American Council for an Energy-Efficient Economy

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American Council for an Energy-Efficient Economy

Response to House Select Committee on the Climate Crisis Request for Information

November 22, 2019

Thank you for the opportunity to provide input on U.S. climate policy. The American Council for an Energy-Efficient Economy (ACEEE), a nonprofit 501(c)(3) organization, acts as a catalyst to advance energy efficiency policies, programs, technologies, investments, and behaviors. We believe that the United States can harness the full potential of energy efficiency to achieve greater economic prosperity, energy security, and environmental protection for all of its people.

We will first address some cross-cutting issues (questions 3-5) and briefly propose some sector-specific policies (questions 1, 2, and 5), before giving longer descriptions of how energy efficiency can transform each economic sector. We conclude by showing the combined potential savings from energy efficiency.

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Cross-Cutting Issues

Energy efficiency should be the foundation of U.S. climate change policy

Without energy savings due to energy efficiency (both policy and market driven) since 1980, our energy use in 2018 would have been about two-thirds higher than it was, carbon dioxide (CO_2) emissions would have been similarly higher, and our energy bills would have been almost $800 billion more as well. In a recent paper, we find that energy efficiency measures beyond business-as-usual could *cut expected total U.S. energy use and greenhouse gas emissions in 2050 in half*, getting us halfway to your zero emissions goal.[1] Dramatically scaling up government policies and investments (even without comprehensive climate policy) could help achieve about 90% of those reductions—while reducing energy bills by another $700 billion a year. Energy efficiency also creates jobs, increases worker productivity and business competitiveness, reduces air pollution, and improves health and comfort.

[Question 4] While a carbon price is important, we also need complementary policies and funding to curtail CO_2 emissions

Reviews of carbon pricing around the world show that at their current levels, scopes, and designs the prices have led to relatively modest impacts on emissions.[2] Moreover, a carbon price does not remove the well-known market barriers that prevent large amounts of cost-effective energy efficiency investments. Thus, decades of experience have shown that government energy efficiency policies and investments can achieve additional carbon emission reductions (and often more cost-effectively) to what carbon pricing or other broad market signals can do on their own.

- *Policies* including vehicle fuel economy and emissions standards, appliance efficiency standards, building energy codes, efficiency labeling, and research funding have all made significant carbon reductions while saving consumers billions of dollars—all should be strengthened. New policies are also needed, for example to make new homes and buildings zero-energy and to make deep energy retrofits throughout existing homes and buildings.
- Returning credit fees to consumers and businesses in the form of energy efficiency *programs* (or providing funds in other ways, such as under an energy efficiency resource standard) would provide ongoing financial benefits from reduced energy bills while at the same time providing further CO_2 emissions reductions. We recommend funding for state and utility programs, national market transformation incentives, transportation programs, and research and development.

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[1] S. Nadel and L. Ungar, *Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050* (ACEEE 2019). The full report is available at aceee.org/halfway-there.

[2] S. Nadel, "Learning from 19 Carbon Taxes: What Does the Evidence Show?," *2016 ACEEE Summer Study on Energy Efficiency in Buildings*, aceee.org/files/proceedings/2016/data/papers/9_49.pdf. On the importance of use of the proceeds for efficiency, see S. Nadel and C. Kubes, *State and Provincial Efforts to Put a Price on Greenhouse Gas Emissions, with Implications for Energy Efficiency* (ACEEE 2019), aceee.org/white-paper/carbon-tax-010319.

[Questions 3, 4] Policies and funding should help those who could be hurt by the transition, as well as promoting the transition

As with any major economic transition, some people will be disadvantaged, and the set of policies can try to address that. But we should ensure that such policies are aligned with the incentive to save energy.

- Any *free allocation of credits* or funds should not interfere with the incentive to reduce emissions by saving energy. In particular, updated allocations based on energy use or production and allowances that reduce utility rates will weaken the policy.
- Targeted energy efficiency and transit and mobility programs are an effective way to return funds to *low-income families*. The investment can lower their energy and transportation costs long-term while also further reducing emissions. A major expansion of the Department of Energy (DOE) Weatherization Assistance Program would be a start.
- Industrial policies need to address *workforce transitions, stranded corporate assets, and border adjustments* for energy-intensive trade-exposed industries. Besides political risk, a shift of industrial production to more carbon-intensive plants overseas could have large impacts on global emissions.

[Question 11] Energy efficiency is a key tool to improve the resilience of communities to climate change.

Energy efficiency can support community resilience by strengthening local energy systems and delivering more reliable and affordable energy for communities, households, and businesses. As shown in table 1, the myriad benefits of energy efficiency can make it an effective strategy for improving the resilience of community systems. We disaggregate those benefits here, but energy efficiency's potential effectiveness as a resilience tool is best recognized when we consider them as a cohesive set. Together, they help reduce vulnerabilities to hazards while increasing communities' capacity to cope.

Table 1. Resilience benefits of energy efficiency[3]

Benefit type	Energy efficiency outcome	Resilience benefit
Survivability	Reduced electric demand	Increased reliability during times of stress on electric system and increased ability to respond to system emergencies
	Backup power supply from combined heat and power (CHP) and microgrids	Ability to maintain energy supply during emergency or disruption
	Efficient buildings that maintain temperatures	Residents can shelter in place as long as buildings' structural integrity is maintained.
	Multiple modes of transportation and efficient vehicles	Several travel options that can be used during evacuations and disruptions
Social and economic	Local economic resources may stay in the community	Stronger local economy that is less susceptible to hazards and disruptions
	Reduced exposure to energy price volatility	Economy is better positioned to manage energy price increases, and households and businesses are better able to plan for future.

[3] Tables adapted from D. Ribeiro et al., *Enhancing Community Resilience through Energy Efficiency* (ACEEE 2015), aceee.org/sites/default/files/publications/researchreports/u1508.pdf.

Benefit type	Energy efficiency outcome	Resilience benefit
	Reduced spending on energy	Ability to spend income on other needs, increasing disposable income (especially important for low-income families)
	Improved indoor air quality, emission of fewer local pollutants, and reduced exposure to thermal extremes	Fewer public health stressors
Climate mitigation and adaptation	Reduced greenhouse gas emissions from power sector	Mitigation of climate change
	Cost-effective efficiency investments	More leeway to maximize investment in resilient redundancy measures, including adaptation measures

When considering energy efficiency, there are many options and measures to draw from. Table 2 details energy efficiency measures that reduce vulnerability and increase capacity to cope.

Table 2. Energy efficiency measures that reduce vulnerability and increase capacity to cope

Energy efficiency measure	Resilience implications
CHP	Provides backup power, allows facilities receiving backup power to double as shelter for displaced residents, reduces overall net emissions, and potentially increases cost savings
Microgrids	May disconnect from grid during power outage, maintaining power supply; allows facilities receiving backup power to double as shelter for displaced residents; reduces overall net emissions; and potentially increases cost savings
Transportation alternatives	Multiple transportation modes that can be used during evacuations and everyday disruptions
District energy systems	Provides heating, cooling, and electricity using local energy sources and reduces peak power demand through thermal energy storage
Utility energy efficiency programs	Increases reliability and reduces utility costs
Energy-efficient buildings	Allows residents/tenants to shelter in place longer, reduces annual energy spending, and reduces overall net emissions. Can help vulnerable populations avoid dangerous and occasionally life-threatening situations in which weather and economics present a dual threat
Green infrastructure	Reduces localized flooding due to storms, reduces energy demand, and reduces urban heat island (UHI) effect in cities and electricity demand
Cool roofs and surfaces	Reduces UHI effect and electricity demand and reduces overall net emissions
Transit-oriented development	Increases economic development opportunities; provides transportation cost savings and reduces impacts of transportation service and fuel supply disruptions and price volatility; and may improve air quality
Electric vehicles	Can provide on-site short-term emergency power

Building energy codes are one specific example of the connection between energy efficiency and resilience. The insurance industry, members of Congress of both parties, and current administration officials have all recognized the importance of building codes for resilience. Building energy codes (as well as health and safety codes) are an important tool to help low-income and other families limit the energy bill costs due to climate change, limit the indoor temperature and air quality hazards due to climate change, and make buildings and energy systems more survivable after disasters. Federal requirements for assisted housing (see especially 42 USC 12709), disaster recovery assistance, and other federal grant programs should recognize this. The current national model codes, the 2018 International Energy conservation Code and ANSI/ASHRAE/IES Standard 90.1-2016, should be a minimum. The 2018 International Green Construction Code has stronger resilience provisions for commercial buildings and should at least be preferred.

Providing mobility options and flexible transportation systems, and development patterns that facilitate their use, also assist survivability in the face of disasters. The Department of Transportation's competitive TIGER (now BUILD) grants have been an effective way to help communities improve transportation systems. More broadly, applying climate and resilience metrics to transportation funding decisions is important. Increased disaster mitigation funding with a focus on building requirements and transportation systems also would help.

All these energy efficiency measures will have the dual benefit of reducing climate change as well as adapting to it.

Sector-specific policy recommendations

[Question 1.a] Transportation

Decarbonizing the transportation sector will likely require multiple sector-specific strategies to achieve the necessary reductions. Setting *national targets* for transportation sector GHG emissions would provide the benchmarks to help ensure that transportation strategies in combination will deliver the necessary reductions.

Vehicle electrification will reduce transportation-related carbon emissions due to the superior efficiency of electric motors. Additional carbon reductions will follow from electrification to the extent that electricity generation efficiency increases, and the generation mix becomes cleaner. Targets for EVs and EV infrastructure in climate legislation that also includes grid emissions targets could help ensure that this transition achieves its potential.

There are also opportunities to reduce transportation emissions by *reducing dependence on solo driving* and other high-emissions modes. The climate change title of America's Transportation Infrastructure Act of 2019, introduced in the Senate Environment and Public Works Committee in August, demonstrates multiple mechanisms to reduce transportation sector emissions, including:

- $3 billion for state and local projects to lower carbon emissions and additional funding for those that succeed in reducing emissions
- Greater project flexibility for states and cities with CO_2 reduction plans

Depending on the progress of the transportation bill, a climate bill could complement and expand the transportation bill's climate change title.

The rise of mobile computing and the integration of advanced *information and communications technologies* into transportation systems is resulting in rapid, dramatic changes in how people and goods travel. This change represents another big opportunity to reduce the sector's carbon footprint, for example if personal vehicle ownership were to plummet and be largely replaced by app-enabled shared rides in urban and suburban areas. As several studies have demonstrated, however, the emergence of connected and automated vehicles could offset these gains by lowering the cost of driving and thus increasing vehicle miles traveled. Climate legislation has a role to play in ensuring that emerging technologies are deployed in ways that help to resolve rather than aggravate the climate crisis. Measures such as pricing of low-occupancy miles or charges on mobility services that unnecessarily increase miles traveled could support a successful transition.

As a large and growing source of GHG emissions, *freight transport* may warrant special attention in a climate bill. Due to the freight industry's focus on economic efficiency, it is relatively quick to adopt new technologies based on real-time information and automation of cargo tracking and handling. But, again, there is no guarantee that fuel use and emission reductions will follow. The climate bill could help to ensure they do. A freight title could:

- Establish a CO_2 emissions *reporting requirement* for major shippers and carriers
- Fund a *port/freight hub initiative* to cut emissions dramatically by applying information and communications technologies to streamline operations and to optimize vehicle loading and modal integration

In the next section we specifically address decarbonization policy opportunities through saving fuel in four transportation areas:

1) Light- and heavy-duty vehicle fuel economy
2) Reductions in passenger vehicle-miles traveled (VMT)
3) Reductions in freight transport energy use
4) Aviation efficiency improvements

[Question 1.b] Electric Power

The bulk power system delivers electric power to multiple sectors of the economy. The most important policy to decarbonize the bulk power system through energy savings is a performance standard for utility programs that help their customers save energy. About half the states have an energy efficiency resource standard (EERS), a requirement to achieve a specified level of verified electricity or natural gas savings. EERS is linked to decarbonization policies for other sectors. An EERS would drive decarbonization of electric power while also encouraging and incorporating decarbonization polices for buildings and for industrial power. Other electric power decarbonization polices, such as those for transmission and distribution, focus on the bulk power system itself.

Energy efficiency program savings can be combined with generation resource requirements in a Clean Energy Standard in multiple ways. Most states adopt separate energy efficiency and renewable energy requirements, requiring utilities to meet both. Some states have a "loading order," directing utilities to achieve all cost-effective energy efficiency and then requiring use of clean sources to meet a portion of remaining demand. One could also adopt a joint requirement to be met through any combination of efficiency and clean sources. If the requirement is expressed as a percentage of total sales, the verified efficiency savings that are counted in the numerator could be added to the total sales in the denominator so efficiency does not weaken the standard.

Policy opportunities and energy savings opportunities among these two categories are detailed in the next section:

1) Energy efficiency resource standard
2) Conservation voltage reduction and reductions in losses from transmission and distribution systems

Electrification is an important abatement tool *if* additional clean electric generation is available when and where it is needed and *if* the shift is to efficient equipment.

Some states and localities have become very focused on a shift from direct use of fossil fuels to electric equipment and vehicles. Electrification will be an important tool in achieving zero emissions. It is especially important to move away from carbon-intensive gasoline and diesel vehicles. Electrification will be an important tool for industrial decarbonization, but will require many years of additional research, development and deployment at increasing implementation scales. But electrification is not the whole solution on its own. Realizing these benefits requires a cleaner electric power sector and shifting to more efficient equipment. Otherwise electrification may shift GHG emissions rather than significantly reducing them.

We would note that as long as natural gas prices are as low as they are, influencing a shift from gas to electricity or even simple measures to reduce gas use may be very difficult. Therefore, electrification efforts will likely need to start with uses currently served by motor fuels, propane and fuel oil, for which the economics of electrification have a lower hurdle.

[Question 1.c] Industry

The industrial sector is diverse, complex, and interconnected. It accounts for almost a quarter of the GHG emissions in this country, and dramatic reductions in emissions from this sector are essential if we are to address climate change. A diverse portfolio of policies will be required to significantly curtail CO_2 emissions. Existing policy tools and technologies can yield substantial reductions in emissions, yet only scratch the surface of potential reductions that could be achieved through expansion of programs, new technologies, and fundamental changes to industrial processes. The colossal gap between existing policies and technologies and the massive potential for industrial efficiency presents a complex problem for policymakers to address.

Because of the complexity of the required response we propose a framework for the many individual policies that will be needed over the next three decades. We recommend a portfolio approach with responses grouped into five categories:

1. Immediate expansion of and sustained support for **federal industrial deployment programs**: Increasing use of best current technologies and practices will require significant expansion of DOE’s Industrial Assessment Center (IAC) and strategic energy management activities as well as a new focus on technical assistance for the manufacturing facilities with

the greatest GHG emissions (analogous to the former Save Energy Now program). New authorization language would be helpful.

2. **Technology commercialization** research and demonstration: Promoting successful commercialization of emerging technologies requires greater DOE support for demonstrations throughout scale-up levels, as well as for addressing intellectual property and anti-trust barriers to cooperative research.

3. Development and implementation of **transformative industrial process technologies**: Achieving greater long-term savings will require RD&D at DOE on transformative technologies using industry-government partnerships such as the Industries of the Future program, as well as authorization for a program on *industrial* carbon capture, utilization, and sequestration. A risk-sharing program backed by the Treasury also would facilitate needed investments.

4. Procurement of **low-carbon products and demand-side approaches**: Federal infrastructure spending and procurement should be used to spur the development and commercialization of products with a low-carbon footprint, including advanced cement, steel, and polymers. Besides purchase requirements, disclosure of GHG emissions and development of standardized metrics and labeling are needed.

5. **Sectoral policy approaches** for major carbon-producing industries: For a few key sectors voluntary agreements that include science-based, sector-wide GHG targets, technical assistance and incentives, and emissions trading will help achieve the above steps.

All of these categories are detailed in the next section, along with additional considerations.

[Question 1.d] Buildings

The buildings sector accounts for close to 40% of current US energy use and carbon emissions. Our analysis described in the next section found that carbon emissions from the buildings sector could be cut by a little over 50% by 2050 through a suite of complementary policy efforts focused on increasing efficiency in new and existing buildings along with building electrification.

New construction

State and local governments increasingly are adopting policies to support the transition to zero energy and zero carbon new buildings by 2030. While building codes are adopted and implemented at the state and local level, Congress can take steps to support and encourage the transition to zero energy and carbon codes.

1. Adopt H.R. 3962 introduced by Reps. David McKinley (R-WV) and Peter Welch (D-VT). This bill includes provisions promoting regular updates of national model codes and state codes, state and local "stretch" codes that go beyond the model codes, and better compliance with codes. It will not require zero energy codes but will set up a process that will further steady code improvements.

2. Go beyond the McKinley-Welch provisions to set targets for zero energy codes and to direct DOE to assist cities and states in adopting zero energy or carbon codes and to assist model code bodies to gradually ramp their codes down to zero energy or carbon levels. In addition, DOE should conduct R&D on ways to achieve zero energy performance in building types for which few examples of zero energy performance exist (e.g. hospitals and supermarkets, both building types with high energy intensity).

3. Provide tax incentives for zero energy homes and buildings, with the incentives phasing out once about a quarter of new homes and buildings are zero net energy.

4. Require that new federal buildings, as of a future date (perhaps three years from date of enactment) be zero energy buildings. In this way the federal government can be a leader, showing the way for others.

5. Strengthen federal requirements for the efficiency of new manufactured housing and new and rehabilitated housing that receives federal support (public housing, federally guaranteed loans, disaster rebuilding), with a process for continued improvements.

Existing Buildings

Improvements to the existing stock of homes and commercial buildings represents the largest opportunity and a significant challenge for energy savings and carbon reductions by mid-century. Most of the buildings that will be in use in 2050 are those we live, work, and play in today. Energy efficiency retrofits, coupled with smart building controls, can reduce energy consumption in existing buildings by 50-70%, allowing many buildings to achieve zero energy. Despite the energy savings and other benefits achieved through building retrofits, capturing these savings has proven very challenging. Congress can take steps to encourage and accelerate the rate of retrofits in existing buildings.

1. Have the federal government lead by example by requiring agencies to undertake deep energy retrofits at the time federal buildings are undergoing major renovations. GSA has done a variety of these projects.

2. Direct DOE to expand work with cities and states on energy use benchmarking and retrofit programs and existing building standards. More than 20 cities and three states now require commercial building benchmarking, which typically results in energy use reductions of 3-8% over a few years. DOE should also expand R&D on ways to improve energy retrofits and lower retrofit costs.

3. Expand existing building retrofit programs and establish new programs. DOE now operates the Weatherization Assistance Program to weatherize the residences of low- and moderate-income families. In addition to DOE’s low-income weatherization program addressed above, a program should be started to encourage whole-home retrofits by middle-income residents; Representatives Welch and McKinley have introduced such a bill, called the HOMES Act (H.R. 2043), and there also are related tax incentive proposals.

4. Expand federal support for applying information and communication technologies to improve building efficiency, including through the Smart Building Acceleration Act (HR 2044) introduced by Representatives Welch and Kinzinger.

5. As mentioned in the industrial section, expand and better coordinate federal support for strategic energy management, which also applies to large commercial buildings.

Appliances and Equipment

Higher efficiency appliances and equipment are critical to reducing carbon emissions from both new and existing buildings. Federal and state appliance efficiency standards, ENERGY STAR labeling, and utility and other incentive programs have been very successful in dozens of product categories. However, the core DOE appliance standards program has stalled. Congress should step up oversight, continue support for ENERGY STAR, and develop more effective tax incentives.

1. In order to encourage DOE to stay on track with regular updates to standards, and to create a pathway for progress if DOE does not act, Congress should sunset federal preemption of state standards if DOE misses legislative deadlines for revising standards.

2. Congress should also directly enact new standards when manufacturers and the energy efficiency community can come to agreement. Congress also could enact the light bulb standard that DOE is trying to roll back in order to end legal uncertainty.

3. Congress should adopt performance-based federal tax incentives. An interim step for heating and cooling equipment is to update the now expired 25C credits as in HR 4506 by Representatives Gomez and Kelly.

4. DOE should work with industry to expand R&D on improved efficiency equipment, and also on ways to improve equipment installation and maintenance (it is not uncommon for poor installation or maintenance to reduce efficiency of some equipment by 20%).

The next section gives much greater detail on the role in decarbonization of:

1) Zero energy new buildings and homes
2) Smart buildings and homes
3) Home and building retrofits
4) Appliance and equipment efficiency
5) Electrification of space and water heating in existing homes and buildings

Decarbonization by Sector

This section is adapted from the paper *Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050*.[1] All in-text citations are in that paper.

Transportation Opportunities

1. Light- and heavy-duty vehicle fuel economy

The fuel economy of US light-duty vehicles—that is, cars and light trucks such as minivans and many SUVs and pickup trucks—has increased substantially in recent years, driven by increases in federal fuel economy standards triggered by the Energy Independence and Security Act of 2007 (EISA). EISA also mandated that federal agencies develop fuel economy standards for heavy-duty vehicles, which range from heavy pickup trucks to 18-wheelers. The first standards took effect in 2014 and were extended in 2016. Under these two rounds of standards, new heavy-duty vehicle fuel use is projected to decrease by an average of 37% by 2027, relative to 2010 vehicles (Khan 2016).

Now light-duty electric vehicles (EVs) are starting to take off, with many new models being introduced each year, including several with ranges exceeding 200 miles and priced under $40,000 (e.g., the Chevrolet Bolt and Tesla Model 3). Electric vehicles are generally more efficient and have lower emissions than gasoline or diesel internal combustion engine (ICE) vehicles (see figure 1 below). Thus operating costs are typically lower for EVs than for ICE vehicles (Logtenberg, Pawley, and Saxifrage 2018). Recent projections are that EVs will reach parity in terms of annual cost of ownership in 2022–2024 (Deloitte 2019).[4] And according to one optimistic estimate, EVs could reach first-cost parity with large ICE vehicles in Europe as soon as 2022 (Bullard 2019). Forecasts of future market share are being revised upward (Lacey 2017). Forecasts by Bloomberg New Energy Finance (BNEF) and Energy Innovation estimate that EVs may account for 35% of new US light-duty vehicle sales by 2030 and 65% by 2050 (Rissman 2018).

Achieving these gains will require continued efforts to extend the range and bring down the cost of EVs (with battery costs particularly important). Also, many more public charging stations will be needed, particularly for multifamily buildings, in low-income communities, for ride-sharing vehicles, and along interstate highways. Utilities are increasingly playing a role in the expansion of charging infrastructure, with utilities and their customers typically paying to bring electric service to charging locations and private companies installing the charging stations themselves (Khan and Vaidyanathan 2018). Finally, fuel economy (CAFE) and GHG emissions standards for vehicles can be regularly updated; such updates will continue to drive fuel economy improvements including increased sales of EVs.

[4] Annual cost of ownership assumes that the vehicle purchase is financed with a loan and includes annual operating costs.

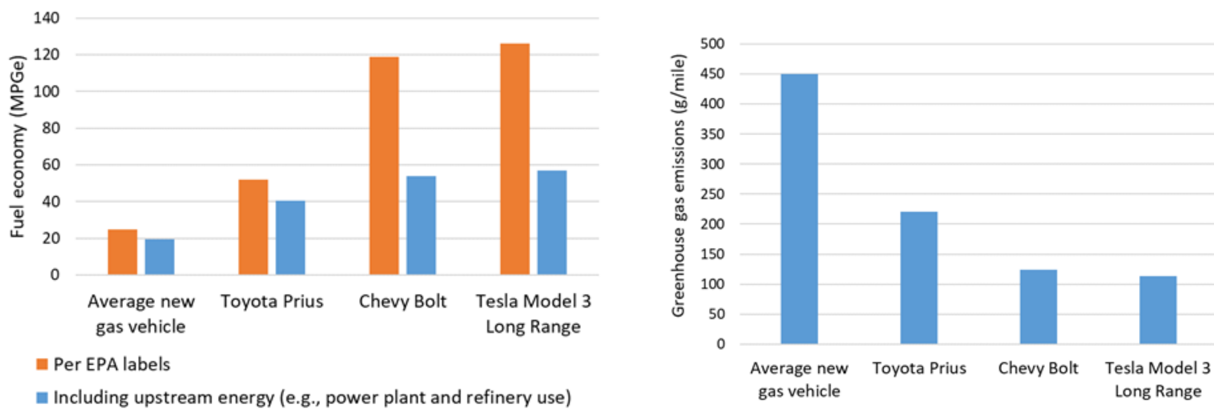

Figure 1. Comparison of two EVs, a hybrid car, and the average new vehicle on fuel economy and emissions per mile, based on US government fuel economy and emissions labels for 2018 vehicles. Our adjustments for upstream system losses are based on a 45% efficient power plant and 28% upstream energy losses for gasoline (the latter derived from Argonne National Laboratory's GREET 2018 model). GHG emissions are derived by ACEEE from GREET 2018 using the current national average generation mix.

Savings Opportunity

For our light-duty vehicle estimates, we assume substantial growth in the market share of electric vehicles as well as continued improvements in the fuel economy of petroleum-powered vehicles. We assume that EVs will represent 50% of new vehicle sales by 2033 (per the BNEF forecast) and will continue to ramp up market share until reaching 80% in 2042 (with the remaining 20% hard to electrify). As EVs shift away from premium vehicles, we assume the efficiency will start at 3.4 miles/kWh and increase by 2% each year. For the remaining ICE vehicles, we assume that the current 2025 fuel economy standards will be implemented, and that fuel economy will improve 4% per year from 2025–2030 and 2% per year thereafter. These assumptions modestly exceed the midrange case but fall well short of the optimistic case estimated by the National Research Council (2013). This National Research Council study finds that fuel economy improvements of this magnitude will be cost effective.

For our analysis of medium- and heavy-duty vehicles, we assume a gradual increase in EVs, ramping up to 50% of the stock by 2050. Gao et al. (2018) estimate energy savings for 10 types of commercial vehicles, with the primary energy savings averaging 36% (using Gao's electricity sector assumptions) but ramping up to 45% by 2050, adjusting for our assumptions about improving power sector heat rates. For ICE vehicles, we assume a 2% annual improvement in fuel economy beginning in 2028 (the first year of the next round of fuel economy standards). This level of improvement was found to be achievable and cost effective through 2035 by the Global Fuel Economy Initiative and the International Council on Clean Transportation (Delgado et al. 2016). Substantial additional opportunities in engine efficiency, aerodynamics, and automation would enable continued improvement through 2050.

Based on published estimates, we incorporate 10% direct rebound for light vehicles and 8% for heavy vehicles (Nadel 2016c; EPA and NHTSA 2016).[5] For the switch to EVs we assume that the net cost savings of electricity per mile versus gasoline or diesel causes a corresponding increase

[5] The 8% figure is a weighted average based on fuel consumption; EPA and NHSTA estimate 15% for vocational vehicles and 5% for tractor trailers.

in the amount of driving and hence electricity use; because the percentage cost savings is large, we assume a nonlinear rebound based on constant price elasticity.

Policies

Achieving these savings will require continual improvements in the federal fuel economy standards, as well as continued R&D efforts (e.g., the DOE SuperTruck program) and expanded efforts to promote EVs and other high-efficiency vehicles such as hybrid trucks.[6] As noted above, growth in EVs will require large expansions in charging infrastructure. Improved electric rate structures will be needed to encourage charging during off-peak periods while not unduly penalizing vehicles that must charge during peak periods.

Our policy analysis assumes the full savings for light-duty and heavy-duty vehicles. As described above, fuel economy and GHG emissions standards have driven rapid fuel economy improvements in recent years. California's zero emission vehicle requirements (also adopted by nine other states), along with federal tax incentives and state purchase incentives, have been important drivers for EVs and plug-in hybrid vehicles. Although the current federal administration is poised to issue a rule to weaken light-duty vehicle standards (including state standards), that attempt will be challenged by California and other states in court. Strengthening these policies and support for charging infrastructure could achieve the savings described above.

2. Reductions in passenger vehicle miles traveled (VMT)

New mobility options, especially in urban areas, could reduce many people's need to drive or own a personal vehicle over time. These options include ride sharing, car sharing, improved public transit systems, and on-demand flexible-route services. Continued revitalization of US urban cores and inner suburbs both supports and benefits from these developments. With the increase in compact growth patterns and pedestrian- and bike-friendly streets, residents will rely on nonmotorized modes to meet more of their work and nonwork mobility needs. On-demand shared-use vehicle services that are reliable and affordable will allow many households to forgo vehicle ownership altogether. These changes should permit a substantial decline in VMT overall. Such a result is not guaranteed, however, especially if these mobility services replace public transit and provide single-occupant vehicle services to children and others who do not currently drive. Telecommuting and e-commerce can also reduce vehicle use, although some of the reductions will be offset by home office and delivery firm energy use.

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[6] For more information on the SuperTruck program, see energy.gov/sites/prod/files/2016/06/f32/Adoption%20of%20New%20Fuel%20Efficient%20Technologies%20from%20SuperTruck%20-%206-22-16%20%28002%29.pdf.

California is establishing a policy framework that shows one way VMT reductions might be achieved, providing a potential model for other states and communities. Under S.B. 375, the Sustainable Communities and Climate Protection Act of 2008, and with guidance from the California Air Resources Board, metropolitan planning organizations (MPOs) covering 95% of the state's population adopted plans in 2018 to reduce VMT per capita from 2005 levels by 13–19% by 2035 (California ARB 2018). The primary mechanism for achieving S.B. 375 targets is the coordination of transportation and land use planning. The MPOs have prepared Sustainable Communities Strategies for inclusion in their Regional Transportation Plan updates, spelling out land use, housing, and transportation measures that will reduce the number and length of car trips projected to occur in each region. More recently California passed S.B. 1014 (2018) to create a Clean Miles Standard, a GHG emissions standard based on passenger miles for services such as Lyft and Uber. Besides using EVs, these services can meet the standard by more efficient dispatch and increased ride sharing.

There also is a lot of discussion of VMT and congestion fees as a funding mechanism for needed infrastructure investments. The primary funding source for federal investment in roads and transit is the gasoline tax. But the federal gas tax (18.4 cents per gallon) has not increased since 1993 even as inflation has raised prices overall by about 75%. Thus, there is a chronic shortage of infrastructure funds. In addition, there is concern that the shift to EVs and increasing fuel economy will shrink gas tax revenues even more in the future. One solution would be to charge a fee based on VMT, perhaps a fee that varies with the amount of congestion. Oregon has experimented with a voluntary road usage charge, OReGO, though in Oregon's case the VMT fee is in lieu of gasoline taxes.[7] London has instituted and New York City is planning a fee to drive downtown on weekdays, and many toll roads have dynamic tolls based on demand, in part to keep traffic flowing.

No similar policy framework currently exists at the federal level. However, the US Department of Transportation (DOT) did adopt regulations in 2017 directing federal transportation funding recipients—including state DOTs and MPOs—to set targets for mobile source GHG emissions and measure performance toward meeting those targets.[8] This regulation was repealed in 2018 following the change in federal administration.[9] Establishing such targets would help achieve the substantial VMT reductions we model.

Savings Opportunity

DOE's Transportation Energy Futures project estimated that, by 2050, energy demand of light-duty vehicles could be reduced by about 20% through changes to the built environment (higher densities, mixed-use development, walkable neighborhoods) and other trip-reduction strategies (NREL 2013). Vaidyanathan (2014) estimates a potential 13% reduction in light-duty fuel use by 2030 from six strategies based on ICT, including car sharing, real-time transit information, and vehicle-to-vehicle communications. Fulton, Mason, and Meroux (2017) discuss additional strategies for optimizing urban transportation. Combining the NREL and Vaidyanathan

[7] See www.oregon.gov/ODOT/Programs/Pages/OReGO.aspx.
[8] See www.federalregister.gov/documents/2017/01/18/2017-00681/national-performance-management-measures-assessing-performance-of-the-national-highway-system.
[9] See www.federalregister.gov/documents/2018/05/31/2018-11652/national-performance-management-measures-assessing-performance-of-the-national-highway-system.

estimates and adjusting for modest overlap, we estimate that VMT can be reduced by 30% in 2050 relative to the *AEO 2019* reference case. This savings estimate incorporates direct rebound effects.

The *AEO 2019* projects an average annual VMT growth of 0.6% from 2018 to 2050, which is only slightly higher than population growth (0.5% per year). Achieving a 30% reduction in VMT by 2050 relative to this projection would require an average *reduction* in VMT per capita of 1.1% per year. The US urban population (including suburban areas) is more than 80% of total population, and that percentage is growing (Census Bureau 2012); we assume that VMT reduction strategies would affect primarily this population. Consequently, urban residents would need to reduce their VMT per capita by about 1.4% per year to achieve the requisite overall reduction.

Our savings estimates do not factor in use of autonomous vehicles. On the one hand, fully autonomous vehicles have the potential to greatly reduce fuel use, in part because shared rides will likely be cheaper when there is no driver to pay. Also, vehicles can be much lighter if collisions can be reduced and are of less concern. On the other hand, investigations of autonomous vehicle scenarios to date point out the various ways their emergence could increase the amount of driving (Brown, Gonder, and Repac 2014). Net effects are thus difficult to predict and will depend on policy choices.

Policies

For our policy analysis we model a nationwide VMT fee along with congestion fees. The VMT fee applies to light-duty vehicles and phases in to 3 cents per mile over five years. This would be in addition to the current gas taxes. To estimate the impact on driving, we conservatively assume a constant price elasticity of demand of –0.1, analogous to the 10% rebound effect we also assume for light-duty vehicle use. We believe such a fee would be motivated in large part by infrastructure needs, but we do not model any impacts from associated infrastructure spending. We assume congestion fees collectively would result in a similar reduction in driving and energy use (after any rebound due to the reduced congestion). VMT and congestion fees do raise equity concerns, which might be partially offset by returning a portion of income to low- and moderate-income households.

3. Reductions in freight transportation energy use

Apart from improving the fuel efficiency of individual trucks, highway freight transport can reduce fuel use through a variety of techniques. For example, seamless transitions among highway, rail, water, and air modes will increasingly allow a dynamic, multimodal assignment of goods to the network; this can improve efficiency in multiple ways, including moving loads via the least energy-intensive mode that meets each load's needs. Improved management of supply chains also can reduce and shorten freight shipments. In addition, freight energy use can be reduced by avoiding empty backhauls and increasing the truck load factor, such as through collaborative shipping arrangements. Collaborative shipping could also help increase use of rail, allowing multiple shippers to share a railcar, replacing some use of trucks. Such strategies can draw on growing applications of ICT to mobility. Another strategy is platooning with vehicle-to-vehicle communications. Two-truck platoons with a separation distance of 40–50 feet have been estimated to reduce the trucks' average fuel consumption by 7%. Considering constraints on platooning, this could deliver 4% savings on average in real-world driving (NACFE 2016).

Although freight transportation's evolution will depend largely on the actions of the private sector, the public sector can promote a transition to a less energy-intensive system through actions such as:

- Setting targets for reduced energy use and emissions as program objectives and project selection criteria for freight funding programs and state freight plans
- Helping to standardize information-sharing protocols and equipment to facilitate collaboration and shared use of assets in goods movement
- Promoting innovation through strategic investments in ICT applications to the freight system
- Investing in the development of infrastructure and services that multiple unrelated companies can use
- Conducting further analysis of energy savings, nonenergy benefits, and the costs of alternative future freight scenarios
- Investing in rail, shipping, and intermodal infrastructure to increase the share of less energy-intensive modes.

Savings Opportunity

A 2013 ACEEE survey of literature on the potential to reduce freight energy use found a large range of estimates (Foster and Langer 2013). Studies that took a supply chain perspective and considered changes in factors such as distance traveled, modal mix, and shared usage of vehicles found potential for savings of more than 20% in the medium term (by about 2030), not including vehicle efficiency technology gains. On the basis of this analysis, we assume 25% freight system energy reductions by 2050 (including direct rebound).

Policies

For our policy analysis we again assume a VMT fee and congestion fees for heavy-duty vehicles. Because of their weight, trucks and other heavy vehicles cause major wear and tear on roads and other infrastructure. Thus several countries and the state of Illinois have implemented VMT fees for trucks. While such a fee should vary with weight and other attributes, here we model nationwide fees with a similar cost per gallon of fuel as for light-duty vehicles (9.4 cents per mile for an average truck), along with congestion fees that achieve similar savings. Again, this would be in addition to the current diesel and gas taxes. To estimate the impact on driving, we conservatively assume a constant price elasticity of demand of –0.08, analogous to the 8% rebound effect for heavy-duty vehicle use.

4. Aviation efficiency improvements

Energy savings **2.4** quadrillion BTUs

CO_2 emission reductions **157** million metric tons

Aviation accounts for nearly 4% of projected 2050 energy use. Furthermore, energy use for aviation is expected to grow more rapidly than all other transportation segments, as well as most non-transportation segments (EIA 2019a).

Energy use per revenue seat mile declined by nearly 50% from 1980 to 2012 (Nadel, Elliott, and Langer 2015). While there are now few empty seats that can still be filled, there remain a variety of other opportunities to further reduce energy use. Airplane manufacturers and airlines are very interested in improving airframe and operational efficiencies, as fuel is a substantial portion of airline operating costs. Manufacturers do substantial R&D, financed in part by military contracts. Operational efficiencies are also a function of air traffic control operation and should be aided by the major upgrade of Federal Aviation Administration systems that is now underway.

In October 2016, the International Civil Aviation Organization (ICAO) reached consensus on capping GHG emissions for international aviation at 2020 levels. Under the plan, 65 nations agreed to a voluntary cap-and-trade program for the 2021–2026 period and a mandatory cap-and-trade program starting in 2027 (Lowy 2016). Many environmental activists were seeking a stronger plan (von Kaenel 2016). In July 2016, the EPA issued an endangerment finding for GHG emissions from aircraft (EPA 2016), a precursor to regulating the emissions; such standards would likely go beyond the ICAO agreement. With the change in administration, such standards have been put on hold, but they could be revived by a future administration. Absent such standards, the European Union in all likelihood will apply its GHG Emissions Trading Scheme to European routes of US airlines. GHG emissions regulations will encourage a variety of actions, particularly efficiency improvements (airframe and operational) such as those we model here and displacement of traditional jet fuel with lower-carbon alternatives such as biofuels and electric engines (the latter primarily on short flights).

Savings Opportunity

Greene and Plotkin (2011) examine opportunities to reduce aviation energy use including improved engines and airframes, operational efficiency, and changes in travel. Their mid-case estimate is 32% savings in 2035 and 56% savings in 2050 compared with the *AEO 2010* reference case (extrapolated to 2050). Support for operational savings comes from a recent study in which pilots flying for Virgin Atlantic were reminded and encouraged to save fuel when flying; those pilots reduced fuel use by 7–20% (Gosnell, List, and Metcalfe 2016). Changes in travel could, for example, include businesses using more video meetings and less travel. For our analysis, we use the Greene and Plotkin percentage savings, applied to our *AEO 2019* baseline with linear ramp-up. We apply these savings to all jet fuel use in order to include similar savings in military aviation. We could not find any published estimates on direct rebound in the aviation sector, so absent other data, we assume 5% rebound.

Policies

For our policy analysis we model an airplane fuel efficiency or GHG emissions standard applied to domestic US flights. We assume such a standard would be set at a level to achieve the engine and airframe efficiency estimated by Greene and Plotkin, 25% savings by 2035 and 50% by 2050, but adjusted for our baseline. Since these are equipment standards, we do not include Greene and Plotkin's estimate of operational savings in our policy analysis.

Electric and Natural Gas Utility Opportunities

1. Energy efficiency resource standard (EERS)

We include one policy, an energy efficiency resource standard (EERS), that cuts across multiple economic sectors and efficiency opportunities. EERS policies also stand out for having many years of success in delivering energy savings.

Most energy efficiency programs in the United States are funded by electricity and natural gas utility ratepayers and run by the utilities or, in some cases, by state agencies or so-called energy efficiency utilities.[10] These programs (residential, commercial, and industrial) provide rebates, incentives to businesses and retailers, and technical assistance. Most are under regulatory oversight and are subject to independent evaluation and cost-effectiveness tests.

About half the states require these programs to meet savings targets, sometimes called EERS. A few states, especially in the Northeast, are meeting targets to achieve new electricity savings each year of more than 2% of electricity sales. (As the savings persist over 10 years, on average, in time such savings would accumulate to about 20% of sales.) The leading states have savings goals of more than 3% per year. Natural gas savings have been somewhat lower, as there are fewer programs and natural gas offers fewer opportunities for cost-effective savings (ACEEE 2019). Most municipal utilities and rural electric cooperatives are not currently subject to state EERS, but many run their own efficiency programs.

For our policy analysis we model energy efficiency programs based on a ramp-up to 2% new electricity savings and 1% new natural gas savings each year from 2020 to 2025 (as a percentage of the average policy scenario electric and natural gas use over the previous three years).

Because many currently available technologies would be adopted under the codes and standards described earlier, achieving these savings would require bolder and more creative programs to find new savings.

Although states are sometimes allowing large industrial ratepayers to opt out of paying for and using the programs, we assume the same level of savings in each sector and do not reduce the industrial targets. As EVs become commonplace, transportation electricity use increases in our analysis and is included under the policy. We assume that utility programs would achieve the same level of savings in the new transportation electricity use, either through more-efficient electric vehicles or initiatives to decrease driving (we did not assume any further shift to EVs

[10] An energy efficiency utility is chartered by a state legislature or state public utility commission to operate energy efficiency programs under the oversight of the utility commission. Examples include Efficiency Vermont, the District of Columbia Sustainable Energy Utility, and the Energy Trust of Oregon.

beyond what occurs under the vehicle standards). Reported savings are only what is additional to the current levels of savings (0.7% new electric savings each year and 0.4% gas savings), which we assume are continued indefinitely in the AEO 2019 baseline. In this analysis, electric savings in all sectors last an average of 10.6 years, and natural gas savings persist 16.1 years, with straight-line decay (Molina 2014).

An EERS policy interacts significantly with other policies. All other electricity and natural gas policies affect the baseline energy use to which the EERS target percentages are applied. In addition, utility-sector efficiency programs often promote and receive credit for market transformation in building retrofits and energy management and in high-efficiency equipment sales, measures that are counted under other policies. Thus our overlap calculation assumes that half of the commercial building benchmarking standard, Home Energy Score standard, and near-term industrial policy savings (but not industrial steps 2 and 3) overlaps with up to half the respective sectoral savings under EERS.

2. Conservation voltage reduction and reductions in losses from transmission and distribution systems

In the United States, about 5% of electricity generated is lost during the transmission and distribution (T&D) of power.11 Additional energy is lost from electric wires in homes, buildings, and factories.

At the grid level, losses can be reduced through use of lower-loss wires and transformers and improved control of voltage and other power parameters. Improved transformers, such as those with amorphous steel cores, can reduce losses by about 50–70% relative to current new transformers (York et al. 2017). Also, greater use of distributed generation can reduce grid losses as power never enters the grid or is generated closer to the load (grid losses depend in part on the distance that power is transmitted).

Additional losses in some equipment in homes and buildings can be avoided by improved voltage control on utility circuits, reducing overvoltage through a measure often called conservation voltage reduction (CVR), or volt/VAR optimization if combined with reactive power management. CVR can be cost effectively employed using sensors at the ends of distribution feeders to sense actual voltage and then reducing voltage to the minimum required levels.

Multiple utilities are now implementing CVR (York et al. 2015a), and the number is growing every year. A few utilities, such as Baltimore Gas and Electric, are beginning to implement CVR

[11] See www.eia.gov/tools/faqs/faq.cfm?id=105&t=3.

on a widespread basis (Exelon 2017). A few other utilities, like Hawaiian Electric and Xcel Colorado, are testing grid-edge optimization technologies to make CVR more effective (St. John 2018). Additional testing of volt/VAR grid-edge optimization techniques would be useful to see if the additional 2% savings achieved on a few circuits can be achieved in a widespread manner. Utilities generally make purchase decisions for transformers on a life-cycle cost basis, but with a "band of equivalence" that selects less-efficient transformers with lower first cost even when their life-cycle costs are a little higher. The District of Columbia and Maryland have eliminated this band of equivalence, and as a result sales of amorphous core transformers are significantly higher (York et al. 2017).

More broadly, utilities are gradually improving their T&D systems; losses were more than 7% as recently as 2002, so losses have been reduced by one-fourth (Nadel, Elliott, and Langer 2015). Smart grid efforts and intelligent grid optimization could help continue the trend. Utility regulators can monitor, support, and ensure implementation of CVR and T&D loss reduction programs.

Savings Opportunity

T&D losses average about 4% in Germany and about 4.5% in Japan (World Bank 2018). These countries are more compact than the United States, with improved controls and other technologies, as well as greater use of distributed generation. Still, we estimate that the United States can, by 2040, reduce T&D losses to Japan's level, saving 0.5% on the utility side of the meter and not including CVR and volt/VAR where savings are primarily on the customer side of the meter. York et al. (2015a) summarize eight different studies on the savings from CVR, finding average savings of 2.3%. In addition, volt/VAR grid-edge optimization techniques, which on some circuits have demonstrated up to 2% additional CVR savings, are now reaching the market (Moghe et al. 2016). Considering all of these factors, we estimate total T&D savings of 4.5% are possible, with savings achieved over a growing portion of the grid over the 2020–2040 period, reaching 80% of the grid by 2040.

Policies

As these savings are under the control of regulated and publicly owned utilities, we assume that regulators, cities, and cooperative boards could achieve all the savings.

Industry Opportunities

The industrial sector is diverse, complex and interconnected – and it accounts for almost a quarter of the greenhouse gas (GHG) emissions in this country, so dramatic reductions in emissions from this sector are essential if we are to address climate change. The challenge posed by the committee is ambitious, and the response will need to be comprehensive and complex. Because the sector is intertwined in the U.S. economy, a diverse portfolio of policies will be required to transition toward GHG neutrality by mid-century. It's crucial to develop and pursue a policy framework, starting NOW with parallel investments in a portfolio of near, mid, and longer-term programs.

This effort will face many challenges. Among the challenges that decarbonization of the industrial sector will encounter are:

- Time frame – the industrial sector makes investments over a long timeframe. To dramatically reduce GHG emissions over the next three decades will require significant replacement of existing investments.
- Economics, low price of energy and carbon – energy prices, particularly natural gas, are historically low, and most proposed prices for carbon are modest, so economic signals for reducing energy use are weak. Justification for unilateral, risky investments to transform corporate operations based on relatively weak drivers competes poorly with higher return investments that are more attractive to stockholders.
- Carbon price is not sufficient – While putting a price on carbon is important as an economic signal, a carbon price is not sufficient for decarbonization of the industrial sector because of multiple economic barriers. A reasonable carbon price alone will not yield the needed investment. We need other supportive policies and federal investment, particularly related to global competitiveness that would require additional policies to ameliorate.
- Rapid scaling of investments – To achieve the committee's goals will require rapid scaling of new practices, technologies and product changes that would strain existing infrastructure and workforce.
- Workforce – The industrial sector is already contending with a shrinking and aging workforce. To both implement the investments and operate advanced, low-carbon plants will require a new generation of trained workers.

Because of the complexity of the required response we propose a framework for the many individual policies that will be needed over the next three decades. We suggest a portfolio approach, with responses grouped into five categories:

1. Immediate expansion of and sustained support for **federal industrial deployment programs**
2. **Technology commercialization** research and demonstration
3. Development and implementation **of transformative industrial process** technologies
4. Procurement of **low-carbon products and demand-side approaches**
5. **Sectoral policy approaches** for major carbon-producing industries

The policies within this portfolio could be grouped in multiple ways, but we feel this suggested grouping could help provide the committee a framework for their development of legislation.

A number of specific policy and program proposals already exist based on past successes, which should be built upon and expanded. ACEEE believes energy efficiency should provide the foundation for that response because of its proven effectiveness and ability for rapid implementation.

We will also need new and innovative ideas that will emerge as we broaden our understanding of markets, technologies, opportunities and challenges. Policy development should be agile, include evaluation (by third parties), and incorporate learning from those evaluations in next stage policies to achieve continued progress toward decarbonization.

Federal Industrial Policy Framework

Below we provide greater detail into each element of the suggested framework.

1. Immediate expansion of and sustained support for federal industrial programs

The Advanced Manufacturing Office (AMO) at the Department of Energy (DOE) has been the primary federal agency focused on manufacturing technologies research and deployment. Their current portfolio includes a number of successful programs, and they have a three-decade history of working collaboratively with industry on energy efficiency and productivity efforts. With additional resources and authorization, AMO is positioned to respond to the climate crisis much as it did to the natural gas crisis in 2005 when it launched the Save Energy Now program,[12] which deployed experts to the most natural gas intensive manufacturing plants, quickly producing significant natural gas savings through energy efficiency.

Among the policies that should be considered are:

- Create a team of federal experts, building on the model of Save Energy Now, to advise manufacturing facilities with the heaviest carbon dioxide emissions on the most advanced technologies for energy efficiency and emissions reductions. The effort would target the top 500 carbon dioxide-emitting industrial facilities, and mobilize "SWAT" teams of DOE staff, contractors, and national lab staff to work with plant staff to implement energy efficiency savings, put in place energy management systems, and train plant staff to achieve sustained carbon reductions. This program would coordinate with state and utility programs to leverage their expertise and incentives to expand impact.
- Expand and enhance DOE's Industrial Assessment Center (IAC) program to include trades and program marketing to both provide technical assistance to small and medium manufacturers and expand the trained workforce.[13]
- Strategic Energy Management (SEM)[14] has been demonstrated to be an important strategy to reduce energy use at facilities. An effective and impactful approach would be

[12] For information on the impact of Save Energy Now see: www.energy.gov/sites/prod/files/2013/11/f4/webcast_2009-0212_large%20plant_assessments_1.pdf

[13] Some expansion provisions are included in H.R. 3962 (Welch-McKinley). For recommendations see D. Trombley, et al. 2009: aceee.org/files/proceedings/2009/data/papers/5_134.pdf#page=1

[14] SEM programs support individual facilities in developing an energy management plan that sets goals and creates a system to support meeting those energy efficiency and carbon reduction goals. The ISO 50001 Energy Management standard is the most formal manifestation of SEM, but other efforts including DOE's 50001 Ready tool support scaling of SEM across facilities of varied sizes and sophistications. A robust SEM plan has been demonstrated to reduce energy use at facilities, but also positions firms to implement other energy efficiency measures. DOE/AMO should be encouraged to expand its efforts to promote SEM and support utility, state and regional efforts to support facilities in implementing plans. For more information on SEM see: semhub.com/what-is-sem.

to incentivize all companies to have an energy manager and to actively pursue aggressive energy conservation and efficiency targets, as companies that have both have demonstrated an average 11% improvement in energy efficiency.[15] For small and mid-sized companies that struggle to provide resources for an energy manager there should be supplemental funds to support those individuals based on performance targets, leveraging the learnings of similar programs in Europe and Canada.

2. Technology commercialization research and demonstration

Achieving deeper savings will require innovative technologies and concepts. But as they move to greater scale, additional challenges/questions arise, deployment costs increase as additional technical and market issues are uncovered, and implementation timelines lengthen as engineers work through these issues. Additional challenges and risks include equipment changes, integration issues, and changing economics. Hence, additional research is needed to address these additional challenges to accelerated deployment/adoption of technologies at commercial scale. Without RD&D support, promising technologies that have received substantial initial public investment can stall, leave the domestic portfolio or be dropped entirely.

To realize the benefits that these R&D investments have identified, AMO should establish an effort to support commercialization of technologies that offer near-term potential to decarbonize industrial processes. These efforts should include:

- Expand AMO support for demonstrations at increasing scale to help bridge commercialization gaps and leverage expertise across multiple sectors. Authorize AMO to be engaged and to support demos as emerging and transformative technology progress through to commercial scale and ensure that funds are allocated.
- Lower technology and market hurdles to public-private-partnerships that aggressively pursue scale-up of promising technologies. For example, address intellectual property (IP) ownership so that the IP is held in common, but all have the right to practice.
- Revise policies that balance anti-trust needs with those of accelerated development and deployment of technologies. For example, provide enough flexibility in anti-trust regulations that companies can work together on transformative technology that lowers energy and GHG emissions for the industry as a whole.

3. Development and implementation of transformative industrial process technologies

To achieve the ambitious decarbonization goals sought by the Committee, industry will need new knowledge, technologies, and practices. Many industrial processes must be transformed. The DOE/AMO has supported RD&D on transformative process technologies over the past three decades through partnerships with industry, such as the Industries of the Future Program, which could serve as a model for an even more aggressive effort. These partnerships have been effective in producing research results that have impact and that can be brought to market faster than typical government research.[16] A key element of this effort was

[15] Gale Boyd, Duke University, personal communication 2019.

[16] The Industries of the Future program was noted for its success in the National Research Council assessment of DOE research: *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy*

the creation of industry-specific roadmaps that identified critical research needs for the industries and established a focused research plan to address them. Many of the trade associations have continued to maintain their roadmaps since the program ended, so they are available to inform research needs.

We recommend:

- Establish a focused RD&D program at DOE on transformative process technologies and practices building on past industry/government partnerships such as Industries of the Future
- Establish an *industrial* carbon capture, utilization, and sequestration program activity at DOE/AMO. Currently AMO lacks authorization to address this topic, and it is important that AMO and industrial facilities be part of DOE CCUS efforts. A strong focus is needed on utilization (beyond enhanced oil recovery) specific to the industrial sectors (e.g., chemicals production, petroleum refining, steel, cement) where GHG emissions reductions are most needed and where the CO_2 and CO can be reused to create value-generating products.
- Establish an R&D and investment risk-sharing program backed by the Treasury for research, demonstration and investment in new, carbon-reducing industrial process technologies.[17]

4. Procurement of low-carbon products and demand-side approaches

Market demand for products with desirable attributes, such as a low-carbon footprint, can support companies that provide large quantities of manufactured products (used in infrastructure, construction, defense, etc. Including cement, steel, polymers) with aggressive energy and GHG reduction goals. The US federal government is the largest single purchaser of goods in the world at $450 billion/year.[18] About 55% of the GHG emissions attributed to public institutions are the result of government-purchased goods and products.[19]

We recommend that federal sustainable purchasing efforts be expanded to low-carbon products, which would help to accelerate market demand for these products and serve as a model state and local governments and the private sector. Among the steps that could be implemented immediately:

- Promote using federal funds on supplies, materials, services, etc. that are manufactured and sourced in the US and that have a lower-carbon footprint. For example, build upon Executive Order 13423 by specifying that procurement include the preference for lower-carbon products.
- Require bidders on federal projects to disclose annual greenhouse gas emissions data and carbon footprint for the proposed materials, services, etc.
- Develop standardized metrics for reporting the carbon footprint of products and use of that information in product labeling that is consistent, verifiable, and readily understood

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Research 1978 to 2000, 2001, www.nap.edu/catalog/10165.html, and *Prospective Evaluation of Applied Energy Research and Development at DOE (Phase Two)*, 2007, www.nap.edu/catalog/11806.html.

[17] Concept memo for an Industrial Transformation Risk Sharing Program, ACEEE, 2019.

[18] www.epa.gov/greenerproducts/selling-greener-products-and-services-federal-government

[19] A. Hasanbeigi et al., *Curbing Carbon from Consumptions: The Role of Green Public Procurement* (Global Efficiency Intelligence 2019). www.globalefficiencyintel.com/curbing-carbon-green-public-procurement

by consumers. These tools provide a foundation for private sector action such as corporate purchasing policies and consumer labeling.

These efforts would lay a foundation for future efforts to reduce the carbon intensity of products and services used throughout the economy

5. Sectoral policy approaches for major carbon-emitting industries

A majority of industrial GHG emissions are from a few sectors, and these energy-intensive sectors can have a broad distribution in the energy intensity of manufacturing facilities, from companies that have been aggressive in pursuing productivity and energy improvements to those that lag far behind and typically have older technology.

An effective approach to addressing decarbonization of these carbon-intensive industries and facilitating implementation in these sectors of measures under categories 1-4 above would be to build upon the polices in other countries referred to as voluntary agreements.[20]

We recommend that the federal government encourage and support these voluntary agreements by:

- Supporting the research needed to set science-based, sector-wide targets for carbon emissions in consultation with the companies in the sector
- Providing access to technical assistance, investment incentives, and tax reduction to firms committing to and showing progress toward the target
- Allowing flexibility in meeting the target by allowing emissions trading among the companies within individual industries, and potentially across the sector as a whole though some broader cap-and-trade mechanism.

Implementation considerations

The implementation of this policy portfolio will require many complementary policies if it is to succeed.

Investment

Transforming the industrial sector will require an unprecedent investment in industrial infrastructure over the next three decades. The industrial sector contribution to the economy accounts for over $2 trillion each year,[21] so transforming the sector will require durable investment strategies to finance new assets in the range of 200-400 $ billion/year over multiple decades.[22] Annual, sustained federal funding in the billion-dollar range is needed to aggressively pursue the radical transformation required.

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[20] See this ACEEE report for more information of past experience with voluntary agreements: www2.aceee.org/l/310911/2018-01-11/hyh1h

[21] Federal Reserve: fred.stlouisfed.org/series/USMANRQGSP

[22] J.H. Williams, B. Haley, F. Kahrl, J. Moore, A.D. Jones, M.S. Torn, H. McJeon, *Pathways to deep decarbonization in the United States* (Deep Decarbonization Pathways Project of the Sustainable Development Solutions Network 2015). usddpp.org/downloads/2014-technical-report.pdf.

Historically tax policies have been used to influence investment decisions through such strategies as accelerated depreciation and investment tax credits. The impact of these strategies has diminished over the past few decades as corporate tax rates have declined and tax credits have proliferated.

Thus, we recommend that a suite of policies, both public and private, be developed to finance these investments. These policies will need to address the needs of both large corporations, which have access to low-cost capital, as well as small and medium-sized companies, which have historically been challenged in accessing capital. We suggest several specific policy approaches/ programs that be considered:

- Broaden the proposed Green Bank's (HR 3423 by Rep. Himes) applicability to include supporting investments that enable industrial transformation. The Green Bank will need to offer a portfolio of products to meet the needs of different projects, industries and sizes of companies. We suggest that a Risk Sharing Program (described below) be included in the capabilities of the Green Bank to address the challenge of managing the risks of investing in the technologies, processes and products.
  Expand the applicability of the Community Development Financial Institutions Fund[23] (CDFI) to addressing the financing needs for carbon reducing investments in the industrial. We suggest building upon CDFI models such as the Ohio Air Quality Development Authority[24] to help kickstart progress for industrial clusters that advance technologies and infrastructure to enable industrial transformation.

No single strategy will address all investment needs, and as markets change, different approaches will be most valuable, so an agile policy approach is needed.

Strategies to lower investment hurdles

- *Revolving loan funds* – these lending programs, which can be federally, state or private sector-administered, provide loans to companies to supplement private sector lending. Past experience has shown that lending through commercial or mission-driven lenders can be more successful than government-administered programs since these organization already have the infrastructure to underwrite and service the loans, and many have existing relationship with the companies.
- *Loan guarantees and loan-loss reserve funds* – these credit enhancement strategies can help make private sector financing more accessible to companies that have trouble accessing capital markets at affordable rates.
- *Tax credits* – as noted above, many companies are not able to make use of additional tax credits. Grants in lieu of credits can address this challenge, though many tax experts oppose them because of the difficulty of oversight.
- *Grants or in-kind services* – these are the preferred incentive mechanisms by most companies. The funds can go to cover some or all of the cost of an investment, and in

[23] The Community Development Financial Institutions Fund (CDFI Fund) plays an important role in generating economic growth and opportunity by offering tailored resources and innovative programs that invest federal dollars alongside private sector capital through mission-driven financial institutions that take a market-based approach to supporting expanding financing in communities that lack access to financing. www.cdfifund.gov/Pages/default.aspx

[24] ohioairquality.ohio.gov

some cases include engineering, planning and permitting costs. These grants can be administered by a federal agency, which can provide oversight, or by state agencies, which in many cases are closer to small and medium-sized companies, making access to the grants easier. In addition to direct grants, several successful programs have made in-kind technical services available to companies, which can help address the barrier of upfront costs that are difficult to finance, which can allow conventional financing to complete the investment. While reporting is important, the requirements of documentation/reporting must be well below the carbon savings or value generated from the program

- *Risk sharing fund* – as mentioned above, the risk in implementing a new process or product can be large. This risk can stem from failure of the technology or product to be cost-competitive in the marketplace or can result from external factors such as economic downturns or trade challenges that can jeopardize a company. The fund, much like a loan-loss reserve, could backstop the company by limiting losses due to unforeseen events, reducing a major barrier to investment.
- *Manufacturer rebates for products* – these are a special kind of grant that a manufacturer can receive for initial sales of a new product. The rebates can go to the manufacturer or to the purchaser and can help to recoup the initial cost of tool-up for the manufacture of the product – usually referred to as the non-recurring engineering cost. This strategy is currently being used to promote electric cars and has been proposed for high-efficiency transformers and motors in HR 3962 (Welch-McKinley).
- *Public, private, philanthropic partnerships* – for some transformative technologies that require very large investment, leveraging multiple funders may be necessary. A recent example is the ELYSIS[25] effort to commercialize carbon-free aluminum metal production funded by Apple, Rio Tinto, Alcoa and the governments of Canada and Québec. Partnerships such as this may be best applied to high-cost, high-risk, transformative process or materials changes.

Industrial Transformation Risk Sharing Program

Background

The industrial sector has made steady progress on improving energy efficiency and reducing greenhouse gas emissions (GHG) for decades. To meet the need to reduce GHG to stabilize the climate, industry will need to accelerate its rate of energy efficiency improvements and implement technologies that further reduce GHG emissions through the commercialization of new, transformative technologies and practices, and through the investment required to implement these at scale in domestic industrial facilities.

This transformation will necessitate a significant increase in investments by industrial companies, and with this increase comes increased financial risk to the companies from economic downturns, market dislocations, regulatory uncertainty and technology challenges. In the current economic environment, most major corporations have access to the capital necessary to make these investments but will likely be challenged to take on this additional risk. While some risks are expected and can be managed under normal business circumstances, the level of investment envisioned to transform industry could pose a threat to the economic viability of firms in a worse-case scenario.

[25] www.elysis.com/en

To address this barrier to expanded industrial investments in energy efficiency and GHG reductions, **we suggest the implementation of a program that back stops the risk associated with making these new investments.** This idea builds on the concept of financing of a loan-loss reserve (LLR), which is a fund, usually publicly established, that back-stops lenders in the event that defaults on a loan portfolio exceed expectations, allowing them to make loans to borrowers that would otherwise be too risky. The LLR allows the public funds to be leveraged to a greater degree than a direct lending program, since the public dollars do not have to meet the full principal of the investment. A similar concept also exists in insurance, where a policy is issued to cover losses that exceed a level when unanticipated events occur.

Proposal Outline

The proposed program would be administrated by the U.S. Department of Energy. A fund of $50 million dollars would be established that would be available to secure research or deployment investments made by industrial firms in new, energy efficiency and GHG reducing technologies. This program would apply to investments made through cash, loans, partnerships and other financial instruments. Companies seeking the coverage would apply to the Department and provide information on the proposed investments to allow agency staff to evaluate the risk associated with the investment. Based on the risk assessment, an investment guarantee would be made for a specified period to the applying company, covered by the fund in the event that losses occur that exceed the level specified in the guarantee. Any information provided would be held in confidence by the Department to prevent disclosure that might jeopardize the firm applying.

Workforce

The industrial sector faces dual challenges of an aging workforce and limited interest in industrial careers by young people. When ACEEE speaks with companies, the issue of hiring always comes up, irrespective of the topic. A comprehensive effort is needed to create interest in industrial careers, strengthen existing institutions and create new structures to prepare young people for the industrial jobs of the future and provide support throughout out their careers to create a stable workforce. Significant emphasis has been put on university training in science, technology, engineering and math, but there is also a need to create a new generation of trades and technicians through work-based training and internships to maintain and operate factories.

A comprehensive strategy will be needed to address these challenges. We recommend that:

- The National Academies undertake a study to collect input from all stakeholders to identify the steps that the federal government should pursue to address this industrial labor crisis and create a stable industrial workforce.
- Congress enact the proposals for expanding the Industrial Assessment Centers program, again in HR 3962 (Welch-McKinley), which includes expansion into trade schools creates an apprenticeship program we discussed above. This proven program model could have near-term impacts while we plan for more comprehensive efforts in the future.

Savings Opportunity

We model the above plan with savings estimates adapted from Rissman et al. (2019):

1. Therkelsen et al. (2015) finds that an SEM program saved an average of 11% of energy use in 10 disparate factories by the second year. Rogers et al. (2013) estimate that smart manufacturing could reduce industrial energy use by about 20%. And Elliott and Nadel (2003) estimate 20–50% savings in fan and pump system energy use from system optimization. We model this set of measures as 20% energy savings per facility, gradually ramping up on a straight-line basis to 80% of facilities by 2050.

2. We estimate a further 15% savings from these technologies, with initial applications in 2025, ramping up to 65% of facilities by 2050.

3+4. We estimate 15% savings from these technologies, with initial applications in 2035, ramping up to 50% of facilities by 2050.

Note steps 2 through 4 are combined as “Industrial Emerging Technologies” in results below. Step 5 helps achieve the savings of all the other steps. We estimate direct rebound effects of 5%, as lower energy costs could translate into slightly lower product costs and hence slightly higher demand. We assume the full savings from the three steps could be achieved through policies.

Buildings Opportunities

1. Zero energy new buildings and homes

Thousands of new homes and hundreds of commercial buildings have been built that produce at least as much energy as they use on an annual basis. Commonly labeled *zero energy buildings* (ZEB) or *zero net energy* (ZNE), 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. Related to ZEB are ultra-low-energy (ULE) buildings. By reducing energy use, ULE construction makes ZEB much more feasible and is sometimes labeled “ZEB ready.” The New Buildings Institute has documented nearly 500 commercial buildings in the United States that, as of late 2017, were either verified ZEB, not-yet-verified ZEB, or ULE (NBI 2018). The Net-Zero Energy Coalition has identified more than 6,000 ZEB or ZEB-ready homes and residential buildings in the United States that collectively contain nearly 14,000 housing units (NZEC 2018). The positive economics of ZEB has been documented in a variety of studies, including Corvidae, Gartman, and Peterson (2019) for homes and NREL (2014) for commercial buildings. As the number of ZEB homes and buildings increases, we would expect the economics to improve as designers and builders gain experience and develop improved practices.

Several efforts are targeting the adoption of ZEB (or ULE) building energy codes by around 2030; for example, such targets are envisioned by California, Canada, and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, for its stretch code) (California Energy Commission 2018; National Research Council Canada 2018; ASHRAE 2008). A voluntary zero-energy appendix for the residential model code, the International Energy

Conservation Code (IECC), is under consideration by code officials now and likely to be adopted for the 2021 version of the code in the coming weeks. Many cities are adopting stretch codes with greater efficiency (if short of ZEB or ULE levels), and Massachusetts and New York State have issued such codes for their cities to adopt (NBI 2019). In recent months, more than a dozen municipalities in California have adopted new code provisions requiring all-electric new residential (i.e., no fossil fuel connections/end-uses in new homes). However the national model energy codes, especially for homes, are progressing slowly.

In addition, several utility and nonutility program administrators have specifically aimed programs at promoting ZEB construction locally. Notable examples include an Energy Trust of Oregon program for commercial buildings and a New York State Energy Research and Development Authority program for new single-family and multifamily homes (York et al. 2015a).

Amann (2014) and Perry (2018) discuss obstacles to the goal of widespread ZNE use by 2030 and suggest a combination of R&D, implementation, and building code strategies for reaching the target. R&D needs include development of workable system performance metrics and of outcome-based code approaches that look at how much energy buildings use once occupied. Implementation strategies include building rating and labeling, public sector leadership, stretch codes and green codes, beyond-code guidelines, incentives, and valuing efficiency in financial transactions.[26] 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. To reach the goal, all of these strategies must contribute in a comprehensive effort.

Savings Opportunity

For our opportunity savings estimate, we assume that 90% of new construction by baseline energy use in 2040 and beyond achieves ZEB or ULE performance, with the savings ramping in over the 2031–2040 period. Based on data from the New Buildings Institute, for new construction we assume 70% energy savings relative to reference case efficiency levels, with the remaining 30% coming from a mix of on-site or off-site renewable energy systems (C. Higgins, research director, New Buildings Institute, pers. comm., July 8, 2019).[27] The 10% of new construction not affected is either in locations or in building types, such as hospitals, for which energy intensities are high and ZNE performance is challenging. With loads this low in ZEB or ULE buildings, we assume most buildings will install heat pumps, saving the cost of including

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[26] *Stretch codes* are codes adopted by local jurisdictions that exceed statewide codes. *Green codes* include many environmental features in addition to energy efficiency and are typically voluntary, although a few jurisdictions have adopted mandatory green codes. Valuing efficiency may mean including efficiency features in building appraisals and considering both energy and mortgage costs in mortgage underwriting decisions.

[27] The shift to renewable energy for the remaining energy use does not affect our energy savings estimates but is reflected in our GHG savings calculations, with half of this renewable energy assumed to be on-site and not registering in the electric grid, and half assumed to be off-site (either community-level or utility-level systems) and included in the increased percentage of electricity we assume to be from renewables. Although *AEO* does not include rooftop solar in primary energy use, we do not count that as energy savings from efficiency.

gas in the building. For highly efficient new construction, even in very cold locations such as New England, heat pumps can generally supply all needed heat (Nadel 2018a). For residential and commercial new construction between 2020 and 2030, we use the new construction savings estimates developed by York et al. (2015a), resulting in 24% commercial and 22% residential savings ramping in starting in 2020. For the reference case we assume that average new home energy use and new commercial building energy intensity would be the same as in the building stock each year; although new homes and buildings are more efficient, new homes are larger, and new commercial buildings have higher loads. Because most of the savings are from ZEB buildings, we assume renewable energy systems would be sized to cover typical rebound effects, and rebound is already included in the savings described above.

Policies

For our policy analysis we assume rapid model energy code improvements, quick adoption across the country, and effective compliance, but without specific ZEB construction requirements. We assume that future model building energy codes (International Energy Conservation Code for homes and ANSI/ASHRAE/IES Standard 90.1 for commercial buildings) would achieve about 10% energy savings in each three-year code cycle; that the codes would be implemented nationwide over five years; and that loss of savings due to noncompliance would start at 20% for homes and 50% for commercial buildings, decreasing by 10% each year—all significant advances over the status quo. The *AEO 2019* baseline case does not assume future code improvements but does include gradual efficiency gains; therefore we subtracted a bit from the above savings, especially for continued implementation of recent savings in 90.1. The result is that savings due to codes compared with the baseline rise to 61% in 2050 for homes and to 53% in 2050 for commercial buildings. We reduce the savings estimates for codes to account for direct rebound (10% in homes, 5% in commercial buildings).

2. Smart buildings and homes

One large class of system improvements is *intelligent efficiency*—that is, the use of information and communications technology (ICT), access to real-time information, and smart algorithms to help optimize energy-using systems (Elliott, Molina, and Trombley 2012). A simple example of an intelligent efficiency measure is a learning thermostat (e.g., Nest or ecobee) that monitors home temperature and occupancy, weather, and other parameters and finds ways to improve heating and cooling system operation after learning a household's patterns (e.g., when people are home and which temperatures they like).

Rogers et al. (2013) discuss a variety of needed steps to promote realization of these savings. These steps include adopting common communication protocols so that systems from different vendors can talk to each other; developing systems for using ICT to document savings so that utility and other incentive programs can include intelligent efficiency approaches; better educating home and building owners on intelligent efficiency capabilities and benefits; documenting best practices from early projects; and demonstrating projects in promising market niches that lack documented results. Incentive programs—such as cost-sharing of smart building service fees to encourage building owners to take advantage of these emerging services—can help accelerate progress (Rogers 2018). Continued R&D support is also needed, particularly for smart energy management systems for smaller buildings. Many utility programs are providing incentives, especially for learning thermostats, and the Smart Building Acceleration Act (H.R. 2044) would establish a research and development program at DOE and encourage deployment in federal buildings.

Savings Opportunity

For homes, King (2018) documents ways to achieve 17% average whole home savings from smart strategies. There are additional available savings from providing real-time energy use feedback (York et al. 2015a). The cost effectiveness of all of these strategies has not been documented, but York et al. (2015a) provide data on how savings from smart thermostats cost an average of about 3 cents per kWh saved. For our analysis, we assume 15% average whole home savings. Obtaining 15% average savings will require improved technology that can be installed easily and at moderate cost. We gradually ramp up to 80% penetration of these measures by 2050. More sophisticated systems used in commercial and industrial buildings offer even greater reductions in energy use. Rogers et al. (2013) estimate a 28% average electricity savings available in commercial buildings (weighted average across all end uses). King and Perry (2017) estimate that smart building systems can reduce building energy use by 30% or more. York et al. (2015a) find typical costs of 2–3 cents per kWh saved. For our analysis, we round down to 20% savings across all fuels. Kramer et al. (2018) find more than 20% savings in several buildings with energy management information systems that have been optimized over a three-year period. In our analysis, smart building savings apply to a gradually growing share of the building stock, reaching 95% in 2050. We estimate that direct rebound will reduce residential savings by 10% and commercial savings by 5%.

Policies

For our policy analysis, we include three broad policies that would spur deployment of smart homes and buildings as well as home and building retrofits: a commercial building standard based on energy use benchmarking, a standard based on a home energy rating for homes that are sold or rented, and an energy efficiency resource standard for utility energy efficiency programs. We discuss the first and second in the next section and the third in a separate section below.

3. Home and building retrofits

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 critically important. Residential programs such as Home Performance with ENERGY STAR can reduce energy use by 20–30% (Belzer et al. 2007; Liaukus 2014), 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 was projected to reduce energy use by 38% (Harrington and Carmichael 2009), but performance data from the first three years show even greater savings (C 40 Cities et al. 2014). Likewise, a study on 10 deep energy retrofits of federal buildings found average savings of 38%, with savings in individual projects ranging from 18–100% (Shonder 2014).[28]

However participation in retrofit programs is generally low. For example, Neme, Gottstein, and Hamilton (2011) and York et al. (2015b) find that the highest participation rates for residential comprehensive retrofit programs across broad numbers of customers approached but did not reach 2% of those eligible each year. Some geographically targeted or single-measure programs had higher participation rates and provide lessons on how to increase participation rates in the future. Furthermore, only a fraction of retrofits come close to the energy savings level 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). To achieve this, we will need multiple strategies, including building energy use transparency (e.g., benchmarking energy use, rating energy efficiency, and access to energy use data), contractor training and certification, home and building owner education and technical assistance, incentives and financing for energy efficiency improvements, continuing R&D efforts to identify better and easier ways to improve the efficiency of existing buildings, and improved program designs to increase participation rates and savings per home. Cluett and Amman (2016) discuss a variety of promising strategies. Low-income households and communities are a particular challenge, as they rarely have the funds to conduct retrofits. Increased grant funding will be needed, complemented with long-term financing that can be used by some moderate-income households.

The US Environmental Protection Agency's ENERGY STAR Portfolio Manager is a user-friendly tool used to benchmark a commercial building's actual energy use against that of similar buildings. It gives a score of 1–100 that is based on percentile (e.g., a score of 75 is supposed to mean a building is more efficient than 75% of similar buildings). Forty percent of commercial building space has used the tool.[29] Benchmarking energy use can help to get the attention of building owners and can motivate capital and operational improvements. Many cities, including New York, Los Angeles, and Philadelphia, and two states, California and Washington, require large commercial (and often multifamily) buildings to benchmark their energy use and publicly disclose the results. The cities have typically found 3–8% energy savings in buildings in the first few years (Mims et al. 2017).

For homes DOE has developed a Home Energy Score tool that gives an efficiency rating of 1–10 based on detailed information about the home—not actual energy use data—collected by a

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[28] See also J.T. Amann, *Unlocking Ultra-Low Energy Performance in Existing Buildings* (ACEEE 2017), aceee.org/unlocking-ultra-low-energy-performance-existing. Most of the savings are from energy efficiency improvements, but the projects with very large savings (e.g., 60% and 100%) also include solar systems.
[29] See energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager and links for more information on ENERGY STAR Portfolio Manager. See buildingrating.org/ for more information on local and state policies.

trained assessor. The tool also gives suggestions for improving the efficiency. The scores are loosely based on percentiles such that in each region 50% of homes should have a score of 1–5 and 50% a score of 6–10. (The 15% of homes with the highest estimated energy use should have a score of 1, the best 10% a score of 10.) More than 100,000 homes have been scored to date.[30]

A few jurisdictions have begun to implement efficiency requirements for existing buildings, which promise much greater savings. Washington, DC, New York City, and Washington State recently passed laws for large commercial and some multifamily buildings. In Washington, DC, buildings must meet a standard that will be set no lower than the median ENERGY STAR score, or else reduce energy use by at least 20%, starting in 2026 (DC Council 2019). The standard is to be updated every five years. The Washington State law is somewhat similar (Washington State Legislature 2019). New York City set carbon emissions intensity standards starting in 2024 that are expected to result in 26% average energy savings in covered buildings; the standards can also be met with local renewable energy credits or offsets (Urban Green Council 2019). Other policies have focused on multifamily residences. Boulder, Colorado, has a regulation requiring that multifamily buildings built before mid-2001 earn a specified number of energy efficiency points by 2019 before they can be rented (Boulder 2018).[31]

Similar regulations are being adopted internationally. In the United Kingdom, owners of rental apartments were required to upgrade to an E level on Europe's A–G building efficiency scale by 2018.[32] And France has a law requiring existing homes (including single-family) to meet steadily more stringent energy efficiency requirements, with the targets set many years in advance. Under the French law, all F- and G-rated homes must be retrofitted to at least the E level by 2025 before they can be sold or rented. In this way, building owners have many years of lead time to determine when and how to upgrade their buildings (BPIE 2015). France also has a longer-term goal of requiring an A rating by 2050 and is discussing the possibility of interim dates by which D, C, and B ratings might be required.[33] Implementing regulations for the early tiers still must be developed; the latter goals do not yet have the force of law.

Savings Opportunity

For our savings estimate, we assume 30% whole building energy savings on average. These savings are applied to energy use after subtracting savings from measures discussed in prior sections, thereby avoiding a double counting of savings. We estimate that 65% of homes will be gradually retrofit by 2050 (about 2% per year) and that 80% of commercial building floor area will be gradually retrofit as owners periodically update large buildings to retain their market position.[34] We do not include electrification in these savings estimates; electrification is treated separately, as discussed later in this paper. We reduce these savings estimates to account for direct rebound (10% in homes, 5% in commercial buildings).

[30] Detailed information is available at homeenergyscore.gov.
[31] Buildings built after mid 2001 need to meet building energy codes that provide similar savings.
[32] See rla.org.uk/landlord/guides/minimum-energy-efficiency-standards.shtml.
[33] See legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000031044385&categorieLien=id (in French).
[34] Alternatively, the same commercial building savings would be achieved by deep retrofits that save an average of 50% of energy use in 48% of buildings.

Policies

For this analysis we assume that commercial buildings with low benchmarks would be required to increase efficiency to bring their scores up. They could do this through a combination of building retrofits, improved energy management, and behavior changes. Loosely based on the law in Washington, DC, we assume the policy would affect buildings of more than 50,000 square feet in 2022, 25,000 square feet in 2024, and 10,000 square feet in 2027, taking percentages of total commercial energy use from the 2012 Commercial Building Energy Consumption Survey (CBECS) (EIA 2016b). We assume that buildings below an ENERGY STAR benchmark of 50 would need to reach a score of 50 or reduce energy use by 20%, ramped in over five years, and then improve their score by at least 10 points or achieve an additional 20% savings every 10 years (hence a score of 70 or combined savings of 49% by 2047–2052). We roughly estimate the impact using the curve of average energy use by ENERGY STAR score for office buildings (ENERGY STAR 2019, fig. 5). The result is savings of 12% of covered energy use under the first standard, 23% under the second, and 32% under the third when fully phased in. We assume that half the savings from appliance standards and ENERGY STAR in commercial buildings would contribute to meeting this standard. But any direct rebound effect would require additional savings to meet this performance standard.

We also include a standard for homes based on the home's estimated efficiency rather than its actual energy use and applying only to homes that are rented or sold. We assume a policy requiring all homes that change occupants due to rental or sale to be brought up to a minimum Home Energy Score: 2 starting in 2025, increasing by 1 every five years thereafter, except that no home ever has to increase its score by more than 3 (thus in 2045, when the minimum score is 6, a home that started as a 1 would need to be brought up only to 4). We estimate the relative energy use by bin by taking a simple average of the bin caps for the 996 Home Energy Score regions, and then calculate the savings from bringing homes from the middle of each bin to the required cap. We then calculate savings for rented and owned homes separately (neglecting shifts between the pools), using Residential Energy Consumption Survey data for relative energy use and assuming 5.9% annual sales of owned homes (based on National Association of Realtors sales data for 2016–2018), and 20% annual turnover of rented homes (a conservative blended estimate for apartments and single-family homes). We account for homes turning over multiple times, assuming no correlation between turnover year-to-year. The potential savings for requiring efficiency at the bin 2 level is 2% of total residential energy use, rising to 16% for bin 6, but because of slow turnover the savings for owned homes barely reach half of that. We reduce savings by 10% to account for rebound.

4. Appliance and equipment efficiency

Many types of appliances and equipment have made dramatic efficiency gains over the past four decades, driven in part by efficiency standards and labeling. Federal minimum energy efficiency standards currently affect more than 50 types of appliances, equipment, and lighting, ranging from residential refrigerators to industrial pumps. The US Department of Energy

(DOE) estimates that standards already established (and therefore included in our *AEO 2019* baseline) will, on a cumulative basis, save more than 130 quads of energy through 2030, reducing energy bills by nearly $2 trillion (DOE 2016).

In addition to minimum efficiency standards, the efficiency of new equipment purchases is affected by voluntary equipment efficiency specifications such as ENERGY STAR. ENERGY STAR has specifications on more than 50 different products, some of which are also covered by minimum efficiency standards. When the same product has both a standard and an ENERGY STAR specification, the standard covers all or most product sales, while ENERGY STAR affects only some sales, but at a higher efficiency level.

Achievement of the full savings potential will require various steps, including improved test procedures on some products (so that rated efficiencies better represent performance in the field, especially for "smart" products with adaptive controls); market introduction of an increased number of models at today's highest efficiency levels; efforts by manufacturers, distributors, utilities, governments, and large customers to promote these most-efficient products; and, ultimately, rulemakings by DOE to adopt new standards that require increased but cost-effective levels of efficiency for all products.

Savings Opportunity

We base our analysis on previous work on potential savings from new appliance efficiency standards. Our savings estimates involve dozens of products, with about 70% of the savings coming from a dozen products: residential water heaters, central air conditioners/heat pumps, showerheads, clothes dryers, refrigerators, faucets, and furnaces, as well as commercial/industrial fans, electric motors, transformers, air compressors, and packaged unitary air conditioners and heat pumps.

A 2016 report estimates savings for the next set of standards, covering those that should be set and take effect over the 2017–2029 period (deLaski et al. 2016). That report includes only savings that are technically feasible and already achieved in commercially available products and estimates annual savings in 2035 and 2050. We worked with the authors to estimate annual savings numbers with delayed effective dates for the early standards (none have been set to date). We also add savings from several proposed state standards discussed by Mauer, deLaski, and DiMascio (2017). We add an allowance for additional efficiency improvements in the 2030–2040 period (discussed in Appendix A) and deduct 8% for direct rebound effects (the weighted average of 10% for the residential sector and 5% for commercial and industrial). This analysis of potential may be conservative, as it does not include savings from larger systems (e.g., entire HVAC systems rather than individual components), and it does not include savings opportunities enabled by improved test procedures.

To estimate the additional savings from above-standard efficiency levels and products without standards, in our 2016 analysis we looked at annual savings data for minimum efficiency standards and ENERGY STAR over the 2005–2015 period and calculated a ratio (Nadel 2016b). Over those 11 years, average ENERGY STAR savings were 34% of the savings from minimum efficiency standards. However, as products improve in efficiency, opportunities for additional ENERGY STAR savings decline. Therefore for this report we take savings from new standards and add an additional 25% to include ENERGY STAR's potential impact (somewhat lower than the historic 34%).

Policies

For appliance and equipment efficiency, the opportunity savings estimate is based entirely on policies: minimum efficiency standards and ENERGY STAR. These savings are currently at risk—the current DOE leadership has stopped setting appliance standards, proposed process changes that would make it more difficult to set future standards, and repeatedly proposed to end funding for ENERGY STAR. However DOE says it will try to meet legal deadlines, Congress has rejected ENERGY STAR budget cuts, and process changes may well be modified by future administrations. Therefore, for this potential estimate, we assume that implementation of standards can quickly get back on track and that the long-term potential is still large.

5. Electrification of space and water heating in existing homes and buildings

With the electric grid steadily getting cleaner and reducing emissions, the electrification of space and water heating is a decarbonization strategy that is becoming more viable. Current technology options for space and water heating in buildings include electric resistance heat, heat pumps (primarily air-source but also ground-source), and either condensing or non-condensing use of fuels (natural gas, oil, or propane furnaces or boilers). If high-efficiency heat pumps use electricity from low- or no-carbon generation, they can achieve substantial energy savings as well as emissions reductions. Converting to heat pumps at the time an existing air conditioner, furnace, or boiler needs to be replaced often will save money on a life-cycle cost basis, particularly relative to oil and propane, but also relative to natural gas in warm climates. For the North, further work is needed to improve the availability and performance of cold-climate heat pumps. Even in the South, at current natural gas prices, a recent study found that the economics of conversion may not be compelling to consumers; while there are life-cycle cost savings, payback periods are often long (Nadel 2016a, 2018b). The Rocky Mountain Institute draws a similar conclusion but also finds heat pumps generally cost effective in new construction (Corvidae et al. 2019). There have not been many studies on electrification in the commercial sector, although Kim et al. (2017) find energy and economic savings from use of variable refrigerant flow (VRF) systems in medium-size office buildings.[35]

[35] Use of renewable natural gas is another potential route to decarbonizing gas uses, but the amount of renewable natural gas potentially available is likely to be much lower than current natural gas use. If renewable natural gas supplies are limited, use of renewable natural gas should probably first go to end uses that will be very difficult to serve with electricity, such as high-temperature industrial processes, some industrial feedstock uses, and long-haul trucks.

To realize these savings, near-term efforts should focus on market niches where electrification may be more attractive, and on improving the availability, performance, and cost of cold-climate heat pumps. Potential near-term market niches include new construction (benefiting from the avoided cost of installing gas service), particularly in the South; homes without air-conditioning but where air-conditioning is desired (including many homes with boilers); and homes and buildings using expensive fuels such as fuel oil and propane. To spur use of heat pumps in new construction, building codes could favor such use, and/or utility commissions could consider limitations on extension of gas distribution systems to new areas. Incentives to buy high-efficiency heat pumps are important, especially when homeowners replace equipment at the end of its life. Incentives for induction stoves can help homes to go "all electric," avoiding the need for gas lines in new development. However rules against the funding of fuel switching prevent such incentives in many states. To spur substantial conversions of homes and buildings now using natural gas, a price on carbon and/or incentives for conversions to heat pumps will be needed to help improve conversion economics and drive retrofit activity.

Savings Opportunity

For our analysis of electrification of existing homes and buildings, we use conversion rates (percentage of buildings converting from fossil fuel systems to electric systems) from a high-electrification scenario developed by NREL. This scenario includes gradual electrification in residential and commercial sectors by 2050 by converting about 50% of residences and 45% of commercial buildings. We heavily weight these conversions to buildings using oil and propane, and we increasingly also include buildings using natural gas in the 2030s and beyond. Energy savings from electrification will vary with the climate and building. We used estimates of average US primary energy savings of 21% for homes (Nadel 2018a) and 28% for commercial buildings (Kim et al. 2017). These estimates are based on current heat rates; as heat rates improve the primary energy savings increase, a factor we take into account for homes.[36]

To account for overlap with all of the measures discussed previously, we subtract savings from prior measures that affect building space and water heating before analyzing electrification. As a result, the loads to be electrified are substantially smaller than if electrification were applied to current loads. Applying efficiency measures first reduces the cost of electrification (smaller heat pumps are needed) and also improves the ability of heat pumps to serve loads while maintaining comfort on very cold days. We do not assume any rebound as energy cost savings are relatively small.

Policies

For our policy analysis we assume that a combination of the rules, fees, and incentives discussed above in this section spur the fuel switching.

[36] We do not make a similar adjustment for commercial buildings because commercial building savings data are very limited and not solid enough to justify adjustments.

Analysis of emissions reductions

We modeled the combined impact of the above energy efficiency opportunities across buildings, industry, transportation, and the electric grid. We used the *Annual Energy Outlook 2019* (*AEO*) as our baseline (adjusted to include more renewables and less coal in the electricity mix).

The energy efficiency opportunities we examined could collectively reduce expected 2050 US GHG emissions by about half. They would cut primary energy use by 49% (47 quadrillion Btus). The efficiency savings would reduce carbon dioxide (CO_2) emissions by 57% (2.5 billion metric tons, as shown in figure 2). The emissions reductions are greater than the energy reductions because we included a shift from fossil fuel use to electricity for both vehicles and buildings (with electricity from a much cleaner power sector). When we include other GHGs such as methane in the total, the efficiency savings reduce total 2050 GHG emissions by 49%.

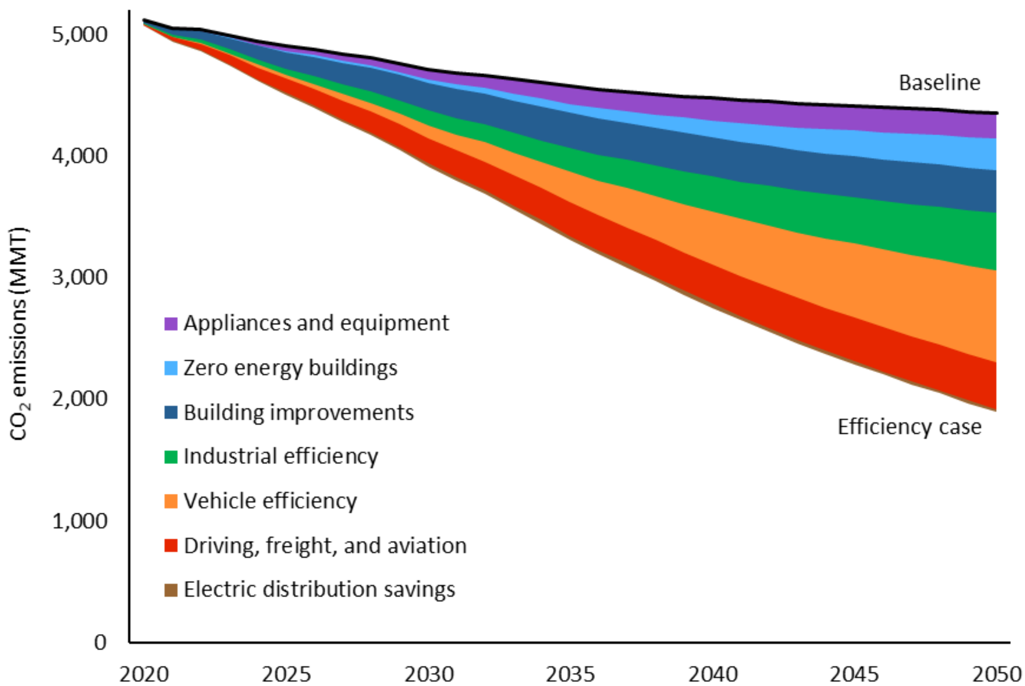

Figure 2. Reduction in carbon dioxide emissions from combined opportunities

We can also make comparisons with overall US GHG abatement goals. This requires inclusion of emissions of other GHGs. For this analysis we assume net emissions not included in the *AEO* will remain at 2017 levels through 2050, at 596 MMT per year. We also exclude the reduction in fugitive emissions of methane due to reduced natural gas and coal use in our efficiency scenario. With these assumptions, in our efficiency case total US GHG emissions are reduced by 49% by 2050 relative to the reference case projection. This reduction is two-thirds of the total GHG abatement needed from the reference case projection to reach a goal of 80% reduction in 2050 compared with 2005 levels (i.e., reaching 1,320 MMT emissions).

Emissions reductions by sector

Energy and emissions reductions can be found in each of the major end-use sectors—residential, commercial, industrial, transportation—as well as the power sector. The four end-use sectors each account for between 19% and 32% of the total energy savings, with savings a little higher in the transportation and industrial sectors. Emissions reductions from the transportation sector are nearly half the total reductions due to both efficiency gains in carbon-intensive oil-based fuels and switching to substantially cleaner electricity. The industrial sector also has significant emissions reductions due to extensive use of fossil fuels in the sector. Emissions reductions are smaller in the residential and commercial sectors, as much of the savings are in electricity (with a much cleaner grid by 2050) and natural gas (the cleanest of the fossil fuels). These trends are illustrated in figure 3.[37]

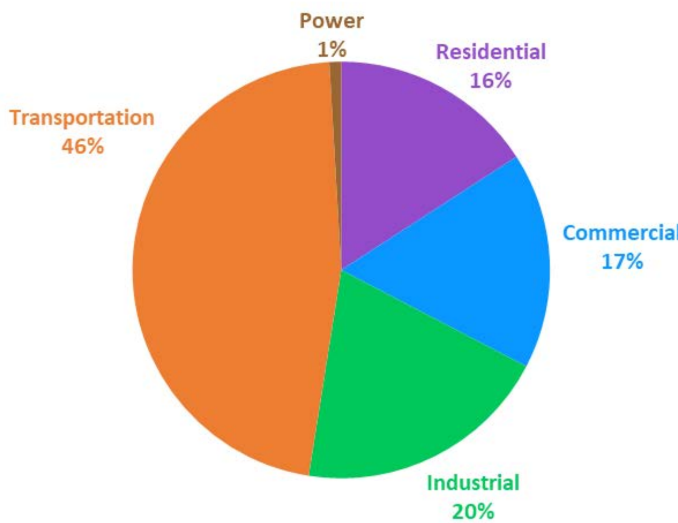

Figure 3. Allocation of emissions reductions among sectors

Emissions reductions by measure

Each of the 11 efficiency opportunities we examined contributes to putting us on the path to a 50% reduction in energy use. The largest energy savings come from industrial efficiency measures, which combined contribute about 12% of total energy use reduction in 2050. Other measures that account for at least 5% energy savings in 2050 are zero energy homes and buildings (6% combined), efficient passenger and commercial vehicles (9% combined), appliances and equipment (6%), and improvements to existing buildings (7% including smart homes/buildings and residential/commercial retrofits).[38]

The proportion of total 2050 emissions savings by measure (with some measures subdivided into constituent parts) is illustrated in figure 4. Efficient vehicles (passenger and commercial) result in about 17% of all emissions reductions, much more than their 9% energy savings.

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[37] Note that the Power wedge only includes the grid opportunity. End-use electricity savings are large but are distributed in the sector wedges.

[38] Note the percentages in the pie graphs are the portion of the total savings, but the percentages in the text are of total energy use or emissions, and hence differ.

Likewise, the percentage of emissions reductions due to building electrification is nearly double its percentage of energy savings. In both cases, as noted earlier, the larger proportions of emissions reductions are due to the replacement of higher-emission fossil fuels with lower-emission electricity.

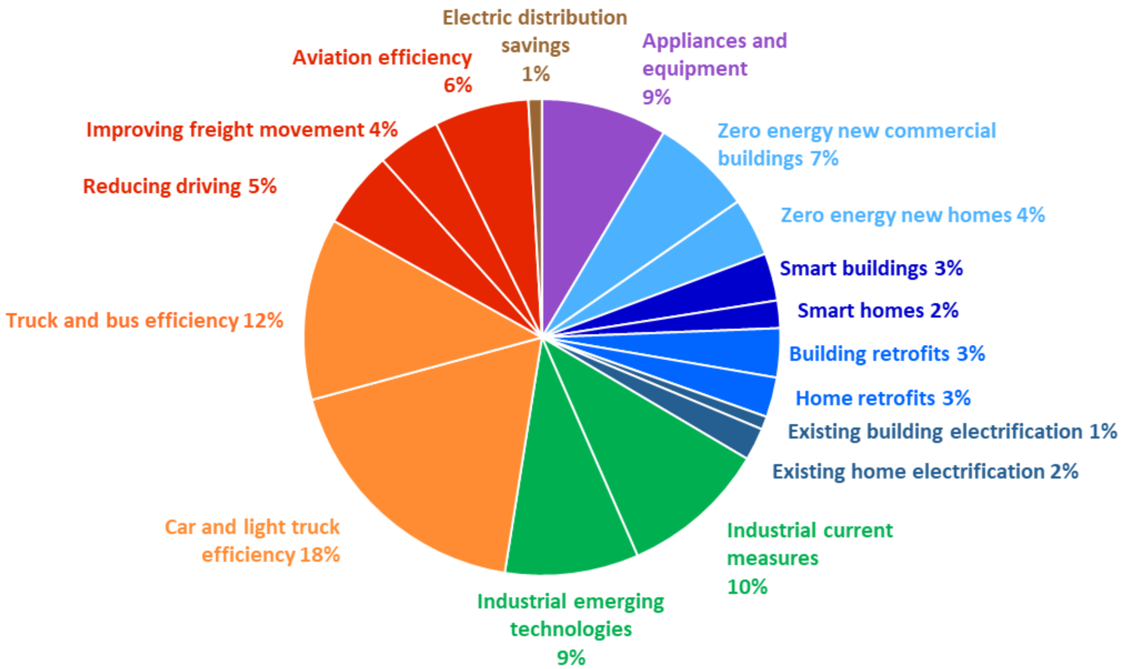

Figure 4. Allocation of CO_2 emissions reductions among measures

Emissions reductions by policy

We separately examined potential emissions reductions for the set of policies at all levels of government. All of the policies we examined make significant contributions to energy savings and emissions reductions. The proportion of total 2050 emissions savings by policy is illustrated in figure 5 (in these figures, we did not remove overlap of savings to allow better comparison of the individual policies). The largest savings are from industrial policies, vehicle standards, and appliance and equipment standards, saving 11, 8, and 5 quads respectively in 2050. These measures stand out due to the large savings that are possible in new processes, vehicles, and equipment and, in the latter two cases, due to the effectiveness of standards. For each of these we assumed the full corresponding efficiency opportunities could be achieved through the respective policies, though the industrial policies will need to be better defined and tested.

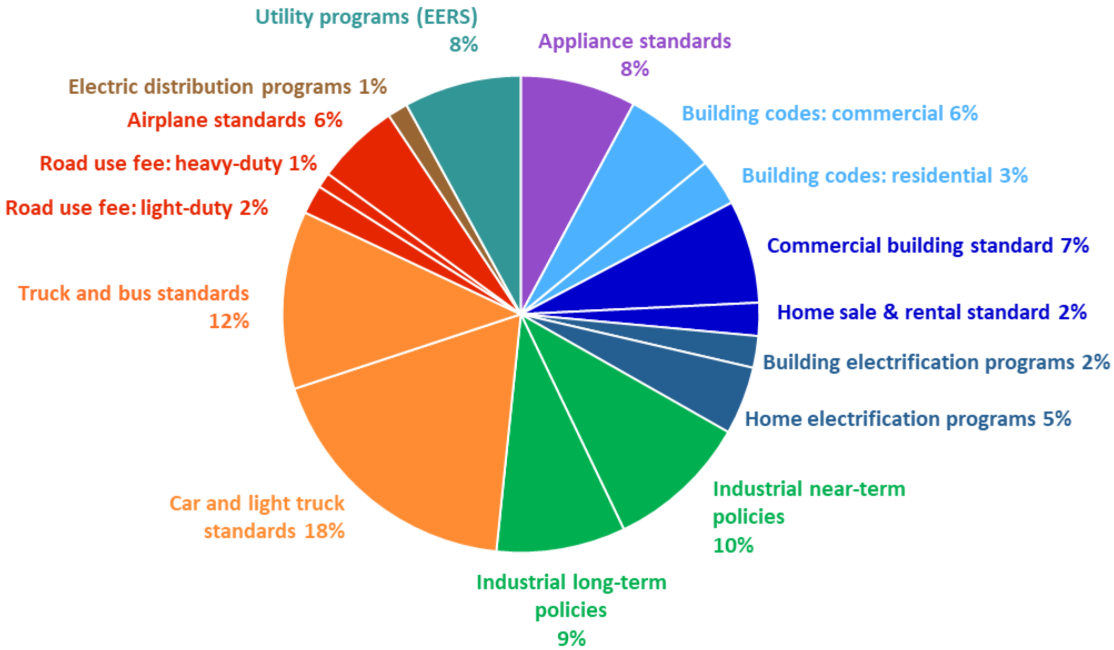

Figure 5. Allocation of CO_2 savings among policies

Building energy codes for new construction and standards for existing commercial buildings and homes contributed about 5 quads each in 2050, with commercial building savings much larger than residential in both cases. The codes that we modeled (with more rapid improvements than we have seen historically) would achieve about four-fifths of the ZEB savings. The existing commercial building standard is not exactly equivalent to the smart buildings and building retrofit opportunities but would achieve a similar level of savings. The home sale and rental requirement achieves about a third of the corresponding residential savings in part because we assumed the requirements would apply only when home occupants change. We should note that standards for existing homes and commercial buildings are relatively new and untested.

Strengthened efficiency programs under energy efficiency resource standards also could achieve 5 quads of savings in every economic sector, with more rapid growth than the buildings policies, but we believe the measures taken under EERS would have substantial overlap with the above policies, and thus would facilitate them as much as add to them.

The other transportation policies make somewhat smaller contributions. The airplane efficiency standard we model would achieve almost 90% of the opportunity (the rest involves operational and behavioral changes). The vehicle miles traveled fee and congestion fees would achieve about 30% of the corresponding savings for light-duty vehicles and 25% of the savings for heavy-duty vehicles (the difference is mostly due to lower assumed elasticity of demand). We do not have extensive experience with any of these policies, and other policies also would be needed to achieve significant additional transportation reductions over the three decades in this analysis.

Summary of analysis

Our analysis finds that the 11 efficiency opportunities we examine, if pursued aggressively, would reduce US energy-related carbon dioxide emissions by 57% in 2050 relative to base-case estimates. When other GHGs are included, energy efficiency reduces total 2050 GHG emissions by about half. Our policy analysis identifies a set of policies that if fully implemented could achieve about 90% of these savings. Of course, technologies and demographics will surely surprise us in the decades to come; the specific numbers are an illustrative scenario.

In any case, this is not a prediction but a challenge. Achieving these energy savings will require an unprecedented expansion of energy efficiency policies and investments, affecting how we work, live, shop, and move around, including

- Rapid upgrades to vehicle standards, building energy codes, equipment efficiency standards, ENERGY STAR specifications, and energy efficiency resource standards
- Substantial improvements to existing factories, homes, commercial buildings, and the electric grid, and better management of energy use in all of them
- Efforts throughout the country to provide more mobility options and more-efficient freight and aviation systems
- Development and adoption of new industrial processes and systems
- A switch to electric vehicles, equipment, and industrial processes when these need to be replaced (along with a more efficient and cleaner power sector).

While all of these opportunities are important, those with the largest savings are industrial efficiency improvements, ZNE buildings and homes, light- and heavy-duty vehicle fuel economy and electrification, appliance and equipment efficiency efforts, and upgrades to existing homes and buildings.

A comparison of our opportunity and policy pathways shows that the gap between opportunity and policy is largest for transportation system improvements (VMT reduction and freight optimization) and improvements to existing buildings. Although we assume full savings from industrial efficiency policies, those policies are not well defined. More attention is needed to develop policies that will spur energy savings and emissions reductions in these areas. Fortunately, transportation systems and existing buildings are two areas in which cities and regions that have adopted climate goals can experiment with bold policies.

To achieve the savings, we must also continue to invest in research, development, and demonstration (RD&D) to identify and validate new efficiency measures; these measures will provide additional savings opportunities that we can only imagine today and that will complement the measures we examine. RD&D will also be essential for developing and testing many of the emerging industrial and transportation technologies we include and for continuing to drive costs down.

While we expect vast consumer savings, even our current efficiency measures were not implemented solely to save money. Through these steps, we can not only reduce energy use but also improve productivity, the economy, personal comfort, air quality, and public health. And we can slash GHG emissions, getting roughly halfway to our long-term energy and climate goals.