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Paying Too Much for Energy?
The True Costs of Our Energy Choices

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ABSTRACT

Energy consumption is critical to economic growth and quality of life. America's energy system, however, is malfunctioning. The status quo is characterized by a tilted playing field, where energy choices are based on the visible costs that appear on utility bills and at gas pumps. This system masks the "external" costs arising from those energy choices, including shorter lives, higher health care expenses, a changing climate, and weakened national security. As a result, we pay unnecessarily high costs for energy. New "rules of the road" could level the energy playing field. Drawing from our work for The Hamilton Project, this paper offers four principles for reforming U.S. energy policies in order to increase Americans' well-being.

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Whether by heating our homes in winter, keeping the lights on in our offices, powering factories that manufacture goods, or fueling our automobiles, energy drives our economy and supports our quality of life. Thanks in part to an economic infrastructure heavily dependent on energy use–roads and highways, ports and railways, broadband and computer networks, manufacturing plants and shipping facilities–American workers and businesses are among the most productive in the world and the most globally integrated. A century of innovation, fueled by cheap and plentiful energy largely from coal, oil, and natural gas, has allowed the nation to transition from an agriculture-based economy to one based on high-value-added manufacturing and services aided by computerization. Our standard of living–among the highest on earth– would not be possible without energy and the systems that have been developed to harness it.

Elsewhere in the world, developing economies are trying to catch up–both in terms of economic growth and quality of life–and are expanding their energy production infrastructures accordingly. For example, major rural electrification projects are under way in China and India to increase access to energy in villages and to mechanize farming tasks. Furthermore, both countries are rapidly increasing electricity production to feed their sharp industrial growth. Abroad, as at home, rising living standards and robust economic growth require access to plentiful, reliable, and inexpensive energy.

Unfortunately, the sources of energy that we have grown to rely on are more expensive than we once thought. The true cost of energy includes the price we pay at the gas pump or what shows up on the electric bill—known as the "private costs" —and also the less obvious impact of energy use on health, the environment, and national security. Economists refer to these additional damages as negative externalities, or "external costs". A more holistic accounting of the total costs of energy consumption that includes both the private and external costs is known as the

social cost of energy use.   Recent events like the Deepwater Horizon oil spill, the death of

twenty-nine West Virginia coal miners in the worst mining disaster in twenty-five years, and the

crisis at Japan's Fukushima Daiichi Nuclear Power Plant are salient examples of the health and

environmental costs, and economic risks, of our current energy sources. While these tragic

disasters are the most obvious symbols of these costs, they are by no means the largest.

Our primary sources of energy impose significant health costs–particularly on infants and

the elderly, our most vulnerable. For instance, even though many air pollutants are regulated

under the Clean Air Act, fine particle pollution, or soot, still is estimated to contribute to roughly

one out of every twenty premature deaths in the United States.[1] Indeed, soot from coal power

plants alone is estimated to cause thousands of premature deaths and hundreds of thousands of

cases of illness each year.[2] The resulting damages include costs from days missed at work and

school due to illness, increases in emergency room and hospital visits, and other losses

associated with premature deaths. In other countries the costs are still greater; recent research

suggests that life expectancies in northern China are about five years shorter than in southern

China due to the higher pollution levels in the north.[3] The National Academy of Sciences

recently estimated total non-climate-change-related damages associated with energy

consumption and use to be more than $120 billion in the United States in 2005. Nearly all of

these damages resulted from the effects of air pollution on our health and wellness.[4]

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[1] Environmental Protection Agency, Office of Air and Radiation, "EPA's Transport Rule: What Does It Mean for Environmental Justice Communities?" September 2010, http://www.epa.gov/airtransport/pdfs/WebinarTransportRuleMaterials.pdf.
[2] Abt Associates, "Power Plant Emissions: Particulate Matter-Related Health Damages and the Benefits of Alternative Emission Reduction Scenarios," Report for the Clean Air Task Force, June 2004, http://www.abtassociates.com/reports/Final_Power_Plant_Emissions_June_2004.pdf.
[3] Yuyu Chen, Avraham Ebenstein, Michael Greenstone, and Hongbin Li, "The Long-Run Impact of Air Pollution on Life Expectancy: Evidence from China's Huai River Policy," working paper, 2012.
[4] National Academy of Sciences, *Hidden Costs of Energy* (Washington, D.C.: National Academies Press, 2010), 154.

The external costs associated with using carbon-intensive fuels also include climate change. If carbon dioxide (CO_2) emissions continue to rise at the current rate, they are likely to drive temperature changes that will have significant environmental and health consequences: rising sea levels, more frequent and more severe storms, increased flooding and drought, and other dramatic changes in weather patterns. These changes in turn could result in an increase in water- and insect-borne diseases, a loss of biodiversity, and the loss of human lives and livelihoods.[5] The U.S. government recently developed a measure to monetize the damages caused by CO_2 emissions: that is, the social cost of carbon. By this metric, carbon emissions in the United States resulted in almost $120 billion in damages globally in 2009.[6] Other environmental costs associated with our current energy sources include the impact of acid rain on vegetation and lakes, the effect of ozone on agricultural productivity, and oil leaks and spills. Further, recent concerns about local damages associated with hydraulic fracturing ("fracking") extraction techniques underscore the land-use issues related to fuel extraction.

There are additional economic, political, and national security risks associated with current domestic energy policies. Oil plays an important role in the American economy: it powers most of the transportation sector and is an important input in many industries. Continuing turmoil in the Middle East has raised the profile of energy security and the geopolitical implications of reliance on oil. In part to protect major oil supplies, the United States has

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[5] Intergovernmental Panel on Climate Change, "Summary for Policymakers," in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. Susan Solomon, Dahe Qin, Martin Manning, Zhenlin Chen, Melinda Marquis, Kristen Averyt, Melinda M.B. Tignor, and Henry LeRoy Miller, Jr. (Cambridge and New York: Cambridge University Press, 2007).
[6] Interagency Working Group on Social Cost of Carbon, "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," February 2010, http://www.epa.gov/oms/climate/regulations/scc-tsd.pdf; Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2009," 2011, Table ES-2, http://www.epa.gov/climatechange/emissions/downloads11/US-GHG-Inventory-2011-Executive-Summary.pdf.

maintained a military presence in the Middle East for more than fifty years. On several occasions, it has become mired in military interventions to prevent oil supply disruptions, among other objectives.

These costs–ranging from increases in lung disease and infant mortality to problems associated with climate change–have been quantified and can be expressed in dollar terms. And these costs can far exceed the price that appears on our utility bills or at the gas pump. For example, we estimate that it costs about 3.2¢ for an existing coal plant to produce a kilowatt hour (kWh) of electricity. But this inexpensive sticker price belies the more significant damages (estimated at roughly 5.6¢ per kWh) of coal-generated electricity to our well-being: shorter lives, higher health care bills, and a changing climate that poses risks to our way of life. The true social cost is almost three times the amount that appears on our utility bills.

Current energy policy tilts the balance in favor of energy sources that appear cheap only because their costs to health, the climate, and national security are obscured or indirect. A better approach to energy policy should encourage fairer competition between energy sources by placing them on equal footing. Based on our work for The Hamilton Project, this paper offers four principles for reforming U.S. energy policies that would move the country in this direction.

* * *

The Benefits of Energy Use. The development and exploitation of inexpensive energy sources has been a key driver of economic development and quality of life. The story of the expansion of the U.S. economy, and of the advances and innovations that have made life better for Americans, leaps from one energy-harvesting invention to another: the cotton gin, the steam engine, the light bulb, the internal combustion engine, the turbine, the mechanized factory, the electrified city, and the computer. The development of coal, oil, natural gas, nuclear power and other energy sources

made all this progress possible and has helped support activity that is integral to our economy and quality of life.

Windmills and watermills, the first modes of generating mechanical energy, were used almost entirely for rudimentary tasks such as grinding grain and pumping water. The development of the steam engine in Britain in the mid-eighteenth century gave birth to industry by powering factories and cotton mills. In the late nineteenth century, the internal combustion engine, which runs the entire modern motor vehicle fleet, was invented. Around the same time, the light bulb was developed, allowing businesses to keep their doors open even after the sun had set and making it possible for employees to extend their workdays.

Today our economy is heavily reliant on electric power to run businesses and maintain quality of life. Data centers and server farms in the United States require massive amounts of energy. In 2006, they consumed 61 billion kWh of electricity (1.5 percent of total U.S. electricity consumption), more than was consumed by the nation's televisions.[7] Oil fuels more than 90 percent of the nation's motor vehicle fleet and is a critical fuel input for the entire transportation network. The benefits that energy provides, from home heating to facilitation of trade, are integral to our way of life. The United States consumes about one-fifth (21 percent) of the world's energy, despite having less than 5 percent of the world's population.[8]

But U.S. dominance in energy use is about to change. Developing countries–especially China and India–are rapidly increasing the amount of energy they consume as their economies grow and their citizens aspire to better living conditions (Figure 1). While access to plentiful

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[7] Environmental Protection Agency, ENERGY STAR Program, *Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431*, August 2007, 7.
[8] Energy Information Administration, "Shares of World Energy Consumption in the United States, China, and India, 1990–2035," in *2010 International Energy Outlook* (Washington, D.C.: Department of Energy, 2010), Figure 14, http://www.eia.doe.gov/oiaf/ieo/world.html.

energy is important to maintaining the standard of living in the United States, it has taken on an even more vital role in emerging markets as they transition to a higher standard of living and more energy-intensive economies.

[Insert Figure 1 - World Energy Consumption by Country, 1980 to 2008]

A lack of reliable access to energy has been a major deterrent to economic growth and improved quality of life in most of the developing world. Almost one-fourth of the world's population–most of which lives in sub-Saharan Africa and South Asia–lacks access to electricity.[9] Twice that number–half the world's population–lacks access to clean cooking energy and relies on traditional biomass fuels (wood, dung, coal, and agricultural by-products) that produce smoke and other air pollutants.[10] Indeed, indoor smoke from solid fuels is believed to have been the sixth-leading cause of death and fifth-leading cause of disability in low-income countries in 2004.[11] "Energy poverty" and "fuel poverty" contribute to poverty, health problems that can result in lower life expectancy, diminished access to education and other productive activities, and lower rates of economic growth and productivity.

From facilitating trade to raising income and improving health, reliable access to energy could help reduce poverty and improve life expectancy in developing nations around the world. As these nations grow and transition, however, their reliance on fossil fuel–based energy sources will surge, creating another set of global challenges resulting from climate change.

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[9] International Energy Agency, "Energy Poverty: How to Make Modern Energy Access Universal?" in *World Energy Outlook 2010* (Paris: Organisation for Economic Co-operation and Development, September 2010), 7, http://www.worldenergyoutlook.org/docs/weo2010/weo2010_poverty.pdf.
[10] United Nations Development Programme and World Health Organization, "The Energy Access Situation in Developing Countries," November 2009, 1, http://content.undp.org/go/cms-service/stream/asset/?asset_id=2205620.
[11] World Health Organization, "Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks," 2009, 11–12,
http://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf.

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The External Costs of Energy Use. The benefits of the energy sources that we currently rely on are obvious. But it is increasingly clear that the costs of our current sources go well beyond what we pay at the pump or to the utility company. These additional costs of energy use take a variety of forms, from the erosion of living standards to the diversion of taxpayer funds and other critical resources. They include increased health costs, shortened life spans, higher military expenditures and foreign policy constraints, expensive environmental cleanups, and the broad impacts of climate change–all of which are real costs that we impose on ourselves and on future generations.

Health effects of current energy sources. The combustion of fossil fuels results in the release of pollutants that have a significant impact on the health and well-being of American society and the world. Air pollution's greatest costs to society come from health impacts, which make up approximately 94 percent of external non-climate costs.[12] Particulate air pollution, or soot, is associated with elevated mortality rates for adults and infants.[13] In 2010, soot from U.S. coal-fired power plants was estimated to have caused 23,600 premature deaths and more than 500,000 cases of respiratory illness.[14] Soot and other pollutants such as sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen oxides (NO_x), which lead to ozone, all pose threats to well-being, including higher mortality rates, more hospital admissions, restricted activity days, and increased expenditures on medications for respiratory problems.[15]

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[12] Nicholas Muller and Robert Mendelsohn, "Measuring the Aggregate Damages of Air Pollution in the United States," *Journal of Environmental Economics and Management* 54 (2007): 1–14.
[13] Kenneth Chay and Michael Greenstone, "The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession," *Quarterly Journal of Economics* 118 (3) (August 2003).
[14] Abt Associates, "Power Plant Emissions."
[15] Olivier Deschenes, Michael Greenstone, and Joseph Shapiro, "Defending against Environmental Insults: Drugs, Emergencies, Mortality and the NO_x Budget Program Emissions Market," working paper, 2011.

The National Academy of Sciences estimates that electricity generation from coal, oil-fueled vehicles and transportation, and electricity production from natural gas caused an estimated $120 billion in non-climate-change-related damages in 2005 (Figure 2).[16] Health-related damages account for almost all of these costs.

[Insert Figure 2 - Main Sources of Non-Climate-Change-Related Damages, in 2005]

The health consequences of other energy sources can be severe, as the nuclear crisis in Japan reminds us. Prior experiences with nuclear disasters suggest that they increase the incidence of cancer. Even at doses once thought to be harmless, children born in regions of Sweden that experienced higher radiation fallout from the disaster at Chernobyl have been shown to have reduced cognitive abilities, measured by school performance.[17]

Climate-Change Impacts. Since the start of the Industrial Revolution, humans have been emitting a growing amount of greenhouse gases such as CO_2, methane, and NO_x into the atmosphere. Figure 3 shows that the concentration of CO_2 in the atmosphere has risen by more than 23 percent over the past fifty years.[18] According to the Intergovernmental Panel on Climate Change, these rising levels of CO_2 and other greenhouse gases will cause rising average global temperatures in the coming years and decades. If current emissions trends continue, global temperatures will increase by an estimated 4.3ºF to 11.5ºF (2.4ºC to 6.4ºC) by the end of the century, depending on the climate model and assumptions about economic growth.[19]

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[16] National Academy of Sciences, *Hidden Costs of Energy*.
[17] Douglas Almond, Lena Edlund, and Marten Palme, "Chernobyl's Subclinical Legacy: Prenatal Exposure to Radioactive Fallout and School Outcomes in Sweden," *Quarterly Journal of Economics* 124 (4) (2009).
[18] KNMI Climate Explorer, http://climexp.knmi.nl/.
[19] Intergovernmental Panel on Climate Change, "Summary for Policymakers," in *Climate Change 2007*, ed. Solomon et al.

[Insert Figure 3 - Mean Global Temperature and Atmospheric CO_2 Concentrations, 1900 to 2099]

The increase in average temperature is well-documented, but it is less clear how this will affect our lives. One way to illustrate the effect is to look at the incidence of very hot days. Figure 4 reports the current number of days per year when the temperature experienced by the average American falls into certain ranges. In recent history, it has been extremely rare for the average daily temperature (calculated as the average of the daily maximum and minimum) to exceed 90ºF; the average American experiences about one such day per year. But in the future, such extremely hot days are projected to become much more regular, occurring about forty times a year. This means the United States will experience roughly four times as many days when the temperature is hotter than 90ºF than days when it is below 30ºF. This projected change is troubling because the greatest damages from temperature, in terms of elevated rates of mortality and morbidity and reduced agricultural productivity, are concentrated at these high temperatures.[20]

[Insert Figure 4- Current and Predicted End-of-Century Daily Temperatures]

In addition to the increase in temperatures, the higher concentrations of greenhouse gases are expected to lead to other changes on our planet, including changes in precipitation patterns, weather variability, and rising sea levels. Together, these changes in climate are expected to lead to a series of adverse outcomes ranging from reduced agricultural productivity, increased

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[20] Olivier Deschenes and Michael Greenstone, "Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US," *American Economic Journal: Applied Economics*, 3(4) (2011): 152–85; Robin Burgess, Olivier Deschenes, Dave Donaldson and Michael Greenstone, "Weather and Death in India," working paper, 2011, http://dl.dropbox.com/u/2734209/BDDG_Weather_and_Death_paper.pdf

mortality rates, higher flood risks, greater rates of species extinction, compromised ecosystem services, and even increased conflict over scarce natural resources. Furthermore, there is rising concern about the possibility of a catastrophic event, such as a potentially discontinuous "tipping point" in the behavior of earth systems.

In the abstract, it is easy to understand that there is a wide range of risks for the United States and the world population associated with climate change. The challenge of summarizing and monetizing the costs–a necessary next step for informing policy-makers–has only recently been addressed. In 2010, a U.S. government working group estimated the global damages associated with the release of an additional ton of CO_2 into the atmosphere, calling their estimate the social cost of carbon (SCC). The group concluded that the current SCC is roughly \$21 per ton of CO_2 emissions.[21] To put that number in context, at a cost of \$21 per ton, carbon emissions in the United States last year resulted in roughly \$120 billion in global damages. The damages within the United States are projected to be smaller, ranging from about 7 to 23 percent of the total. Of course, the global and domestic damages apply regardless of where on the planet the emissions occur.[22]

With this estimate of the SCC, policy-makers now have a bright-line rule to identify effective policies, because they can quantify the benefits of regulations that would reduce carbon emissions. Indeed, the SCC has already become a standard tool in the evaluation of national policy choices. Since the release of the SCC values, the monetized benefits of CO_2 emission reductions have been included in at least seven major regulations (those with costs or benefits

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[21] The \$21 figure is the central value, and the U.S. government also recommended conducting sensitivity analyses at \$5, \$35, and \$65. See Interagency Working Group on the Social Cost of Carbon, "Technical Support Document."
[22] For more information on how the SCC values were developed, see Michael Greenstone, Elizabeth Kopits, and Ann Wolverton, "Estimating the Social Cost of Carbon for Use in Federal Rulemakings: A Summary and Interpretation," NBER Working Paper No. 16913, National Bureau of Economic Research, March 2011, http://www.nber.org/papers/w16913.pdf.

above $100 million) across three federal departments and agencies. In Table 1 (discussed below), we use the SCC to quantify the climate-related damages from various energy sources.

Other environmental and economic effects. Other aspects of energy production and consumption also impose external costs. For example, extracting, transporting, and consuming fuels such as coal and petroleum have adverse effects on the environment and impair our quality of life. The methods used to extract fuel, such as coal mining or offshore oil drilling, can be very disruptive to the surrounding ecosystem. Strip-mining, a form of surface mining that peels back layers of soil and rock to expose seams of mineral, destroys vegetation, displaces wildlife, and often permanently changes soil composition. The Deepwater Horizon oil spill in 2010, which damaged both local ecosystems and local economies, is one illustration of the consequences of accidents. Air pollutants, like those that form acid rain or the airborne mercury from burning coal, have negative effects on trees, wildlife, ocean life, and soil quality. The smog that results from air pollutants impairs visibility and interferes with enjoyment of national parks and other scenic vistas.

Pollution also results in economic damages. Ozone can slow plant and crop growth and increase plants' vulnerability to disease.[23] Recent evidence suggests that air pollution has a significant impact on the health and productivity of workers and children's absenteeism rates at school.[24] Ozone, even at levels below Environmental Protection Agency (EPA) standards, has been shown to reduce the productivity of agricultural workers in California.[25]

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[23] Denise L. Mauzerall and Xiaoping Wang, "Protecting Agricultural Crops from the Effects of Tropospheric Ozone Exposure: Reconciling Science and Standard Setting in the United States, Europe and Asia," *Annual Review of Energy and the Environment* 26 (2001): 237–268; John Reilly, Sergey Paltsev, Benjamin Felzer, Xiaoping Wang, David Kicklighter, Jerry Melillo, et al., "Global Economic Effects of Changes in Crops, Pasture, and Forests due to Changing Climate, Carbon Dioxide, and Ozone," *Energy Policy* 35 (11) (2007): 5370–5383.
[24] Rema Hanna and Paulina Oliva, "The Effect of Pollution on Labor Supply: Evidence from a Natural Experiment in Mexico City," NBER Working Paper No. 17302, National Bureau of Economic Research, August 2011; Janet

Even some alternative energy sources, several of which have been heralded as the future

of energy use, have significant environmental costs. Biofuels such as ethanol were once

considered a promising substitute for carbon-intensive fuels. However, clearing the land,

growing, transporting, and processing the crops used for biofuels results in large emissions of

CO_2. Examining the entire life cycle of production and consumption of biofuels suggests that at

least some of them may be, on balance, worse for the environment than the entire energy cycle

for oil.

Macroeconomic stability and international security. Energy security has been a critical

concern for U.S. policy-makers since at least the oil shocks of the 1970s. Although U.S. oil

intensity–the amount of oil the United States consumes per dollar of economic activity–has been

declining by about 2 percent per year since 1980, our economy remains heavily dependent on

oil.[26] In the transportation sector, there are almost no substitutes; oil meets more than 90 percent

of U.S. fuel needs.[27] Consequently, oil continues to play both a substantive and symbolic role in

the economy. The challenges that arise from U.S. reliance on oil have both economic and

geopolitical dimensions.

Dependence on oil imposes macroeconomic risks from oil shocks. Ten of the eleven

postwar recessions followed an increase in the price of oil, including the most recent recession.[28]

While some research suggests that oil shocks have had steadily smaller effects on economic

Currie, Eric Hanushek, E. Megan Kahn, Matthew Neidell, and Steven Rivkin, "Does Pollution Increase School Absences?" *The Review of Economics and Statistics* 91 (4) (2009): 682–694.

[25] Joshua S. Graff Zivin and Matthew J. Neidell, "The Impact of Pollution on Worker Productivity," NBER Working Paper No. 17004, National Bureau of Economic Research, April 2011, http://www.columbia.edu/~mn2191/w17004.pdf.

[26] Adam Sieminski, "Energy and the Economy," 2010 EIA-SAIS Energy Conference, Washington, D.C., April 6–7, 2010, http://www.eia.doe.gov/conference/2010/session5/sieminski.pdf.

[27] National Academy of Sciences, *Hidden Costs of Energy*.

[28] James Hamilton, "Oil Prices and the Economic Downturn," Testimony Prepared for the Joint Economic Committee of the U.S. Congress, May 2009; James Hamilton, "Historical Oil Shocks," working paper, Department of Economics, University of California, San Diego, February 2011, Table 1, 33, http://dss.ucsd.edu/~jhamilto/oil_history.pdf.

activity since the 1970s–perhaps because our economy's oil intensity has been diminishing, because policy-makers have learned how to respond better to these shocks, or because the U.S. economy is more flexible today than it was–evidence from the most recent recession suggests that our vulnerability to oil shocks has not disappeared.[29]

Oil consumption also raises geopolitical and national security issues. For more than fifty years, the United States has maintained a military presence in the Persian Gulf. Although it is difficult to disentangle energy security from other national security goals, the need to guard against the possibility of oil disruptions has added urgency to U.S. military action. According to Brent Scowcroft, the national security adviser under Presidents Gerald Ford and George H.W. Bush, "What gave enormous urgency to [the Persian Gulf War] was the issue of oil."[30]

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Estimates of Private and External Costs of Various Energy Sources. Smart energy policy must take into account the full social cost of energy production. This includes the private costs of building, maintaining, operating, and fueling electricity generating plants or transportation vehicles, as well as the external costs to health and the environment. Making good energy policy decisions has been especially difficult because the extent of the private and external costs has not always been clear. Indeed, without access to full, transparent information about the true costs of energy sources, policy-makers have not had the tools to make the best choices for the economy and the welfare of the American people. With an "apples to apples" comparison of actual costs,

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[29] Olivier Blanchard and Jordi Gali, "The Macroeconomic Effects of Oil Price Shocks: Why are the 2000s So Different from the 1970s?" NBER Working Paper No. 13368, National Bureau of Economic Research, September 2007; James Hamilton, "Causes and Consequences of the Oil Shock of 2007–2008," Department of Economics, University of California, San Diego, April 2009, http://dss.ucsd.edu/~jhamilto/Hamilton_oil_shock_08.pdf.
[30] "Oral History: Brent Scowcroft," interview with PBS *Frontline*, January 1996, http://www.pbs.org/wgbh/pages/frontline/gulf/oral/scowcroft/1.html.

we can help level the playing field among the various energy sources by providing more-accurate information for the public discussion around energy policy.

Table 1 provides new and what we believe are the most complete estimates of the costs of electricity production for several energy-producing technologies, including coal, natural gas, nuclear, wind, solar, and hydroelectric. It reports the full life-cycle costs of creating new electricity-generating capacity using different types of electricity sources; that is, it shows the total social cost per unit of energy of starting up and operating a new plant over the entire lifetime of the plant (sometimes called the "levelized cost") including the health and environmental costs associated with electricity production. These costs are divided into private costs (the cost of building, fueling, operating, and maintaining a plant); non-carbon external costs (primarily the costs to health); and carbon-related external costs due to climate change.[31] The sources for the estimates of the private costs are based on our calculations, described in detail in our paper for The Hamilton Project[32]; estimates for non-carbon costs are from the National Academy of Sciences[33]; and estimates for carbon-related costs are from the Interagency Working Group on the Social Cost of Carbon.[34] We are unaware of any previous effort to pull these cost components together.

[Insert Table 1- The Private, External and Social Costs of Electricity Generation]

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[31] Energy is usually measured in kWh, which is equal to the amount of energy consumed by a 100-watt light bulb if turned on for ten hours.

[32] Michael Greenstone and Adam Looney, "A Strategy for America's Energy Future: Illuminating Energy's Full Costs," The Hamilton Project strategy paper, Brookings Institution, May 2011, http://www.hamiltonproject.org/files/downloads_and_links/05_energy_greenstone_looney.pdf.

[33] National Academy of Sciences, *Hidden Costs of Energy*.

[34] Interagency Working Group on Social Cost of Carbon, "Technical Support Document."

Although we attempt to draw on the best available data and research when producing these estimates, there is substantial uncertainty around many of these costs. For some energy sources, estimates of non-carbon external costs are difficult to quantify or are simply not available. For example, for nuclear and hydroelectric power, the costs from nuclear accidents or from damage to fisheries are very real, but few studies have reliably estimated those costs. Additionally, the prices of fuel sources are determined by market forces, and can rise or fall over time, leading to changes in private costs. Similarly, innovation has reduced the costs of many emerging technologies and may continue to reduce costs in the future.

The fifth column shows estimates of the levelized private costs of generating new electricity from different sources. For baseline power (power that is not subject to interruption), hydroelectric and coal are the least expensive energy sources when measured by private costs.

However, these private costs do not take into account the significant external costs stemming from many electricity sources. The sixth column shows the non-carbon external costs associated with different types of electricity sources, such as negative effects on health and the environment. Coal has high non-carbon external costs of 3.4¢ per kWh–roughly the same size as its private costs for existing capacity and more than 50 percent of its private costs for new capacity. The next column shows the costs associated with carbon emissions, assuming an SCC of $21.4 per ton (the preferred estimate of the Interagency Working Group on Social Cost of Carbon).

The final column shows the social costs, which is the sum of all private and external costs. The costs of several electricity sources increase dramatically when the full costs of production are included. For example, the social cost of existing coal plants is more than double the private cost (8.8¢ compared to 3.2¢); the social cost of new conventional coal plants is

roughly 83 percent higher than the private costs (11.5¢ compared to 6.2¢), making coal the most expensive new nonrenewable source of energy. Conversely, for many other electricity-producing technologies, such as hydro, nuclear, wind, and solar, the private costs make up the vast majority of the social costs.

Estimates of the costs of "intermittent" energy sources–wind and solar–must also be adjusted to reflect the fact that they cannot be compared directly to those of base-loading technologies: wind power plants produce power only when there is wind, and solar power plants produce power only when there is sunlight. Sunny and windy times of the day or year do not always correspond to times when demand for power is greatest. Consequently, these types of energy are less valuable even if the cost per kWh is the same as coal, natural gas, or other "dispatching" energy sources (sources that can be turned on and off to produce power when needed most). Similarly, cost estimates for "peaking" generation technologies, such as natural gas combustion turbines, overstate their costs because they are specifically designed to be used in times of very high demand for electricity.

To put these sources on comparable footing, we created hypothetical plants that include intermittent technologies paired with a peaking generation technology (natural gas combustion turbines) that could meet energy needs during periods when solar or wind power is unavailable. These estimates, which we label "Combined Peaking and Intermittent" in Table 1, suggest that some versions of these combined plants could be competitive with many existing technologies if the full social costs of energy production were taken into account. For example, the combined wind/combustion turbine power plant would have social costs almost 2¢ per kWh less than that of new coal capacity. However, this combined wind/combustion turbine technology would still have significantly higher social costs than many other options, including new conventional

natural gas power plants and existing coal power plants. Furthermore, the wind and solar estimates are based on siting plants in optimal locations for harvesting these energy sources; the cost estimates would be higher, potentially significantly so, in other locations.

Figure 5 summarizes several of the most important electricity sources from Table 1. These sources are shown in order of their private costs. The private costs are in black, the non-carbon external costs (mostly health costs) are black-and-white checkered, and carbon costs due to climate change are in light gray. The dramatic differences in the private and social costs of different energy sources illustrate how the low-private-cost energy sources we rely on often come with high external costs.

[Insert Figure 5- The Private, External and Social Costs of Electricity Generation]

When private costs alone are considered, existing coal power plants appear to be a great deal. These plants account for roughly 45 percent of the electricity in the United States, and they do so at an average price of 3.2¢ per kWh. This appears to be a bargain, but the true costs are much higher–in fact, they are 170 percent higher. Each kWh of coal-generated electricity comes with an additional 5.6¢ per kWh of damages to our well-being, from a combined 3.4¢ per kWh of non-climate-change-related damages (primarily health-related) and 2.2¢ per kWh of climate-change-related damages. Although these costs are not listed on our monthly utility bills, they are nevertheless real. They show up in shorter life spans, higher health care bills, and a changing climate that poses risks to our way of life.

Figure 5 also reports on the costs of other electricity sources. Electricity from new coal plants is more expensive than from existing plants, largely due to the capital costs of building the plant; however, because new plants are slightly cleaner, external costs are modestly lower. Once

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the full costs of all energy sources are accounted for, natural gas power plants are among the least expensive electricity sources. This outcome reflects the low prices of natural gas due to the recent dramatic increase in reserves and the fact that the health and environmental costs associated with natural gas are lower than for other fossil fuels. (At the time of writing, the environmental costs associated with the extraction of natural gas through 'fracking' are largely unknown and could increase the social costs of natural gas use.)

For vehicles and transportation, the story is similar. From sticker prices on new cars to the price at the pump, the private costs of transportation are readily apparent to most Americans. The private costs to purchase, maintain, and fuel the average car add up to about $0.51 per vehicle mile traveled over the car's lifetime.[35] But cars, trucks, and other vehicles also impose costs by polluting the air, emitting greenhouse gases, contributing to traffic on busy roads, and through injuries and deaths from car crashes.[36] These external costs amount to more than $0.10 per vehicle mile traveled, or roughly $16,000 for a car that is driven 150,000 miles[37]–which represents more than 20 percent of the car's lifetime private costs.

An additional consequence of the costs in Table 1 is that industry and consumers have little incentive to change their energy preferences based on comparison of direct costs. This is because coal and gasoline are comparatively inexpensive when only their private costs are considered.

In addition to the private and external costs of these energy sources, policies to influence energy production also consume significant fiscal resources. Table 2 details the many subsidies

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[35] Internal Revenue Service, "2011 Standard Mileage Rates," Notice 2010-88, 2010.
[36] Ian W.H. Parry and Kenneth A. Small, "Does Britain or the United States Have the Right Gasoline Tax?" *American Economic Review* 95 (4) (2005): 1276–1289.
[37] Ian W.H. Parry, Margaret Walls, and Winston Harrington, "Automobile Externalities and Policies," Discussion Paper 06-26 (rev. ed.), Resources for the Future, January 2007, http://www.rff.org/documents/RFF-DP-06-26-REV.pdf.

and financial incentives for different types of energy production provided by federal, state, and local governments. The higher cost per kWh for some sources is frequently justified as the result of efforts to jump-start innovations that are necessary to lower costs.

[Insert Table 2 - Federal Energy Subsidies]

Other government programs also give a boost to preferred energy sources. Liability for nuclear disasters is capped at $12.6 billion, and oil companies' responsibility for spills is capped at $350 million for onshore facilities and $75 million for offshore facilities.[38] Thus, these energy producers are protected from the risks they impose on society, liabilities that other businesses are required to shoulder.[39] Additionally, federal and state legislation has granted a host of subsidies for ethanol production and use, including a tax credit equal to $0.45 per gallon for blending ethanol with other fuels and a variety of other standards that require the use of ethanol.[40] These subsidies impose a substantial fiscal cost on taxpayers while creating market distortions.

Efforts to address the environmental, health, and climate-related effects of our current energy sources are often derided as too costly. But Table 1 emphasizes that many current energy sources are already more costly than perceived; those costs are simply more diffuse and less salient because they indirectly impact health, economic activity, the environment, and national

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[38] Environmental Protection Agency, "Oil Pollution Act Overview," http://www.epa.gov/oem/content/lawsregs/opaover.htm; Nuclear Regulatory Commission, Office of Public Affairs, "Fact Sheet on Nuclear Insurance and Disaster Relief Funds," August 2010, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/funds-fs.pdf.

[39] Michael Greenstone, "The Benefits of Cap-and-Trade Would Have Exceeded Its Costs," Up Front blog, The Hamilton Project, Brookings Institution, July 2010, http://www.brookings.edu/opinions/2010/0730_climate_change_greenstone.aspx.

[40] Department of Energy, "Volumetric Ethanol Excise Tax Credit (VEETC)," http://www.afdc.energy.gov/afdc/laws/law/US/399; Environmental Protection Agency, Office of Transportation and Air Quality, "EPA Finalizes 2011 Renewable Fuel Standards," November 2010, http://www.epa.gov/otaq/fuels/renewablefuels/420f10056.pdf; John Collins Rudolf, "End Ethanol Subsidies, Senators Say," *The New York Times*, November 30, 2010, http://green.blogs.nytimes.com/2010/11/30/end-ethanol-subsidies-senators-say/.

security. Although there are undoubtedly costs associated with moving to energy sources that require higher private outlays, the introduction of policies that cause producers of all energy sources to recognize the full social (i.e. private *plus* external) costs will level the playing field and improve our well-being.

For example, EPA analyses indicate that the benefits of recently proposed policies to address climate change would have exceeded their costs. The analyses suggest cumulative domestic costs of a cap-and-trade bill at $600 billion to $1 trillion through 2050.[41] But the global cumulative benefits of the emissions reductions produced by enacting a cap-and-trade system would be approximately $1.5 trillion to $1.7 trillion over the same period, indicating that the benefits would have been much larger than the costs. Although a substantial proportion of these benefits would accrue outside the United States, many believe that the adoption of such a carbon policy would lead other countries to implement similar policies to reduce carbon emissions that would produce substantial benefits for the United States.

* * *

Reforming Energy Policy. Energy consumption is critical to economic growth and quality of life. America's energy system, however, is malfunctioning. The status quo is characterized by a tilted playing field, where energy choices are based on the visible costs that appear on utility bills and at the gas pump. This system masks the external costs arising from those energy choices, including shorter lives, higher health care expenses, a changing climate, and weakened national security. As a result, society pays unnecessarily high costs for energy.

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[41] Greenstone, "The Benefits of Cap-and-Trade Would Have Exceeded Its Costs."

New "rules of the road" could level the energy playing field. Drawing from our work for The Hamilton Project, we offer the following principles for reforming U.S. energy policies in order to increase Americans' well-being:

1. *Appropriately price the external costs of energy production and use.* Fossil fuels such as coal, oil, and natural gas have costs beyond what users pay to the utility company or at the gas pump. These costs–ranging from increases in lung disease and infant mortality to problems associated with climate change–have been quantified and can be expressed in dollar terms. As argued in the Hamilton Project paper "An Economic Strategy to Address Climate Change and Promote Energy Security"[42] and elsewhere, the best approach is to price these costs directly, through cap and trade or tax policies. If firms and consumers faced the full cost of their energy use, they would have a greater incentive to make more-informed and socially efficient decisions about energy consumption.

2. *Fund basic research development and demonstration.* Many believe that technological innovations are the solution to finding cleaner low-cost energy sources–in other words, that we will innovate our way out of our energy and climate change problems. Unfortunately, there is little incentive for the private sector to undertake either basic research or technology demonstration projects that are good for society because they may not offer the promise of a profitable private return. One impediment is the lack of a clear price signal that provides the right incentive for innovation. A second impediment is the fact that the fruits of basic research and demonstration investments–ideas and methods, as well as information about the commercial viability of these innovations–are hard to capture as they are easily shared among competitors.

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[42] Jason Furman, Jason Bordoff, Manasi A. Deshpande, and Pascal Noel, "An Economic Strategy to Address Climate Change and Promote Energy Security," The Hamilton Project strategy paper, Brookings Institution, October 2007, http://www.brookings.edu/~/media/Files/rc/papers/2007/10climatechange_furman/10_climatechange_furman.pdf.

This impediment would exist even in the presence of cap and trade or a tax based on carbon's social costs. This creates a critical role for government research to provide funding and support for the types of basic research that could help facilitate the creation of low-cost, clean energy sources.
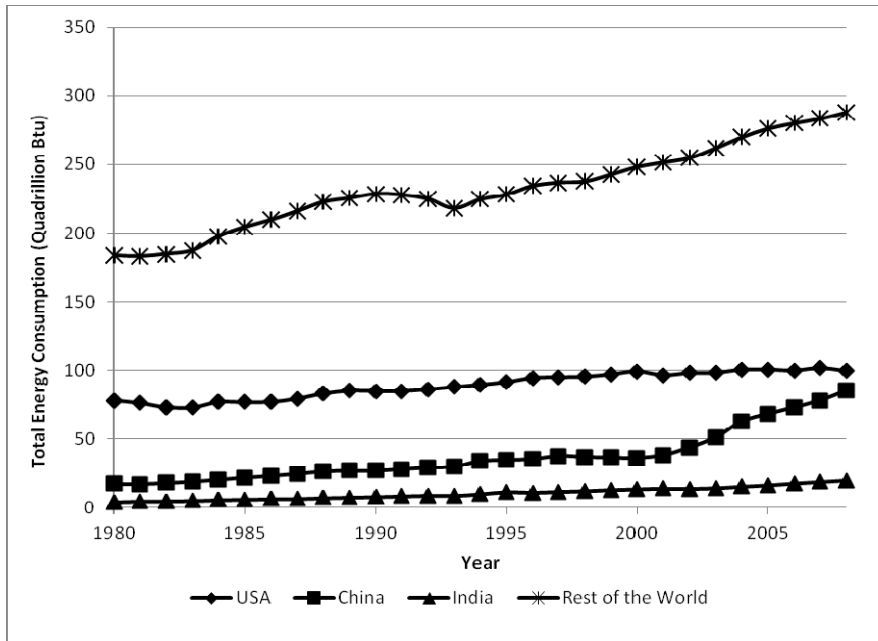
3. *Make regulations more efficient.* Regulation has played, and will continue to play, a significant role in addressing the environmental and health consequences of energy consumption. The current process for promulgating regulations needs to be updated to promote rules that are more efficient and cost-effective. By requiring cost-benefit analysis to evaluate the potential impact of regulations and by assessing the reliability of empirical studies that are used to complete that analysis, we can greatly enhance the effectiveness and reputation of our environmental regulatory system. Furthermore, to ensure their ongoing value, an independent, automatic retrospective review of economically significant regulations is critical. If these reviews find that the costs exceed the benefits, then the regulations should be amended or removed. Finally, genuine reform may involve rethinking and potentially eliminating regulations that become superfluous or counterproductive after energy sources are priced.

4. *Address climate change on a global scale.* Climate change is distinct from many environmental and energy-related issues in that it is global in scope and requires a global effort to address. Although the United States is a leading emitter today, in the future the bulk of emissions growth will come from developing countries. From a pragmatic standpoint, this means that any viable effort to address climate change must involve a coordinated approach by many countries. Negotiations have been complicated, however, and there are smaller steps that can be taken immediately to start down the path toward a global solution. This effort can begin today with a number of measures such as building the capability to monitor total net emissions at the

country level (this could be a building block for a trading system) through a combination of satellite- and land-based measurement systems. This would provide evidence of carbon emissions by countries and eliminate issues surrounding the accuracy of reporting, which has been a stumbling block in international negotiations.
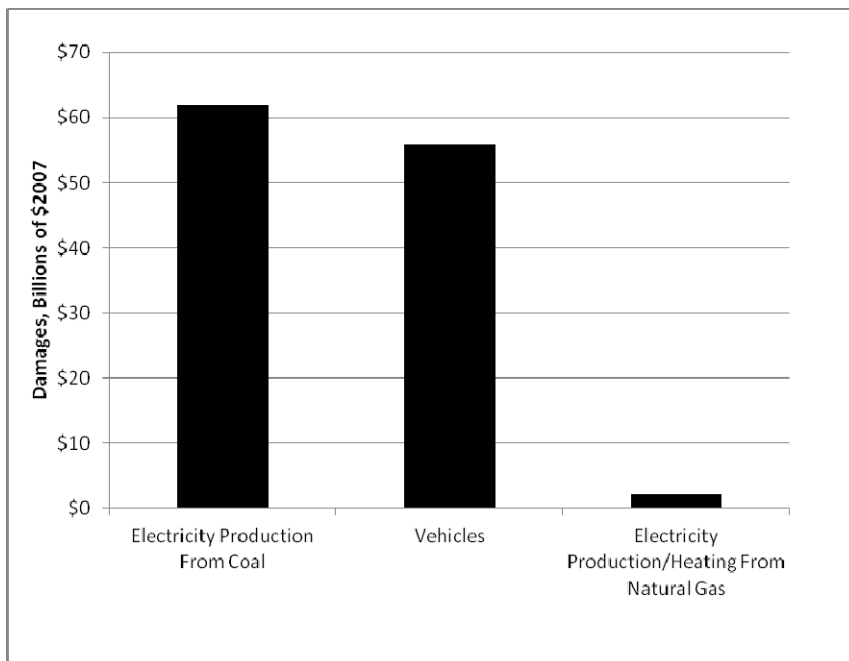
A fundamental change in our energy policy will not be easy and will come with costs, with some industries and regions in the U.S. economy being more affected than others. This is because U.S. households and businesses have made decisions based on the expectation of access to energy sources with relatively low private costs. One solution is to offer compensation to those that are harmed. On net, however, the recognition of the full costs of our energy choices would deliver a future of healthier and longer lives, an improved environment, and greater national security.

Figure 1. World Energy Consumption by Country, 1980 to 2008

Source: Energy Information Administration, International Energy Statistics Database, November 2009, http://www.eia.gov/emeu/international.
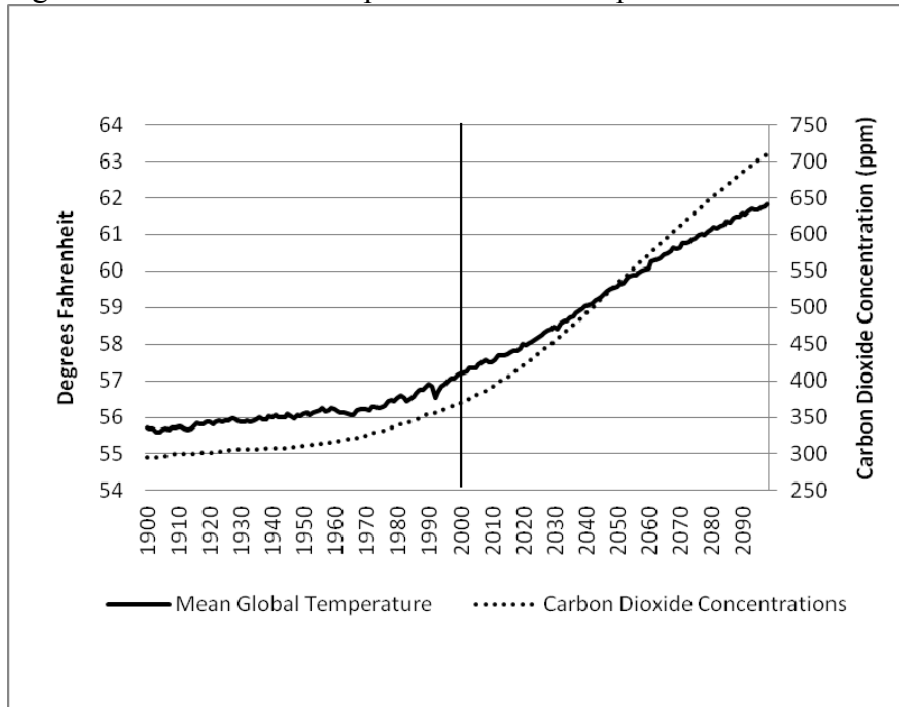
Figure 2. Main Sources of Non-Climate-Change-Related Damages, in 2005

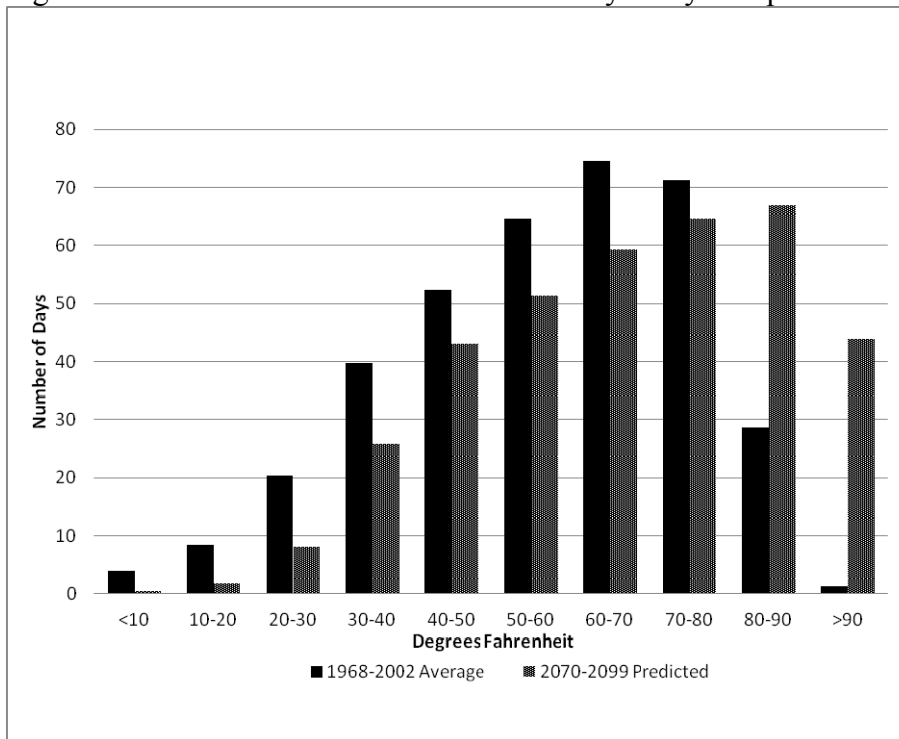Vehicle costs refer to the total life-cycle costs of producing and operating.
Source: National Academy of Sciences, *Hidden Costs of Energy* (Washington, D.C.: National Academies Press, 2010).

Figure 3. Mean Global Temperature and Atmospheric CO_2 Concentrations, 1900 to 2099

Multimodel average temperature; SRES A1B scenario. Source: KNMI Climate Explorer, http://climexp.knmi.nl/.

Figure 4. Current and Predicted End-of-Century Daily Temperatures

Hadley 3-A1Fl predictions, error corrected. Source: Olivier Deschenes and Michael Greenstone, "Climate Change, Mortality, and Adaptation."

Figure 5. The Private, External and Social Costs of Electricity Generation

*The non-carbon external costs of nuclear power, including the risk of serious accidents, have not been quantified for this figure. Non-carbon external costs include only damages associated with operating the plant, not "upstream" costs from mining, drilling, and extraction of fuels (including any environmental costs associated with fracking), or from plant construction. Sources: See notes for Table 1.

Table 1. The Private, External and Social Costs of Electricity Generation

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Type	Technology	Capacity Factor[c] (percent)	Share of Current Generation[d] (percent)	Private Costs[ef] (¢/kWh)	Non-Carbon External Costs (¢/kWh)[i]	Carbon-External Costs[k] (¢/kWh)	Social Costs[m] (¢/kWh)
A. Existing Capacity[a]							
Fossil Fuels	*Existing Coal*	85	45	3.2	3.4	2.2	8.8
	Existing Natural Gas	87	24	4.9	0.2	1.0	6.0
Other Traditional	*Existing Nuclear*	90	20	2.2	Unable to Quantify	≈0	2.2
B. New Capacity[b]							
Base-Loading Technologies							
Fossil Fuels	*Coal (Dual Unit Advanced PC)*	85		6.2	3.4	1.9	11.5
	Natural Gas (Conventional Combined Cycle)	87		5.5	0.2	0.8	6.5
Other Traditional	*Nuclear (PWR)*	90		8.2-10.5[g]	Unable to Quantify	≈0	8.2-10.5
	Hydro	52		6.4	Unable to Quantify	≈0	6.4
Renewables	*Geothermal*	92		8.3	Unable to Quantify	0.1	8.4
	Biomass	83		9.5	Unable to Quantify	0.0-2.7[l]	9.5-12.1
Combined Peaking and Intermittent	*Wind (Onshore) backed up with Natural Gas Combustion Turbine*	85		8.9	0.1	0.8	9.7
	Solar (PV) backed up with Natural Gas Combustion Turbine	85		12.2	0.1	0.9	13.2
Peaking Generating Technologies							
Modified Traditional	*Natural Gas (Conventional Combustion Turbine)*	30		10.8	0.2	1.3	12.2
Intermittent Generating Technologies							
Renewables	*Wind (Onshore)*	34		8.0[h]	Unable to Quantify	≈0	8.0
	Wind (Offshore)	34		19.1[h]	Unable to Quantify	≈0	19.1
	Solar (PV)	25		19.5[h]	Unable to Quantify	≈0	19.5
	Solar (Thermal)	18		29.7[h]	Unable to Quantify	≈0	29.7

Notes and Sources for Table 1:

All dollar figures are in 2010 U.S. Dollars (USD). Values not originally reported in 2010 USD are inflated using the Consumer Price Index. A technical appendix (available on request) includes a full description of the methodology and assumptions used to generate these estimates. Cost figures may not sum due to rounding. PC stands for pulverized coal, PV for photovoltaic, and PWR for pressurized water reactor.

Sources: Authors' calculations; Yangbo Du and John E. Parsons, "Update on the Costs of Nuclear Power," Working Paper 09-004, MIT Center for Energy and Environmental Policy Research, May 2009, http://web.mit.edu/mitei/docs/spotlights/nuclear-fuel-cycle-du.pdf; Energy Information Administration, *Annual Energy Outlook 2011* (Washington, D.C.: Department of Energy, April 2011), http://www.eia.gov/forecasts/aeo/.; Energy Information Administration, "Updated Capital Costs for Electricity Generating Plants," November 2010, http://www.eia.gov/oiaf/beck_plantcosts/pdf/updatedplantcosts.pdf; Energy Information Administration, "Consumption Price and Expenditure Estimates, State Energy Data System (SEDS)," June 2010, Table S6a, http://www.eia.gov/states/hf.jsp?incfile=sep_sum/plain_html/sum_pr_eu.html; Energy Information Administration, "Levelized Cost of New Generation Resources in the *Annual Energy Outlook 2011*," 2010, http://www.eia.doe.gov/oiaf/aeo/electricity_generation.html; Energy Information Administration, "Monthly Energy Review," April 2011, Table 7.2a, "Electricity Net Generation: Total (All Sectors)," http://www.eia.doe.gov/totalenergy/data/monthly/query/mer_data.asp?table=T07.02; Energy Information Administration, "Electric Power Annual," April 2011 (rev.), Table 5.3, http://www.eia.doe.gov/cneaf/electricity/epa/epat5p3.html; Energy Information Administration, "Electric Power Monthly," April 2011, Tables 4.10.A and 4.13.A, http://www.eia.doe.gov/electricity/data.cfm#avgcost; Energy Information Administration, "Updates by Energy Source, State Energy Data System (SEDS)," April 2011, Table F23, http://www.eia.gov/states/hf.jsp?incfile=sep_fuel/html/fuel_nu.html; Interagency Working Group on Social Cost of Carbon, "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," February 2010, http://www.epa.gov/oms/climate/regulations/scc-tsd.pdf; Internal Revenue Service, "How to Depreciate Property," Publication 946, Cat. No. 13081F, 2011; National Academy of Sciences, *Hidden Costs of Energy* (Washington, D.C.: National Academies Press, 2010).

a. Estimates for existing coal, natural gas, and nuclear facilities assume the same fuel costs and capacity factors as the new coal dual unit advanced PC, the new natural gas conventional combined cycle, and the new nuclear (PWR) plants, respectively. Existing plants are assumed to have two-thirds the operating, management, and maintenance costs of the corresponding new plants to reflect the fact that existing plants, on average, are subject to less stringent environmental standards and use older technologies. Existing plants are assumed to have fully depreciated all initial capital costs. To account for the fact that existing plants are, on average, less efficient than new plants, we use the estimated heat rates for existing plants in 2009 from Energy Information Administration, "Electric Power Annual," April 2011 (rev.), Table 5.3, http://www.eia.doe.gov/cneaf/electricity/epa/epat5p3.html. The heat rates are 10,461 Btu/kWh for coal, 8,160 Btu/kWh for natural gas, and 10,460 Btu/kWh for nuclear.
b. These estimates do not include experimental technologies such as plants with carbon capture and sequestration or integrated gasification combined-cycle plants.
c. Source: Energy Information Administration, "Levelized Cost of New Generation Resources in the *Annual Energy Outlook 2011*," 2011, http://www.eia.doe.gov/oiaf/aeo/electricity_generation.html.
d. Source: Energy Information Administration, "Monthly Energy Review," April 2011, Table 7.2a, "Electricity Net Generation: Total (All Sectors)," http://www.eia.doe.gov/totalenergy/data/monthly/query/mer_data.asp?table=T07.02.
e. Private cost estimates for new capacity are levelized costs: they reflect the present discounted value of the total cost of constructing, maintaining, and operating an electricity-generating plant over its entire lifetime and are expressed in terms of real cents per kWh.
f. Authors' estimates based on a model developed by Yangbo Du and John E. Parsons, "Update on the Costs of Nuclear Power," Working Paper 09-004, MIT Center for Energy and Environmental Policy Research, May 2009, http://web.mit.edu/mitei/docs/spotlights/nuclear-fuel-cycle-du.pdf. Most cost inputs for new capacity, including overnight capital costs, operation and management costs, and heat rates, come from Energy Information Administration, "Updated Capital Costs for Electricity Generating Plants," November 2010, http://www.eia.gov/oiaf/beck_plantcosts/pdf/updatedplantcosts.pdf. Fuel price estimates for coal and natural gas come from Energy Information Administration, "Electric Power Monthly," April

2011, Tables 4.10.A and 4.13.A, http://www.eia.doe.gov/electricity/data.cfm#avgcost; those for nuclear power come from Energy Information Administration, "Updates by Energy Source, State Energy Data System (SEDS)," April 2011, Table F23, http://www.eia.gov/states/hf.jsp?incfile=sep_fuel/html/fuel_nu.html; and those for biomass come from Energy Information Administration, "Consumption Price and Expenditure Estimates, State Energy Data System (SEDS)," June 2010, Table S6a, http://www.eia.gov/states/hf.jsp?incfile=sep_sum/plain_html/sum_pr_eu.html. All plants are assumed to have identical forty-year lifetimes. Estimates for new capacity refer to plants coming online in 2017 to compensate for the significant lead time required to construct many types of new plants.

g. Range reflects alternative financing costs. The low end of the range assumes a weighted average cost of capital of 7.8 percent (the same assumption for all other technologies), while the high end of the range assumes a weighted average cost of capital of 10 percent. This approach follows *The Future of Nuclear Power: An Interdisciplinary MIT Study* (Cambridge, Mass.: Massachusetts Institute of Technology, 2003), http://web.mit.edu/nuclearpower/; and Du and Parsons, "Update on the Costs of Nuclear Power." The capital cost estimates from Energy Information Administration, "Updated Capital Costs for Electricity Generating Plants" assume that the nuclear plant is built in a brownfield site; greenfield sites may be more expensive.

h. Estimates for wind and solar are based on current market costs, which have been declining due to advances in technology. Some analysts argue that improved technology will substantially reduce the price of wind and solar power. For example, if overnight capital costs of solar PV were reduced to $2,000/kW, levelized costs for solar PV would drop to 8.6¢/kWh.

i. Source: National Academy of Sciences, *Hidden Costs of Energy*, 92 (coal) and 118 (natural gas). The NAS estimates the monetized costs resulting from emissions of SO_2, NO_x, and PM2.5 and PM10 (two forms of particulate matter) from existing natural gas and coal power plants, assuming a value of a statistical life of $6 million (in 2000 USD). These estimates do not include external costs other than from those four air pollutants, nor do they include "upstream" costs resulting from mining, drilling, construction, and other activities not directly associated with electricity generation. While it is likely that new plants are more efficient, the assumption that both existing and new plants have the same external costs reflects the fact that both existing and new plants are included under the same SO_2 and NO_x cap-and-trade cap.

j. Reliable estimates of the non-carbon external costs are unavailable for many electricity-generation technologies, even for technologies like nuclear or hydroelectric, which have demonstrable environmental or health costs. We label non-carbon external costs of these technologies "Unable to Quantify."

k. Source: For tons of CO_2/Btu or tons of CO_2/MWh (megawatt hour), see Energy Information Administration, "Updated Capital Costs for Electricity Generating Plants"; for external costs of carbon at $22.5/ton of CO_2 (2010 USD), see the Interagency Working Group on Social Cost of Carbon, "Technical Support Document."

l. The range of carbon emissions estimates reflects uncertainty regarding the source of biomass fuel materials.

m. Intermittent energy sources, such as wind and solar, produce power only during periods of sufficient wind and sunlight. The costs in this table do not attempt to monetize the reduction in value that this intermittency imposes on energy users. On an adjusted basis, wind and solar would be more costly. Conversely, peaking generating technologies, such as natural gas combustion turbines, are used only during periods of fluctuating high demand, and thus appear expensive in this comparison. For a more detailed discussion, see Paul Joskow, "Comparing the Costs of Intermittent and Dispatchable Electricity Generating Technologies," CEEPR Working Paper, MIT Center for Energy and Environmental Policy Research, September 2010, http://econ-www.mit.edu/files/6317. In an attempt to define a more appropriate comparison of wind and solar to other base-loading technologies, "Combined Peaking and Intermittent" presents estimates of hybrid wind and solar PV facilities that are backed up by natural gas combustion turbines during periods of intermittency. These hypothetical plants assume that a renewable source is paired with a natural gas combustion turbine of sufficient capacity such that the turbine could fully substitute for the renewable source if it produced no output during some time periods. The average capacity factor of the paired natural gas combustion turbine is chosen such that the average capacity factor for the combined plant is equal to 85 percent (roughly the capacity factor for traditional coal and natural gas combined-cycle plants).

Table 2. Federal Energy Subsidies

Type	FY 2007 Net Generation (billion KWh)	Federal Subsidy and Support Value 2007 (million dollars)
Coal	1,946	854
Refined Coal	72	2,156
Natural Gas and Petroleum Liquids	919	227
Nuclear	794	1,267
Biomass (and biofuels)	40	36
Geothermal	15	14
Hydroelectric	258	174
Solar	1	14
Wind	31	724
Landfill Gas	6	8
Municipal Solid Waste	9	1

Source: Energy Information Administration, "Federal Financial Interventions and Subsidies in Energy Markets: 2007," April 2008, Table 35, http://www.eia.doe.gov/oiaf/servicerpt/subsidy2/.