

Energy Efficiency 101

Explainer by **Kathryne Cleary** and **Karen Palmer** — June 2020

1. Introduction

Energy efficiency refers to using less energy to provide an energy service. For example, energy-efficient LED light bulbs are able to produce the same amount of light as incandescent light bulbs by using **75 to 80 percent** less electricity. Since energy production typically creates pollution and greenhouse gases, improving the energy efficiency of certain technologies has the potential to significantly reduce energy consumption and consequently reduce emissions from the energy sector.

Investing in energy efficiency is often described as being a “win-win”: by reducing the amount of energy used, efficiency measures can reduce energy consumption (and, consequently, impacts from energy use) and save customers money. Energy-efficient devices can cost more upfront (such as LED light bulbs relative to incandescent bulbs), but they often generate net savings for energy consumers in the long run.

This explainer explores methods for improving energy efficiency in buildings and transportation, barriers to greater adoption of energy-efficient technologies, challenges in effectively reducing energy use after the adoption of new technologies, and policy options for overcoming these barriers.

2. Methods for Improving Energy Efficiency

Energy technologies convert energy sources into **energy services**, such as lighting, mobility, and heat. During any energy conversion, some energy is lost. The energy efficiency of a technology improves when

it loses less energy during the conversion. Several technologies and design features are available to improve the efficiency of energy use in the buildings and transportation sectors.

There are a range of energy-efficient devices, appliances, and other equipment available for many electricity end-uses that provide the same service using less energy, either through improvements in efficiency of appliances (such as stoves, air conditioners, and refrigerators), or through the use of technologies that consume less fuel (such as hybrid or electric vehicles relative to gasoline cars). Other measures can also be taken to reduce energy consumption, such as improving the insulation of buildings.

2.1. Buildings

As of 2018, buildings contributed **36 percent** of total carbon dioxide emissions from energy use in the United States. Reducing energy use from buildings is therefore critical for mitigating the impacts of climate change. Buildings can become more energy-efficient through the use of more efficient technologies and from optimal building design.

Buildings use two main types of energy sources: **electricity** and **fossil fuels** (natural gas or oil for heating, cooling, or cooking purposes). In residences and commercial buildings, consumers power most appliances and equipment with electricity. Over time, new iterations of these appliances—such as washing machines, refrigerators, or air conditioners—have improved technologically to become more energy-efficient, in part due to some policies like appliance

standards (discussed in the Policy section below). As consumers switch to these more efficient technologies, energy use associated with providing the same energy services decreases.

In addition to replacing older, less efficient appliances with newer, more efficient ones, various measures can be taken to improve the energy efficiency of buildings through better design and insulation. For new buildings, architectural design can be altered to improve the efficiency of the building, such as **strategically designing window placement** to better accommodate heating or cooling needs (for more on energy-efficient home design, see [here](#)). **Weatherization** of existing buildings, such as sealing sources of air leakage and improving home insulation, can reduce energy waste, enabling consumers to use less energy to achieve the same level of comfort.

2.2. Transportation

The transportation sector, like the buildings sector, contributed to **36 percent** of total US carbon dioxide emissions in 2018. Options for improving energy efficiency in transportation are to design features for vehicles to improve fuel economy and a sector-wide transition to more efficient vehicles.

The energy efficiency of vehicles is typically referred to as “fuel economy,” which is expressed in the number of miles that can be travelled per gallon of gasoline. The fuel economy of a vehicle can be improved in several **ways**, such as reducing the vehicle’s weight or improving engine design to use less fuel. Hybrid cars, for example, have start-stop engines that will turn off when the vehicle comes to a stop in order to prevent wasting fuel during idling. Some similar **options** are available for reducing energy use in trucks, such as designing trucks to reduce air resistance.

Another option for improving energy efficiency of transportation is switching from gasoline or diesel to more efficient hybrid or electric vehicles. Most light- and heavy-duty vehicles use an **internal combustion engine**, which converts the potential energy in gasoline or diesel fuel into kinetic energy to propel a vehicle. Internal combustion engines are notoriously inefficient and only

convert about **12 to 30 percent** of fuel to kinetic energy. By contrast, hybrid vehicles (which use both gasoline and electricity) and electric vehicles are much more fuel-efficient: all-electric vehicles have a fuel efficiency rating of about **77 percent**. Switching from all-gasoline to hybrid or electric vehicles also has environmental benefits, as detailed in our [Electrification 101](#) explainer.

3. Challenges for Energy Efficiency

Energy efficiency improvements face some challenges with respect to both adoption, due to the energy efficiency gap, and efficacy, due to the rebound effect. These concepts are explained in the next section.

3.1. The Energy Efficiency Gap

Even though consumers can often save money from investing in energy-efficient devices, **research** suggests that consumers do not tend to do so, leaving many apparent cost-saving investments on the table. This phenomenon is referred to as the “energy efficiency gap,” since investment in energy efficiency should theoretically be higher than it is today.

In addition to the gap from a consumer perspective, which focuses on costs to individuals, there is also an efficiency gap from a societal perspective, which considers both private costs and external costs (such as the environmental costs of energy production). Society would generally benefit from investing in energy efficiency improvements when the sum of private and environmental costs of an energy-efficient investment is lower than for an alternative investment. For example, in some cases, it could make more sense for society to reduce energy consumption rather than invest in a new gas plant that will have higher combined economic and environmental costs for society. Therefore, as energy efficiency has public benefits that may not count toward a consumer’s personal benefit, the optimal level of energy efficiency adoption is higher for society overall than for private consumers, and thus the societal “gap” is even larger than the private one.

3.2. Possible Explanations for the Gap

There are many potential explanations for the energy efficiency gap.

Market Failures: Sometimes, consumers act **rationally (in their own best interest)**, but markets fail to account for other factors that prevent an efficient outcome from being reached. An example of a market failure is the **principal-agent problem**, where, in the energy efficiency context, differing incentives between owners of energy-using equipment and those who use the equipment result in **perverse incentives** (incentives with effects that are the opposite of what is intended) for energy efficiency investments. For example, if a landlord purchases the home's appliances but their tenant pays the electric bill, then the landlord is not incentivized to invest in sometimes costly energy-efficient appliances because they will not benefit from the resulting energy savings.

The principal-agent problem can be especially common when the rental market does a poor job of signaling differences in energy costs to consumers. Theoretically, a landlord should be able to raise the rent if they invest in energy-efficient appliances because the tenant would benefit from lower electricity bills. However, prospective tenants may not realize the energy savings advantage and choose to rent elsewhere due to the higher rent price, thus discouraging the landlord from making the investment. This type of misalignment prevents the market from reaching the optimal outcome.

A **lack of information** is also considered to be a market failure if its absence prevents a consumer from making a rational decision. For example, if a used car salesperson misrepresents information on the gas mileage of vehicles to a potential customer, the customer may purchase a different vehicle than if they had correct information. Economic theory assumes that consumers will make rational decisions given the information at hand, so if relevant information is not available, consumers may underinvest in energy efficiency.

Credit constraints are another example of market failures that may explain the energy efficiency gap. If consumers are unable to purchase more expensive equipment that would lead to energy savings over the

long term, it could be indicative of a failure of the market if consumers are unable to obtain credit for investments that have high associated savings (see [Gillingham and Palmer, 2014](#)).

Behavioral Failures: Behavioral failures occur when a consumer does not act rationally. One example of this type of failure is **loss aversion**, which describes an overweighting of losses over gains. A consumer could be averse to purchasing an appliance with a higher upfront cost, even if the lifetime energy savings benefits outweigh the costs, because they are averse to the immediate monetary loss (for example, see [Greene et al, 2013](#)).

Another type of behavioral failure is **inattention**, which refers to a consumer either ignoring or misunderstanding information relevant to the decision they are making and, consequently, making an irrational decision. For example, information on a product's energy usage may be available, but the customer may choose not to read or consider it when making a purchasing decision.

Hidden Costs: In some instances, the energy efficiency gap may be overstated due to factors that are unaccounted for. For example, a consumer might prefer a gasoline car over a more efficient electric car for non-energy-related reasons, such as vehicle performance or lack of availability of charging infrastructure. Once these factors are accounted for, the market does in fact reach the efficient outcome. While hidden costs could explain some of the energy efficiency gap, studies suggest it is likely only part of the answer and offer additional explanations as being either market failures or behavioral failures (see [Gerarden et al 2017](#) and [Gillingham and Palmer 2014](#)).

3.3. The Rebound Effect

In addition to the barriers present for adoption of energy-efficient technologies, some challenges exist for reducing overall energy consumption even after energy efficiency has improved. The **rebound effect** refers to the phenomenon that improved energy efficiency can lead, to some extent, to an increase in energy use because the cost of the energy service declines.

Energy services have a downward-sloping demand curve, meaning that if the price declines, consumers will purchase more of it. This rebound effect thus offsets some of the savings associated with energy efficiency improvements.

One hypothetical example of the rebound effect is a household that upgrades their washing machine to a more efficient model. Because the new model is more efficient and thus cheaper to operate, the household may end up running the washing machine more often, which therefore offsets some of the energy savings associated with upgrading to the more efficient model.

The rebound effect can vary significantly by sector and type of efficiency improvement, and various studies have found different estimates for the rebound effect. Some studies find very large rebound effects that arguably mitigate the benefits of improving energy efficiency. **Frodel et al (2012)**, for example, find a rebound effect of 57 percent in transportation (meaning 57 percent of the energy savings are offset by the increase in energy use). Other studies find much smaller rebounds in other sectors. **Gillingham et al, 2013**, for example, argue that the rebound effect for household appliances is around 5 to 10 percent. While many studies

have various findings, most agree that the rebound effect does not offset all of the energy reducing gains from switching to energy efficiency technologies, and thus there are still benefits from improving energy efficiency.

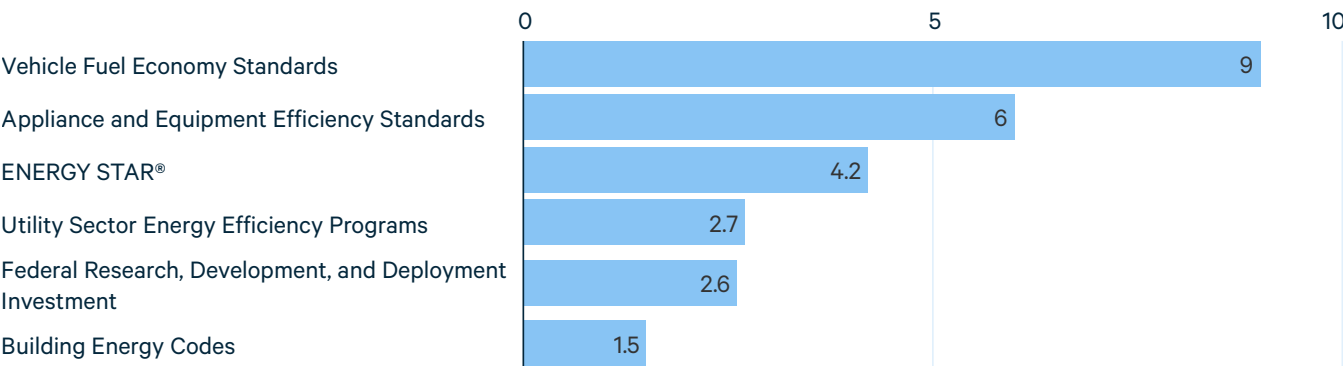
4. Policy Interventions to Encourage Energy Efficiency

Government policy and other behavioral interventions can be used to overcome some of the barriers to adopting energy-efficient equipment. Energy efficiency policies and interventions usually target the above-mentioned failures associated with the energy efficiency gap and are commonly used throughout the United States. Figure 1 shows the estimated effects of six energy efficiency policies on reducing energy use in 2017.

4.1. Information Labeling

To address lack of information, policymakers can require that information about energy savings be displayed on certain products. **Energy Guide** appliance labels,

Figure 1. Estimated Energy Savings from Major US Efficiency Policies and Programs, 2017



Estimates show that six energy efficiency policies and programs reduced US energy use by about 25 quadrillion British thermal units in 2017 (a 20 percent decrease relative to expected energy use without these policies.)

Units are quadrillion British thermal units. Values are approximate and come from studies with varied methodologies. Estimates of savings from these programs are typically based on engineering calculations that, in several cases, economic research indicates do not accurately reflect realized savings (Gillingham et al, 2018, “Advances in evaluating energy efficiency policies and programs”). More research is needed to better understand the consequences of these policies and the cost effectiveness of different approaches.

Source: [American Council for an Energy-Efficient Economy](#)

for example, are required by the federal government for many (though not all) appliances and display the energy cost of different appliances, thus ensuring that that relevant information is available to the customer. These labels can also correct behavioral failures related to inattention if they are designed to be obvious and simple to read.

4.2. Certification Systems

Certification systems are another form of information labeling that signal to consumers which products or technologies are the most energy efficient. **Energy Star**, for example, is a voluntary rating system run by the US government that certifies appliances that meet a certain energy efficiency standard. Manufacturers apply for Energy-Star certification and the government tests products to make sure they meet the performance criteria for certification. Energy Star–certified appliances are available for most home equipment, such as televisions, water heaters, dishwashers, and others.

Energy Star also issues certifications for energy-efficient homes and commercial buildings. In order to qualify for an Energy Star rating, a residential home must be 10 percent more efficient relative to code requirements. Another certification system for buildings is **LEED** (Leadership in Energy and Environmental Design), which is run by the US Green Buildings Council, a non-profit organization. LEED ratings are based on a point system, and buildings with higher points earn a higher rating (LEED Platinum is the highest possible rating).

4.3. Subsidies

Financial incentives are another approach to encourage adoption of energy-efficient technologies. For example, energy appliance subsidies can help correct for market and behavioral failures: if the subsidized price of an energy-efficient appliance is lower than the price of an equivalent but less efficient option, customers are encouraged to pick the efficient option without having to pay more up front. Utilities across the country offer rebates for technologies like fuel-efficient air conditioners, LED light bulbs, dishwashers, heat pumps,

and many others. Rebates are available in many utility service territories for both residential and commercial customers (see **DSIRE** for more information on available incentives).

4.4. Nudges

Another intervention used by governments and utilities to encourage energy conservation is a “nudge.” A nudge attempts to change the consumer’s behavior by presenting information in a strategic way. For instance, some electric bills include information about customers’ neighbors’ energy use, which creates social pressure and competition and therefore encourages consumers to reduce their energy consumption relative to their neighbors.

4.5. Performance Requirements

Performance standards are common in both the transportation and buildings sectors to improve efficiency of end-use technologies.

Performance standards on energy equipment are commonly used all **over the world** to ensure that products meet a certain minimum efficiency rating. In the US, the Department of Energy sets **minimum efficiency standards** on many categories of appliances used in homes and commercial buildings in order to promote energy saving.

Many states also have **building energy code requirements**. While building codes **vary from state to state** with no federal standard, many states require that new construction meet particularly strict standards for energy efficiency, such as California and Massachusetts. Some cities have also adopted strict building energy code requirements, such as the requirement in Washington, DC, that all new public buildings meet LEED Silver standards.

For vehicles, the National Highway Traffic Safety Administration (NHTSA) regulates vehicle fuel economy and requires that the average fuel economy of the new vehicle fleet increase over time. These requirements are called the **Corporate Average Fuel Economy** (CAFE) standards and apply to both the light- and

heavy-duty vehicle fleets (though with different requirements). Requiring that the new vehicle fleet meet more [stringent fuel economy standards](#) is one way to improve energy efficiency in transportation as new vehicles replace existing ones and use less fuel.

5. Moving Forward with Energy Efficiency

Market interventions and policies have managed to successfully increase adoption of efficient technologies and encourage energy conservation (see [Newell and Siikamaki 2014](#), [Ayres et al 2013](#), [Alberini and Bigano 2015](#)), albeit with energy savings that often fall short of predicted savings. Continued research on hidden costs, consumer behavior, and the effectiveness of market interventions will help inform the reasons for the gap and how best to correct it.

Resources for the Future (RFF) is an independent, nonprofit research institution in Washington, DC. Its mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement. The views expressed here are those of the individual authors and may differ from those of other RFF experts, its officers, or its directors.

Kathryne Cleary is a senior research associate at Resources for the Future. She works on RFF's Future of Power Initiative.

Karen Palmer is a senior fellow and director of the Future of Power Initiative at Resources for the Future. She is an expert on the economics of environmental, climate and public utility regulation of the electric power sector.