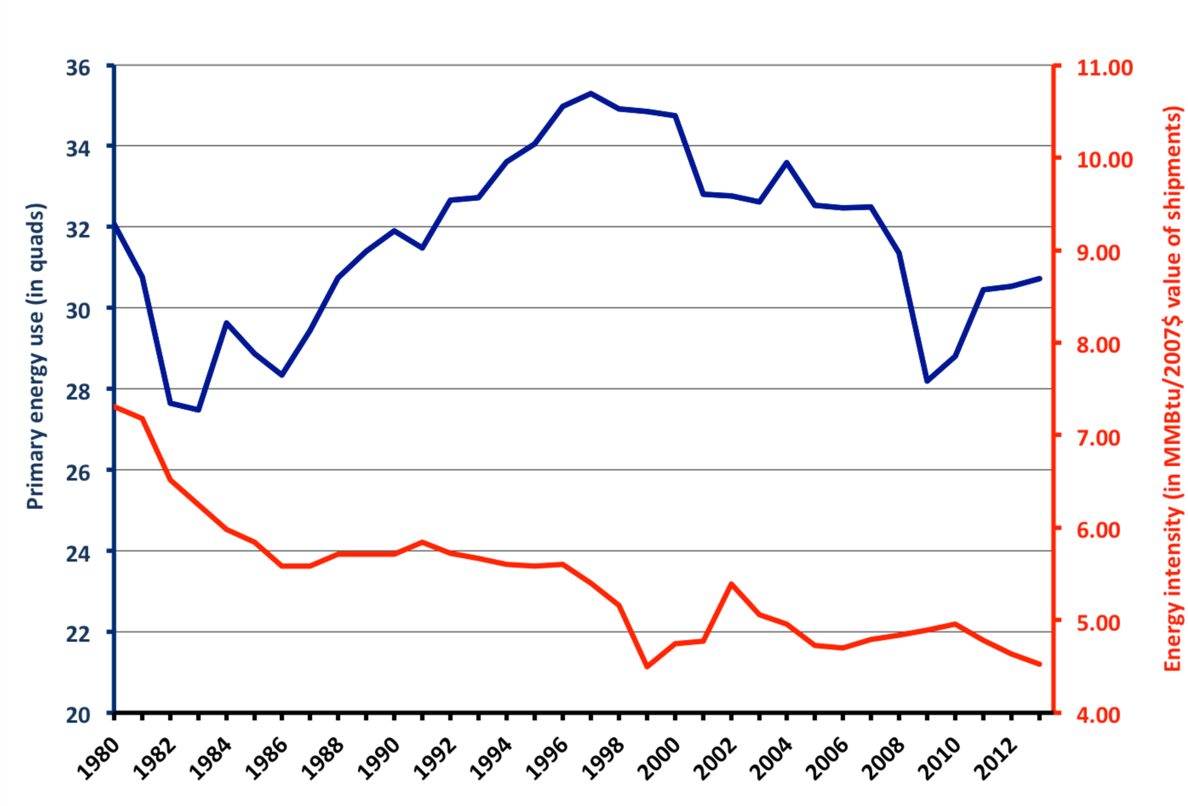

Figure 8. Industrial energy use (upper line) and energy intensity (lower line), 1980–2013. *Source:* ACEEE based on multiple EIA data sources.

While some of this change in intensity is a result of structural shifts in the industrial sector, much of it can be attributed to technology and practice improvements in energy-intensive industries. For example, the steel industry has seen major modernization investments, which have resulted in a 28% reduction in Btus per ton of steel produced between 1990 and 2004 (EPA 2007). A large factor in this improvement has been a shift toward more reliance on secondary steel (melting recycled steel) and less reliance on primary steel (producing steel from iron ore through a reduction process). Importantly, this shift from primary to secondary product was enabled by the development of technologies that allow the use of scrap to produce high-strength steel alloys (Elliott 1994). Similarly, the chemical industry has reduced energy use per unit of product by about 40% since 1980.[8]

Also contributing to reducing industrial energy use are system approaches such as combined heat and power (CHP), also referred to as cogeneration. CHP is an energy-efficient method of generating both electricity and useful thermal energy in a single, integrated system. A CHP system saves energy by recovering heat that would otherwise be wasted from power-only generation and using it to satisfy on-site thermal energy needs.

[8] Unpublished data provided by the American Chemistry Council.

The modern CHP era was inaugurated by the passage of the Public Regulatory Policy Act of 1978 (PURPA), which included a provision that legalized sales of non-utility-generated of electricity to the grid. While there was some limited electric generation at large industrial facilities prior to PURPA, its passage spurred a more than fourfold increase in CHP installation by the early 1990s (see figure 9). The prospects for CHP were further advanced by provisions in the Energy Policy Act of 1992, with CHP capacity almost doubling by the early 2000s. The uncertainty created by natural gas price volatility beginning in the early 2000s, combined with the recessions of 2001 and 2007–2009, largely stalled additions to CHP capacity. However, with the recent economic recovery and relatively low natural gas prices, we have seen interest in CHP returning, particularly in institutional markets, where the added benefit of electric reliability is increasingly valued.

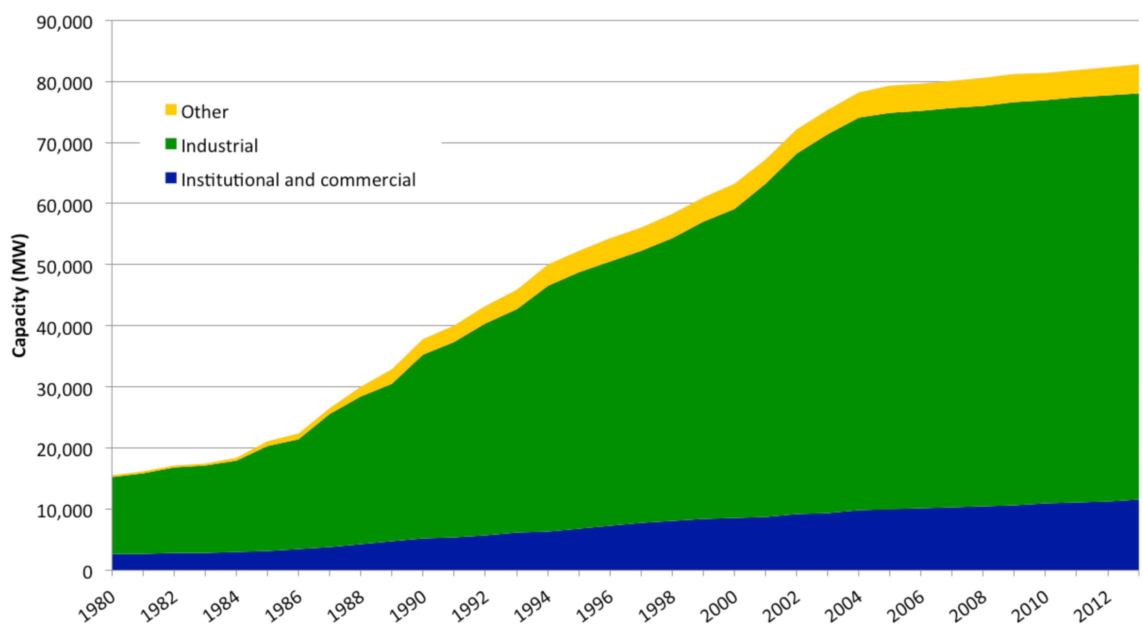

Figure 9. CHP capacity in the United States by sector. *Source:* Data from ICF.

The industrial sector has made steady efficiency progress over the past 35 years, reducing industrial energy intensity by more than one-third. This progress is the result of improvements in many industrial processes, substantial growth in CHP, better motor systems (Nadel et al. 2002), and wider application of energy control systems to industrial processes (Rogers 2014). Improved energy management is also a factor; a comparison of the 1998 and 2010 Manufacturing Energy Consumption Surveys shows more than a fourfold increase in the number of companies with energy managers.[9]

[9] The number increased from 2,245 companies in 1998 to 12, 536 in 2010. See http://www.eia.gov/consumption/manufacturing/data/2010/#r10. Data on this variable were not collected in surveys prior to 1998.

TRANSPORTATION

Energy use in the transportation sector has increased by about 38% over the 1980–2014 period (EIA 2015a), slightly less than the 40% increase in population over this period per US Census Bureau data.[10] The transportation sector has consumed between 25 and 29% of total energy throughout the past few decades. However this statistic obscures major shifts that have occurred and, most important, shifts now under way. These changes have arisen in two primary determinants of transportation energy use: how much transport of people and goods occurs, and how fuel efficient are the vehicles used to transport those people and goods.

Transportation energy use by mode is summarized in figure 10. Light vehicles (cars and light trucks) account for the majority of energy use (59%). Medium/heavy trucks account for 22%, and air travel for 8%. The remaining 11% includes energy used by buses, pipelines, and water and rail transportation.

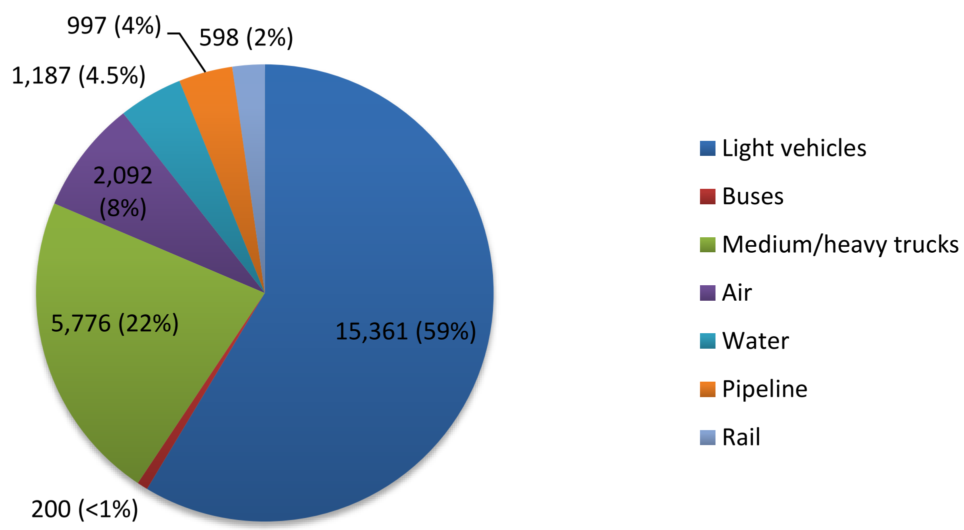

Figure 10. 2012 transportation energy use by mode (trillion Btus). *Source:* ORNL 2014.

Fuel Efficiency of Highway Vehicles

Over the past 35 years, American passenger vehicles (cars and light trucks) have achieved remarkable gains in both performance, as measured by power and acceleration, and fuel economy, though which of these attributes receives priority in a given time period shifts substantially with fuel prices, vehicle standards, and consumer tastes. These trends for light vehicles are summarized in figure 11. Fuel economy improved dramatically from 1975 to 1980, driven by fuel economy standards, as discussed later in this paper. It stagnated through 2005 (when fuel economy standards did not appreciably change) but has steadily increased since then. Since 1980, both weight and horsepower have increased as well, in part

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[10] Historic data can be found at http://www.census.gov/popest/data/historical/index.html; current data at http://www.census.gov/popest/data/index.html.

due to the rising proportion of sport-utility vehicles, minivans, and pickup trucks in the vehicle mix, and in part reflecting improvements in vehicle performance. EPA (2014c) estimates that average 0-to-60 acceleration times declined 46%, from 15.6 seconds to 8.4 seconds, between 1980 and 2013.

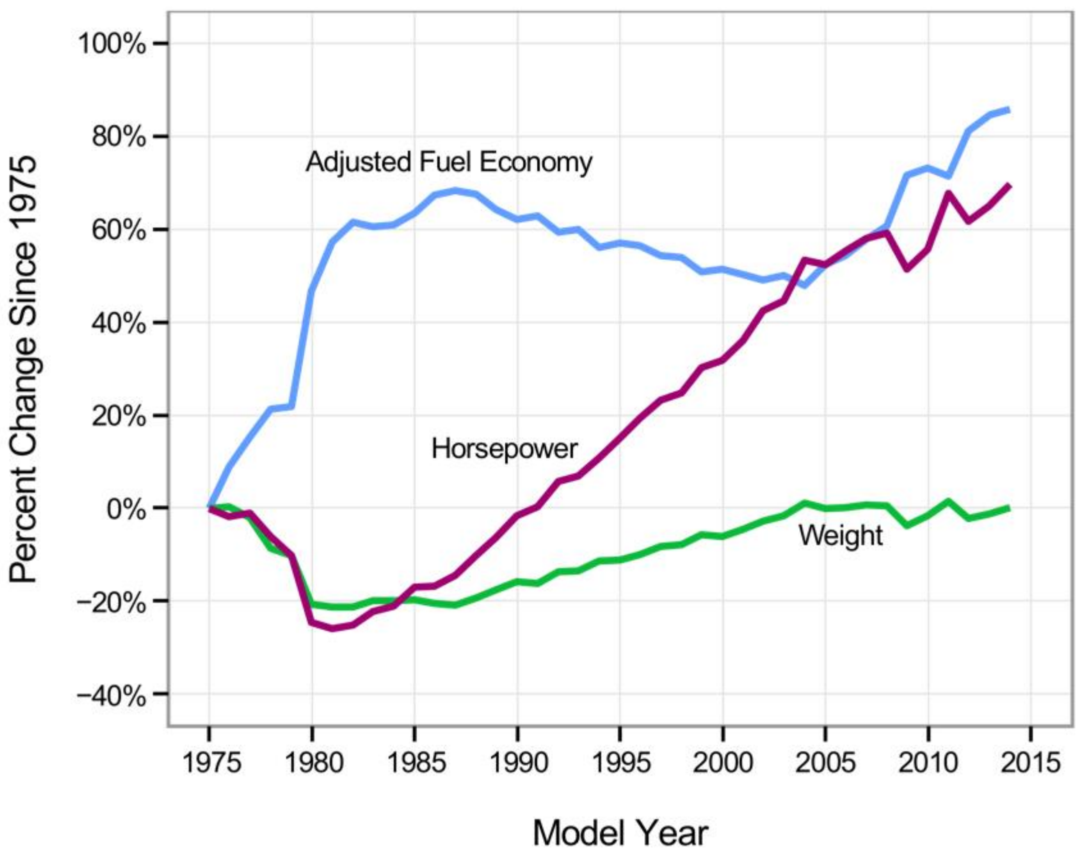

Figure 11. Light-duty vehicle fuel economy, weight, and horsepower by model year. Adjusted fuel economy is a value EPA obtains by adjusting a vehicle's certified, or laboratory, fuel economy to better reflect real-world performance. The adjusted values, which are on average about 20% lower than laboratory values, appear on the window stickers of new vehicles. *Source:* EPA 2014.

While gasoline-powered vehicles are expected to continue their dominance for another decade, the presence of alternative power trains in the market is growing. Hybrid vehicles currently make up about 3% of vehicle sales (Hybridcars.com 2015), and battery electrics and fuel cell vehicles are being offered in an increasing number of models by many different manufacturers, due in part to the requirements of California's Zero Emission Vehicle (ZEV) Program.

For commercial vehicles, high diesel fuel prices in recent years and intense competitive and economic pressures in the trucking industry have elevated shippers' and carriers' interest in fuel efficiency. Improvements in aerodynamics and tires, along with operational changes such as idle reduction and speed control, have made inroads over the past several years, in part through programs such as EPA's SmartWay Program (a partnership with many trucking firms) and California's tractor-trailer greenhouse gas (GHG) emissions reduction regulation, applicable to fleets operating in California. The first federal heavy-duty vehicle fuel efficiency standards, adopted in 2011, along with the US Department of Energy's SuperTruck program (an R&D initiative to improve fuel economy), are now helping to establish a long-term trajectory of continuous technology improvement that includes engine and transmission efficiency and power train integration, along with more advanced designs for other parts of the vehicle. These advances, just starting to show up in vehicle fuel economy figures, are expected to grow in the next few years as fuel economy standards, which call for efficiency gains of 9 to 23% (varying by vehicle class), take full effect by 2017 (derived from Khan et al. 2015).

Aviation

After highway vehicles, aviation is the next-largest consumer of energy in the transport sector, accounting for 8% of transportation energy use in 2012 (ORNL 2014). While both passenger and cargo miles by air dipped during the Great Recession, the volume of air travel has otherwise increased sharply in recent decades. In 2013, revenue passenger miles were 3.2 times greater than in 1980, and revenue cargo ton-miles were 4.3 times greater. Over the same period, energy use in aviation grew by a much smaller percentage, 64%. The considerably slower increase in energy use relative to passenger and cargo miles was due in part to a 39% increase in passenger load factor (ORNL 2014), but aircraft efficiency clearly increased substantially as well. To provide just one example of fuel economy increase, the Boeing 737-300 made its first flight in 1984 and the 737-900ER made its first flight in 2006. The former can travel 68 miles per gallon (mpg) per seat in regional service (i.e., a flight of 500 nautical miles) while the latter can go 91 mpg per seat (Wikipedia 2015). Trends in energy use per seat-mile are shown in figure 12.

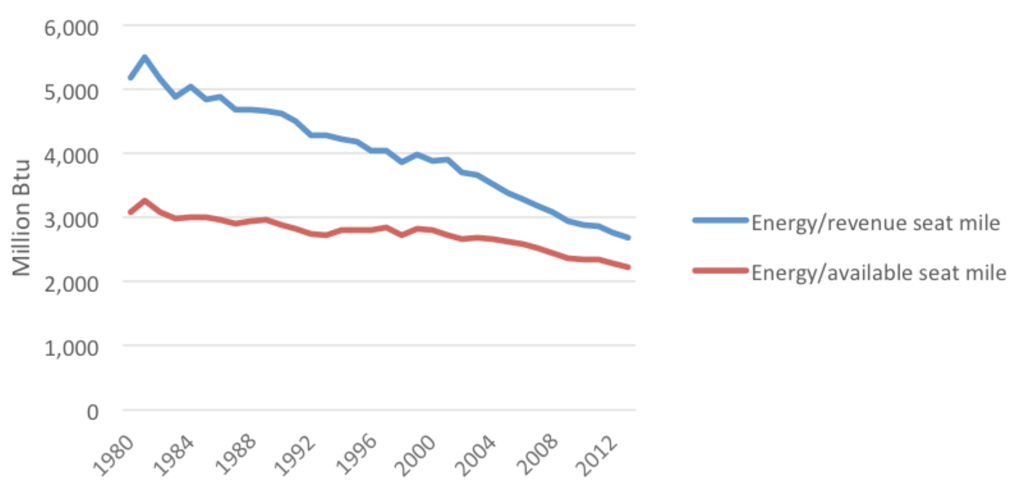

Figure 12. Average energy use per seat-mile for US carriers. Revenue seat miles are for paying passengers and reflect increased load factor. Available seat miles include both occupied and empty seats and therefore do not reflect load factor. Both of these measures assign all the energy use to passenger seats and ignore the fact that freight loads have increased more rapidly than passenger loads. If freight energy were excluded, both of these lines would be steeper. *Source:* ORNL 2014.

Use of Public Transit

After decades of decline triggered by the growth in personal automobile ownership starting in the 1950s, public transit use stabilized in the 1980s and began to climb upward again in the mid-1990s (BTS 2014). As shown in figure 13, growth in public transit use has substantially outstripped both population growth and growth in driving over the past decade (APTA 2014).

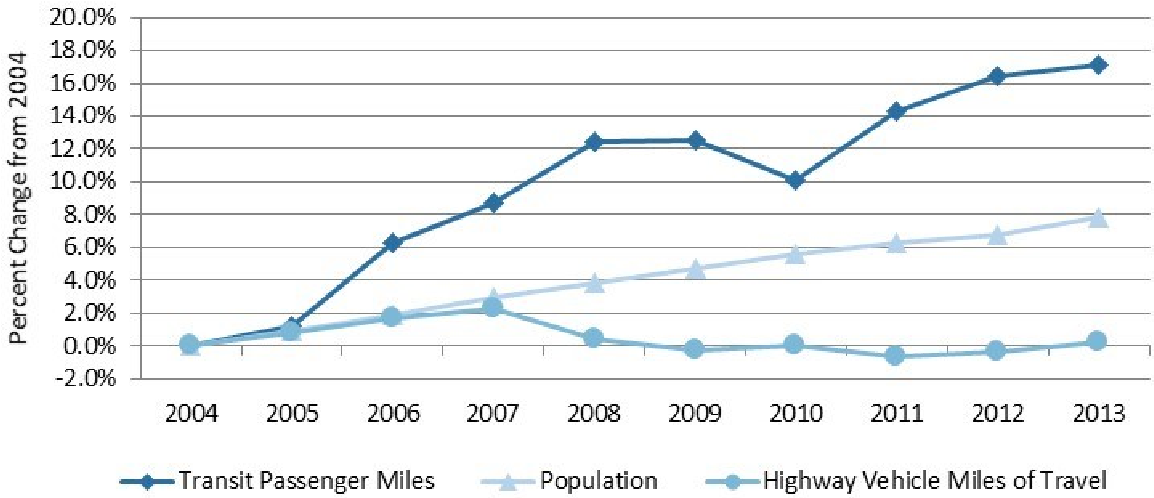

Figure 13. Population, transit, and highway vehicle use trends, 2004–2013. *Source:* APTA 2014.

Walking and bicycling have also increased in recent years, perhaps due to an influx of young people to urban areas, government infrastructure investment aimed at increasing urban foot traffic and the associated economic gains, and interest in the health benefits of active modes. Commuting by walking and biking increased by 12% and 50%, respectively, nationwide between 2006 and 2012, though these mode shares remain small, at 2.8% and 0.6%, respectively, in 2012 (Alliance for Biking & Walking 2014).[11]

Freight Movement

In goods movement, trucks account for the vast majority of tons carried and value carried. They also consume about two-thirds of the fuel used for this purpose (EIA 2015d). However, because rail is commonly used to move heavy loads over long distances, rail is the leading mode in terms of ton-miles carried, accounting for 45% of the total in 2012 (ORNL 2014). Mode shift from air or truck to rail or ship presents a significant opportunity for energy savings, but the categories of goods that are candidates for such shifts are limited by considerations of timeliness and reliability of transport, as well as length and location of the trip. Efforts to shift freight toward less energy-intensive modes have focused mainly on truck-rail intermodal services. While representing only 6.5% of ton-miles in 2012 (ORNL 2014), intermodal is one of the fastest-growing segments of freight transport.

Demand for Transportation Services

In addition to fuel efficiency of the vehicles and modes of transport used, person-miles and ton-miles of travel determine transportation energy use. Improving the efficiency of the transport system by reshaping demand (while preserving or enhancing economic

[11] Earlier data are not available.

opportunities) is increasingly important, especially in view of changing demographics and the emergence of real-time information services.

After six decades of strong growth, vehicle miles traveled (VMT) on US roadways began to decline in 2007. While VMT turned upward again a few years later and has now surpassed 2007 levels (figure 14), the growth rate has not caught up with population growth, and VMT per capita has returned to mid-1990s levels. Stalling VMT was undoubtedly in part a reflection of the Great Recession, but multiple demographic factors appear to be producing a fundamental shift toward lower growth going forward. These factors include an aging population, a leveling-off of women's participation in the workforce, and the influx of young professionals into urban areas. At the same time, an increasing number of services and social and entertainment opportunities are available in forms that do not require travel. Accommodating preferences for a lifestyle that involves fewer and shorter trips, whether through location-efficient development patterns or support for services based on mobile computing, is thus a potentially significant avenue for advancing transportation efficiency.

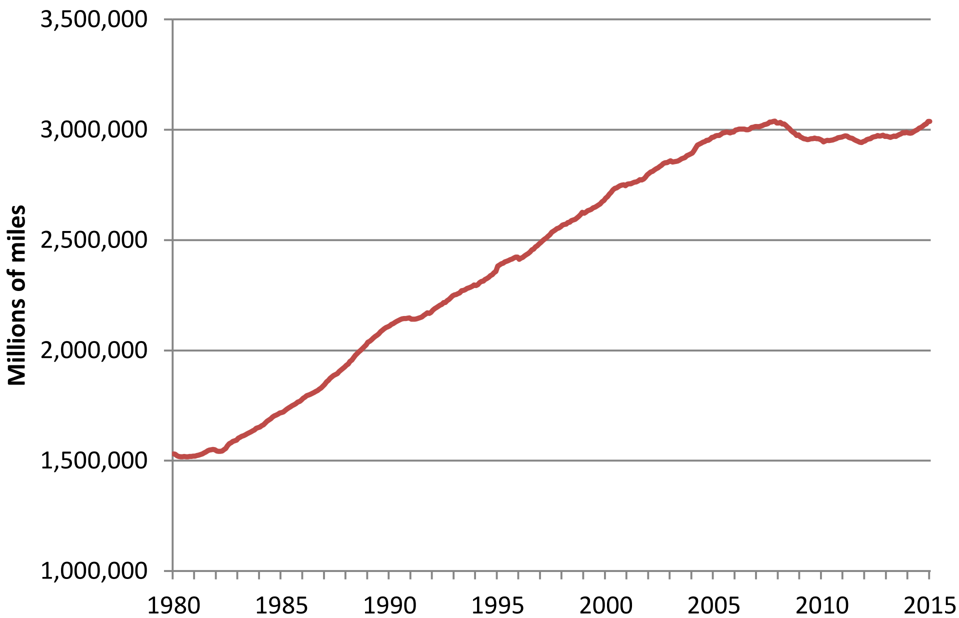

Figure 14. Estimated moving 12-month total vehicle miles traveled on all roads. *Source:* FHWA 2015.

In the freight sector, ton-miles continue to grow, and fuel consumed by freight trucks is projected to become a substantially greater fraction of total transportation fuel use. However, for goods as for people, opportunities are arising to meet the needs of economic activity with fewer miles traveled. For example, shippers and carriers are using information and communications technologies to optimize routing, reduce empty backhauls and partial-load shipments, and restructure warehouse and distribution facility networks (Langer and Vaidyanathan 2014).

To sum up, transportation energy use, both total and per capita, peaked in 2007 after decades of growth. This change in course is largely a result of gains in the fuel efficiency of highway vehicles and declines in passenger vehicle miles traveled. Current regulatory regimes for fuel efficiency will continue to drive down transportation energy use gradually. Travel demand has already resumed its rise after a hiatus due to economic conditions, but emerging opportunities to decouple the growth in miles traveled from economic growth through transportation system efficiency could permit faster reductions in transportation energy use.

UTILITIES

Most of the energy used in the utility sector is to provide electricity and natural gas to the other sectors, and as such was discussed above. Most utilities also offer energy efficiency programs for their end-use customers, which we will discuss in the policy section below. In addition, utilities can improve energy efficiency in their own operations by, for example, using less energy to generate each kWh and reducing losses in transmission, pipeline, and distribution systems. EIA tracks heat rates (Btus of energy needed to generate 1 kWh of power) as well as electric system transmission and distribution (T&D) system losses. These data are plotted in figure 15.

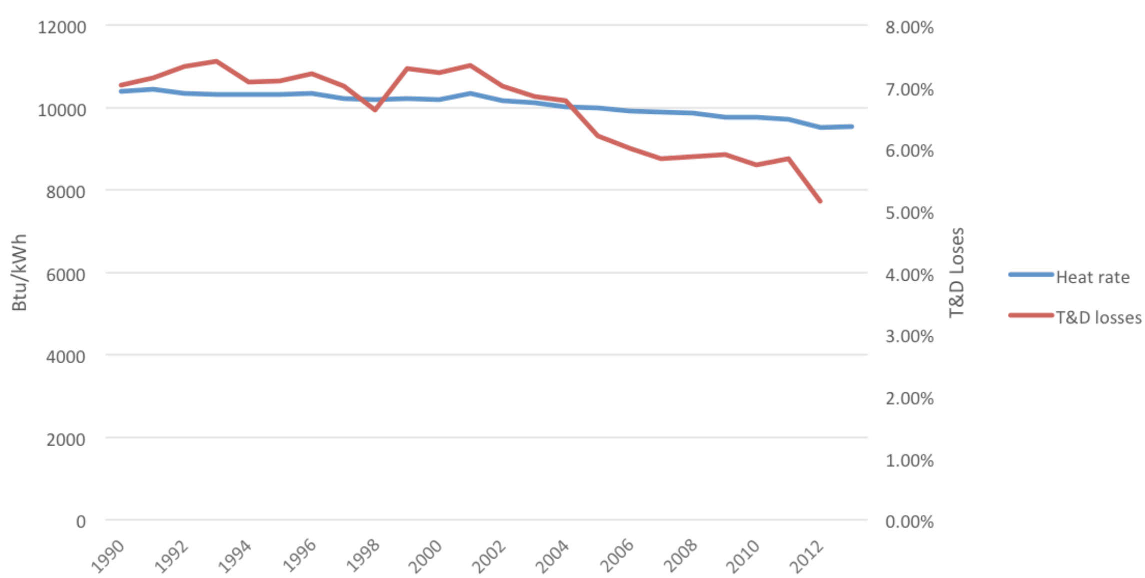

Figure 15. Average power plant heat rate (in blue, expressed in Btu/kWh) and transmission and distribution (T&D) losses (in red, expressed as % of electricity entering the grid). *Sources:* Heat rates from EIA 2015a; T&D losses from EIA 2014.

Since 1980, the average nationwide heat rate has improved 8.2%, driven by greater use of high-efficiency combined-cycle power plants. Since 1990, T&D losses have declined by 27%; we have not seen any studies explaining the improvement (pre-1990 data are not available). Furthermore, the efficiency of new generating plants has improved substantially in recent years, with the largest improvements in plants using natural gas. For example, while the average natural gas plant had a heat rate of more than 10,000 Btus per kWh in 2001 (EIA 2015a; earlier data were not reported), the best new plants have heat rates below 6,000 Btus per kWh (GE 2014).

In summary, like the other sectors, the utility sector has registered significant efficiency gains, with improvements primarily happening since the turn of the century.

SUMMARY

The energy intensity of the US economy has steadily improved since 1980, with the majority of this improvement due to energy efficiency. Each of the major sectors has shown gains, with residential sector energy use per capita down 11% since 1980, commercial-sector use per square foot down 18% since its 1999 peak, industrial use per dollar value added down more than one-third, transportation energy use down 12% below its peak in 2007, power plant heat rates 8% lower than in 1980, and electric system transmission and distribution losses down 27% since 1990. The data summarized above also indicate that some of these trends, such as those for new construction and new vehicles, may be accelerating.

Energy Efficiency Drivers over the Past 35 Years

The sections above summarize some of the progress that has been made in advancing energy efficiency in the past 35 years. In this section we discuss factors that have helped drive these energy efficiency improvements over the past 35 years. First we discuss market drivers, then policy drivers. In a subsequent section we discuss how some of these drivers can be applied in the next 35 years.

MARKET DRIVERS

Energy Prices

Rising energy prices would be a logical first place to look for factors driving energy efficiency actions. However, while real energy prices approximately doubled in the 1970s, since then real prices for fossil fuels have fluctuated but are now roughly at 1980 levels, and real electricity prices have actually declined (EIA 2015a). These trends are shown in figure 16 for residential energy prices (we show residential since EIA tracks real prices for the residential sector but not for other sectors; trends in other sectors are roughly similar).

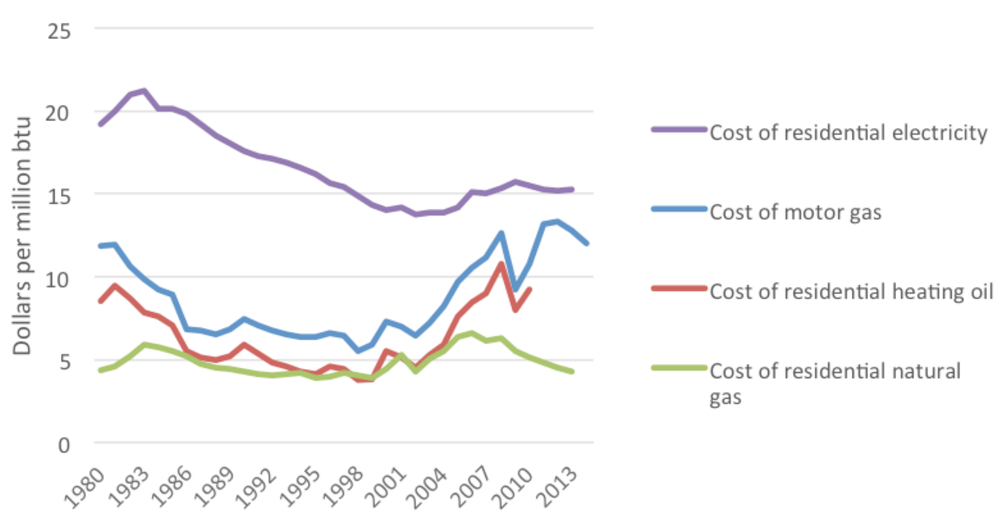

Figure 16. Real energy prices for consumers, 1980–2014 (1982–1984$). *Source:* EIA 2015a.

Higher prices may have been an efficiency motivator in some regions and some years, but overall they do not appear to have been a primary driver during the post-1980 period, particularly for electricity (declining real prices) and natural gas (level real prices).[12] Increasing oil and gasoline prices in recent years may have contributed to recent efficiency gains; in particular, high transportation fuel prices clearly have been a factor in vehicle fuel economy advances in the past decade, affecting both the type of vehicle purchased (e.g., car versus SUV) and fuel economy within each vehicle class.

Cost Savings

While higher prices may not be a driver, energy prices are high enough that businesses and consumers can save substantial amounts of money from energy efficiency investments. Typically, the more cost effective an investment is, the more likely it is that the investment will be made. A simplistic way to think about this is through a payback acceptance curve. Such a curve shows the proportion of consumers or businesses that will make an investment at various cost-effectiveness levels. A sample curve of this type is shown in figure 17, which estimates the proportion of residential and nonresidential customers who invest in efficiency measures as a function of the simple payback period of an energy efficiency measure (e.g., if a measure costs $300 and saves $100 per year, it will take three years for the energy savings to pay back the cost of the measure). Figure 17 indicates that for measures with a simple payback of three years, about half of residential consumers will make the investment and about one-quarter of business consumers will do so. Payback acceptance curves oversimplify complex decision-making processes, and the particular data points in a curve are subject to substantial uncertainty. For purposes of this discussion, the takeaway is that for short payback periods, consumers and businesses will adopt efficiency measures to a significant degree.

12 Energy prices have been volatile, and for some businesses, lowering energy use to reduce exposure to price volatility could have motivated some efficiency investments. We are not aware of any retrospective analysis on this issue.

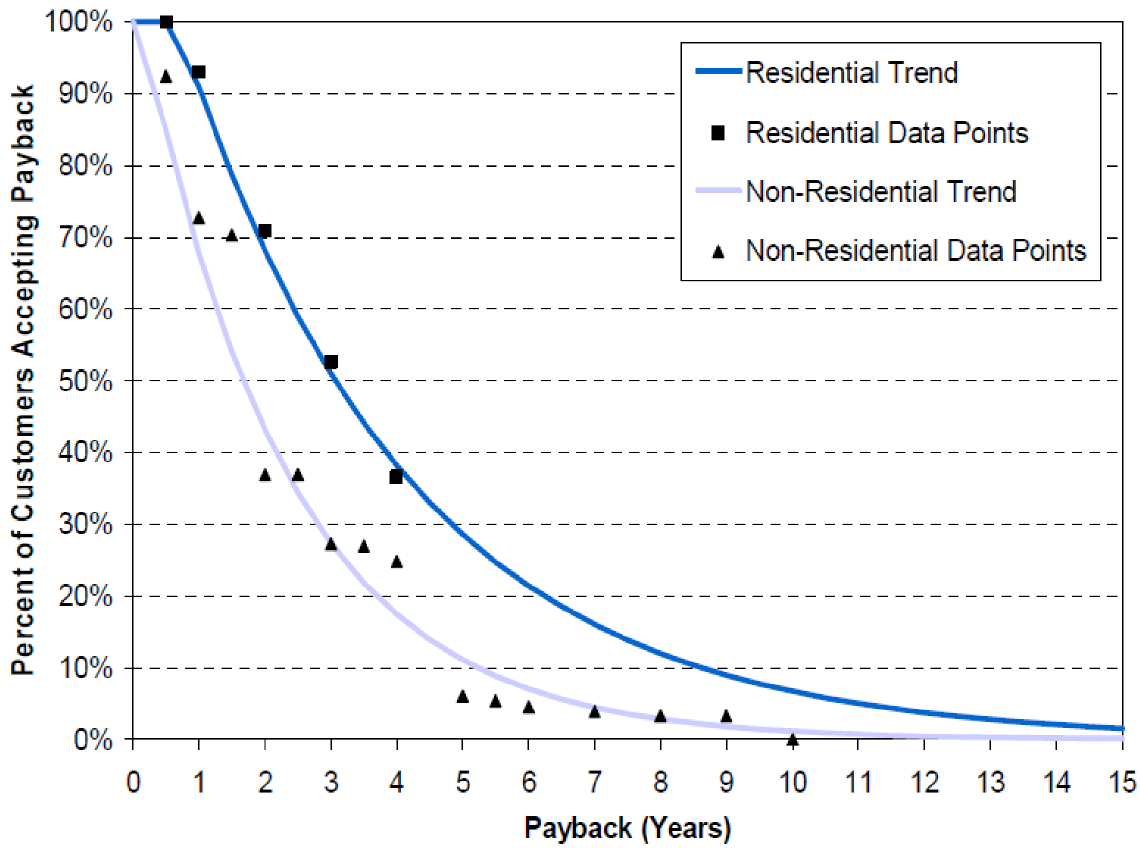

Figure 17. Sample payback acceptance curve. This graph is illustrative but far from precise; see discussion in text. *Source:* Delmarva Energy 2007.

Multiple Benefits of Energy-Saving Investments

A major driver for many consumers and businesses is that energy efficiency investments often provide not only energy bill savings but a variety of other benefits as well. For example, Amann (2006) reviewed the literature on additional benefits for retrofits of single-family homes and found a variety of gains many homeowners valued, including improved comfort, aesthetic enhancements, and better indoor air quality. Measurements of co-benefits are imprecise as methodologies vary and data can be uncertain. Depending on the study, the value of co-benefits was found to range from 50 to 300% of household energy bill savings. Similarly, for multifamily buildings, Cluett and Amann (2015) summarized studies that documented maintenance, durability, property value, and rental value benefits, among others. According to one study, their average total value was 71% of energy bill savings.

In the commercial sector, researchers at Carnegie Mellon University documented a variety of health and productivity benefits associated with energy efficiency (Loftness et al. 2003). And in the industrial sector, Russell (2015) summarized several studies that document employee, product quality, and other benefits. He found three studies that quantified the co-benefits, finding that they were 42%, 44%, and 122% of the direct energy bill savings.

There are also times when energy efficiency improves as a result of addressing other needs. For example, new capital investments made to update production lines, reduce pollution, or minimize waste often also save energy (ASE 2013a).

Corporate and Individual Sustainability Efforts

Many companies have embraced sustainability as a corporate goal in order to improve their image and their bottom line. Their sustainability efforts can include product offerings as well as their operations. For example, General Electric launched an "ecomagination" initiative that now includes dozens of products, ranging from appliances to jet engines to railroad locomotives. According to Winston (2014), these products have reaped revenues of $160 billion, with revenues growing twice as fast as total company sales. More broadly, Willard (2012) provides multiple examples of corporate sustainability efforts increasing revenue, reducing expenses, improving employee productivity, and lowering risks. He also summarizes several studies of the impact of corporate sustainability initiatives on stock price, finding on average a small but positive impact. Thorpe (2013) interviewed many corporate executives and found that out of 59 subjects, 51 believed that their corporate sustainability programs increased employee happiness; 45 believed these efforts helped them attract better talent or develop better employees.

Similarly, a significant segment of individual consumers are interested in eco-friendly products and services, both to help the environment and to show friends and neighbors how green they are. For example, the 2014 EcoPulse survey found that 70% of consumers look for greener products when shopping, the highest level seen in its annual survey (Shelton Group 2015). Lutzenhiser (2006) found that reducing energy and resource use for environmental benefits was a significant driver of consumer investments in home retrofits. Research on "conspicuous conservation" (also known as the Prius effect) demonstrates that green-motivated consumers seek out and are willing to pay a premium for products that signal their environmental bona fides (Sexton 2011).

POLICIES

Policies to promote energy efficiency have been adopted at the federal, state, and local levels since the first oil embargo in 1973. In the sections below, we discuss some of the major efforts and their impacts. These policies generally work with and help to leverage market activities by addressing many of the market barriers that impede uptake of energy efficiency actions.[13] Many of these policies address multiple sectors, so rather than grouping by sector, we list them in rough order of their energy-saving impacts.

Appliance and Equipment Standards

California and other states began to adopt minimum efficiency requirements for appliances and other energy-using equipment in the 1970s. Federal appliance standards were enacted by Congress and signed by President Reagan in 1987 and started to take effect in 1990.[14] Over time, Congresses, working with most presidents, have added additional product

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[13] For a discussion of some of these market barriers, see Choi et al. 2009.

[14] This was the National Appliance Energy Conservation Act of 1987.

categories, and the US Department of Energy (DOE) has periodically updated most of the standards (Nadel and Goldstein 1996). At present, more than 50 products are covered by federal standards, and state laws cover some additional items. These standards cover products used in the residential, commercial, and industrial sectors. The impact of standards can be seen in figure 5 above: the steep declines in some individual years generally coincide with the years new standards took effect.

A 2012 analysis estimated that on a cumulative basis, standards set by 2012 will save consumers and businesses more than $1 trillion by 2035 (Lowenberger et al. 2012). These calculations incorporate both the higher up-front cost of more efficient products and the energy bill savings achieved over the life of the products. An analysis by Mauer et al. (2013) found that in many cases consumer amenity and utility increased even as energy was saved. And a retrospective analysis by Nadel and deLaski (2013) found that the actual cost increases for products due to standards were generally much less than anticipated. In other words, as manufacturers designed new, complying products, they found ways to reduce product costs. Electric and natural gas savings from standards by year are plotted in figure 18. Savings in 2015 and beyond include only standards established by December 2014; future updates are not included in this figure. The 2014 savings amount to 12% of US electricity consumption and 4% of US end-use natural gas demand (i.e., not including natural gas used for power generation and pipelines).[15]

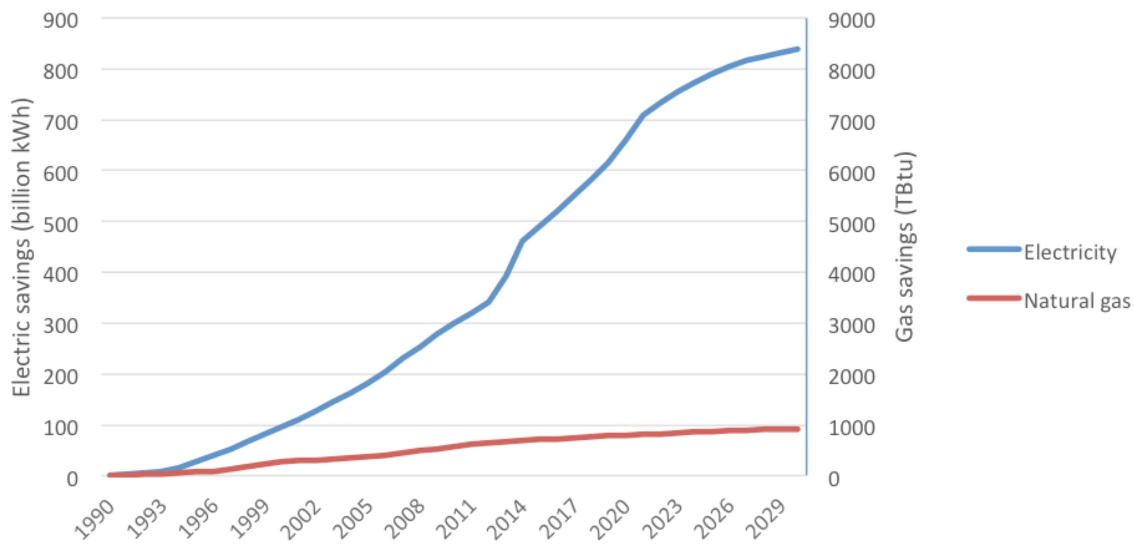

Figure 18. Savings from national appliance and equipment efficiency standards by year.
Source: Appliance Standards Awareness Project (unpublished update of analysis in Lowenberger et al. 2012).

Utility Sector Energy Efficiency Programs

Utilities often offer energy efficiency programs to help their customers save energy. The programs are funded by ratepayers for the benefit of all ratepayers, because it is less expensive for a utility to save a kWh than to generate one. As a result, energy efficiency

[15] Calculations are ACEEE's, using data from EIA 2015a.

programs help reduce rates relative to what they would be without energy efficiency programs.[16] ACEEE has reviewed evaluations of the cost of energy efficiency savings to utilities every few years. Similar to previous assessments, the most recent evaluation found an average cost of 2.8 cents per kWh saved, which is less than half the cost of generating a kWh (Molina 2014).[17] In 2013, the last year for which data are available, utilities budgeted $7.7 billion for energy efficiency programs (Gilleo et al. 2014). The substantial energy savings from these programs are summarized in figure 19. In 2013, these programs saved a total of about 160 billion kWh of electricity in the residential, commercial, and industrial sectors. This includes 25 billion kWh from measures installed in 2013 alone (EIA 2015e) plus about 135 billion kWh from measures installed in earlier years and still in place (ACEEE estimate). These savings represent 4.1% of US 2013 electricity consumption (EIA 2015a). In some leading states, energy efficiency savings from measures installed in 2013 were more than 1.5% of 2013 electricity sales (Gilleo et al. 2014) and total savings, including measures installed in prior years, were more than 10% of electricity sales.[18] Figure 20 shows savings by state from measures installed in 2013.

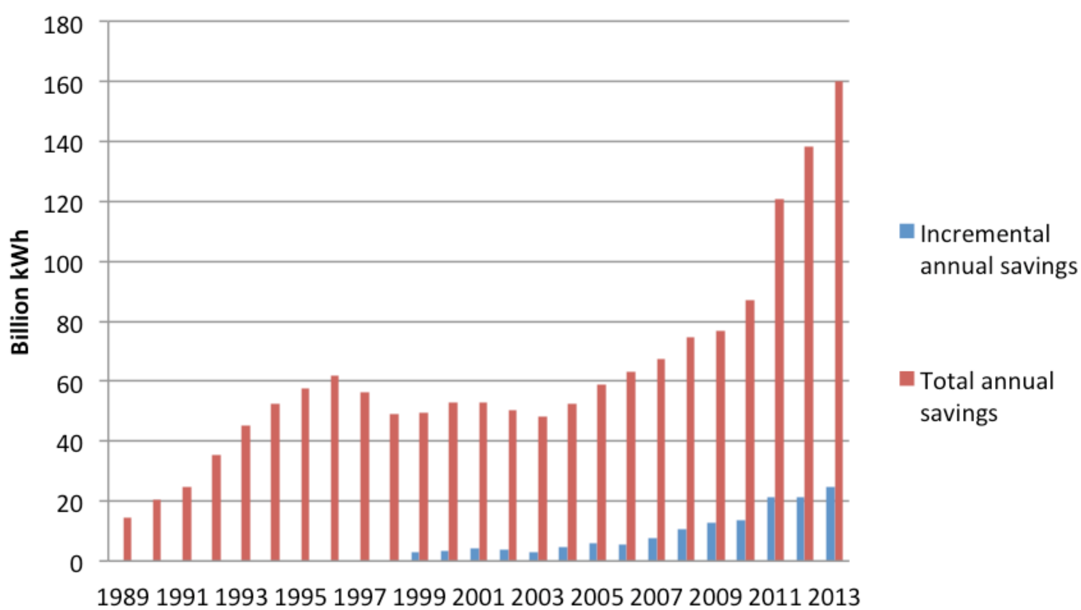

Figure 19. Electricity savings from utility sector energy efficiency programs by year. Incremental annual savings are savings from measures installed that year. Total annual savings are those achieved in a year from measures installed that year and in prior years. *Source:* ACEEE analysis of data in EIA 2015e and EIA 2012. Total annual savings in 2013 estimated by ACEEE because EIA no longer provides this figure.

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[16] Rates may still go up with efficiency investments, but they will generally go up less than if new energy supplies are used to meet demand instead of energy efficiency.

[17] In addition to the utility costs, end users generally also pay a portion of measure costs.

[18] ACEEE analysis is based on EIA data at http://www.eia.gov/electricity/data/eia861/.

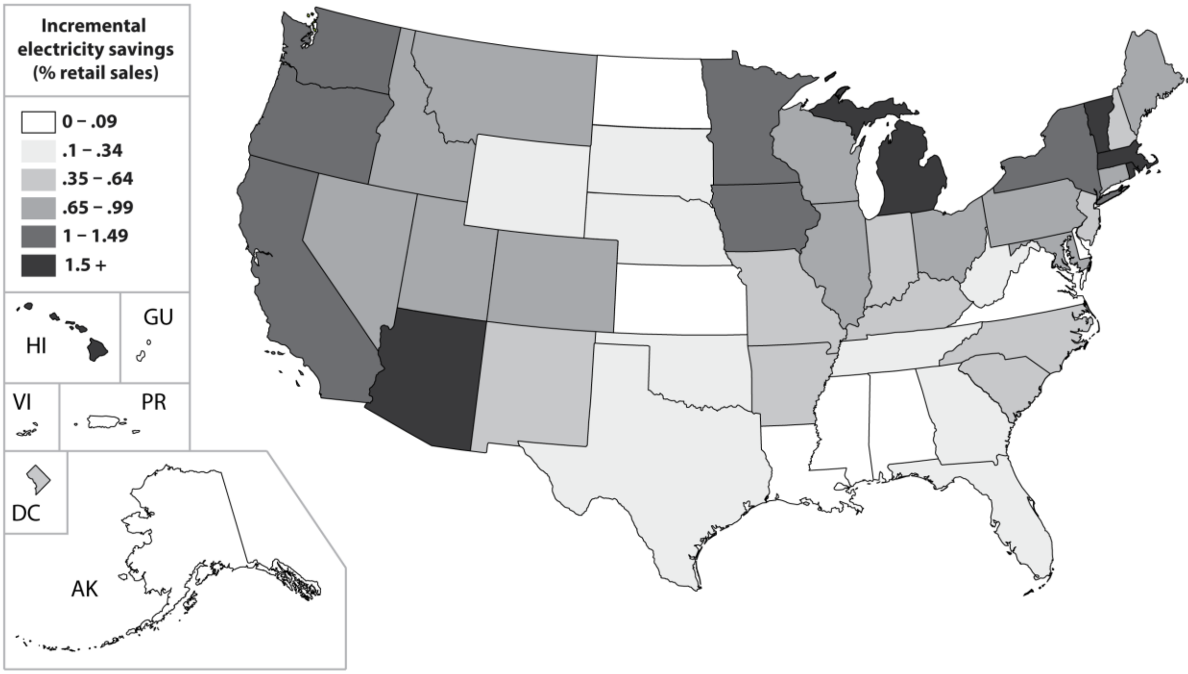

Figure 20. Utility sector energy efficiency program savings by state from measures installed in 2013 as a percentage of state 2013 electricity sales. *Source:* Gilleo et al. 2014.

Fuel Economy Standards

Corporate Average Fuel Economy (CAFE) standards for personal vehicles, first adopted in 1975 in the wake of the OPEC oil embargo, resulted in an approximate doubling of the fuel economy of personal vehicles a decade later. Following this period of rapid advance in fuel economy were two decades of slowly declining fuel economy, beginning in 1986 (figure 11). The Energy Independence and Security Act of 2007 (EISA) ended this period of stagnation by requiring that federal standards be set to achieve at least 35 miles per gallon on average by 2020; this set off a series of rulemakings culminating in 2012 with standards out to 2025, requiring that vehicles achieve an estimated average of about 49 miles per gallon in that year.[19] Fuel economy standards set pursuant to EISA will result in roughly a doubling of average fuel economy between model years 2008 and 2025; consumers purchasing these more efficient vehicles with a five-year loan will immediately realize a net benefit through fuel savings that exceed the increase in monthly car payments. Fuel economy standards over time are illustrated in figure 21. Key factors in the strength of this regulatory program have been California’s adoption of standards for greenhouse gas emissions from personal vehicles and the EPA’s subsequent actions to do the same.

[19] Mile-per-gallon values in this paragraph are the laboratory test values used for the fuel economy certification process. Label, or “real-world,” values are approximately 20% lower on average. This figure incorporates the impact of several fuel economy credits in the standard. Without these credits the 2025 figure would exceed 50 mpg.

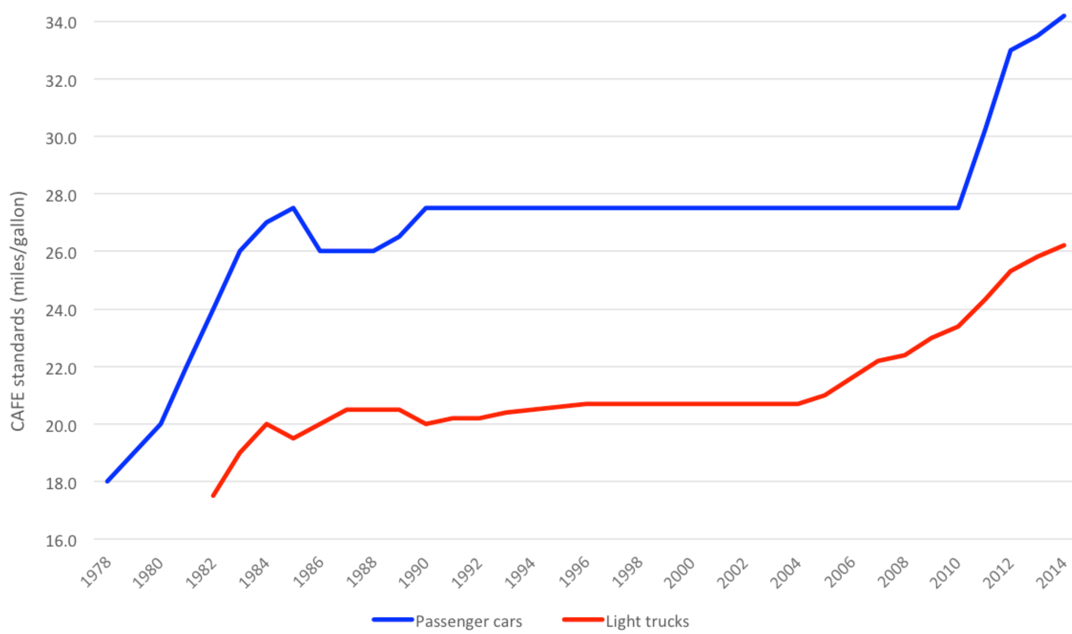

Figure 21. Fuel economy standards for cars and light trucks. *Source:* DOT 2014.

Also established under EISA were the first fuel efficiency standards for heavy-duty vehicles, i.e., those of more than 8,500 pounds gross vehicle weight rating. The first phase of this program was adopted in 2011 and set standards for tractor trucks, heavy-duty pickups and vans, and vocational vehicles (all other trucks and buses) out to the 2019 model year. The standards are projected to reduce new heavy-duty vehicle fuel consumption by 16% on average by model year 2018 (Khan and Langer 2011). A second phase of the standards, now under development and to be finalized in spring 2016, could increase the average fuel consumption reduction to 40% by 2025 or a little later (ACEEE et al. 2014).

ENERGY STAR

ENERGY STAR is a voluntary program operated by EPA. It was begun in 1992 and is designed to give recognition to efficient products and buildings, encouraging manufacturers to upgrade their products and building owners to upgrade their new and existing buildings. The ENERGY STAR product label typically recognizes the top 25% of products on the market in terms of energy efficiency, and the buildings label recognizes buildings in the upper quartile of energy performance for their type and region. ENERGY STAR also has a smaller component addressing industrial energy efficiency.

EPA's annual report estimates that in 2013, ENERGY STAR saved more than 380 billion kWh of electricity—over 5% of US electricity consumption—and saved more than $30 billion on energy bills.[20] The agency notes that these annual benefits have tripled in the past 10 years (EPA 2014a). A few examples are worth noting: when flat-screen high definition

[20] There is probably some overlap between these savings and the savings discussed earlier for appliance and equipment efficiency standards and for utility sector energy efficiency programs.

televisions first came to market, they often used more than 500 kWh per year (Horowitz et al. 2005). Due to the impact of ENERGY STAR as well as minimum efficiency standards established by California, typical new sets on the market in early 2015 used about 150 kWh per year or less.[21] Likewise, ENERGY STAR was the foundation of a voluntary agreement under which most pay-tv companies (cable, satellite, and telephone) agreed to reduce the power use of their set-top boxes by 10% to 45%, depending on model, by 2017 (DOE et al. 2013).

Research and Development

DOE has had a major energy efficiency research and development program since the 1970s. The program works with national laboratories, universities, and private industry to develop and commercialize new energy-saving technologies. In 2001, the National Academy of Sciences examined a sample of DOE R&D projects and found that the three projects with the largest benefits produced gains worth more than three times the cost of the *entire* program over the 1978–2000 period (NRC 2001). In other words, the benefits from a few home runs more than justified the entire program from a societal perspective, even ignoring the program's many smaller successes. The three home runs were advanced compressors for refrigerators, electronic ballasts for fluorescent lamps, and low-emissivity glass. Once developed, these technologies achieved widespread adoption when they were incorporated into appliance efficiency standards and building codes. More recently, a 2013 DOE analysis documented another home run—LED lighting—where DOE research, demonstrations, test protocols, and tests contributed to technology development, price reductions, and increased consumer acceptance (DOE 2013).

Building Codes

States and municipalities have been adopting energy efficiency requirements in their building codes since the 1970s. Building energy codes address energy efficiency features in new construction and substantial renovation; in a few cases they also apply to more limited renovations. A significant majority of states have adopted energy codes, and in most of the remainder at least some municipalities have adopted codes. Most states adopt national model codes whose requirements vary by climate zone. The leading model codes are the International Energy Conservation Code (IECC) and Standard 90.1 for commercial buildings developed by ASHRAE. These model codes are updated every three years, and most states periodically adopt the more recent versions. Figure 22 summarizes average energy savings from each model code relative to baseline homes and buildings that met 1975 model codes. As can be seen, the 2012 residential code is reducing energy use covered by the code about 40% and the 2010 commercial code is reducing energy uses covered by the code by nearly 50%, relative to the 1980 baseline.[22] Pacific Northwest National Laboratory (PNNL)

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[21] ENERGY STAR–certified models accounted for 84% of television sales in 2013 (EPA 2014b). In the most common screen-size category (35 to 50 inches), ENERGY STAR televisions use about 50–150 kWh per year (http://www.energystar.gov/productfinder/product/certified-televisions/results).

[22] The residential code primarily covers energy used for space heating and cooling and water heating. The commercial code covers these end uses as well as lighting and ventilation. Both codes have been gradually adding other energy uses.

conducted an analysis on savings and estimated that building codes reduced US energy use by more than 0.5% in 2012 and will save more than 2% of estimated use in 2040 (Livingston et al. 2014).[23]

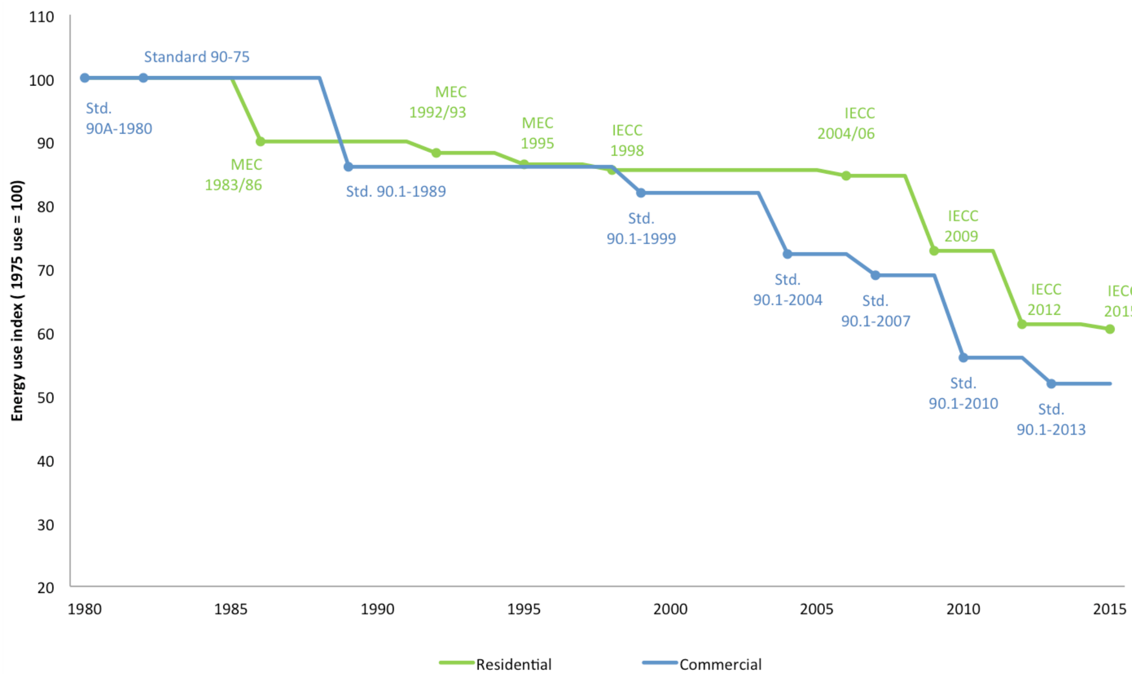

Figure 22. Energy savings from residential and commercial model codes relative to a 1975 base. ***Source:*** **Amann 2014.**

Market Transformation

Market transformation has been defined as a strategic effort "by utility and other organizations to intervene in the market, causing beneficial, lasting changes in the structure or function of the market…[and] leading to increases in the adoption of energy-efficient products, services, and/or practices" (Schlegel et al. 1997). Market transformation is typically pursued through multipronged initiatives to address market barriers that impede the use of particular energy-saving technologies or practices. Often, more than one organization will be involved in implementing an initiative, and activities will evolve as the market development of a measure progresses. For example, figure 23 shows a typical market diffusion curve and some of the interventions that can be used at different stages along this curve.

[23] PNNL estimates 0.5 quad of savings and 2.2 quads in 2040, not including four large states—California, Florida, Oregon, and Washington—that have their own codes and do not use the model codes. Even excluding these states, these savings are more than 0.5% of 2012 consumption (EIA 2015a) and more than 2% of 2040 projected consumption (EIA 2015d). When these four states are included, the "more than" qualifier applies.

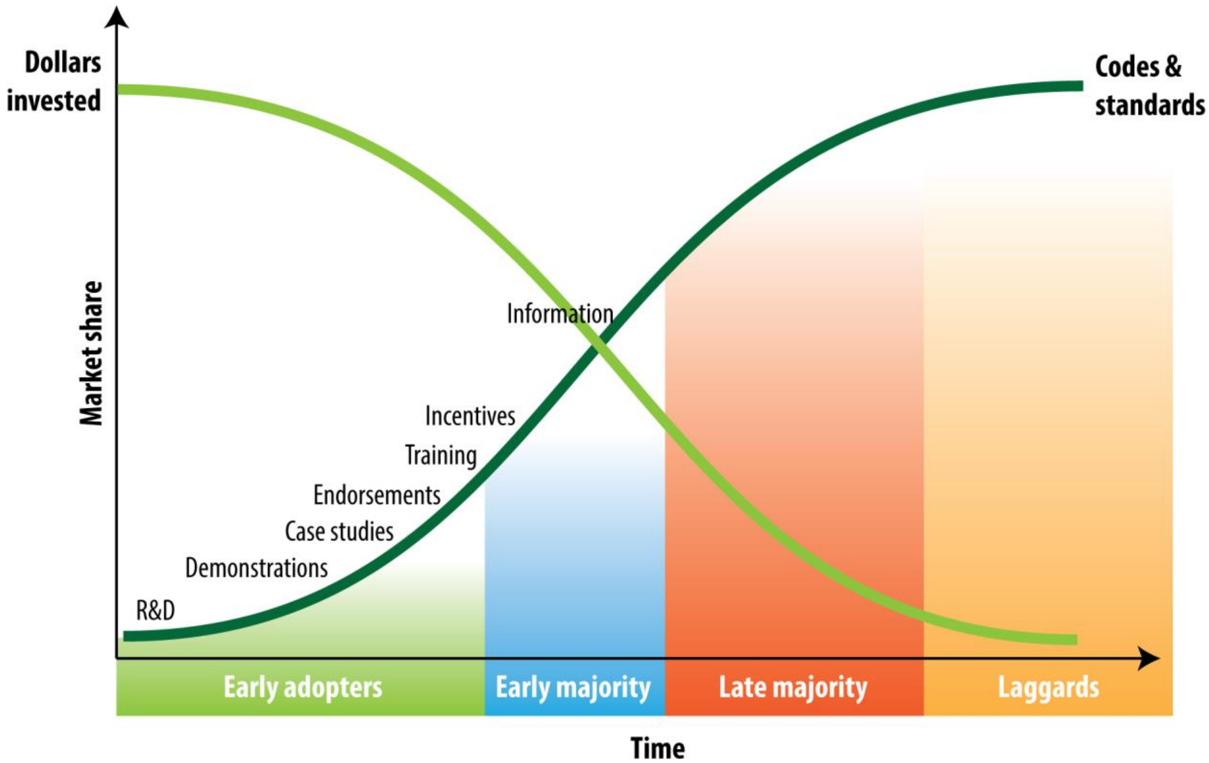

Figure 23. Market diffusion curve and common interventions at different stages. *Source:* Northwest Energy Efficiency Alliance; labels for common interventions added by ACEEE.

Successful market transformation efforts have included initiatives to promote high-efficiency clothes washers, furnaces, electric motors, and manufactured housing. Nadel et al. (2003) discuss these and other successful and partly successful market transformation initiatives, and lessons learned from these efforts. The authors also discuss the fact that market transformation has not worked in all markets where it has been tried; some markets are more amenable than others.

Energy-Saving Performance Contracts

An energy-saving performance contract (ESPC) is a long-term contract between an energy service company (ESCo) and a large energy user. The ESCo conducts an energy audit, provides financing, oversees measure installation and operation, and in exchange receives regular payments from the customer, often a percentage of the savings achieved. In some cases, the ESCo even provides a savings guarantee. ESCo investments and revenues have been growing steadily, as shown in figure 24. A recent Lawrence Berkeley National Laboratory analysis estimates that in 2012, ESCos collectively saved 34 TWh of electricity (Carvallo et al. 2014). Of these savings, 78% (24 TWh) came from public and institutional facilities (government, schools, and hospitals), and of these, 15 TWh did not include any utility incentives. Thus ESPCs are a substantial additional source of energy savings beyond the savings achieved under utility programs.

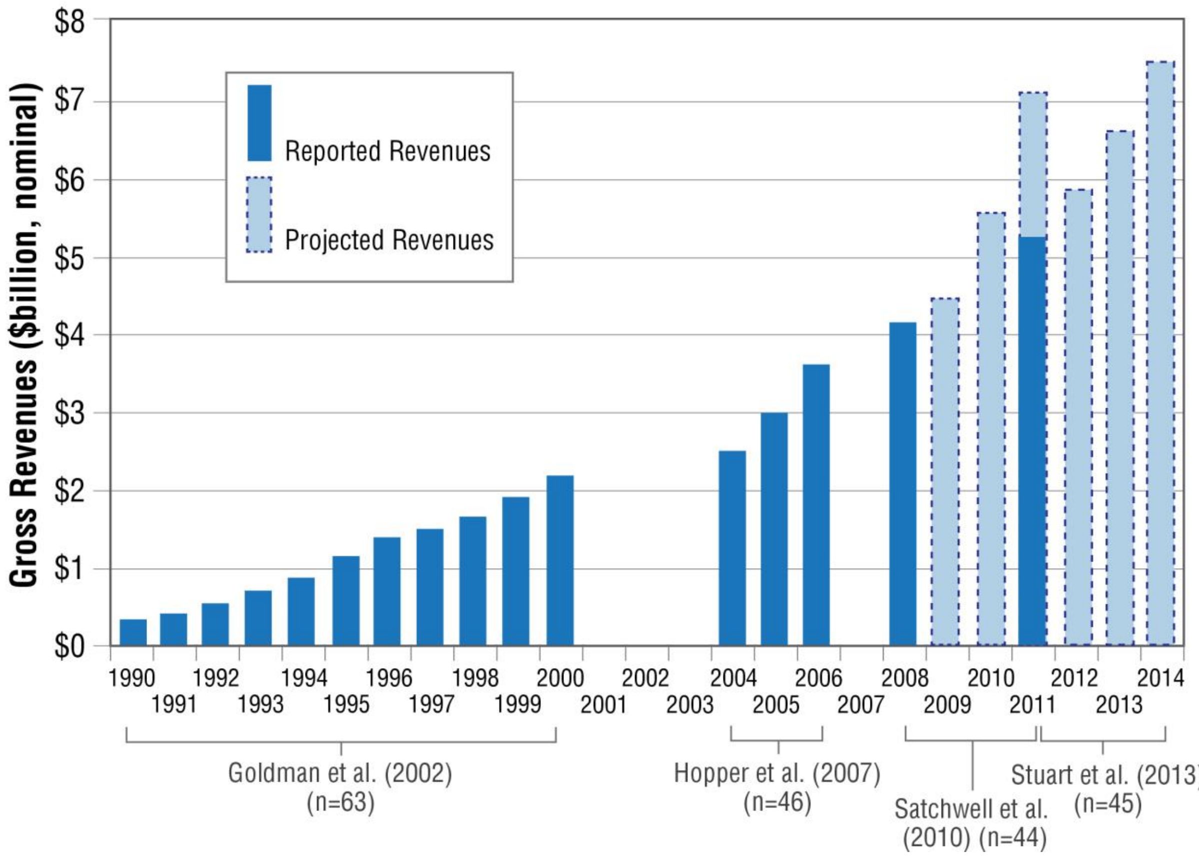

Figure 24. Reported and projected ESCo industry revenues by year. *Source:* Stuart et al. 2013.

Tax Incentives

Congress has enacted tax credits for energy-efficient equipment on two occasions, in 1978 and 2005. A review of the literature on the 1978 tax credits concluded, "[I]t appears that both the residential and industrial tax credits in effect during 1978–1985 cost the Treasury a substantial amount of money but had relatively little net impact on fostering energy efficiency improvements" (Nadel and Farley 2013). The credits were relatively small in percentage terms, and eligibility was limited to widely available and commonly adopted efficiency measures. Consequently, free-rider levels were high (free riders are taxpayers who would have made the efficiency investment even without the incentive) (Nadel and Farley 2013). Learning from this experience, the 2005 tax incentives (subsequently extended and revised) generally targeted equipment and construction practices with low market share and experienced less of this problem. A subsequent review (Gold and Nadel 2011) found that the incentives for appliances, hybrid vehicles, and new homes in particular helped spur manufacturers and builders to introduce new products and designs, encouraging a market transformation in which these previously niche products and designs became common. Due to these effects, Gold and Nadel estimated that energy savings from these tax incentives were about 50% higher than had been estimated when the incentives were first enacted.

Energy Guide Label

Since the 1970s, federal law has required that many types of home appliances bear a standard "Energy Guide" label containing information on energy use and operating cost. The label and the test procedures that underlie them are critical ingredients in the appliance standards and ENERGY STAR programs discussed above. On the other hand, evaluations of the labeling program have found that the current label is not very motivating to many consumers (Amann and Egan 2002). Later in this paper we discuss ways to improve the impact of the label.

Financing Programs

Another significant energy efficiency effort has been financing programs that provide loans for energy-saving investments. Such loans cover the up-front cost of efficiency investments, and the value of the energy savings helps the borrower repay the loan. These programs have been operated by states, municipalities, and utilities. Over time, hundreds of programs have been offered. Most have had low participation, although several have provided hundreds of millions of dollars of loans. Based on two studies, we estimate that loan programs have cumulatively lent about $3 billion for energy efficiency, which is much less than utility energy efficiency programs spend in a single year (Hayes et al. 2011; Financing Solutions Working Group 2014).[24] Both of these reports note that financing appeals to only some customers. New directions in financing that can potentially be more influential are discussed later in this paper.

DISCUSSION

Many market drivers and policies have contributed to improvements in energy efficiency, and it is difficult to tease out the relative contribution of each driver and policy. However one data point does indicate that equipment efficiency standards and utility energy efficiency programs have been important contributors to reduced electricity use in the residential and commercial sectors in recent years. Specifically, Nadel and Young (2014) conducted a statistical analysis to try to understand factors contributing to changes in residential and commercial electricity use per capita over the 2007–2013 period. They found that the combination of equipment efficiency standards and utility demand-side management programs had a strong downward and statistically significant impact on electricity consumption per capita, while weather, GDP, and price all had small upward impacts (see figure 25). This study did not look at other policies. Nadel and Young also examined industrial electricity use but found that the downward impact of efficiency standards and programs on industrial electricity use was not statistically significant. EIA has also looked at declining electricity use and attributes the trend to weather patterns and efficiency improvements in the residential, commercial, and industrial sectors (EIA 2013c).

[24] These studies estimate cumulative loan amounts of $1.6 billion and $1.8 billion, respectively. There is some overlap between these two estimates, hence the rough combined figure of $3 billion lent.

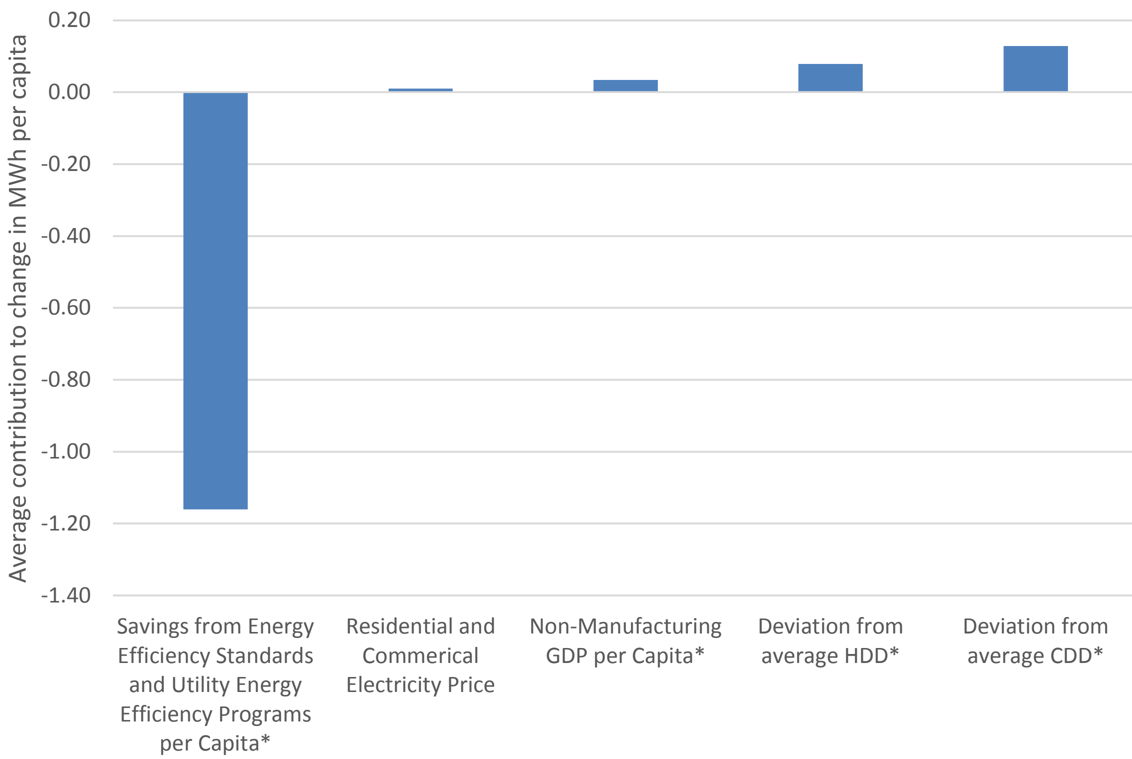

Figure 25. Contribution of different variables to change in residential and commercial sector electricity use per capita 2007–2013. Asterisked variables are statistically significant with 95% confidence. HDD and CDD are heating degree days and cooling degree days; these are measures of temperatures each day that trigger the need for space heating and cooling. *Source:* Nadel and Young 2014.

Several lessons can be distilled from this review of market forces and policies:

- Market forces have been a contributor to energy efficiency progress. Businesses have developed new energy efficiency products and services and successfully sold them based on direct cost savings as well as non-energy benefits.
- Policies to spur energy efficiency actions have played a very important role. Appliance, equipment, and vehicle efficiency standards; utility demand-side management (DSM) programs; ENERGY STAR, building codes; and federal R&D in particular stand out for the large energy savings they have achieved.
- Many times market forces and policies work together, complementing each other and increasing energy savings relative to what each can accomplish on its own. Examples of such synergies include the voluntary ENERGY STAR program and the SmartWay transport program, use of energy-saving performance contracts, and efforts to improve the business case for utility investments in energy efficiency (Molina et al. 2015). And the presence of such policies as utility energy efficiency incentives has encouraged market actors to develop and sell new products and services.

ACEEE's Role

ACEEE was founded in 1980 and has played a significant role in the developments of the past 35 years. For example, ACEEE wrote one of the first reports on the potential for appliance standards to reduce energy consumption (Geller 1983) and has played an active role in negotiating each of the major laws establishing appliance standards.

ACEEE has also actively supported encouraging utilities to operate energy efficiency programs for their customers, dating back to the mid-1980s (Geller 1986). ACEEE has issued dozens of reports and hosted many conferences to help utilities and utility regulators learn best energy efficiency program practices.

The market transformation approach to program design was first suggested in 2002 at an ACEEE conference (Eckman et al. 2002). Since then, ACEEE has released many reports on the subject, sponsored 18 annual Market Transformation Symposiums that discuss recent developments and lessons learned, and advised on the ENERGY STAR program since its inception in 1992.

ACEEE has promoted industrial energy efficiency and combined heat and power since the 1990s, helping many agencies and utilities to understand opportunities, barriers, and ways to overcome these barriers.

ACEEE led efforts to promote fuel economy standards for heavy-duty trucks, culminating in a provision establishing such a program in EISA. ACEEE is also a central player in efforts to set new fuel economy standards for light-duty vehicles and to promote improvements in freight efficiency and reductions in vehicle miles traveled.

In addition, ACEEE has been very active in the development and promotion of national model energy codes, as well as efforts to improve code implementation. ACEEE has also supported policy actions at the federal, state, and local levels, evaluating policies and supporting those that have performed well. For example, our annual *State Energy Efficiency Scorecard* and biennial *City Energy Efficiency Scorecard* have helped motivate actions at the state and local levels.

CHALLENGES

Much progress has been made on energy efficiency in the past 35 years, but challenges to continued progress remain. First, while many programs and policies have been successful, not all have worked well. We need to continue to study implementation experience in order to understand what works well in particular situations and what does not. We need to be honest about failures as well as successes so that we can learn from all our experiences. For example, to note one challenging area, while we have made great strides in improving the efficiency of new home construction, efforts to improve older homes have lagged. Quite a few states have established home retrofit programs, but most such programs have reached less than 5% of eligible homes (Neme et al. 2011).

Second, in recent years, domestic natural gas and oil production has increased while prices of these fuels have declined. It is unclear whether these recent price declines represent a long-term trend. Lower prices reduce the economic savings from energy efficiency, although most energy efficiency opportunities remain cost effective (Young et al. 2012). Lower prices can also reduce the incentive for new energy efficiency policy actions (although, to date, this impact has been modest).

Third, while energy efficiency policies have historically enjoyed broad support across the political spectrum, in some places this support has eroded. Broad political support has allowed the federal government and many states to enact energy efficiency laws and policies, including equipment and vehicle efficiency standards and support for utility investments in energy efficiency. These laws and policies have been supported by most elected officials. But in the past few years there have been some attacks on energy efficiency, based on arguments that choices about energy efficiency should be left strictly or primarily to markets, without a significant government or utility role (for example, see Loris 2013). While these attacks have been limited thus far, they could in the future undermine progress.

Fourth, growth in energy use has slowed, but except for a few recent years, it has not stopped. Growing population, rising average incomes, increasing home size, and the proliferation of new energy-using gadgets account for much of this increase. The next few years will tell whether energy use resumes its growth, or whether a leveling-off is the new normal. Many studies have found that widespread adoption of cost-effective efficiency investments can lead to absolute declines in energy use (see, for example, Granade et al. 2009). Thus, while we have made good progress, there is much more that can be done.

The Next 35 Years

OPPORTUNITIES

While energy efficiency has accomplished much over the past 35 years, much more can be done. In 2012, Laitner et al. looked at opportunities to reduce energy use by 2050. This study examined each sector separately and for each sector considered two scenarios: (1) an "advanced" scenario that includes increased penetration of known advanced technologies, and (2) a "phoenix" scenario that also includes greater infrastructure improvements and some displacement of the existing stock to make way for new and denser development.[25] Overall, the study found an opportunity to reduce energy use in 2050 by an average of 42% in the advanced scenario relative to a business-as-usual reference case (36–52% savings depending on the sector, with residential highest and industrial lowest). In the phoenix scenario, average savings were 59% in 2050 relative to the reference case. These findings are summarized in figure 26.

[25] This scenario was named "phoenix" for the concept that more efficient new development can rise from the rubble of older, inefficient development.

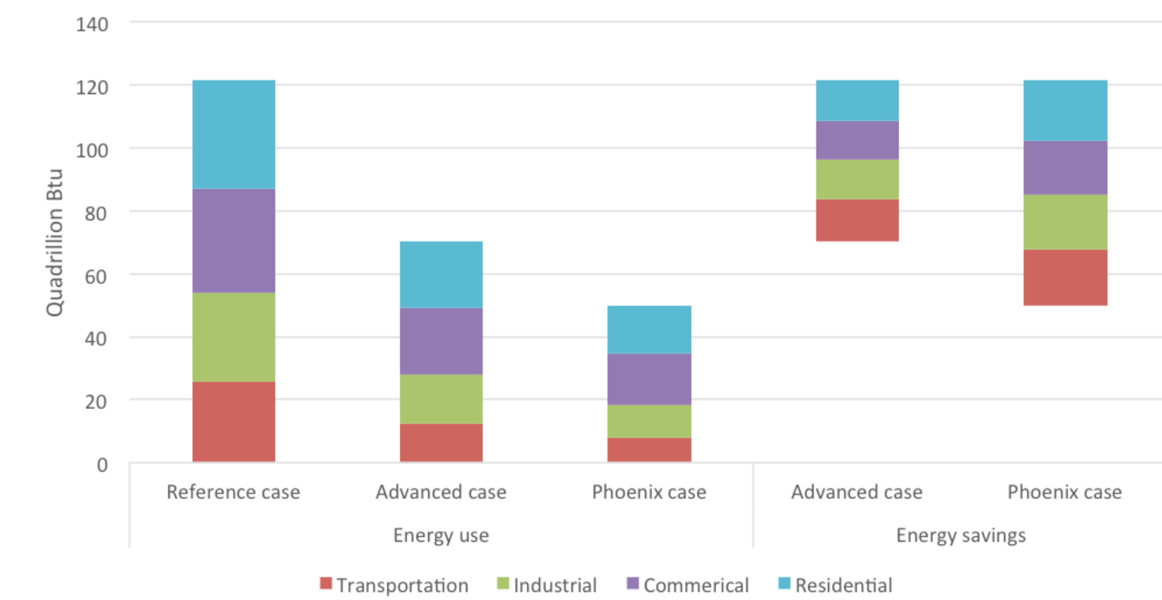

Figure 26. Energy efficiency scenarios in 2050. *Source:* Laitner et al. 2012.

Looked at another way, the advanced and phoenix scenarios work out to an efficiency improvement per dollar of GDP of 3.4% and 4.2% per year, respectively (Laitner et al. 2012). This improvement is substantially more than the 2.0% per year we have achieved over the past 35 years and dramatically more than the approximately 1.2% per year improvement we have seen after adjusting for the impacts of structural change.[26] In other words, there are large available opportunities to accelerate energy productivity improvements.

If these efficiency improvements are realized, Laitner et al. find that by 2050 we will have modestly increased the size of our economy, increased employment by more than a million jobs, lowered cumulative energy bills by more than $10 trillion, and reduced greenhouse gas emissions.

Many different technologies and practices contribute to these energy savings. In the paragraphs below we discuss some of the larger opportunities.

Look Beyond the Equipment to the System

Substantial progress has been made in improving individual pieces of equipment, as shown in figure 5 on page 7. While there are still opportunities for improvements of this nature, more and more energy savings will come from optimizing entire systems, such as lighting, HVAC, industrial process, and freight management. To provide just one example, nearly half of commercial building floor area is heated and cooled by packaged rooftop units. Current systems are mostly optimized for operation under high-temperature conditions, and a typical new system might have both a peak and an average energy efficiency ratio (EER) of 11.[27] DOE has recently worked with several manufacturers on systems that

[26] See pages 1 and 2 of this paper.

[27] Tested across a range of operating conditions and averaged. This test is called integrated EER (or IEER).

optimize operations across a range of conditions, using advanced controls and multispeed fans, among other things, that improve heating, cooling, and ventilation efficiency. Relative to a typical new system, some of these systems have average EERs greater than 20, reducing energy use by more than 40% (Rickey 2013). Further savings can be achieved by optimizing in-building systems for distributing heat and cooling.

One large class of system improvements has been labeled "intelligent efficiency"—that is, the use of information and communications technology, access to real-time information, and smart algorithms to help optimize energy-using systems (Elliott et al. 2012). A simple example of an intelligent efficiency measure is a Nest thermostat that monitors system parameters and finds ways to improve system operation after learning a household's patterns (e.g., when people are home and what temperatures they like). Heating and cooling average savings of around 12% have been found (Nest 2015). More sophisticated systems used in the commercial and industrial sectors can reduce energy use by 20% or more (Rogers 2014). There are also substantial opportunities in the transportation sector, ranging from new apps that make using public transportation, ride sharing, and bike sharing more convenient (Vaidyanathan 2014) to sophisticated freight logistics systems (Langer and Vaidyanathan 2014). There are also opportunities to reduce energy use and improve reliability through the smart grid.[28]

Reduce Miscellaneous Energy Loads

Electronic and "other" energy loads are increasing and account for a growing share of home energy use. EIA estimates that such loads were 26% of residential source energy use in 2014 and will grow to 30% by 2025. These trends are even more pronounced in the commercial sector, where office equipment and "other uses" accounted for an estimated 42% of commercial sector source energy use in 2014 and are projected to reach 50% by 2031 (EIA 2015d). Such uses need more attention; some will be easy to tame and others much harder. To illustrate the possibilities, the California Energy Commission recently proposed new efficiency standards for desktop computers that it estimates would reduce energy use by 60% relative to an ENERGY STAR version 5.2 unit (CEC 2015).

Promote Zero Net Energy and Ultra-Low-Energy Buildings

Hundreds of new homes and commercial buildings have been built that produce at least as much energy as they use on an annual basis (NBI 2015). Commonly labeled "zero net energy" buildings, they combine high levels of energy efficiency with solar or other renewable energy systems to meet average building loads over the course of a year. (Those without a renewable energy system have been labeled ultra-low-energy buildings [Amann 2014].) These buildings' efficiency features alone typically reduce energy use by about 40% relative to an average new building. The concept of zero net energy has been an inspiration for many architects, engineers, and policymakers,[29] and as solar and battery systems and

[28] See, for example, http://energy.gov/oe/services/technology-development/smart-grid.

[29] See, for example, the 2030 Challenge: http://www.architecture2030.org/2030_challenge/the_2030_challenge.

prices improve, zero net energy buildings are likely to grow in popularity. Amann (2014) discusses ways to make ultra-low- and zero net energy buildings the norm by 2030.

Develop and Promote Industrial Process Improvements

New improvements to industrial processes continue to be developed, offering opportunities to reduce energy use in most processes. Sometimes the savings are small; other times they are dramatic. An example of the latter is submerged combustion melting, which can reduce energy use for melting glass and metal by 20–50%, depending on the application (Purnode 2008). While most glass and metal are melted by passing hot combustion air over them, submerged combustion melting improves material heating by firing fuels directly into the surface of the material to be melted. Other examples include electrochemical processing for titanium and tantalum. Improvement of these processes not only saves energy but could also enable growth in the use of these lightweight, high-strength materials, providing indirect energy savings as they displace heavier metals (Economist 2013).

Develop and Increase Use of Advanced Vehicles

Hybrid, fuel cell, and battery electric passenger vehicles can achieve fuel economies on the order of 50%, 100%, and 250%, respectively, higher than comparable gasoline vehicles today on a miles-per-Btu basis, although this comparison ignores the energy used in generating and delivering the fuel to the vehicle (DOE and EPA 2015). And improved aerodynamics, engines, transmissions, and auxiliaries can reduce tractor-trailer truck fuel consumption by 46% from 2010 levels by about 2025 (ACEEE et al. 2014). Additional fuel economy savings can be achieved in the 2025–2050 period. Furthermore, rapid technology advances are occurring in the areas of interconnected and autonomous, or self-driving, vehicles. As a result, lower vehicle weights will become possible in the long term, as crash avoidance supersedes crash mitigation, and this will further reduce fuel consumption. Net energy impacts are less clear, however, because such vehicles could spur substantial increases in miles traveled (Gearhardt 2014).

Take Building Energy Retrofits to a Higher Level

A substantial portion of the homes and commercial buildings that will be standing in 2050 have already been built. This reality makes retrofitting existing buildings very important. Programs such as Home Performance with ENERGY STAR can reduce energy use by 20–30% (for example, see Belzer et al. 2007), and retrofits saving 50% or more have been documented (Cluett and Amann 2014). Similar savings are possible in commercial buildings. For example, a retrofit of the Empire State Building in New York reduced energy use by 38% (Harrington and Carmichael 2009). However, as discussed earlier, participation in retrofit programs is generally low. Furthermore, only a small fraction of retrofits come close to the level of energy savings seen in the Empire State Building. We need to improve our building retrofit efforts to go wider (involving more buildings) and deeper (achieving more savings per building). In retrofitting buildings, particular attention needs to be directed toward markets that have historically been underserved, such as low-income housing and small businesses. Another opportunity to improve existing buildings comes after natural disasters: a good time to pay attention to energy efficiency is when major repairs are required.

Improve the Efficiency of the Electric Grid

As noted earlier, there has been considerable progress promoting CHP systems, but much more potential remains. For example, Hayes et al. (2014) estimate that installation of about 20,000 MW of new, medium-scale CHP systems by 2030 is an achievable goal. These systems are generally more than twice as efficient as the typical conventional system operating today. Likewise, new, advanced combined cycle power plants can achieve average heat rates under 6,000 Btus per kWh (GE 2014), reducing fuel use by more than one-third relative to fuel use at the average plant in operation today (see figure 15). Energy use in transmission and distribution systems can also be reduced, as part of grid modernization and other efforts. For example, field studies conducted by the Electric Power Research Institute found average energy savings of 2.3% from optimizing voltage on distribution circuits (EPRI 2010). The electric grid is becoming increasingly complex, with the expansion of variable energy resources such as renewables and other clean distributed generation. Improved sensors, controls, data sharing, and software will enable more efficient grid operation and improve system reliability.

Promote Sustainable Development and Transportation Patterns

Changing development patterns can also result in substantial energy savings. For example, in 2009, the average single-family home used 38 million Btus per resident while the average multifamily unit used 27 million Btus per resident (both site energy use) (EIA 2013a). Density, land use mix, connectivity, and accessibility are key urban form drivers of energy use (Seto et al. 2014). Higher densities make increased use of public and self-powered transportation possible and can also enable ride sharing, facilitated by such services as Uber and Lyft. A study of the Chicago metropolitan region showed that households within a half mile of public transportation use 43% less fuel than the average for the region (CNT 2010). Similarly, concentration of activities related to goods movement in freight hubs permits greater use of intermodal shipping, reductions in movements of partially loaded or empty vehicles, and sharing of warehousing and value-added facilities.

Change Wasteful Behaviors

Influencing the decisions people make in how they use energy can also achieve substantial savings. For example, Shui (2012) found approximately 4–5% average energy savings from several efforts to encourage employees in hospitals and government buildings to use energy more efficiently. Foster and Mazur-Stommen (2012) found 4% average savings from providing real-time feedback to households about their energy use and offering information to help interpret and manage these numbers. And Grossberg et al. (2015) found savings of 3–6% in large-scale uses of games and competitions designed to encourage reduced energy consumption. Combining these and other opportunities, Dietz et al. (2009) estimate that energy savings as high as 20% can be achieved from behavioral actions at the household level.

PATHWAY TO AN ENERGY-EFFICIENT FUTURE

If, as discussed above, we are looking to roughly double the rate of efficiency improvement in the next 35 years relative to the past 35, we need to take our efforts to promote energy efficiency to a new level, which means both doing it better and doing it smarter. Given limited time and resources, we will need to identify priorities, emphasizing the largest opportunities and those where strategic intervention can make a difference. To inspire action, energy efficiency targets will also need to address societal priorities such as a strong, competitive economy that improves people's lives, a secure nation, a clean environment, and resilient communities (most of these are discussed on pages 2–3; we discuss resiliency below).

At a broad level, ACEEE has established an organizational goal to cut projected US 2050 energy use in half. President Obama expressed a similar goal in his 2013 State of the Union address: to cut energy waste by 50%. Our sister organization, the Alliance to Save Energy, has a goal to double energy productivity—that is, the amount of goods and services produced per unit of energy consumed—by 2030 (ASE 2013b). While these may seem like lofty goals, we believe they are more than achievable with smart planning and a commitment to action. The previous section discussed many of the largest and most strategic energy-saving opportunities to realize these goals. In order to make substantial progress in each of these areas, we will need to:

- Harness and transform markets
- Make efficiency a key strategy for the utility of the future
- Expand federal, state, and local policy efforts

Markets

As our look at the past has shown, large savings can often be achieved by understanding, harnessing, and transforming important markets. The market is a powerful force and can often be used to encourage efficiency actions and investments. We need to increase demand for efficient goods and services, develop and implement market transformation strategies, and expand the availability of financing.

DEMAND FOR EFFICIENT GOODS AND SERVICES

Educated consumers (including industrial customers) will choose to save energy and money and to enjoy the many other benefits of energy efficiency. Two approaches are particularly promising.

Provide information and improve transparency. Many consumers do not understand that there often are large differences in operating costs among different homes, buildings, and pieces of equipment. Providing consumer information on what is possible, including the relative energy use of different options, can sometimes lead to more efficient choices. For example, appliances and other types of equipment can be rated in an easy-to-understand way that facilitates energy-saving comparisons. Many other countries have successfully promoted efficient equipment with labels that rate products on a letter or star scale (see figure 27); these experiences, as well as a specific proposal for the United States, are described by Amann and Egan (2002).

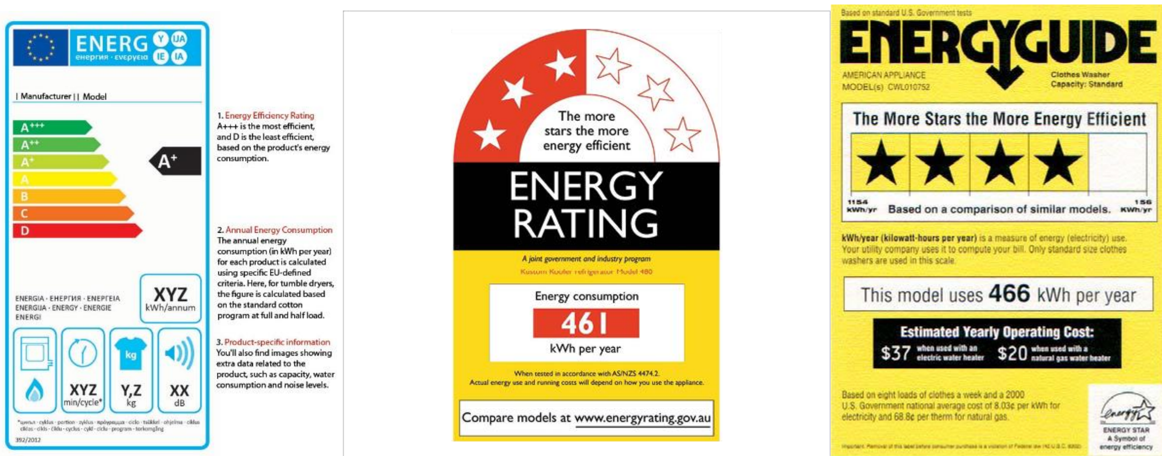

Figure 27. Sample appliance labels from Europe and Australia and a recommended label for the United States. *Source:* Amann and Egan 2002.

Similarly, a growing number of cities and states have adopted ordinances requiring that the energy use of commercial buildings and/or homes be disclosed to potential purchasers or renters so they can make informed decisions. Many of these ordinances also provide comparative information among buildings that can motivate owners to improve their properties, even when they are not selling or renting (Burr et al. 2011, Cluett and Amann 2013). A working paper by Palmer and Wells (2015) statistically analyzed energy bills in several cities with such ordinances and found that on average they reduced energy use of covered buildings by 3% in the first year; larger savings could accrue in future years as this information is used more by building owners, purchasers, and tenants. And consumers can be provided information about their energy use in quick and easy-to-understand ways, spurring some users to adjust their energy-use habits (Foster and Mazur-Stommen 2012).

Document benefits beyond energy savings. Earlier we discussed how co-benefits in addition to energy savings can motivate action. For example, interest in more energy-efficient schools and retail stores increased after research found that good, efficient lighting design can improve student scores and retail sales.[30] More work is needed to understand, document, and promote such benefits where they are substantial.

MARKET TRANSFORMATION

For each of the major areas discussed in the Opportunities section above, we must develop multipronged initiatives to address barriers in specific markets and eventually make efficient products and services normal practice. Market transformation efforts will need to engage in each stage of market development as illustrated in figure 23. These include:

- *Research, development, and demonstrations (RD&D)* in order to devise new energy-saving technologies and practices and address specific issues limiting the market penetration of targeted technologies and practices that are already commercialized. Pre-commercial research is often done by governments and universities. As

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[30] For a summary, see http://h-m-g.com/projects/daylighting/summaries%20on%20daylighting.htm.

commercial products are developed, private industry takes the lead, but governments and utilities can assist. RD&D efforts need to continue until specific technologies and practices can be viable in the market (or until continued problems show that viability is unlikely).

- *Market diffusion activities* to grow market share through the early adopter and early majority stages of the market diffusion curve. Such activities may include information and training, financial incentives, and financing. Market diffusion activities for each targeted measure should grow out of an understanding of market barriers and strategies to address these barriers.
- *Execution of a transition strategy* to move through the late majority and laggard stages of the market diffusion curve. Building codes or equipment efficiency standards are common transition strategies. Or markets can transform where demonstrated market benefits are substantial enough that the technology or practice takes off. (Examples of the latter might include intelligent efficiency, where optimized systems often deliver better service; or LED lighting, where the new lights have much longer life and improved light quality and controllability).[31] Once a transition strategy is executed, the process often begins again, with new, even more efficient technologies and practices being developed and helped up the market diffusion curve.

An illustration of the type of multipronged market transformation strategy that is needed is provided for zero net energy and ultra-low-energy buildings in a paper by Amann (2014). In this paper, the author lays out a goal: making zero net energy and ultra-low-energy buildings normal practice in new construction by 2030. She discusses obstacles to this goal and suggests a combination of R&D, implementation, and building code strategies for reaching the target. For example, R&D needs include development of workable system performance metrics and outcome-based code approaches that look at how much energy buildings use once occupied. Implementation strategies include building rating and labeling (discussed below); public sector leadership; stretch codes, green codes, and beyond-code guidelines and incentives;[32] and valuing efficiency in financial transactions.[33] Amann suggests leads for specific activities and identifies specific items for national model codes to address, with some items to be taken up in the next code cycle, some in the 2020s, and some not until 2030. In order to reach the goal, all of these strategies must contribute in a comprehensive effort.

FINANCING

Easy-to-access financing can enable energy efficiency investments among consumers and businesses that are capital constrained. Thus an important step on the pathway to an energy-efficient future is to improve the availability and usefulness of financing. In recent

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[31] In addition, some of the market-based strategies that have been successful in the past, such as ENERGY STAR, should be continued.

[32] Stretch codes are codes adopted by local jurisdictions that exceed statewide codes. Green codes are voluntary and include many environmental features in addition to energy efficiency.

[33] For example, including efficiency features in building appraisals and considering both energy and mortgage costs in mortgage underwriting decisions.

years, a variety of creative loan products have been receiving significant interest, including on-bill financing (Financing Solutions Working Group 2014) and property-assessed clean energy financing.[34] States are establishing "green banks" to spearhead these and other strategies.[35] And firms and organizations are looking at ways to standardize financing packages so that secondary markets can be established for energy efficiency financing, helping capital to flow to these loans (Rosenthal and Bellis 2015). These mechanisms should be refined and promoted and additional creative new mechanisms developed.

Utilities

Energy efficiency programs operated by and under contract to utilities have saved substantial energy, and these savings are growing, as shown in figure 19. But the utility industry is going through profound changes as sales growth slows and as distributed generation gains in importance. Utilities and utility regulators will need to reexamine utility business models, including the role of energy efficiency. In our opinion, new business models should support robust energy efficiency programs, as such programs provide valued services to consumers and help to minimize ratepayer costs (Nadel and Herndon 2014). In some cases, utilities will embrace energy efficiency services on their own (King 2014 and Kuckro 2014); in other cases, regulators will need to encourage efficiency efforts, for example by making energy efficiency results a factor in performance-based ratemaking. Rate design will also play a role; in the future, time-of-use rates are likely to predominate, and if structured well they can fairly allocate costs and encourage efficiency improvements (Faruqui et al. 2012).

Policies

As discussed in the Energy Efficiency Drivers section, government policy has played a substantial role in promoting energy efficiency improvements. Successful policies, such as appliance, equipment, and vehicle standards; building codes; and policies to promote utility energy efficiency investments, should continue. These policies set an efficiency floor but also encourage equipment manufacturers and energy service providers to innovate so that they can offer value-added goods and services, increase sales, and take advantage of the opportunities created by energy efficiency programs and policies.

In addition, creative new policies should be developed, piloted, and, where successful, expanded. Much of the innovation is likely to come from state and municipal programs and policies, where a variety of approaches can be tested before successful policies are moved to higher levels of government. States traditionally lead on utility regulation and building codes. In recent years, municipalities have also begun to step out, spurred by energy efficiency block grants provided under the American Recovery and Reinvestment Act of 2009 and by growing interest in sustainable and resilient cities.

Decisions about the location and scale of development are primarily local, so municipalities and regional consortiums of municipalities need to lead on such issues as transportation and land use planning. Municipalities can and have been leading on some new policy areas such

[34] Information and resources are available at http://www.pacenow.org/about-pace/what-is-pace/.

[35] See http://www.coalitionforgreencapital.com/whats-a-green-bank.html.

as building energy use disclosure and making communities more resilient so they can better weather natural and economic challenges (energy efficiency can play an important role in resiliency efforts, as examined by Ribeiro et al. 2015).

As discussed above, the federal government plays a critical role in energy efficiency R&D, the ENERGY STAR program, and appliance and vehicle efficiency standards. The federal government also supports updates to model building codes and provides funding and technical assistance to states and municipalities on code adoption and implementation. These activities should continue. The federal government can also take the best state and local policies and help extend them around the country. In addition, the federal government generally leads on tax policy, and there are substantial opportunities to remove barriers and provide ramps to energy efficiency as part of tax reform (Nadel and Farley 2013).

Governments at all levels can also help in a few other areas such as data and analysis and climate policy, both of which will help advance energy efficiency.

Data and analysis. In order to develop the most effective energy efficiency programs and policies, good data and analysis are needed in order to best target efforts and learn what works and what does not. The EIA in particular collects much useful data and conducts important analyses, but tight budgets have restricted its efforts. Underfunding data and analysis is pennywise and pound foolish, as discussed by Gold and Elliott (2010). In addition, big data is becoming increasingly recognized as an important source for energy efficiency information and opportunity identification (Fitzgerald and Dwoskin 2014; Walsh 2013). Furthermore, there is a need to expand the number of quality evaluations of energy efficiency programs and policies so we can all learn from experience.

Climate policy. A comprehensive climate policy will likely increase adoption of energy efficiency measures, as these measures are generally the least expensive ways to reduce greenhouse gas emissions (McKinsey and Co. 2010). Quite a few states and municipalities have stepped out on this issue, setting targets and developing plans to meet these targets.[36] With its Clean Power Plan, EPA is now working to establish a long-term policy for emissions from existing power plants. This plan sets state-specific emissions standards based on four building blocks, one of which is savings from energy efficiency programs and policies.[37] Hayes (2015) estimates that states can use energy efficiency to meet, on average, nearly 70% of the proposed targets, reducing projected 2030 electricity use nationwide by 25% relative to 2012 electricity use (Hayes et al. 2014).

Over the longer term, additional economy-wide climate policies are needed. In order to best harness the power of markets to reduce carbon emissions, a fee on such emissions or a cap-and-trade program should be considered. EIA in 2013 examined various emissions fee and cap-and-trade scenarios and found that an economy-wide emissions fee of $30 per ton of carbon dioxide that increases 5% per year would reduce US 2040 energy use by nearly 20%

[36] See http://www.c2es.org/us-states-regions.

[37] See http://www2.epa.gov/carbon-pollution-standards/clean-power-plan-proposed-rule.

relative to its 2040 reference case projection (EIA 2013b). This analysis shows that such policies can have a major impact on energy use.

More broadly, there is a need to build political support for energy efficiency policies. Traditionally energy efficiency policies and programs have enjoyed broad bipartisan support. For example, major energy efficiency laws were signed by Presidents Ford, Carter, George H. W. Bush, and George W. Bush. And as one congressman quipped at a recent congressional hearing, "No one is in favor of energy waste." But in recent years some policymakers have bristled at the idea of any significant government role or government expenditure, and the efficiency-related items the two parties can agree on have become more limited. Voters of all stripes still support energy efficiency. For example, an August 2014 bipartisan survey of Midwest voters found that 94% of Democrats and Independents and 96% of Republicans supported increasing use of energy efficiency to meet their state's future energy needs (Metz and Weigel 2014). In spring 2015 a modest bipartisan energy efficiency bill was enacted (Portman 2015). Still, more effort is needed to bolster the bipartisan support that energy efficiency has traditionally enjoyed. Continued research on the need for, and the effectiveness of, energy efficiency policies—and the substantial benefits, financial and otherwise, that accrue—is essential to this effort.

Conclusion

Energy efficiency has made great strides in the past 35 years, but much more can be accomplished. Overall, we find that energy efficiency improvements since 1980 have reduced US energy use in 2013 by about 58 quads from what it would have been without efficiency policies, programs, and technologies. This is more energy than our 2013 petroleum consumption (38 quads), or more than our coal and natural gas consumption combined (45 quads) (EIA 2015a). In other words, energy efficiency makes our economy more productive and is a fundamental resource for our economic well-being. These energy efficiency improvements have been driven by market forces as well as by a variety of programs and policies. Often the biggest impacts are obtained when markets and policies work together to complement each other.

New buildings in particular have improved substantially, due both to building codes and to the fact that it is easier to improve a new building design than it is to retrofit an existing building. The efficiency of appliances, cars, trucks, and other equipment has increased substantially, driven by federal standards and a variety of voluntary programs that work with standards. There have also been significant improvements in many manufacturing processes and in power plant heat rates and transmission and distribution system efficiency. In the cases of manufacturers and utilities, decisions are generally made by large, well-capitalized companies that are motivated to invest in improvements to save money and improve products, particularly when they face competition or, in the case of utilities, when their costs are regularly reviewed by regulators.

While there have been many energy efficiency improvements, some markets have proved resistant to change. For example, while many homeowners have made some energy efficiency improvements to their homes, the number of homeowners making major energy efficiency retrofits has been limited. Large industrial and commercial firms have made many more improvements than small firms, as small firms often lack the staff, expertise, and access to capital (Trombley 2014).

Human preferences also play a major role and change over time. Some recent trends (e.g., larger houses, more use of trucks as passenger vehicles, and more houses with air conditioning) increase energy use, and others (e.g., a drop in vehicle miles traveled and rising use of public transit) decrease energy consumption.

Looking forward, we find an opportunity to use energy efficiency to reduce 2050 energy consumption by at least 50 quads relative to a business-as-usual reference case. Major efficiency opportunities are available from:

- Optimizing energy-consuming systems, including adopting intelligent efficiency practices
- Taming miscellaneous energy loads
- Promoting zero net energy and ultra-low-energy buildings as well as deep retrofits to existing buildings
- Developing and promoting industrial process improvements and advanced vehicles
- Promoting CHP systems, improving generation efficiency and reducing transmission and distribution losses
- Influencing development and transportation patterns
- Influencing human behavior

In order to harvest these large efficiency opportunities, we must take our efficiency efforts to a new, higher level, improving overall energy productivity by more than 3% per year, up from the 2% annual average over the past 35 years. To do this we need to:

- Increase demand for efficient goods and services, transform key markets by addressing each stage of the market diffusion curve, and increase the availability of financing
- Encourage a reexamination of utility business models to support robust energy efficiency programs
- Continue successful federal, state, and local policies that promote energy efficiency, help develop creative new policies, and build bipartisan political support for policy and program initiatives

These energy efficiency strategies build upon the lessons we have learned over the past 35 years. There is much work to be done, but these efforts will lead to multiple benefits in terms of lower energy bills, a stronger economy, improved energy security, and a cleaner environment. The past shows what efficiency can do and teaches us important lessons that can guide us to be even more efficient in the future.

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