Our Transition

The Center for Climate and Energy Solutions (C2ES) is an independent nonprofit organization working to promote practical, effective policies and actions to address the twin challenges of energy and climate change. Launched in 2011, C2ES is the successor to the Pew Center on Global Climate Change. This report was originally published by the Pew Center on Global Climate Change. For more information, please visit WWW.C2ES.ORG

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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. A portfolio of technologies exists today for achieving cost-effective emission reductions, and emerging technologies hold promise for delivering even more emission reductions in the future. The successful development of these technologies will require 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.

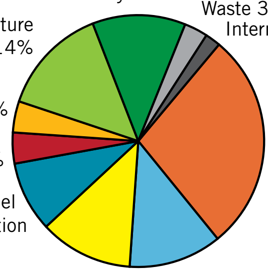
THE DAWNING OF A REVOLUTION

The man-made greenhouse gas (GHG) emissions that are causing climate change come from a wide range of sources, including cars and trucks, power plants, factories, and farms (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 decades-long commitment to develop and deploy 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, societies will pump ever-increasing amounts of GHGs into the atmosphere, leading to damaging effects from global climate change. To avert these dangerous levels of global warming, the time to begin

Figure 1

Global Emissions by Sector in 2005



Source: Climate Analysis Indicators Tool (CAIT) Version 7.0, World Resources Institute, 2010.

PEW CENTER ON Global CLIMATE CHANGE

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making the necessary investments in new technologies is right now. Achieving substantial reductions in GHG emissions is possible—now and in the decades to come. Some emission-reducing technologies (such as hybrid gasoline-electric cars, wind power, and more efficient appliances) are commercially competitive today. Others (such as electric vehicles and carbon capture and storage) are advancing rapidly. 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 GHG 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 that send a clear price signal to the market by putting a financial cost on GHG emissions would make many low-carbon technologies commercially competitive with traditional GHG-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 and development (R&D) to advance 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, technology development, and manufacturing 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 grown substantially over the past decade. For example, from 2001 to 2009, investments in U.S.-based clean energy technology companies grew from less than 1 percent to 12 percent of total venture capital investments with the size of annual clean technology venture investments growing more than six-fold.[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 GHG emissions in the United States can be traced to the electricity, buildings, and transportation sectors. Carbon dioxide (CO_2) from fossil fuel combustion constitutes the bulk of U.S. GHG emissions.

Figure 2

U.S. GHG Emissions by Source, 2008

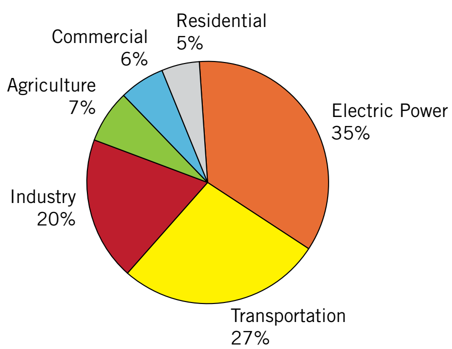
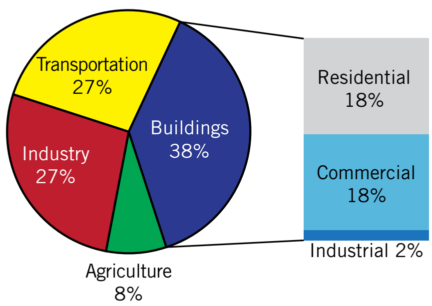


Figure 3

U.S. GHG Emissions by End-Use Sector, 2008



Sources: U.S. EPA, 2010. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*; U.S. Department of Energy, "Manufacturing Energy and Carbon Footprints."[5]

The following pages look at technology options for reducing emissions from each of these critical sectors (for more information on the technologies described below and others see the *Climate TechBook* on the Pew Center's website).

ELECTRICITY AND BUILDINGS

In 2008, the electricity sector produced 35 percent of U.S. GHG emissions, primarily CO_2 from fossil fuel combustion. Most of the electricity generated by the sector is used in the nation's homes, offices, and industrial facilities 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 GHGs. Because they make 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 end-use energy efficiency options. In other words, it is important to think about the roles of both the producers and the consumers of power.

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

Electric Power Options. GHG emissions from the electric power sector come almost exclusively from power plants burning coal and natural gas. Options for reducing these emissions include:

• ***Improved Efficiency.*** Increasing the efficiency of fossil-fueled power plants reduces fuel consumption and GHG emissions per unit of electricity generated.

• ***Fuel Switching.*** Replacing electricity generation from coal power plants with generation from efficient natural gas power plants can reduce emissions since natural gas is a less carbon-intensive fuel than coal. In this way, natural gas might be a "bridge" fuel while non-emitting energy sources (such as nuclear power and renewables) ramp up.

• ***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 generate electricity without producing GHGs—or producing very few when compared to fossil fuels. Most renewable resources can be harnessed on a large-scale basis (for example, via wind farms or large solar arrays) or in more "distributed" forms (for example, by placing solar panels on rooftops). Although wind power can be cost-competitive with fossil-fueled electricity in some cases, other renewables largely remain more costly than electricity from coal and natural gas, and renewables account for only a small share of overall electricity generation in the United States (in 2009 less than 4 percent of total electricity generation came from non-hydro renewables but such generation grew at an average annual rate of 12 percent over the most recent five-year period).[6] Options for expanding the use of renewables include: Renewable Portfolio Standards, which require utilities to acquire a specified share of power from renewable sources; tax credits for renewable energy investments or generation; consumer rebates and other government incentives; GHG emissions standards for power generators; policies that put a price on GHG emissions, such as cap and trade; and government support for R&D to advance renewable energy technologies and lower their costs.

• ***Carbon Capture and Storage (CCS).*** A suite of technologies exists that allows for CO_2 from the combustion or gasification of coal and other fossil fuels to be captured rather than released to the atmosphere. Once captured, CO_2 from fossil fuel use can be injected into and permanently sequestered in underground geologic formations. Because CCS requires expensive equipment and infrastructure to capture, transport, and store CO_2, it is most cost-effectively applied to large stationary sources of CO_2, such as coal-fueled power plants.

Recent years have seen several small-scale CCS demonstration projects completed, and several large-scale projects are proceeding with substantial government financial assistance.[7] Additional government incentives are required to spur investments in large-scale CCS projects beyond those currently planned in order to fully demonstrate the technologies and reduce their cost. Many experts expect CCS to be a major source of GHG emission reductions in the United States and globally.

- ***Nuclear Power.*** In 2009, nuclear power provided one fifth of U.S. electricity and two-thirds of non-emitting electricity generation. The construction of the current fleet of nuclear reactors saw massive budget overruns, delays, and safety concerns, especially after the accident at Three Mile Island in 1979. These factors contributed to a three-decade hiatus from building new nuclear reactors that is only now ending. Government incentives have spurred plans for some new nuclear plants, but for nuclear power to play a more prominent role in U.S. efforts to address climate change, the industry needs to demonstrate that it can build new reactors on time and on budget, and the government needs to develop a plan for long-term nuclear waste management.[8,9]

Options for Buildings. GHG 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 on-site combustion of fossil fuels for buildings' energy needs, such as natural gas use 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 GHG emissions, but consumers often fail to invest in even those options that would save them money. The reasons people do not take advantage of many cost- and energy-saving measures include lack of information and misaligned incentives (e.g., between building owners and tenants).[10] Because of inefficiencies in the generation and distribution of electricity to consumers, reductions in demand by energy users result in even larger primary 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, households and businesses have an array of cost-effective options for limiting their energy use and boosting efficiency. However, households and businesses 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 for 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.*** GHG emissions from the electricity and building sectors also can be reduced through on-site power generation using distributed renewable technologies (such as rooftop solar panels and small-scale wind power) or highly efficient combined heat and power (CHP) systems. Some of these technologies (e.g., rooftop solar panels) remain fairly expensive and thus are not widely used in the marketplace absent subsidies. Expanding their use—which will ultimately reduce costs—requires incentive programs, such as consumer rebates and tax credits. Building standards (such as LEED™ certification) also can help.[11] CHP (or cogeneration) systems make use of the waste heat from on-site electricity generation (e.g., for water heating or industrial processes) and can substantially reduce GHG

A Key Role for Agriculture

Emissions from agriculture account for approximately 7 percent of U.S. GHG emissions. Reducing these emissions can make an important contribution to the overall U.S. effort to address climate change. Agriculture can be a part of the solution in other ways as well. For example, less productive agricultural lands can be reforested with CO_2-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. CO_2 emissions and could be a new profitable opportunity for farmers.[12] In addition, biomass from agricultural sources (including corn and grasses) is being used to produce low-carbon biofuels for transportation and 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.

emissions compared to separate heat and power systems even when cogeneration systems use fossil fuel. Policymakers can promote cogeneration by addressing regulatory barriers.

TRANSPORTATION

The transportation sector is the second largest source of GHG emissions in the United States, primarily from CO_2 from petroleum fuels used by cars and trucks. The ways in which people and goods move from place to place are responsible for more than a quarter of total U.S. GHG emissions and about 14 percent of emissions around the world. Reducing GHG emissions from transportation can be accomplished in four main ways:

- Making cars and trucks more fuel efficient;
- Switching to lower-carbon vehicle fuels;
- Reducing the number of miles traveled; and
- Increasing the efficiency of the transportation system.

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 GHG emissions from conventional cars and trucks are possible using 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). In the United States, Corporate Average Fuel Economy (CAFE) standards have governed light-duty vehicle fuel economy for more than 30 years, but the fuel economy standards remained roughly flat for about the last two decades. The Energy Independence and Security Act of 2007, however, required the Department of Transportation (DOT) to issue more stringent CAFE standards, and a 2007 Supreme Court case opened the door for the Environmental Protection Agency (EPA) to regulate GHG emissions from vehicles under the Clean Air Act. In 2010, DOT and EPA jointly issued new rules for light-duty vehicles that would increase average fuel economy for new vehicles to 35.5 miles per gallon by 2016. Regulation is underway for model years after 2016 and for medium- and heavy-duty vehicles.

Another option for reducing GHG 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. Corn-based ethanol reduces emissions for each gallon of regular gasoline that it replaces by about 20 percent. 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-electric vehicle technologies also can yield emission reductions. Diesels and hybrids use different engines than the standard internal combustion gasoline engine. The key advantage of these technologies is they both offer significant improvements in fuel economy.

By 2035, a gasoline hybrid-electric vehicle could reduce fuel consumption by 65 percent compared to a 2005 Toyota Camry. Also in 2035, an advanced diesel vehicle could reduce fuel consumption by 47 percent.[13]

Longer-Term Options: Electricity, Biofuels, and Hydrogen. Ultimately, reducing GHG 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.

• ***Electric Cars.*** In 2010 automakers launched the first mass-market fully electric vehicles, and major automakers will roll out additional models in the next couple of years. Improvements in battery technology are needed, however, before fully electric vehicles can become cost-competitive with traditional and hybrid vehicles without substantial subsidies. Another option is the "plug-in" hybrid, a hybrid 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 20-mile electric range would result in a CO_2 emission reduction of about 45 percent relative to a regular hybrid.[14] Widespread deployment of plug-in hybrids and fully electric vehicles will necessitate some electric grid and charging infrastructure investments, and the emission benefits from such vehicles will increase as the carbon intensity of electricity generation decreases.

• ***Biofuels.*** As noted above, agriculture can be used to produce transportation fuel. While ethanol currently produced in the United States comes primarily from corn, the technology exists to make other biofuels from cellulosic sources (or the woody and leafy parts of plants). While corn-based ethanol reduces emissions by about 20 percent for every gallon of traditional fuel replaced, cellulosic ethanol and sugar-cane-based ethanol produce about 60 percent lower emissions compared to gasoline.[15,16] (This is because the CO_2 released by combusting biofuels is CO_2 that the feedstock plants had absorbed from the atmosphere as they grew.) 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.[17] With ethanol providing more than 50 percent of light-duty vehicle fuel demand, Brazil has shown that an aggressive policy push can help biofuels become a mainstream fuel choice.[18]

• ***Hydrogen.*** Hydrogen fuel cells, long a staple of the U.S. space program, combine oxygen with hydrogen to create water and electricity via an electro-chemical reaction. 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.[19] 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: lower-cost hydrogen-powered vehicles, infrastructure for distributing hydrogen and fueling stations, and cost-effective hydrogen production that does not emit GHGs.[20, 21]

GETTING IT DONE

To achieve significant reductions in U.S. GHG 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 GHG abatement. Second, a market-based climate policy would put a price on GHG 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, such as barriers to adoption of cost-effective energy efficiency measures.

Government needs to spur investments in new technologies—by making direct investments in R&D, and creating and enhancing incentives for private investment.

Government needs to spur investments in new technologies—by making direct investments in R&D, and creating and enhancing incentives for private investment. The most important benefit of a market-based climate policy 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 market-based climate policy holds the promise of achieving the needed reductions at the lowest cost.

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 best achieve the necessary emission reductions is not clear. A number of existing technologies, though, can provide very large emission reductions, and nascent technologies offer the promise of even more reduction potential. 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:

Climate TechBook (http://www.pewclimate.org/climate-techbook)

In Brief: Update on the 10–50 Solution: Progress Toward a Low-Carbon Future (2010)

In Brief: Clean Energy Markets: Jobs and Opportunities (2010)

Technology Policies to Address Climate Change (2008)

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)

Reducing Greenhouse Gas Emissions from U.S. Transportation (2011)

Biofuels for Transportation: A Climate Perspective (2008)

Agriculture's Role in Greenhouse Gas Mitigation (2006)

ENDNOTES

1 Cap and trade is one such policy. 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: Science and Impacts* at http://www.pewclimate.org/global-warming-basics/climate_change_101.

3 See, e.g., Pew Center on Global Climate Change, 2010, *In Brief: Clean Energy Markets: Jobs and Opportunities* at http://www.pewclimate.org/publications/brief/clean-energy-markets-jobs-and-opportunities.

4 CleanEdge. 2010. *Clean Energy Trends 2010*.

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 2009 renewable energy other than conventional hydropower accounted for 3.6 percent of U.S. net electricity generation. See *Electric Power Monthly* (September 2010 Edition).

7 See CO_2 capture and storage project fact sheets at http://sequestration.mit.edu/tools/projects/index.html.

8 See http://www.nei.org and http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/com_reactors.pdf.

9 Wald, Matthew. 2008. "Nuclear Power May Be in Early Stages of a Revival." *The New York Times*. 23 October.

10 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.

11 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.

12 Paustian, Keith, et al. 2006. *Agriculture's Role in Greenhouse Gas Mitigation*. Pew Center on Global Climate Change.

13 Bandivadekar, A. et al. 2008. *On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions.* Massachusetts Institute of Technology, Laboratory for Energy and the Environment Report No. LFEE 2008-05 RP.

14 Electric Power Research Institute (EPRI) and National Resource Defense Council (NRDC). 2007. *Environmental Assessment of Plug-In Hybrid Electric Vehicles*.

15 U.S. Environmental Protection Agency (EPA). 2010.*Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program: Final Rule.*

16 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.

17 Paustian, Keith, et al. 2006.

18 See http://www.eia.doe.gov/cabs/Brazil/Oil.html.

19 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*.

20 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).

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

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