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

Introduction

Addressing the challenge of global climate change will require a significant reduction in annual greenhouse gas (GHG) emissions in the United States and throughout the world by 2050. This will necessitate a fundamental shift from an economy predominantly based on traditional fossil fuel use to one based on efficiently managed low-carbon energy sources, including technologies that capture and store carbon dioxide (CO_2).

Achievement of this transition depends on both near-term and long-term actions that take advantage of current technologies and opportunities and that also make substantial investments in the technologies of the future. But most of all, the United States needs a clearly enunciated and sustained policy to guide those actions. Too often the debate over GHG emission reductions pits near-term actions against long-term investments in technology, when in fact both are necessary and more effective together.

In 2004, the Pew Center held a workshop (the "10-50" Workshop) to understand the technologies likely to enable a low-carbon future by mid-century (50 years) and identify policy options for the coming decade (10 years) to help "push" and "pull" these technologies into the market. This brief reviews some of the key policies and actions deemed important five years ago and reports on progress against those goals to date; it finds significant progress in pushing low-carbon technologies and underscores the critical remaining need for a policy, such as cap and trade, that puts a price on carbon and "pulls" those technologies into the marketplace.

The Challenge of a Low-Carbon Future

The 2009 Copenhagen Accord, the political agreement negotiated by the United States and other major emitting nations, includes the goal of limiting global temperature rise to 2 degrees Celsius, which the United Nations Intergovernmental Panel on Climate Change (IPCC) says will require a 50 to 80 percent reduction of global CO_2 emissions from the 2000 emissions levels by 2050.[1,2] Under "business-as-usual," global energy consumption in 2050 is projected to be more than double consumption in 2005.[3] Under an aggressive global effort to reduce emissions, this expected increase in energy demand and much of current energy demand would need to be met via increased energy efficiency and non- or low-CO_2-emitting energy sources such as renewables, nuclear power, and the use of fossil fuels with carbon capture and storage (CCS).[4]

The transition to a low-carbon economy will take several decades and will not be easy. In the near term, it will be necessary to take advantage of current technologies and opportunities and to make substantial investments in the technologies of the future. Such a transition could have benefits beyond addressing the threat of dangerous climate change, including increasing energy security, improving public health, and promoting economic growth in low-carbon technology industries.

There are technological challenges inherent in developing and deploying a suite of low-carbon energy technologies while achieving the traditional goals of U.S. energy policy (i.e., providing extensive energy services at low cost and through secure supply to a growing population and economy). Furthermore, low-carbon energy technologies that compete with entrenched conventional (and usually high-GHG-emitting) technologies are likely to encounter market, political, and societal barriers to deployment.

Accordingly, there is a clear need for sustained policies to push and pull low-carbon technologies into the market. Without such policies, businesses and households miss opportunities for cost-effective GHG reductions and investment for the future. A variety of policies, public and private leadership, and broad societal engagement will be needed. Characteristics of the energy sector—long capital investment cycles,[5] a high degree of system inertia, and the tendency for past developments to strongly influence current technology choices—highlight the need to continue and expand policies to promote technological change and enable significant decarbonization by midcentury.

Background on the "10-50" Solution

The "10-50" Solution refers to the long-term vision for a low-carbon economy by midcentury (i.e., within roughly 50 years) and the policies and technology advancements needed in the short and medium term (i.e., roughly the next decade) to put society on a path to realizing the long-term vision. In March 2004, the Pew Center on Global Climate Change and the National Commission on Energy Policy (NCEP) hosted a workshop entitled "The 10-50 Solution: Technologies and Policies for a Low-Carbon Future."[6] The overall goal was to articulate a long-term vision of the technologies and industrial process changes that would have to be in place 50 in the future to address climate change effectively, as well as the policies that would have to be initiated in the short, medium, and long term to achieve this vision.

The 10-50 Workshop focused on five key technology areas: efficiency, hydrogen, carbon sequestration/ coal gasification, advanced nuclear power generation, and renewables. While not an exhaustive list of GHG emission reduction options, these technologies were considered among the most important based on their emission reduction potentials.

The section below summarizes some of the key points brought out in the 10-50 Workshop that remain relevant today.[7] Subsequent sections review technology-specific policy recommendations made in 2004 and highlight the most important technology and policy advances of the last five years (2005 through 2009).

Common Themes and Policy Recommendations

Clear and consistent policy signals are urgently needed. Both broad (economy-wide) and technology-specific policies are essential. There is also a need to balance policy flexibility with reasonable policy certainty. A sustained carbon price signal—e.g., via a GHG cap-and-trade program—is the most important cross-cutting policy driver. Mandatory GHG emission reporting (recently required starting with emissions for calendar year 2010, as discussed below) is an important first step for identifying and stimulating reductions.

A portfolio of technologies and policies will be needed to drive the absolute reductions in GHG emissions necessary to address climate change. No single technology or policy will be sufficient to enable a low-carbon future by 2050. All of the technologies addressed in this brief have the potential to enable significant GHG reductions, but increased research, development, and deployment (RD&D) is necessary in all of them. Efficiency will provide the greatest opportunity in the near term and will remain important over the long term as well. While specific technologies are likely to be important players, one should avoid the temptation to "pick winners." The challenge is to design policies that are neutral enough to promote the development and deployment of a suite of low-carbon technologies while also addressing challenges unique to certain important technologies. Finally, via cooperative international efforts, countries can increase the impact of their own individual efforts to develop low-carbon energy technologies.

A low-carbon technology revolution will require both leadership and broad engagement throughout society. Policies should address climate change in the context of other societal goals (e.g., clean air, energy security) thereby taking advantage of co-benefits and creating public/private partnerships and non-traditional alliances. Leadership is needed in both the public and private sectors, and clear and unambiguous targets set by corporate leaders and governments can have a significant positive effect on achieving GHG reductions. Consumers and citizens must be involved in the transition to a low-carbon economy, and a greater focus on critical energy challenges (both in terms of resources and innovative capacity) is needed from U.S. universities and private-sector research laboratories.

Immediate action is necessary. It is imperative to begin immediately with clear statements of policy and new and expanded cross-cutting and technology-specific policies and investments in order to be well into a transition to a low-carbon economy by 2050.

Key Legislation (2005 to 2009)

Over the last five years, several pieces of legislation have made important changes to U.S. energy and climate policy; the most important of the bills are summarized below in chronological order.

The Energy Policy Act of 2005 (EPAct05)[8] – enacted in August 2005, EPAct05 (H.R. 6) was the first omnibus energy bill enacted in more than a decade and included provisions related to energy efficiency, low-carbon transportation, CCS, nuclear power, and renewables.

America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act, or the America COMPETES Act – enacted in August 2007, the America COMPETES Act (H.R. 2272) increased science and engineering research and education. In particular, it created the Advanced

Research Projects Agency-Energy (ARPA-E) in the U.S. Department of Energy (DOE) with the goal of sponsoring transformational energy technology research projects.[9]

Energy Independence and Security Act of 2007 (EISA07)[10] – enacted in December 2007, EISA07 (H.R. 6) was also a comprehensive energy bill with key provisions concerning energy efficiency and an increase in vehicle fuel economy standards under the Corporate Average Fuel Economy (CAFE) program.

Mandatory Reporting of Greenhouse Gases Rule –the FY2008 Consolidated Appropriations Act (H.R. 2764, enacted in December 2007) required the U.S. Environmental Protection Agency (EPA) to develop a rule for mandatory GHG emission reporting. EPA finalized its reporting rule in October 2009, and large emitters will have to collect data and report on their GHG emissions for calendar year 2010 and thereafter. EPA estimates that the reporting rule will initially apply to approximately 10,000 facilities responsible for 85 percent of U.S. GHG emissions.[11]

Emergency Economic Stabilization Act of 2008 (EESA)[12] – enacted in October 2008, EESA (H.R. 1424) provided for the government to intervene in the mortgage and banking financial crisis. In addition, it included energy tax provisions related to efficiency, renewables, coal gasification, and CCS.

American Recovery and Reinvestment Act of 2009 (ARRA)[13] – ARRA was an economic stimulus bill enacted in February 2009 in response to the economic recession. It included substantial incentives (roughly $80 billion in funding, tax expenditures, and loan guarantees), for climate- and clean energy-related purposes.

Federal Energy RD&D Trends

The sections below discuss in more detail changes to federal energy RD&D programs and funding, which are summarized in Figures 1 and 2 below. Focusing on energy RD&D at DOE, one can see the dramatic decline in such funding following the energy crises of the 1970s. The past five years, however, have seen a sizeable increase in federal energy RD&D funding. Excluding the ARRA funding, fiscal year (FY) 2009 DOE energy RD&D funding was more than 60 percent greater than in FY2004. In particular, nuclear fission and renewable RD&D funding roughly tripled, and fossil energy (including CCS) funding increased roughly 40 percent. Figure 2, shows that the cumulative DOE energy RD&D funding in the years following 2004 is nearly 40 percent greater (even without taking into account the ARRA funding) than the cumulative funding in the same number of years prior to 2004. Figure 2 also shows the significance of the energy RD&D funding included in ARRA; for example, ARRA included nearly half as much fossil energy and CCS RD&D funding as compared to the cumulative total from FY1999 through the FY2010 budget request (excluding ARRA).

Technology-Specific Policies

In addition to the need for broad national policies and investments, certain key technologies also require policies and initiatives to address their own specific challenges. The following sections summarize policy priorities for these key technologies, as understood in 2004 and identified by the 10-50 Workshop, and highlight relevant policy developments that have occurred over the past five years.

Energy Efficiency. The technological potential for energy efficiency improvements now and in the future is significant, yet this potential is not likely to be realized through market forces alone.[14] Accordingly, policies that address the technical, cost, and societal hurdles limiting widespread improvements in energy efficiency are needed. In addition to price signals and reporting, certain standards, incentives, and RD&D programs can increase the use of efficient technologies. These options include:

- adoption and promotion of codes and standards focused on maximizing GHG reductions (e.g., for buildings, vehicles, and appliances);
- increases in public RD&D in innovative energy efficiency technologies; and
- incentives for the private and public procurement of highly efficient technologies.

Policy advancements related to energy efficiency implemented over the last five years include:

- Equipment Standards - EISA07 established higher efficiency standards for certain appliances and lighting equipment.
- Building Codes – EPAct05 required updates to commercial building standards.
- Financial Incentives – EPAct05 included tax incentives for energy efficiency and conservation and established a loan guarantee program for advanced energy efficiency projects. EESA extended and expanded tax incentives. ARRA provided large funding increases for the Weatherization Assistance Program, State Energy Programs, and the Energy Efficiency and Conservation Block Grant Program (established by EISA07).
- Public Sector Leading by Example – EISA07 set federal building energy use reduction goals; ARRA included funding for federal building energy efficiency.
- Smart Grid[15] – EISA07 included provisions to promote smart grid R&D, deployment, and standards-setting; ARRA included funding for smart grid deployment projects.[16]

Transportation. As evidenced by the 10-50 Workshop's focus on hydrogen, hydrogen was widely considered a key option for a future low-carbon transportation sector five years ago. Since 2004, however, interest in hydrogen as a solution for transportation has lessened as interest in biofuels and electrification has grown (for this reason the recommendations from 2004 pertaining to hydrogen are not repeated below).[17] Federal R&D efforts related to hydrogen vehicles and fuel continue while significant advances have been made related to biofuels and electric vehicles. For example, major automakers already offer popular hybrid-electric vehicles, and several automakers have announced plans to sell plug-in hybrid-electric vehicles in the near term. Since 2004, major policy developments related to low-carbon transportation technologies have included:

- Hydrogen - EPAct05 established a hydrogen and fuel cell program with a goal of producing commercial fuel cell vehicles and developing hydrogen infrastructure by 2020, and EISA07 established a series of innovation prizes related to hydrogen (H-Prizes).[18] In 2009, the Secretary of Energy recommended zeroing out hydrogen RD&D funding at DOE owing to concerns about the feasibility of deploying hydrogen vehicles, but Congress appropriated funding nonetheless.[19] DOE reports that it is advancing toward a 2015 decision regarding commercialization of hydrogen fuel cell vehicles.[20]
- Fuel Economy - EISA07 required an increase in combined passenger car/light truck fuel economy to 35 mpg by 2020 (up from roughly 25 mpg in 2007) under the CAFE program. In September 2009, the Obama Administration issued a proposed joint rulemaking for a National Fuel Efficiency Program that would avoid separate EPA GHG standards, National Highway Traffic Safety Administration (NHTSA) CAFE standards, and state GHG standards. Under the proposed national policy, passenger cars and light trucks will have a projected combined average fuel economy of 34.1 miles per gallon by model year 2016.[21]
- Renewable Fuels - EPAct05 established a renewable fuels standard (RFS) requiring the use of renewable fuels (e.g., corn ethanol) blended with gasoline; EISA07 expanded the requirement and mandated that an increasing share of the RFS be met via "advanced biofuels." ARRA included funding for loan guarantees for "leading-edge biofuels" projects.
- (Hybrid-)Electric Vehicles - EPAct05 included a personal tax credit for hybrid-electric vehicle purchases. EISA07 directed DOE to engage in energy storage R&D related to electric-drive vehicles. ARRA expanded tax credits for plug-in (hybrid-)electric vehicles that were enacted by EESA. Under ARRA, the government awarded grants related to electric vehicles, with a particular focus on battery manufacturing.

Carbon Capture and Storage. In 2004, significant efforts were deemed necessary to answer critical R&D questions and to make CCS commercially available. Illustrating this state of affairs, in 2004, the 10-50 Workshiop identified the need for:

- a coordinated international effort to deploy integrated CCS trial projects with coal-fueled power plants that focus on remaining technical issues (e.g., four to six international projects);
- establishment of carbon sequestration trial projects in the United States to validate the integrity of geologic storage (e.g., four such projects);
- removal of policy disincentives to shutting down old coal plants;
- beginning to establish a regulatory framework for underground CO_2 storage;
- conducting R&D to reduce the cost of separation and capture technologies; and
- increasing education efforts to inform citizens about the use of fossil fuels combined with geologic carbon sequestration.

Over the last five years, important developments have occurred related to CCS and advanced coal technologies, including:

- In 2003, DOE announced its plans for the FutureGen plant to demonstrate commercial-scale integrated gasification combined cycle (IGCC) power plant and CCS technology with an industry consortium. In 2008, DOE abandoned this idea, but the agency changed tack again in 2009, with the FutureGen plant now in preliminary design phase and a final decision regarding moving forward with construction and operation expected in early 2010.[22]
- EPAct05 authorized loan guarantees for coal gasification and CCS projects and investment tax credits for gasification projects. In 2006, Duke Energy secured tax credits for a commercial-scale (630 megawatt) IGCC power plant now under construction at Edwardsport, IN. In October 2007, DOE invited three more gasification projects to submit full applications for such guarantees.[23] In September 2008, DOE issued a solicitation for applications for an additional $6 billion for CCS projects. In 2008, EESA increased the investment tax credits available for coal gasification projects and established a tax credit for each ton of captured CO_2 sequestered by qualified CCS projects.
- EPAct05 instructed DOE to conduct coal gasification demonstration projects. DOE's Clean Coal Power Initiative has granted financial awards to advanced gasification projects and, most recently, to new gasification projects integrated with CCS and to post-combustion CCS retrofit projects at existing pulverized coal plants.[24]
- In 2003, DOE launched the Carbon Sequestration Regional Partnerships (CSRPs), which EISA07 authorized to include large-scale demonstrations. The CSRPs have involved three phases starting with characterization of CO_2 storage potential. As part of the second phase, DOE and its partners are operating 22 small-scale injection pilot projects. In the final phase, the program will culminate in nine large-scale CO_2 injection and geological sequestration demonstration projects, with some expected to begin operation in spring 2010.[25]
- EISA07 required the Department of Interior (DOI) to assess national potential for geological CO_2 storage, and DOI published its methodology in March 2009.[26] In addition, DOE's geological sequestration research resulted in the publication of an atlas estimating U.S. geological CO_2 storage capacity.[27]
- In March 2007, EPA issued guidance for permitting small-scale experimental CO_2 injection wells for geological sequestration. In July 2008, EPA issued a proposed rule governing large-scale underground injection of CO_2 for sequestration for the purposes of protecting drinking water under the agency's authority granted by the Safe Drinking Water Act.[28]
- ARRA contained $3.4bn for fossil energy—primarily for CCS projects, including funds allocated to the FutureGen project and the Clean Coal Power Initiative discussed above.
- In 2008, as part of the G-8, the United States endorsed a call for 20 industrial-scale CCS projects globally by 2010 with broad deployment beginning by 2020.[29] In 2003, DOE and the U.S. Department of State launched the Carbon Sequestration Leadership Forum (CSLF), a ministerial-level multilateral

organization with a primary goal of collaboration and information sharing regarding CCS projects, regulations, and standards. At the end of 2009, there were 30 global CCS projects recognized by the CSLF, with ten added in 2009.[30] Also in 2009, the United States increased its bilateral collaboration with China on CCS—both announcing a U.S.-China Clean Energy Research Center, which will include CCS as one of its areas of focus, and agreeing on a five-year cooperative CCS research effort among DOE national laboratories and the Chinese Academy of Sciences.[31]

Advanced Nuclear Power Generation. In 2004, no new nuclear plants had been ordered in the United States since 1978, and no U.S. plant has been completed that was ordered after 1973. Moreover, there were no applications before the Nuclear Regulatory Commission (NRC) to build new reactors. In 2004, the question was whether, in roughly the next decade, the nuclear industry could overcome serious obstacles, including concerns over costs, waste, and safety, and launch a major deployment of nuclear power plants. Near-term policy options considered important for enabling significant expansion of nuclear power in the United States, as highlighted at the 10-50 Workshop, included:

- re-ordering of the priorities of the DOE nuclear fuel cycle R&D to focus on the “once-through” (i.e., without fuel reprocessing) fuel cycle;
- electricity production tax credits for “first mover” nuclear plants;
- significant expansion in size and scope of the U.S. DOE’s nuclear waste management R&D;
- strengthening and reorienting of the current international non-proliferation regime; and
- public dialogue and education regarding the costs and benefits of nuclear power, especially in the context of climate change.

Major policy developments implemented over the last five years related to nuclear power have included the following:

- In 2005, as part of the Nuclear Power 2010 program, DOE and industry partners initiated two new Nuclear Plant Licensing Demonstration Projects to demonstrate the streamlined licensing process created by the Energy Policy Act of 1992 and to complete the certification of first-of-a-kind reactor designs.[32]
- EPAct05 established a nuclear production tax credit (PTC) for plants with licensing applications received by 2009 and built by 2021, loan guarantees for new plants, and regulatory delay compensation; it also extended to 2025 the Price-Anderson Act nuclear reactor liability system.[33]
- In December 2007, Congress authorized DOE to grant $18.5 billion of loan guarantees for new nuclear plants. In December 2009, DOE issued a final rule amending the loan guarantee program rules to address implementation challenges, and the Obama Administration expects to offer conditional loan guarantee commitments to two companies for 3-4 new reactors by 2011.[34,35]
- By the end of 2009, 16 applications for construction and operating licenses for up to 25 new reactors were under review by the Nuclear Regulatory Commission (NRC)—all submitted since 2007.[36]

- In 2004, DOE started the Global Nuclear Energy Partnership (GNEP), which included a focus on deployment of large-scale nuclear fuel reprocessing facilities; however, in 2009 DOE reoriented GNEP, cancelling the program's focus on near-term deployment of reprocessing facilities.[37]
- President Obama, Congressional leaders, and the nuclear industry support the creation of a "blue-ribbon" commission to undertake a reassessment of the federal government's program to manage nuclear waste and produce a roadmap for a sustainable long-term program. While the Obama Administration has stated plans for such a commission, as of January 2010, no commission had yet been created.
- To combat nuclear proliferation, in 2009 the International Atomic Energy Agency, in a move supported by the United States, approved a plan for a multilateral fuel bank to provide low-enriched uranium to countries that demonstrated compliance with non-proliferation.[38]

Renewables. Despite the significant potential for growth of renewables, with the exception of conventional hydropower, these sources currently provide only a small fraction of energy in the United States and around the world. Policy options suggested in 2004 to promote renewables included:
- establishment of a national Renewable Portfolio Standard with set-asides for specific generation technologies and with tradable renewable energy credits;
- a major RD&D effort by DOE focused on the use of renewables beyond niche markets;
- national test beds for new electricity grid systems that enable a broader set of power supply options, including intermittent and distributed energy and combined heat and power;
- increased research on expanding energy storage options;
- pollution fees for polluting energy sources; and
- continued and consistent support (e.g., through tax credits) to help renewables become competitive with fossil fuels for electricity generation.

Over the last five years, major policy developments related to renewable electricity have included the following:

- Renewables Deployment - Recent years have seen rapid growth in renewable electricity generation, albeit from a small base. Non-hydroelectric renewables grew from 2.1 percent of total U.S. electricity generation in 2008 to nearly 3.4 percent in 2009 (through August).[39] Wind power has seen the largest growth in absolute terms. U.S.? cumulative installed wind power capacity projected for the end of 2009 is nearly five times larger than the wind power capacity at the end of 2003, and wind power grew at a compound annual growth rate of 37 percent from 2004 to 2009.[40]
- Tax Credits - The PTC for qualified renewables expired at the end of 2003, but was renewed for one year by Congress in 2004.[41] EPAct05 extended the PTC for 2 years. The PTC was given short-term extensions again in 2006 and 2008 by EESA, which also expanded the PTC to include marine and hydrokinetic projects.[42] In 2009, ARRA extended the PTC for wind and other eligible renewables through 2012 and 2013, respectively. EPAct05 expanded the investment tax credit (ITC) for solar and

geothermal property to include fuel cells, microturbines, and hybrid solar lighting systems and to cover 30 percent of the investment (up from 10 percent). In 2008, EESA extended the ITC through 2016.

- Loan Guarantees – The DOE loan guarantee program created by EPAct05 included a provision for advanced renewables. ARRA funded loan guarantees for renewable electricity and transmission projects (projected to guarantee up to $60 billion in loans). As of January 2009, the DOE had finalized a single loan guarantee (for $535 million) to a solar PV manufacturer.[43]
- RD&D - EISA07 directed DOE to conduct R&D for renewables (e.g., solar thermal, geothermal, hydrokinetic) and energy storage; it also included provisions to promote smart grid R&D, deployment, and standards-setting. ARRA funded renewable R&D (especially biomass and geothermal), advanced battery/battery component manufacturing facilities, grid modernization/smart grid, and electricity storage.
- "Breakthrough" Technologies - ARRA provided $400 million for ARPA-E; this was the first funding appropriated to ARPA-E since its authorization in 2007. As of December 2009, DOE had awarded $250 million through ARPA-E to transformational energy research projects—many related to renewable electricity generation and energy storage.
- Renewable Electricity Standards – Since 2004, Congress has debated but not passed a national renewable electricity standard. In 2004, 13 states had enacted renewable portfolio standards (RPSs).[44] At the end of 2009, 31 states plus the District of Columbia had mandatory renewable or alternative energy standards for electricity.[45]

Conclusions

The past five years have seen significant growth in low-carbon technology RD&D, but more is needed over the short, medium, and long term as well. Similarly, new and expanded tax and other financial incentives for commercial deployment of low-carbon technology are likely to spur more rapid growth. A range of policies have also sought to address technology-specific obstacles; such policies will need to be continued and expanded. Sustained and increased public and private leadership, consumer and citizen involvement, engagement of the research community, and international cooperation will also be key to the transition to a low-carbon future.

Using a portfolio of energy technologies and policies, the United States can be well into a transition to a low-carbon future by 2050. However, achieving such a future necessitates a significant, explicit, and comprehensive commitment to climate-friendly policy and investment. An effective policy approach should work to both push and pull a wide variety of low-carbon energy technologies into the market. Policies like those discussed above can continue to push low-carbon technologies and stimulate further improvements in key technologies, but the most critical step—i.e., putting a price on carbon as a GHG cap-and-trade program would do—is still needed to pull these technologies into the marketplace.

Figure 1: U.S. DOE Energy RD&D Spending FY1978-FY2010 Request[46]

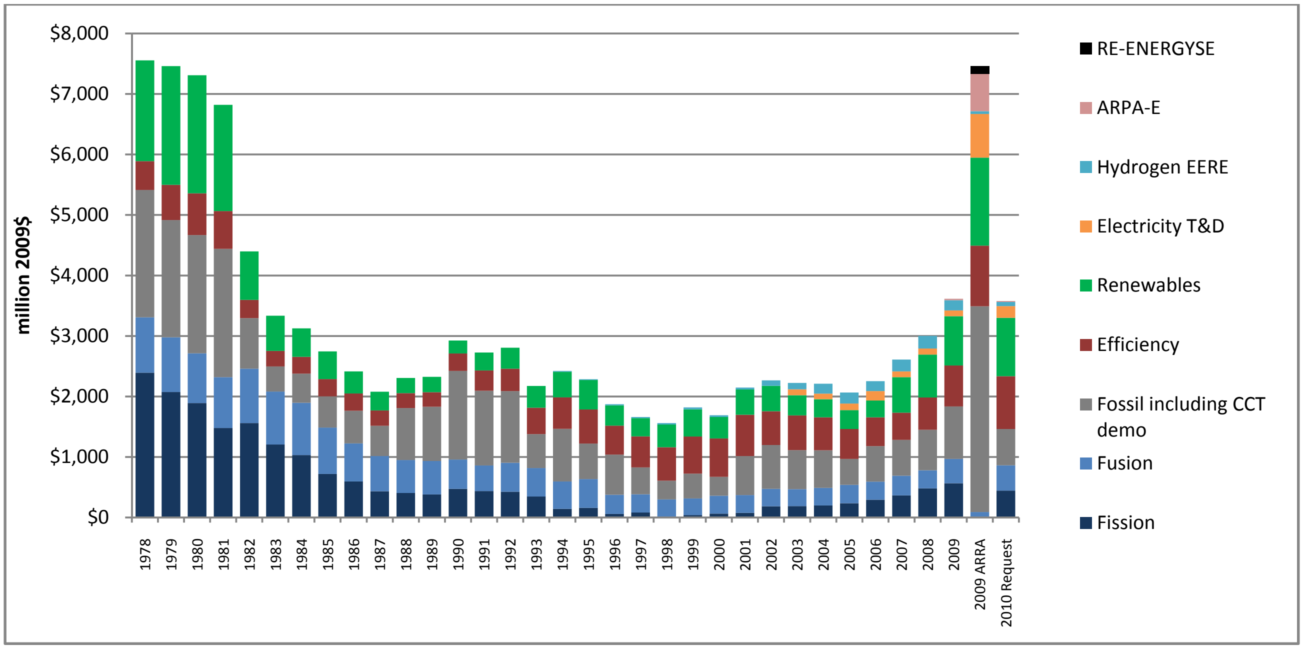
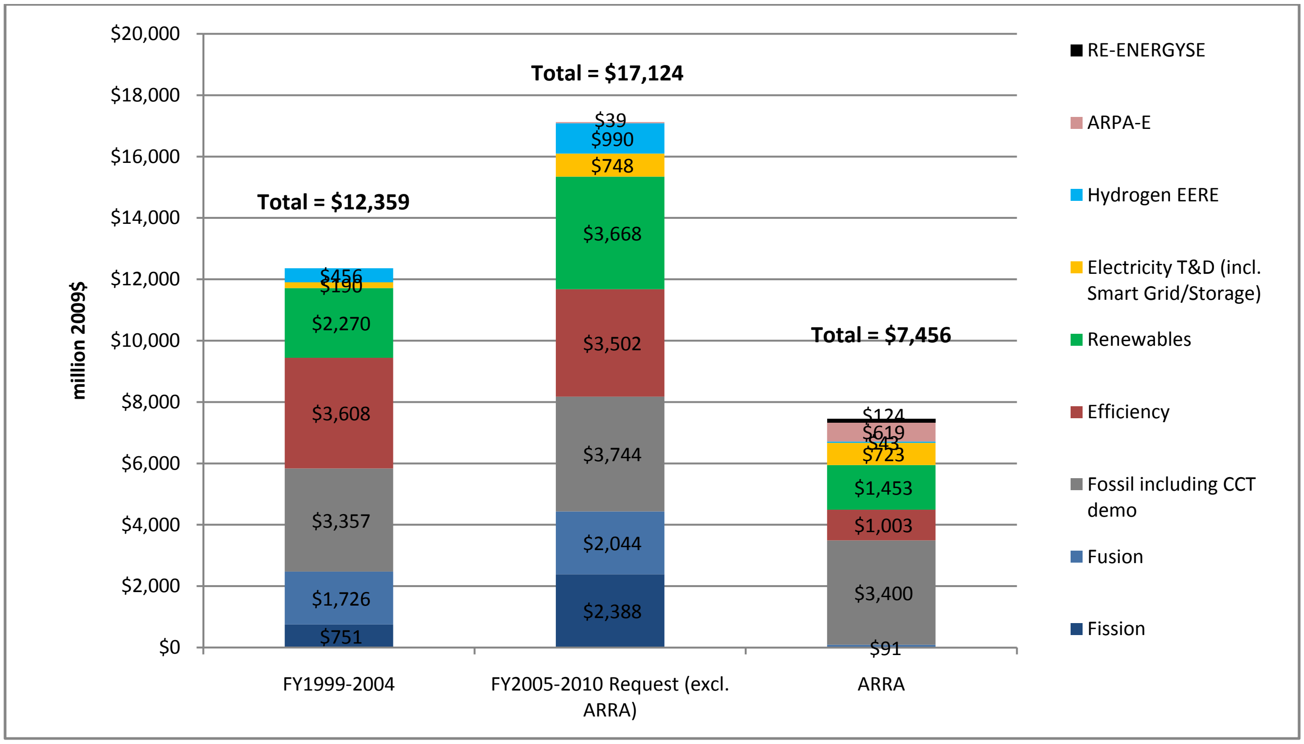


Figure 2: Cumulative Spending on U.S. DOE Energy RD&D[47]



Notes for Figures 1 and 2: CCT = clean coal technology; T&D = transmission and distribution; RE-ENERGYSE funds energy-related higher education. Hydrogen EERE refers to energy efficiency and renewable energy-related hydrogen RD&D.

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[1] Intergovernmental Panel on Climate Change (IPPC), *Climate Change 2007: Mitigation of Climate Change: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. The IPCC concluded that a 50 to 80 percent reduction of global CO_2 emissions from the 2000 emissions levels by 2050 can limit the long-term global average temperature rise to 2.0 to 2.4 degrees Celsius

[2] The political accord agreed to by the United States and many other nations at the 2009 Copenhagen climate summit established 2 degrees as the aspirational goal for limiting climate change. See the Pew Center's summary of the summit.

[3] International Energy Agency (IEA), *Energy Technology Perspectives 2008: Scenarios and Strategies to 2050*, 2008. See Table 2.3.

[4] Although the largest potential for reducing GHG emissions lies in the reduction of CO_2 associated with fossil-fuel energy production and consumption, the reduction of non-CO_2 GHGs also offer opportunities for reducing GHG concentrations in the atmosphere. See Reilly, J.M., H.D. Jacoby, and R.G. Prinn, *Multi-gas Contributors to Global Climate Change: Climate Impacts and Mitigation Costs of Non-CO_2 Gases*, Pew Center on Global Climate Change, 2003.

[5] See Lempert, Robert J., Steven W. Popper, Susan A. Resetar, and Stuart L. Hart, *Capital Cycles and the Timing of Climate Change Policy*, Pew Center on Global Climate Change, 2002. See also Mintzer, Irving M., J. Amber Leonard, and Peter Schwarz, *U.S. Energy Scenarios for the 21st Century*, Pew Center on Global Climate Change, 2003.

[6] The Pew Center/NCEP Workshop on "The 10-50 Solution: Technologies and Policies for a Low-Carbon Future" held at the St. Regis Hotel in Washington, D.C., March 25–26, 2004. More than 100 policy-makers, business leaders, NGO representatives, and leading experts participated in the workshop. A summary of the workshop, a list of attendees, and full workshop proceedings can be found on the Pew Center's website.

[7] This overview by the staff of the Pew Center on Global Climate Change aims to summarize some of the main points and common themes from the workshop papers and the discussions at the workshop and to identify the most significant, relevant policy developments since the workshop. It may not represent the views of the NCEP, of all the authors of 10-50 Workshop background papers, or of all of the 10-50 Workshop participants. The original brief from February 2005 that summarized the 10-50 Workshop can be found on the Pew Center's website.

[8] For a detailed summary of EPAct05, see the Congressional Research Service report, *Energy Policy Act of 2005: Summary and Analysis of Enacted Provisions*, RL33302.

[9] For background on ARPA-E, see the Congressional Research Service report, *Advanced Research Projects Agency - Energy (ARPA-E): Background, Status, and Selected Issues for Congress*, RL34497.

[10] For a detailed summary of EISA07, see the Congressional Research Service report, *Energy Independence and Security Act of 2007: A Summary of Major Provisions*, RL34294.

[11] U.S. Environmental Protection Agency (EPA), "EPA Finalizes the Nation's First Greenhouse Gas Reporting System/Monitoring to begin in 2010," Press Release, 22 September 2009.

[12] For a detailed summary of the energy provisions in EESA, see GovTrack.

[13] For a detailed summary of energy provisions in ARRA, see the Congressional Research Service report, *Energy Provisions in the American Recovery and Reinvestment Act of 2009*, R40412. See also the Pew Center's summary of the funding, loan guarantee, and tax expenditure amounts in ARRA.

[14] For a discussion of the market failures and barriers that limit energy efficiency, see the relevant briefs in the Pew Center's Climate TechBook.

[15] For an explanation of how smart grid technology enables energy efficiency, see the Pew Center's Smart Grid Climate TechBook brief.

[16] For more on smart grid funding from ARRA, see Pew Center blog post.

[17] See, for example, Voorhees, Josh, "Obama Favors Plug-in Hybrids over Hydrogen Vehicles," *Scientific American*, 10 July 2009.

[18] The initial H-Prize competition (scheduled to be completed in February 2010) is for demonstrated advancements in developing an on-board hydrogen storage material for light-duty vehicles. See the H-Prize website for details.

[19] Whoriskey, Peter, "The Hydrogen Car Gets Its Fuel Back," *Washington Post*, 17 October 2009.

[20] See DOE Hydrogen website.

[21] For more information, see the Pew Center's Federal Vehicle Standards webpage.

[22] For more information, see DOE's FutureGen website.

[23] For more information, see DOE's loan guarantee program website.

[24] For more information, see DOE's website for Clean Coal Technology & the Clean Coal Power Initiative.

[25] For more information, see DOE's Carbon Sequestration Regional Partnerships website.

[26] See Burruss et al., *2009, Development of a Probabilistic Assessment Methodology for Evaluation of Carbon Dioxide Storage*, U.S. Geological Survey Open-File Report 2009–1035.

[27] See the National Energy Technology Laboratory's (NETL) *2008 Carbon Sequestration Atlas II of the United States and Canada*.

[28] For more information, see EPA's Geologic Sequestration of Carbon Dioxide website.

[29] "Joint Statement by G8 Energy Ministers," Aomori, Japan, 8 June 2008.

[30] Carbon Sequestration Leadership Forum (CSLF), "CSLF Endorses Ten New Carbon Capture and Storage Projects," Press Release, 12 October 2009.

[31] DOE, "Readout of Secretary Chu Meetings on Carbon Capture and Sequestration and State Grid," Press Release, 16 July 2009.

[32] For more information, see DOE's Nuclear Power 2010 website.

[33] For more information on EPAct05's incentives for nuclear power, see the Congressional Research Service's report, *Nuclear Energy Policy*, 2008, RL33558.

[34] DOE, "Department of Energy Issues Final Rule on Loan Guarantees," Press Release, 7 December 2009.

[35] "Progress Report: The Transformation to A Clean Energy Economy," Memo for the President from the Vice President, 16 December 2009.

[36] For details, see the Nuclear Energy Institute (NEI), *Status and Outlook for Nuclear Energy in the United States*, October 2009.

[37] *Nuclear Engineering International*, "US GNEP Programme Dead, DOE Confirms," 15 April 2009.

[38] Heinrich, Mark and Sylvia Westall, "IAEA Governors Approve First Atom Fuel Bank Plan," *Reuters*, 27 November 2009.

[39] U.S. Energy Information Administration (EIA), *Electric Power Monthly*, November 2009, see Table 1.1.

[40] American Wind Energy Association (AWEA), *3rd Quarter 2009 Market Report*.

[41] For more detail on the PTC see the Database of State Incentives for Renewables & Efficiency (DSIRE), Renewable Electricity Production Tax Credit (PTC).

[42] For an explanation of marine and hydrokinetic electricity generation, see the Pew Center's Climate TechBook.

[43] DOE, "Vice President Biden Announces Finalized $535 Million Loan Guarantee for Solyndra," Press Release, 4 September 2009.

[44] Wiser, Ryan et al., *Evaluating Experience with Renewables Portfolio Standards in the United States*, 2004.

[45] See the Pew Center's Renewable & Alternative Energy Portfolio Standards.

[46] Gallagher, Kelly Sims and Laura Diaz Anadon, "DOE Budget Authority for Energy Research, Development, & Demonstration Database,"12 June 2009.

[47] Gallagher and Anadon, 2009.