THE NATIONAL ACADEMIES

REPORT IN BRIEF

Hidden Costs of Energy

Unpriced Consequences of Energy Production and Use

Energy production and use have many well-known benefits to society, but they also have many adverse effects that are not reflected in market prices. This report from the National Research Council, requested by Congress, examines these "hidden costs," including impacts on human health and the environment. The report calculates the monetary value of a wide range of energy-related burdens and damages, although many other external effects could not be monetized because of insufficient data or for other reasons. Monetized damages totaled more than $120 billion in 2005.

Modern society relies on a supply of cheap, ready energy. Yet, as beneficial as energy is, its production, distribution, and use also cause negative impacts. For example, pollutants from the burning of fossil fuels have effects on human health, grain crops, timber yields, building materials, recreation, and outdoor vistas.

Today's energy prices do not reflect all of its effects. Those costs and benefits, termed "externalities" by economists, are therefore unaccounted for within the current energy system. As a result, consumers and those who make decisions about energy do not receive a complete picture of the energy landscape. Meanwhile, these "hidden" costs, or damages, are passed on to society at large.

To reach a more complete accounting of energy in America, Congress asked the National Research Council to define and evaluate key energy externalities not included in pricing or not fully addressed by government policies. The process used to monetize damages is described in Box 1.

Damages from Electricity

Coal and natural gas together account for about 70 percent of the nation's electricity generation. In terms of greenhouse gases as well as other pollutants, these two forms of electricity substantially exceed nuclear power and dwarf renewable power.

Coal

Coal is a non-renewable fossil fuel that currently accounts for approximately one-third of total U.S. energy production and nearly half of electricity produced; it has also produced more damages in aggregate than any other form of energy production whose damages were monetized by the committee. The model that was used to estimate coal's external costs calculates damages associated with pollution's effects on health, crop yields, building materials, and other areas. Health damages include premature mortality and morbidity (the development of chronic bronchitis or asthma, for example).

Non-climate damages resulting from the use of coal in electricity generation amounted to $62 billion in 2005, or 3.2 cents per kilowatt-hour (kWh). These damages are twenty times higher per kWh than damages from electricity generated by natural gas. More than 90 percent of the damages are associated with premature human mortality. Approximately 85 percent come from SO_2 emissions, most of which are transformed into airborne particulate matter.

The differences in damages among plants were substantial: the 10 percent of plants with the highest damages produced 43 percent of aggregate damages from all plants (see Figure 1); while the 50 percent of plants with the lowest damages produced only 12% of aggregate damages. Each group of plants accounted for 25% of electricity generated from coal. Thus, the damages per kWh were almost 4 times higher for the highest 10% of plants than for the lowest 50%. Most variation in damages per kWh were due to differences in pollution intensity—i.e., to differences in pounds of SO_2 or NO_x emitted per kWh, although plant

Box 1. How Energy Damages Were Assessed

The committee studied the energy technologies that constitute the largest portion of the U.S. energy system or that represent energy sources showing substantial increases (more than 20 percent) in consumption over the past several years. It evaluated the technologies over their full life cycle: fuel extraction, production, distribution, use, and waste disposal.

The damage function approach was used to monetize the impacts associated with air pollution those emissions from electricity generation and transportation. This entailed measuring the emissions of particulate matter (PM), sulfur dioxide (SO_2), and oxides of nitrogen (NO_x) from various sources, translating emissions into ambient air quality and estimating the health and other impacts associated with changes in ambient air quality. Impacts were monetized using estimates of what people would pay to avoid them. Health damage constituted the vast majority of monetized damages, with premature mortality being the single largest health-damage category.

The committee applied these methods to a year close to the present (2005) for which data were available and also to a future year (2030) to gauge the impacts of possible changes in technology.

Though this was a wide-ranging analysis, the committee documented but was not able to monetize health effects related to a class of contaminants referred to as "hazardous pollutants," including lead and mercury. Ecosystem damages, water pollution impacts and the effects of energy on national security were also described but not assigned monetary damages.

To estimate damages from climate change, the committee began by evaluating the greenhouse gas emissions of each technology. Greenhouse gas emissions are the major cause of climate change, which could have severe economic, health, agricultural, and ecological impacts. The committee then considered results from three major Integrated Assessment Models (IAMs). Defining the economic damage of climate change is complex, because it depends on how different levels of emissions change the earth's climate, what impacts those changes will have, and when they will occur. Of particular importance is the rate at which damages increase with temperature (gradually or rapidly) and the discount rate used to bring future damages to bear on the present. However, there is no definitive rate at which to discount future climate damages and the committee did not endorse one. Using the range of rates used in the IAMs, the committee found that the possible damages per ton of CO_2-eq[1] ranged from $1 to $100. However, this range does not adequately account for the possibility of catastrophic changes, such as rapid sea level rise, which would have a drastic effect on these estimates if they could be accounted for.

For illustrative purposes, the committee chose three possible levels of damages per ton of CO_2-eq: low ($10 per ton), middle ($30 per ton), and high ($100 per ton). These were used to compare the magnitude of climate and non-climate damages from energy use.

The analysis did not attempt to anticipate the creation of new policies or technology breakthroughs.

[1] CO_2-eq represents the term carbon dioxide-equivalent. As different greenhouse gases have differing effects on climate change, CO_2-eq expresses the global warming potential of a given stream of greenhouse gases, such as methane, in terms of tons of CO_2.

location also played a role. Differences in pollution intensity reflect the fact that newer plants are subject to more stringent pollution controls.

Estimated Climate-Related Damages from Coal

The CO_2 emissions from coal-fired power are the largest single source of greenhouse gas emissions in the United States. Individual plants differ in how much CO_2 they produce, determined by the technology used to generate power and the plant's age. Depending on how much damage is assigned to one ton of CO_2-eq, climate damages from the average coal plant can range from 1 to 3.0 to 10 cents per kWh, corresponding to damages of $10, $30 and $100 per ton of CO_2-eq. The 3 cents per kWh estimate (equivalent to the $30 per ton figure) marks the point at which climate-related damages equal or exceed the non-climate damages associated with coal.

Natural Gas

Damages from natural gas-fired power plants are much lower than from coal plants. Aggregate non-climate damages associated with air pollutants from the sampled facilities, which generated 71 percent of the electricity from natural gas, were approximately $740 million in 2005. Average annual non-climate damages per plant were $1.49 million, which reflects both lower damages per kWh at gas plants, but also the smaller size of gas-fired plants compared with coal-fired plants. Net generation at the median coal plant was more than 6 times higher than the median gas facility. Non-climate damages per kWh were, on average, an order of magnitude lower for natural gas than for coal, at 0.16 cents

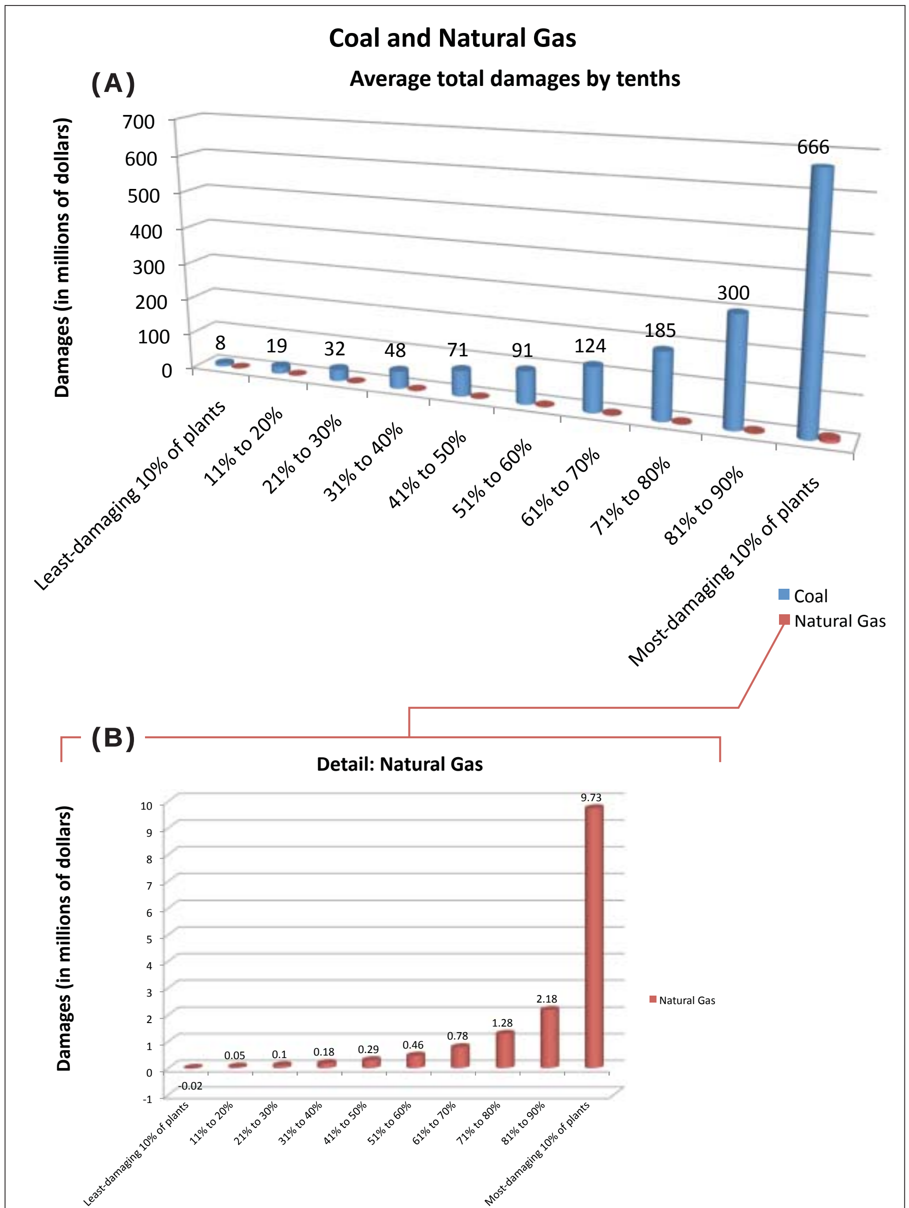


Figure 1. (A) Distribution of aggregate damages by decile (tenths) from 406 coal-fired and 498 natural gas-fired plants. The far left bars represent the 10 percent of plants with the lowest damages while the far right bars are the 10 percent with the highest damages. The numbers at the top of each column are the average damages associated with emissions from coal plants, specifically from sulfur dioxide, nitrogen oxide and particulate matter. (B) Detail from graph A on a smaller scale, showing distribution of aggregate damages by decile among natural gas fired plants.

per kWh for natural gas compared to 3.2 cents per kWh for coal.

As with coal, larger gas-fired plants are often less damaging than smaller ones. Although gas plants are, on average, far less polluting than coal-fired power plants, there are some gas facilities with damages per kWh as large as those of some coal plants. Again, as with coal, there are significant distinctions between plants. The least damaging 50 percent of gas plants, which accounted for 23 percent of net generation, produced 4 percent of the damages, while the most damaging 10 percent of plants, which accounted for 24 percent of net generation, produced 65 percent of the damages (see Figure 1-B).

Estimated Climate-Related Damages from Natural Gas

The CO_2 emissions from gas-fired power plants are significant. A gas-fired power plant produces roughly half of the climate-related damages per unit of energy than a coal-fired plant, from 0.5 to 1.5 to 5 cents per kWh, corresponding to damages of $10, $30 and $100 per ton of CO_2-eq.

Coal and Natural Gas in the Future

Predictions for the future of coal-fired electricity see air pollution damages per kWh falling. It is expected that demand for electricity will increase by 20 percent by 2030. But external costs should decrease by about 40 percent, to around $38 billion, based on expected technological changes and pollution controls assumed by the U.S. Energy Information Administration.

On average, electricity production from natural gas is predicted to increase by 9 percent in 2030 from 2005 levels. Reductions in pollution intensity from natural gas facilities are not as dramatic as for coal plants, but the aggregate damages generated by the 498 gas facilities examined by the committee are still expected to fall from $740 million in 2005 to $650 million in 2030.

Other Sources of Electricity

In general, other sources of electricity, including nuclear power and renewable sources such as wind and solar, have very small external costs in comparison to fossil fuels.

Nuclear power currently provides almost 20 percent of electricity in the United States and has very low lifecycle emissions. Although accidents, security breaches, and releases of high-level nuclear waste are possible, the chances of these situations occurring are so small that it is difficult to accurately compute their damages. In addition, low-level nuclear waste does not pose an immediate threat to human health, safety, or the environment. However, having a permanent repository for high-level radioactive waste is a very contentious issue, and warrants considerably more study on such a repository's potential externalities.

Wind power currently provides only 1.1 percent of the United States' electricity, but has the most potential for growth in renewable energy production. In general, the lifecycle emissions and damages from wind power are extremely low. However, turbine manufacturing does require a significant amount of copper, iron, and rare earth metals, and mining can threaten local water quality and cause significant environmental impacts. Once the turbine is operating, the impacts, including those to wildlife and the landscape, are small and localized.

Solar power is also expanding rapidly but currently provides less than 1 percent of electricity in the United States. It too uses materials that require resource-intensive mining, including silicon and rare minerals. In addition, solar panel manufacturing is energy intensive. However, because solar panels produce no emissions during operation, they still have low lifecycle costs.

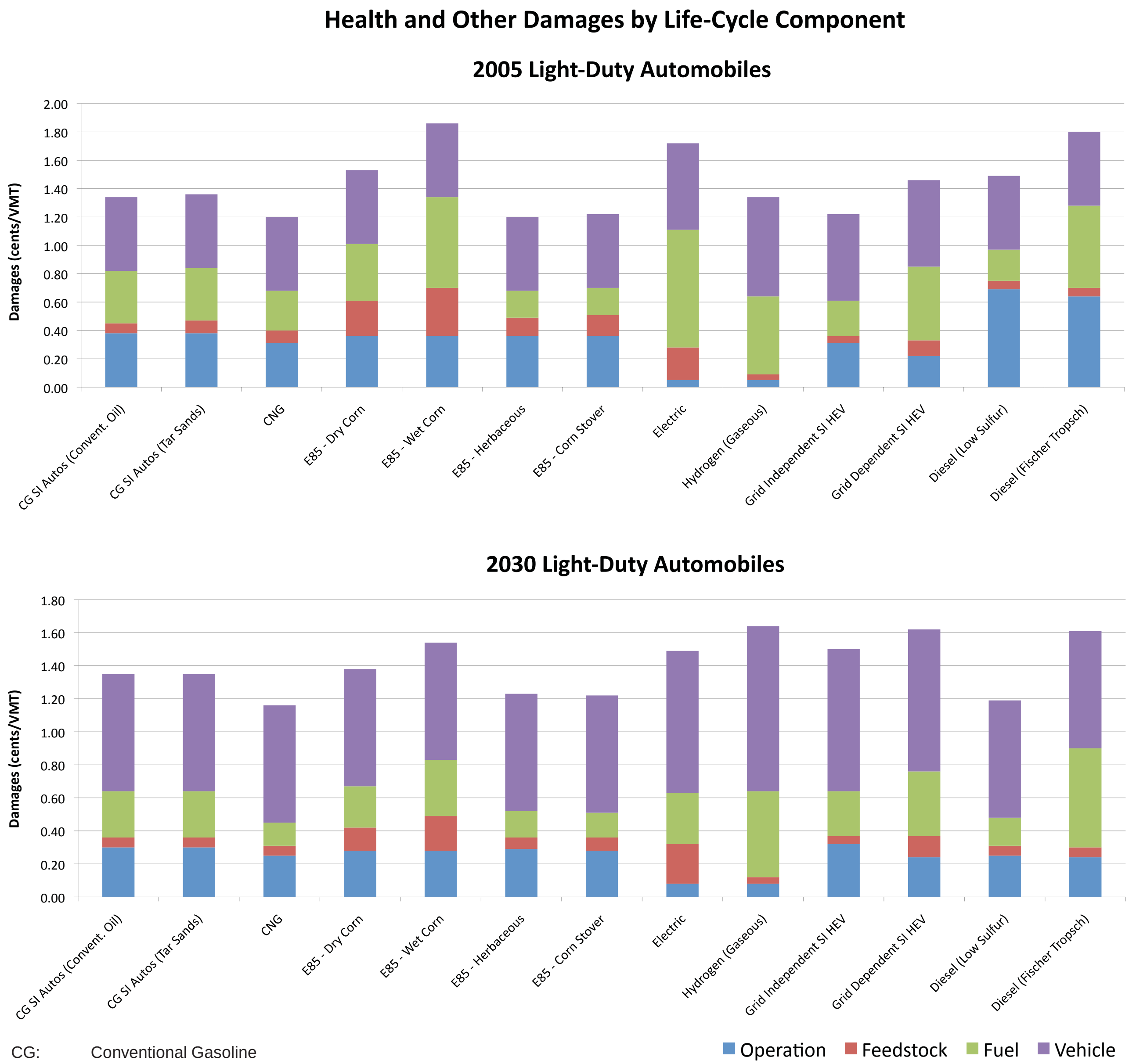
As wind and solar technology improves and provides a higher percentage of electricity in the United States, the externalities from these sources will need to be re-evaluated.

Nuclear, wind, and solar power all produce very low lifecycle greenhouse gas emissions, and are expected to have negligible impacts on climate change.

Damages from Transportation

Transportation accounts for one-third of energy use in the United States and is almost completely dependent on petroleum.

In 2005, highway vehicles caused $56 billion in health and other non-climate damages, with $36 billion from light-duty vehicles (cars and SUVs) and $20 billion from heavy-duty (trucks and buses). That year, the least damaging vehicle-fuel combinations generated 1.2 cents in non-climate damages per vehicle mile travelled, while the most



CG: Conventional Gasoline
SI: Spark Ignition
CNG: Compressed Natural Gas
E85: 85% ethanol/gasoline blend
HEV: Hybrid Electric Vehicle
Grid-dependent: Plug-in hybrid electric vehicle
Fischer Tropsch: a mixture of hydrogen and carbon monoxide—derived from coal, methane, or biomass—converted into liquid fuel
Corn stover and herbaceous biofuels are not commercially available.

Figure 2. The non-climate lifecycle damages of several different combinations of fuels and vehicles for 2005 and projected for 2030. The feedstock damages are the damages produced from the extraction of the resource (oil for gasoline, biomass for ethanol or predominantly fossil fuels for electricity) and its transportation to the refinery. The fuel damages are those from the refining or conversion of the feedstock to usable fuel and its transportation to the dispenser. The vehicle damages are those from the manufacture and production of the vehicle. The operation damages are the tailpipe and evaporative emissions produced while using the vehicle.

damaging generated a little more than 1.70 cents per vehicle mile travelled. Although most people consider only the emissions coming out of their vehicle's tailpipe, emissions from driving a vehicle accounted for only one-quarter to one-third of its total damages. Vehicle manufacturing, the extraction and transportation of raw materials, and the refining or conversion of raw materials into fuel accounted for the rest of the estimated damages.

Surprisingly, nearly all of the combinations of light-duty fuel and vehicle technologies had very similar external damages (see Figure 2). Therefore, it is important to be cautious when interpreting small differences. These distinctions are expected to shrink even further by 2030 when the Corporate Average Fuel Economy (CAFE) standards will require the vehicle fleet to achieve an average fuel economy of 35.5 miles per gallon.

However, some fuels and vehicles had higher non-climate hidden costs than others. Electric vehicles produced some of the highest non-climate damages in 2005 (more than 1.70 cents per vehicle miles travelled). Although they produce no emissions during operation, they rely on electricity powered largely by fossil fuels for their fuel and energy intensive battery manufacturing. These costs are lower in 2030 as new rules reduce pollutant emissions from electricity generation. Although the committee did not include indirect land use in its estimates, corn ethanol also had high hidden costs in 2005 (at 1.52 cents per vehicle mile travelled for E85, which is fuel made with 85% ethanol). Producing corn and converting it into fuel requires a significant amount of electricity and petroleum.

Cellulosic ethanol, generally made of corn stalks or non-food crops that require little energy to grow, had some of the lowest non-climate external costs (in 2005, 1.20-1.21 cents per vehicle mile travelled for E85). Similarly, the fuel production and operation of compressed natural gas vehicles created very few emissions (in 2005, 1.20 cents per vehicle mile travelled). However, there are few compressed natural gas vehicles on the road today and the estimates for growth are low. Hybrid electric vehicles also had some of the lowest costs (in 2005, 1.22 cents per vehicle mile travelled), but as general vehicle efficiency increases, the differences between hybrid and conventional vehicles are expected to shrink.

Diesel vehicles are expected to experience the largest shift in hidden costs over time. In 2005, diesel had some of the highest costs when used in both light and heavy-duty vehicles. However, recent diesel emission standards, which require vehicles beginning in model years 2006 (light duty) and 2007 (heavy duty) to use low-sulfur diesel and particle emission control technology, is expected to dramatically lower tailpipe emissions. If the rule is fully implemented by 2030 as planned, vehicles using low-sulfur diesel should become one of the least damaging vehicles.

Estimated Climate-Related Damages from Transportation

Most vehicle and fuel combinations had similar levels of greenhouse gas emissions in 2005 (see Figure 3). Nonetheless, some fuels and vehicles produced more greenhouse gases over their lifecycle than others. Vehicles using petroleum derived from tar sands[2] produced the most greenhouse gases per vehicle mile travelled. In contrast, cellulosic ethanol had some of the lowest greenhouse gas emissions, because biomass crops can store CO_2 in the soil. As was the case with electricity generation from coal, the mid-range figure used to illustrate climate damages ($30 per ton of CO_2) marks the point at which climate-related damages of transportation across fuel types could be expected to equal or exceed non-climate damages.

By 2030, implementing the higher fuel economy standards will reduce the vehicle fleet's lifecycle contribution to climate change even more than its contribution to non-climate damages.

However, substantially reducing external damages from transportation will require one or more technological breakthroughs. For example, advances that reduce emissions from electricity production, such as the development of affordable technologies for reducing emissions from coal production or achieving a vast increase in low-carbon energy, could drastically decrease damages from electric vehicles.

[2] A very small proportion of petroleum today is produced from tar sands, mostly in Canada. However, that amount may grow substantially in the future if the cost of oil and concerns about national security increase.

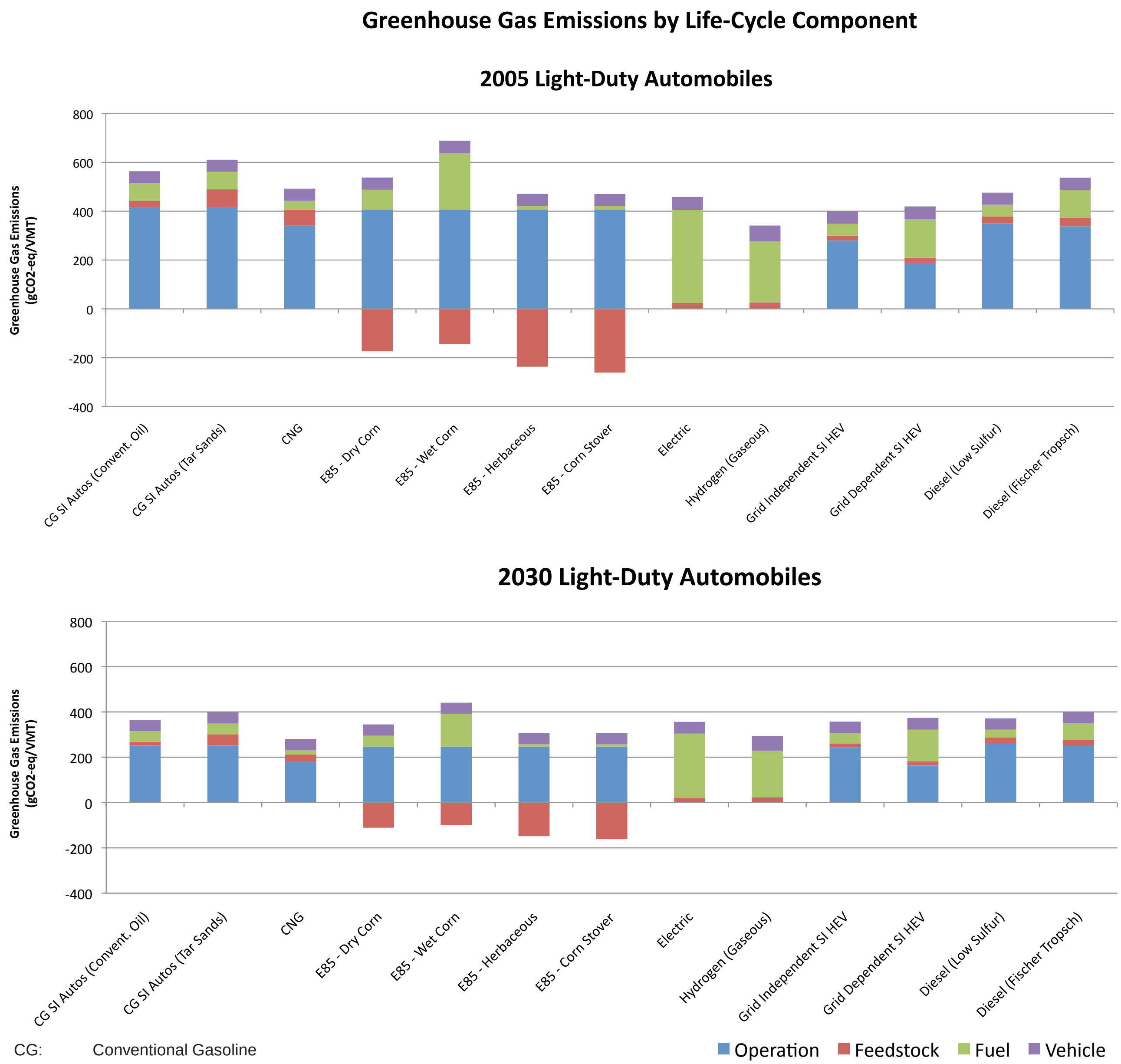


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Figure 3. The lifecycle greenhouse gas emissions (in tons of carbon dioxide-equivalents) of several different combinations of fuels and vehicles for 2005 and projected for 2030. It should be noted that for the four forms of E85 biofuel, the carbon dioxide consumed in their production should be subtracted from the CO_2 generated in their use in order to determine their net CO_2 emissions.

Damages from Heating

Heating is a key part of the energy picture. Around 30 percent of the energy used in the United States goes towards heat, most of it provided by natural gas (electricity also accounts for a small percentage of heat energy). The total non-climate damages from burning natural gas for heat were about $1.4 billion in 2005. Damages from heat in 2030 are anticipated to remain largely the same, as rising demands are offset by lower-emitting sources. Depending on how much damage is assigned to one ton of CO_2-eq, climate damages from heat could be from 70 to 210 to 700 cents per 1000 cubic feet.

Conclusion

In aggregate, the damage estimates presented in this report for various external effects are substantial. The external effects the committee was able to quantify for 2005 add up to more than $120 billion in damages. Although large uncertainties are associated with the committee's estimates, there is little doubt that this aggregate total substantially underestimates the actual damages. Costs cannot presently be estimated with confidence for some effects, including national security.

While not a comprehensive guide to policy, the committee's analysis indicates that regulatory actions can significantly affect energy-related damages. The damages associated with coal-fired electricity generation capture the benefits of further reductions in power plant emissions beyond those required in the 1990 Clean Air Act Amendments. In the case of transportation, recent diesel emission standards are expected to dramatically lower hidden costs of diesel vehicles. Similarly, advances in energy efficiency technologies or policies that reduce emissions (either greenhouse gases or non-climate pollutants) in electricity production could have a ripple effect into many sectors. Not only would such advances reduce emissions from electricity production, but they would also reduce vehicle lifecycle damages, particularly for electric vehicles.

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* Resigned from the committee on August 2, 2009, to accept an appointment as the administrator of the U.S. Energy Information Administration.

The National Academies appointed the above committee of experts to address the specific task requested by the United States Congress. The members volunteered their time for this activity; their report is peer-reviewed and the final product approved by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.

For more information, contact the Board on Environmental Studies and Toxicology at (202) 334-3060 or http://dels.nas.edu/best. *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* is available from the National Academies Press; call (800) 624-6242 or (202) 334-3313, or visit the NAP website at www.nap.edu.