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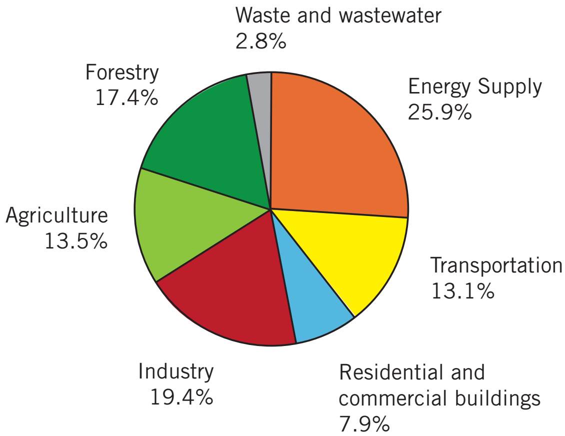
CLIMATE CHANGE 101
Technological Solutions

Achieving the very large reduction in greenhouse gas emissions that scientists say is needed to avoid the worst effects of climate change will not be easy. It will require action across all sectors of the economy, from electricity and transportation to agriculture. Cost-effective opportunities exist today for starting the world on a path toward lower emissions—and there are a number of emerging technologies that hold enormous promise for delivering substantial emission reductions in the future. The successful development of these technologies will require investments in research, incentives for producers and consumers, and emission reduction requirements that drive innovation and guide investments. Governments at all levels need to encourage short-term action to reduce emissions while laying the groundwork for a longer-term technology revolution.

THE DAWNING OF A REVOLUTION

The man-made greenhouse gas (GHG) emissions that are causing global warming come from a wide range of sources, including cars and trucks, power plants, factories, farms, and more (see Figure 1). Because there are so many sources of these gases, there are also many options for reducing emissions, including such readily available steps as improving energy efficiency and changing industrial processes and agricultural practices. However, seriously addressing global climate change will require a decades-long commitment to develop and deploy new, low-carbon technologies around the world. Most importantly, the world needs to fundamentally change the way it produces and consumes energy. The global population is rising fast; in developing and developed countries alike, population and income growth means more people are using more energy, driving more cars and trucks, building more homes, and producing more goods and services. Without a revolution in energy technology, human societies will be pumping ever-increasing amounts of greenhouse gases into the atmosphere. The result will be

Figure 1
Global Emissions by Sector in 2004



Source: *Climate Change 2007: Mitigation.* Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

PEW CENTER ON Global CLIMATE CHANGE — THE PEW CENTER ON THE STATES

This brief is part of a series called *Climate Change 101: Understanding and Responding to Global Climate Change*, published by the Pew Center on Global Climate Change and the Pew Center on the States.

potentially damaging effects from global climate change. To avert these dangerous levels of global warming, the time to begin making the necessary investments in new technologies is right now. Achieving substantial reductions in greenhouse gas emissions is possible—now and in the decades to come. Some emission-reducing technologies (such as hybrid gas-electric cars and wind power) are commercially competitive today. Others (such as plug-in hybrid cars and carbon capture and storage) are being explored. Moreover, a wide range of cutting-edge technologies in early stages of development or technologies that have yet to be invented may provide significant emission reductions in the future.

Right now, the true costs of greenhouse gas emissions are not reflected in the marketplace, meaning there is little incentive for producers or consumers to reduce their contribution to the climate problem. Policies, such as "cap and trade," that send a clear price signal to the market by putting a financial cost on greenhouse gas emissions will make many low-carbon technologies commercially competitive with traditional greenhouse gas-emitting technologies.[1] Moreover, putting a price on carbon would spur companies to invest in developing new low-carbon technologies. Government incentives for consumers and businesses to purchase these technologies can help them enter the mainstream and contribute to substantial reductions in emissions. Governments, however, will also need to invest in research to develop advanced technologies for the future.

Opponents of strong action to address climate change often focus on the economic costs of reducing emissions, but the cost of inaction is even greater.[2] In addition, a global technology revolution will create economic opportunities for businesses and workers, as well as the localities, states, and nations that successfully position themselves as centers of innovation and technology development for a low-carbon world.[3] Even in the absence of national climate change legislation in the United States, private sector investments in clean energy technologies have surged in recent years. From 2003 to 2007, venture capital investments in U.S.-based clean energy technology companies grew an average of 56 percent per year.[4]

LOOKING AT THE KEY TECHNOLOGIES

There is no single, silver-bullet technology that will deliver the reductions in emissions that are needed to protect society from dangerous climate change. Success will require a portfolio of technologies, many of which are available today. Looking across key sectors of the economy, it is possible to identify those technologies that may help the most while currently unknown innovations may also contribute to emission reductions in the future. As shown in Figures 2 and 3, most greenhouse gas emissions in the United States can be traced to the electricity, buildings, and transportation sectors. The following pages look at technology options for reducing emissions from each of these critical sectors.

Figure 2

U.S. GHG Emissions by Sector in 2006

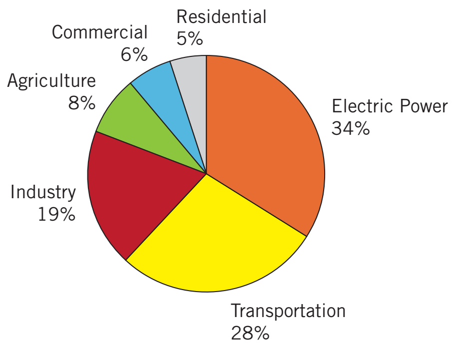
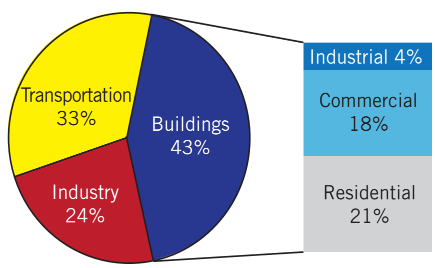


Figure 3

CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector, 2006



Sources: U.S. EPA, 2008. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006;* Pew Center on Global Climate Change, *Towards a Climate-Friendly Built Environment;* U.S. Department of Energy, "Manufacturing Energy Footprint."[5]

ELECTRICITY AND BUILDINGS

In 2006, the electricity sector produced 34 percent of U.S. GHG emissions, primarily carbon dioxide from fossil fuel combustion. Most of the electricity generated by the sector is used in the nation's homes, offices and industrial structures to power everything from heating and cooling systems to lights, computers, refrigerators, and cell phones. Electricity use is not the only way in which buildings contribute to climate change. Non-electrical energy sources such as natural gas furnaces also produce greenhouse gases. Because they make such a significant contribution to the problem, the electricity and building sectors also can play a crucial role in solutions to climate change. Reducing emissions from these closely related sectors requires looking at both electric power generation and energy-efficiency options. In other words, it is important to think about the roles of both the producers and the consumers of power.

Electric Power Options. Greenhouse gas emissions from the electric power sector come primarily from power plants burning coal or natural gas. Options for reducing these emissions include:

> **Success will require a portfolio of technologies, many of which are available today.**

- ***Improved Efficiency.*** Technologies are available today to produce electric power and heat more efficiently using both fossil fuels and renewable energy. State-of-the-art natural gas- and coal-fueled power plants produce electricity much more efficiently than do older plants and thus emit fewer greenhouse gases per unit of electricity generated.

- ***Renewable Energy.*** Renewable energy harnesses the power of the wind, the sun, water, tides, heat from deep inside the earth, and other sources to produce electric power. Biomass, such as agricultural residues and energy crops, can be used to generate electricity and heat when combusted alone or co-fired with coal. Renewables offer the potential to generate electricity without producing greenhouse gases—or producing very little when compared to traditional energy sources. Most renewable resources can be harnessed on a large-scale basis (for example, via wind farms or large geothermal fields) or in more "distributed" forms (for example, by placing solar panels on rooftops). Although larger-scale renewable energy can be cost-competitive with other forms of conventional electricity in some cases, renewables still account for only a very small share of overall electricity generation in the United States.[6] Options for expanding the use of renewables include: Renewable Portfolio Standards, which require generators to produce a specified share of power from renewable sources; tax credits for renewable energy investments or generation; consumer rebates and other government incentives; greenhouse gas emissions standards for power generators; policies that put a price on greenhouse gas emissions, such as cap and trade; and government support for research and development to advance renewable energy technologies and lower their costs.[7]

- ***Carbon Capture and Storage (CCS).*** While not yet commercially available, a suite of technologies exists that allows for carbon dioxide from the combustion or gasification of coal and other fossil fuels to be captured rather than released to the atmosphere. Once captured, carbon dioxide from fossil fuel use can be injected into and stored long-term (i.e., for thousands of years) in underground geological formations. Because CCS requires expensive equipment and infrastructure to capture, transport, and store carbon dioxide, it is most cost-effectively applied to large stationary sources of carbon dioxide, such as coal-fueled power plants. Around the world, several small-scale CCS demonstration projects are underway and larger projects are planned.[8] However, government incentives are required to spur investments in large-scale CCS projects that can fully demonstrate the technologies and reduce their cost. CCS could prove to be a major source of greenhouse gas emission reductions; modeling done by the International Energy Agency (IEA) forecasts that CCS could provide 20 percent of total global GHG emission reductions in 2050 under a global climate agreement.[9]

- ***Nuclear Power.*** Nuclear power currently provides roughly 20 percent of U.S. electricity with virtually no associated greenhouse gas emissions. Yet, for nuclear power to play a more prominent role in U.S. efforts to address climate change, the industry needs to overcome several important hurdles. These include concerns about the cost of nuclear-generated electricity; technical, political, and environmental concerns about nuclear waste disposal; and risks associated with nuclear arms proliferation. No new nuclear plant has been ordered and constructed in the United States since 1973, although there is currently a surge in interest in new nuclear plants with groups of companies pursuing applications for new plants.[10,11]

Options for Buildings. Greenhouse gas emissions attributed to the buildings sector include both the emissions generated by power plants to supply the electricity used in buildings and emissions from the combustion of fossil fuels in buildings, such as natural gas for space and water heating. People consume electricity in buildings for a variety of end uses, including lighting, space heating and cooling, running appliances, and powering electronics. Households and businesses already have many cost-effective options for reducing building energy use and thus greenhouse gas emissions, but consumers often fail to invest in even those options that would save them money. The reasons people do not take advantage of more cost- and energy-saving measures include lack of information and misaligned incentives (e.g., between building owners and tenants).[12] Because of inefficiencies in the generation and distribution of electricity to consumers, reductions in demand by energy users result in even larger energy savings by the generators. For the same reasons, on-site power generation can also lead to emission reductions by avoiding losses of electricity in the transmission and distribution system.

- ***Efficiency.*** There are many ways to increase the overall energy efficiency of buildings. From more efficient lighting and instantaneous hot water heaters to EnergyStar®-certified products and better insulation, consumers and businesses have an array of cost-effective options for limiting their energy use and boosting efficiency.[13] However, consumers often do not take advantage of these options on their own, even when energy efficiency investments would save them money. Policymakers can help promote greater energy efficiency through enhanced building codes; building standards, awards, or certifications to buildings that are energy-efficient; financial incentives for efficient appliances; publicly funded utility efficiency programs; regulatory reforms that reduce barriers to investment in energy efficiency such as decoupling utilities' profits from their sales of electricity and natural gas; appliance standards and labeling; and other steps.

- ***On-site Power Generation.*** Greenhouse gas emissions from the electricity and building sectors also can be reduced through on-site power generation using renewables and other climate-friendly energy resources. Examples include rooftop solar panels, solar water heating, small-scale wind generation, stationary fuel cells powered by natural gas or renewable hydrogen, and geothermal heat-pumps. While the costs for all of these options are falling, some of the technologies remain fairly expensive and thus are not widely used in the marketplace. Expanding their use—which will ultimately reduce costs—may require new incentive programs such as consumer rebates and tax credits. Building standards (such as LEED™–certification) also can help.[14] In addition, combined heat-and-power (or cogeneration) plants, rather than wasting the excess heat generated in the course of producing electricity, capture it for use in heating homes and industrial sites. Policymakers should eliminate regulatory barriers that hinder deployment of on-site generation technologies.

A Key Role for Agriculture

Emissions from agriculture account for approximately 8 percent of U.S. greenhouse gas emissions. Reducing these emissions can make an important contribution to the overall U.S. effort to address climate change. But agriculture can be a part of the solution in other ways as well. For example, less productive agricultural lands can be reforested with carbon dioxide-absorbing trees, and farming practices can be altered to absorb and retain carbon in agricultural soils. At moderate cost, these steps could offset up to 25 percent of current U.S. carbon-dioxide emissions.[15] In addition, biomass from agricultural sources (including corn and grasses) could be used to produce low-carbon biofuels for transportation or used as fuel for electricity generation. Many of the farming practices and land-use changes involved in achieving these reductions have multiple benefits, including improving soil, water, and air quality; increasing wildlife habitat; and providing additional recreational opportunities.

TRANSPORTATION

The transportation sector is the second largest source of greenhouse gas emissions in the United States, primarily from carbon dioxide produced by cars and trucks. The ways in which people and goods move from place to place are responsible for almost one-third of U.S. carbon dioxide emissions and about 13 percent of emissions around the world. Reducing greenhouse gas emissions from transportation can be accomplished in three main ways:

- Adopting new emissions-reducing technologies for cars and trucks;
- Reducing the carbon content of vehicle fuels; and
- Reducing the number of miles traveled.

Historically, it has proven very hard to get people to drive less. The way most Americans live today, cars and trucks are an essential part of their daily lives. There are ways to make Americans less automobile-dependent, such as mass transit, and new options such as car-sharing and smart growth are emerging. The challenge for lawmakers at all levels is to promote and encourage short-term solutions (for example, more hybrid cars and trucks) while facilitating a long-term transition to a low-carbon transportation sector.

To achieve significant reductions in U.S. greenhouse gas emissions, the United States needs to deploy technologies available in the short term and invest in R&D for long-term solutions.

Short-Term Options: Energy Efficiency, Fuel Blending, Advanced Diesels, and Hybrids. Significant reductions in greenhouse gas emissions from conventional cars and trucks are possible through the use of technologies that are commercially available today. Vehicle fuel economy can be improved by increasing the efficiency of the drivetrain (engine and transmission) and by decreasing the amount of energy needed to move the vehicle (through reducing weight, aerodynamic drag, and rolling resistance). One recent study found that available technologies could be deployed to double the average fuel economy of new U.S. cars and light trucks to 45 miles per gallon (mpg) by 2035.[16] In the United States, the Corporate Average Fuel Economy (CAFE) program has regulated light duty vehicle fuel economy for the last 30 years. In 2007, the Energy Independence and Security Act increased CAFE standards, which for passenger cars had been stagnant since 1988. The new standards require that new passenger cars and light trucks, on average, achieve a combined fuel economy of 35 mpg by 2020. California and 16 other states hope to implement even stricter GHG standards that would likely achieve 39 mpg by 2020. These policies can play a crucial role in hastening the rollout of technologies to reduce vehicle emissions.

Another option for reducing greenhouse gas emissions from cars and trucks in the short term is the blending of biofuels, such as ethanol and other biologically-derived fuels, with gasoline. Ethanol derived from corn is currently the dominant biofuel in the United States. Depending on how it is produced and processed, corn-based ethanol can yield reductions of as much as 30 percent in emissions for each gallon of regular gasoline that it replaces. Other biofuels that can be developed over the longer term promise to deliver significantly larger reductions (see below).

The use of advanced diesel and hybrid vehicle technologies also can yield emission reductions. Diesels and hybrids use different engines than the standard internal combustion engine; diesels also use different fuels. The key advantage of these technologies is that they both offer significant improvements in fuel economy. Because hybrid and diesel vehicles use less fuel on a per-mile basis, they produce fewer greenhouse gas emissions when compared to other cars and trucks. When both technologies are combined in a diesel hybrid vehicle, it can yield a 65 percent reduction in greenhouse gas emissions per mile.[17]

Longer-Term Options: Electricity, Biofuels, and Hydrogen. Ultimately, reducing greenhouse gas emissions from cars and trucks to a level where they pose a minimal risk to the climate will require a shift away from petroleum-based fuels. Among the most promising alternatives: running cars and trucks on electricity, next-generation biofuels, and hydrogen.

- ***Biofuels.*** As noted above, agricultural sources can be used to produce transportation fuel. While ethanol currently produced in the United States comes from corn, the technology exists to make biofuels from "cellulosic" sources (or the woody and leafy parts of plants). While corn-based ethanol can reduce emissions by as much as 30 percent for every gallon of traditional fuel replaced, cellulosic ethanol and sugar-cane-based ethanol may enable reductions of up to 100 percent.[18,19] (This is because the carbon dioxide released by combusting these biofuels is carbon dioxide that the feedstock plants had absorbed from the atmosphere.) Another biofuel option is biodiesel, which can be produced from a wide range of oilseed crops (such as soybeans or palm and cotton seeds) and can be used to replace diesel fuel. Biofuels have the technical potential to supply almost one-fifth of U.S. energy use, which could reduce current U.S. GHG emissions by 10 to 24 percent, depending on how the biofuels are produced.[20] With ethanol from sugar cane providing approximately 40 percent of its domestic passenger fuel in terms of energy, Brazil has shown that an aggressive policy push can help biofuels become a mainstream fuel choice.[21]

- ***Electric Cars.*** Before fully electric cars can become commercially viable, improvements in battery technology are needed. Another option is the "plug-in" hybrid, a gasoline-electric vehicle whose battery can be plugged into the electric grid to be charged. Even using the current U.S. mix of electricity sources to charge the vehicles, a plug-in hybrid with a 40-mile electric range would result in a CO_2 reduction of about 15 percent relative to a regular hybrid.[22]

- ***Hydrogen.*** Hydrogen fuel cells, long a staple of the U.S. space program, produce power by combining oxygen with hydrogen to create water. Technological advances and reductions in the costs associated with the use of fuel cells could lay the groundwork for a hydrogen-based transportation system in the decades to come.[23] However, a number of issues still need to be resolved before fuel cells can deliver on the promise of offering a "zero-emission" transportation solution. Among the pieces needed for a hydrogen-based transportation sector are: affordable hydrogen-powered vehicles, infrastructure for distributing hydrogen and fueling stations, and hydrogen production that does not emit greenhouse gases.[24,25]

GETTING IT DONE

To achieve significant reductions in U.S. greenhouse gas emissions, the United States needs to deploy technologies available in the short term and invest in R&D for long-term solutions. Three broad policy efforts would foster low-carbon technologies. First, government funding for R&D would support the development and improvement of a wide array of possible long-term technologies for greenhouse gas abatement. Second, a market-based climate policy, such as cap and trade, would put a price on greenhouse gas emissions. Doing so would spur companies to invest in innovation and deployment of low-carbon technologies. The competitive pressures of the market would drive companies to adopt and improve upon technologies fostered by government-funded and private-sector R&D efforts. Finally, complementary policies are needed to address barriers to the use of climate-friendly technologies.

Government at all levels needs to spur investments in new technologies—by making direct investments in research and development and creating and enhancing incentives for private investment. A cap-and-trade system requires emission reductions while allowing companies to trade emission credits so they can achieve their reductions as cost-effectively as possible. The most important benefit of such an approach is that it establishes a financial value for emission reductions, as well as a cost advantage for technologies that can achieve them. Coupled with government efforts to promote the development and deployment of new technologies, a cap-and-trade program holds the promise of encouraging climate solutions without threatening the competitiveness of U.S. industry.

In order to successfully reduce the threat of climate change, the United States and other nations will have to rely on a wide range of technologies over the next century. The exact portfolio of technologies that will be required to achieve the necessary emission reductions is not clear. What is clear, however, is that policies are needed to aid in the development of new technological solutions and to move many of these technologies into the marketplace. Given the national and global implications of climate change and efforts to address it, leadership from the federal government on these issues is crucial. At the same time, state and local leaders have jurisdiction over many relevant areas, such as transportation planning and electric utility regulation. These leaders will play a key role in the search for solutions, and in making sure that communities across the country can benefit from the technology revolution that is needed to deliver a low-carbon future.

FOR MORE INFORMATION

For more information on the issues discussed above, refer to these publications from the Pew Center on Global Climate Change:

Workshop Proceedings on The 10-50 Solution: Technologies and Policies for a Low-Carbon Future (2004)

Induced Technological Change and Climate Policy (2004)

U.S. Technology and Innovation Policies: Lessons for Climate Change (2003)

Towards a Climate-Friendly Built Environment (2005)

The U.S. Electric Power Sector and Climate Change Mitigation (2005)

Addressing Emissions from Coal Use in Power Generation (2008)

A Program to Accelerate the Deployment of CO_2 Capture and Storage: Rationale, Objectives, and Cost (2007)

Reducing Greenhouse Gas Emissions from the U.S. Transportation Sector (2003)

Comparison of Passenger Vehicle Fuel Economy and GHG Emission Standards Around the World (2004)

Biofuels for Transportation: A Climate Perspective (2008)

Agriculture's Role in Greenhouse Gas Mitigation (2006)

Pew Center on Global Climate Change

These reports are available at www.pewclimate.org.

ENDNOTES

1. For more information on cap and trade, see *Climate Change 101: Cap-and-Trade* at http://www.pewclimate.org/cap-trade.
2. See *Climate Change 101: The Science and Impacts* at http://www.pewclimate.org/global-warming-basics/climate_change_101.
3. See e.g., *Current and Potential Green Jobs in the U.S. Economy*, 2008, prepared by Global Insight for the U.S. Conference of Mayors.
4. CleanEdge. 2008. *Clean Energy Trends 2008*.
5. U.S. Department of Energy, "Manufacturing Energy Footprint," see http://www1.eere.energy.gov/industry/energy_systems/footprints.html.
6. The U.S. Energy Information Administration (EIA) reports that in 2006 renewable energy other than conventional hydropower accounted for 2.4% of U.S. net electricity generation.
7. See e.g., California Energy Commission, "Emerging Renewables Program," available at: http://www.energy.ca.gov/renewables/emerging_renewables/index.html.
8. See CO_2 capture and storage project fact sheets at http://sequestration.mit.edu/tools/projects/index.html.
9. Mandil, Claude. 2007. "The Role of CCS in Climate Change Mitigation." Presentation to IEA-CSLF Early Opportunities Workshop – Global Assessment. Oslo, Norway. June 21-22. See http://www.iea.org/CSLF_Workshop.pdf.
10. See http://www.nei.org and http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/com_reactors.pdf.
11. Wald, Matthew. 2008. "Nuclear Power May Be in Early Stages of a Revival." *The New York Times.* 23 October.
12. For an overview of barriers to energy efficiency, see the *National Action Plan for Energy Efficiency*, 2006, Chapter 1 p. 9, available at http://www.epa.gov/cleanrgy/energy-programs/napee/resources/action-plan.html.
13. EnergyStar is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy aimed at protecting the environment through energy-efficient products and practices. For more information, see www.energystar.gov.
14. The LEED (Leadership in Energy and Environmental Design) Green Building Rating System® is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. For more information, see http://www.usgbc.org.
15. Paustian, Keith, et al. 2006. *Agriculture's Role in Greenhouse Gas Mitigation*. Pew Center on Global Climate Change.
16. Cheah, Lynette et al. 2007. "Factor of Two: Halving the Fuel Consumption of New U.S. Automobiles by 2035." Massachusetts Institute of Technology Laboratory for Energy and the Environment.

17. Greene and Schafer. 2003. *Reducing Greenhouse Gas Emissions from U.S. Transportation*. Pew Center on Global Climate Change.

18. Some researchers have raised concerns over the emissions impact from indirect land-use changes that result from the use of food crops for biofuels. See e.g. Searchinger, Timothy et al. 2007. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change." *Science* 319 (5887): 1238-1240.

19. Pena, Naomi. 2008. *Biofuels for Transportation: A Climate Perspective*. Pew Center on Global Climate Change.

20. Paustian, Keith, et al. 2006.

21. Ribando C., Yacobucci B. *Ethanol and Other Biofuels: Potential for U.S.-Brazil Energy Cooperation*. Congressional Research Service, 2007.

22. Kliesch, James, and Therese Langer. 2006. *Plug-In Hybrids: An Environmental and Economic Performance Outlook*, ACEEE, Report Number T061,

23. Hydrogen fuel cells combine oxygen with hydrogen to create water, and in the process enable the harnessing of electrical energy associated with this process. For more information, see National Research Council, 2008, *Transitions to Alternative Transportation Technologies: A Focus on Hydrogen*.

24. Hydrogen can be produced in a variety of ways, including from coal or natural gas, and from electrolysis (using electricity to split water into hydrogen and oxygen).

25. Mouawad, Jad. 2008. "Pumping Hydrogen." *The New York Times*. 23 September.

Pew Center on Global Climate Change
2101 Wilson Blvd., Suite 550
Arlington, VA 22201
Phone (703) 516-4146
www.pewclimate.org

Pew Center on the States
1025 F Street NW, 9th Floor
Washington, DC 20004-1409
Phone (202) 552-2000
www.pewcenteronthestates.org