CLIMATE CHANGE 101
Technological Solutions

Achieving the 50- to 80-percent 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 substantial new investments in research, incentives for producers and consumers, and emission reduction requirements that drive innovation. 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

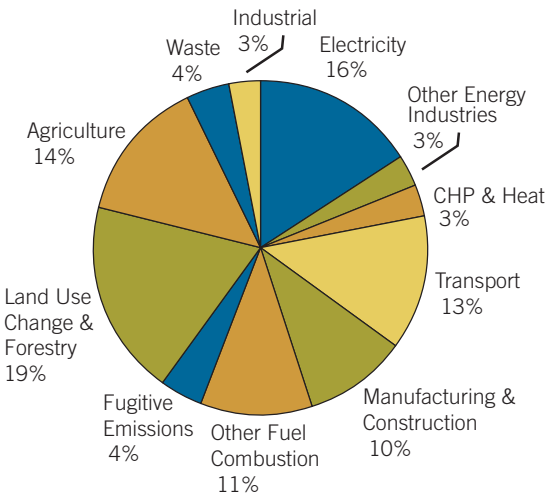
The greenhouse gas (GHG) emissions that are causing global warming come from a wide range of sources, including cars and trucks, power plants, farms, and more (see Figure 1). Because there are so many sources of these gases, there are also many options for reducing emissions, including such readily available 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-GHG 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, and building more homes.

Without a revolution in energy technology, human societies will be pumping ever-increasing amounts of greenhouse gases into the atmosphere, with potentially dramatic effects on

Figure 1

Global GHG Emissions by Sector, 2000



Source: Pew Center on Global Climate Change, *Climate Data: A Sectoral Perspective*

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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.

the global climate. 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 emissions-reducing technologies (such as hybrid gas-electric cars and wind power) are commercially competitive today. Others (such as plug-in hybrid cars and solar power) are on their way. And still more (such as hydrogen fuel cells and storing carbon dioxide emissions underground) show great promise, but additional work is needed to demonstrate their effectiveness and cost-effectiveness.

Almost all of these technologies are going to need help moving from the laboratory to the marketplace. 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. In addition to policies that send a clear "price signal" by placing real limits on emissions, governments will need to invest in research to develop some of the most critical, long-term, climate-friendly technologies and to ensure that they can gain a solid foothold in the marketplace. Consumers and businesses also need government incentives to purchase these technologies so they can enter the mainstream and contribute to substantial reductions in emissions.

Opponents of strong action to address climate change often focus on the economic costs of reducing emissions. Yes, massive investments are needed. But the cost of inaction is even greater. In addition, a global technology revolution will create enormous economic opportunities for businesses and workers, as well as the localities and states that successfully position themselves as centers of innovation and technology development for a low-carbon world.

LOOKING AT THE KEY TECHNOLOGIES

There is no single, silver-bullet technology that will deliver the reductions in emissions that are needed to protect the climate. Success will require a portfolio of solutions, 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. For policymakers, the priority must be to create incentives that will unleash the power of the marketplace to develop solutions, rather than to pick technologies based on predictions of future performance.

As shown in Figures 2 and 3, most greenhouse gas emissions in the United States can be traced to the electricity, building and transportation sectors. The following pages look at technology options for reducing emissions from each of these critical sectors.

GHG Emissions in the United States

Figure 2
Sources of U.S. CO_2 Emissions in 2002

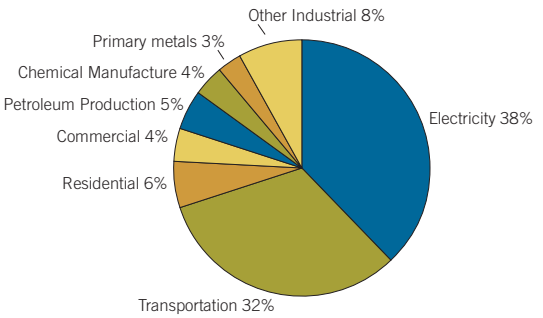
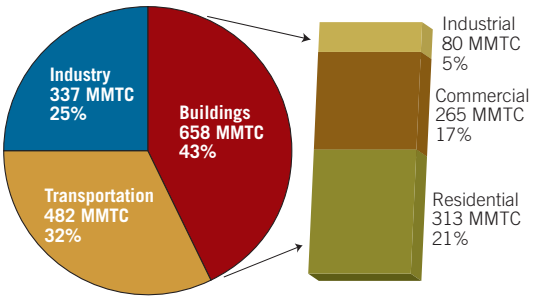


Figure 3
CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector, 2002



Sources: Pew Center on Global Climate Change, *The U.S. Electric Power Sector and Climate Change Mitigation* and *Towards a Climate Friendly Built Environment*

ELECTRICITY AND BUILDINGS

The electricity sector produces 38 percent of U.S. carbon dioxide emissions. 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.

This massive use of electricity 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 on their own.

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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 and building technology options. In other words, it's 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:

- ***Improved Efficiency.*** Technologies are available today to produce electric power and heat more efficiently using both fossil fuels and renewable energy. Power plants using the Integrated Gasification and Combined Cycle (IGCC) process, for example, deliver efficiency gains along with reductions in air pollution by converting coal into a cleaner-burning gas. Additional efficiency gains can come from advanced technologies for other fuel sources in power plants, including natural gas and biomass.

- ***Renewable Energy.*** Renewable energy harnesses the power of the wind, the sun, water, tides and other forces to produce electric power. Agricultural "biomass" products also can be used to generate electricity and heat when combusted 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 count for only a tiny share of overall electricity generation in the United States.[1] Options for expanding the use of renewables include Renewable Portfolio Standards, which require generators to produce a specified share of power from renewable sources; consumer rebates and other government incentives;[2] and further support for research and development to advance the technologies and lower their costs.

- ***Carbon Capture and Sequestration.*** As noted above, IGCC power plants can convert coal into a gas that produces substantially fewer pollutants when burned; the IGCC process also allows for the relatively easy "capture" of carbon for long-term storage in underground geological formations. The United States has built demonstration plants using these technologies, and at least one commercial IGCC plant is being planned. But the overwhelming majority of coal-burning power plants in the United States are conventional plants, and more work is needed to provide power producers with the incentives to build cleaner-burning power plants as soon as possible, and to bring down the costs of capturing carbon from conventional coal plants. Work also is needed to prove that underground storage (or sequestration) of carbon on a large scale is a good long-term option for keeping it out of the atmosphere.

- ***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 among citizens and elected officials about the cost of nuclear-generated

electricity; technical, political and environmental concerns about nuclear waste disposal; and threats associated with increased risk of nuclear arms proliferation. No new nuclear plant has been ordered in the United States since 1979, although groups of companies are currently pursuing applications for new plants.[3]

Options for Buildings. Greenhouse gas emissions from the building sector result primarily from the use of power-hungry items such as lighting fixtures, appliances, and heating and cooling systems.[4] Cost-effective technologies for reducing emissions from buildings are readily available, but they often can't compete in the marketplace. Among the reasons are a lack of consumer information, and "market barriers" such as the high fees that electric utilities often charge for back-up power to customers using their own sources of energy.

Because of inefficiencies in how power is generated and reaches consumers, reductions in demand by energy users result in even larger energy savings by the generator. Options for reducing emissions from buildings include encouraging greater energy efficiency and promoting on-site power generation.

- ***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[5] products and better insulation, consumers and businesses have an array of cost-effective options for limiting their energy use and boosting efficiency. However, consumers often do not take advantage of these options on their own. Policymakers can help promote greater energy efficiency through enhanced building codes; building standards, awards or certifications to buildings that are energy-efficient; suspended sales taxes on efficient appliances; publicly funded utility efficiency programs; regulatory reforms that reduce barriers to energy efficiency; 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,[6] 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)[7] also can help. 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. Many of these technologies already are cost-effective, but they can't compete in the market because of regulatory hurdles and other barriers.

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 United States' overall efforts 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-consuming 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.[8] In addition, biomass from agricultural sources (including corn and grasses) could be used to produce biofuels that can take the place of high-carbon fossil fuels used in transportation and power 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

After the electricity or buildings sector, transportation is the second largest source of greenhouse gas emissions in the United States, primarily carbon dioxide produced by cars and trucks. The ways in which we move from place to place are responsible for almost one-third of U.S. carbon

dioxide emissions, and nearly a quarter of emissions around the world.

Reducing greenhouse gas emissions from transportation can be accomplished in a number of ways. Among the options:

- Adopting new emissions-reducing technologies for cars and trucks;
- Reducing the carbon content of vehicle fuels; and
- Reducing demand for vehicle travel by encouraging "smart growth" and the use of mass transit.

Historically, it has proven very hard to get people to drive less. The way most Americans live today, our cars and trucks are an essential part of our daily lives. There are ways to make Americans less automobile-dependent and new options such as car-sharing and smart growth are emerging.

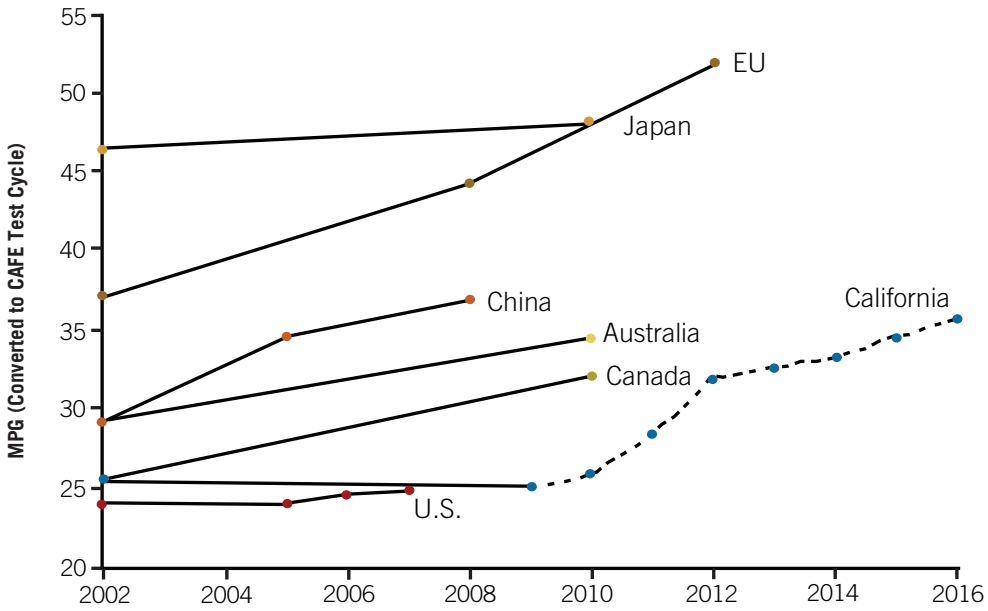
The challenge for lawmakers at all levels is to promote and encourage short-term solutions (for example, more hybrid cars and trucks) while facilitating a long-term transition to alternatively-fueled vehicles.

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 "off-the-shelf" technologies that are commercially available today. One recent study found that commercial (and cost-effective) technologies exist right now to increase fuel economy and/or reduce tailpipe greenhouse gas emissions by as much as 25 percent.[9]

In the United States, however, the average fuel economy of all cars and light trucks sold today is no better than it was in the early 1980s. As Figure 4 shows, governments around the world have adopted more stringent policies than the United States to reduce tailpipe greenhouse gas emissions and/or increase fuel economy. These policies can play a crucial role in hastening the rollout of commercially available technology to reduce vehicle emissions.

Figure 4

Fuel economy and GHG emission standards around the world[10]



Notes: (1) dotted lines denote proposed standards (2) MPG = miles per gallon (3) CAFE is Corporate Average Fuel Economy

Another option for reducing greenhouse gas emissions from cars and trucks in the short term is the blending of 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).

Beyond these "off-the-shelf" options for reducing car and truck emissions, even greater reductions are available through the use of advanced diesel and hybrid vehicle technologies.

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 gas 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.[11]

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 or 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. (This is because any emissions produced through the use of these fuels could be offset as farmers grow more carbon-dioxide-consuming biofuel crops.) Biofuels have the potential to offset 10 to 24 percent of current U.S. greenhouse gas emissions, depending on what fossil fuels are replaced and on how the agricultural product is converted into fuels. 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. With ethanol from sugar cane providing almost half of its domestic passenger fuel, Brazil has shown that an aggressive policy push can help biofuels become a mainstream fuel choice.[12]

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- ***Electric Cars.*** Historically, electric cars have been viewed as a "niche" product, but advances in battery storage are needed. Another option is the "plug-in" hybrid, a gas-electric vehicle that can be charged at home overnight. Even using the current U.S. mix of electricity sources to charge the vehicles, plug-in hybrids can achieve significant reductions in greenhouse gas emissions compared to traditional vehicles, and even traditional hybrids.[13]

- ***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.[14] 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 most important questions: how to produce hydrogen in ways that yield minimal emissions.[15]

GETTING IT DONE

To achieve significant reductions in U.S. greenhouse gas emissions, our nation needs to embrace short-term and long-term solutions. We need to target both supply and demand—engaging consumers and producers of energy in a wide-ranging effort to protect the climate. And we need

broad policies aimed at curbing emissions, together with more targeted policies designed to spur the development of new technologies.

Encouraging greater energy efficiency is a crucial part of the solution. Throughout all sectors of the U.S. economy, gains in energy efficiency can make an important contribution to reducing greenhouse gas emissions—and, in turn, reducing the amount of power needed from new and emerging low-carbon energy sources. One group of experts found that if the United States can boost energy efficiency by 2 percent per year through 2050, we will reduce the amount of power needed from low-carbon sources by two-thirds.[16] Clearly, efficiency across all sectors is essential, both as a path to short-term reductions in emissions and as part of a long-term strategy as well.

Also essential will be a wide-ranging effort to drive innovation. Government at all levels needs to spur investments in new technologies—by making direct investments in research and development, creating and enhancing incentives for private investment, and adopting mandatory targets and other policies that can help create the conditions for technological change.

Among the key climate solutions advocated by many experts is a "cap-and-trade" system that requires emissions 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 value for emissions reductions, as well as an economic advantage for technologies that can achieve them.

Coupled with government efforts to promote the development and deployment of new technologies, cap-and-trade programs hold 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 going to be 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 going to be crucial. At the same time, state and local leaders have jurisdiction over many parts of the economy that are part of the problem—and that can be part of the solution as well. 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 in this white paper, refer to these Pew Center publications:

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

Towards a Climate-Friendly Built Environment (2005)

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

Agriculture's Role in Greenhouse Gas Mitigation (2006)

Induced Technological Change and Climate Policy (2004)

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

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

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

Pew Center on Global Climate Change

These reports are available at www.pewclimate.org.

ENDNOTES

1. The U.S. Energy Information Administration (EIA) projects that electricity generated from all renewable resources will grow from 9.0 percent of total generation in 2004 to 9.4 percent in 2030, with non-hydroelectric renewables growing from 2.2 percent in 2004 to 4.3 percent in the same period.
2. See e.g., California Energy Commission, "Emerging Renewables Program," available at: http://www.energy.ca.gov/renewables/emerging_renewables/index.html.
3. See http://www.nei.org
4. Additional emissions are connected to production and transportation of building materials, but the discussion here covers only reductions connected to energy use in building operations.
5. 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: www.energystar.gov.
6. Stationary fuel cells can also be used in large-scale (e.g., power plant) applications.
7. 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: http://www.usgbc.org.
8. See Paustian et al., *Agriculture's Role in Greenhouse Gas Mitigation,* Pew Center on Global Climate Change, September 2006.
9. See e.g., testimony of K.G. Duleep, Science Committee, U.S. House of Representatives, "Hearing on Improving the Nation's Energy Security: Can Cars and Trucks be Made More Fuel-Efficient?" February 8, 2005, Available at: http://www.house.gov/science/hearings/full05/feb9/KGDuleep.pdf, at pg. 2.
10. From An and Sauer, *Comparison of Passenger Vehicle Fuel Economy and GHG Emission Standards Around the World*, Pew Center on Global Climate Change, December 2004.
11. See Greene and Schafer, *Reducing Greenhouse Gas Emissions From U.S. Transportation*, Pew Center on Global Climate Change, May 2003.
12. See e.g., http://edition.cnn.com/2006/WORLD/americas/03/10/brazil.ethanol.example.ap/index.html
13. For a brief discussion of plug-in hybrids and related policy recommendations, see e.g., "Set America Free: A Blueprint for U.S. Energy Security," *available at*: http://www.setamericafree.org/blueprint.pdf; E2I/EPRI, "The Plug-In Hybrid Electric Vehicle: Today's Car for Tomorrow's Technology—An E2I Initiative," August 2002, *available at*, http://www.epri.com/attachments/285860_1007115Print_081902.pdf; Wired.com, "Support Grows for Plug-In Hybrids," Aug. 17, 2005, http://www.wired.com/news/technology/0,1282,68535,00.html
14. 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 "Fuel Cells 2000: The Online Fuel Cell Information Resource," available at: http://www.fuelcells.org.
15. 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).
16. Holdren, John P. 2004. "Integrating Common Themes: Some Observations for the Workshop on 17 Technologies and Policies for a Low-Carbon Future." 2004. Presentation to the Pew/NCEP 10-50 Workshop, citing a 1997 report by the U.S. President's Council of Advisers on Science and Technology (PCAST).

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