Congressional Research Service

Report R40103

Carbon Control in the U.S. Electricity Sector: Key Implementation Uncertainties

Paul W. Parfomak, Specialist in Energy and Infrastructure Policy

December 23, 2008

Abstract. This report examines key uncertainties associated with the CO2 emissions abatement measures identified in Figure 1. The report describes each measure and discusses expectations for its potential in the context of past experience, technical challenges, infrastructure requirements, or other factors which may inform performance expectations. For each measure, it identifies and discusses a critical uncertainty which may influence its overall viability. The report concludes with a discussion of the implications of these uncertainties in the context of the congressional carbon control debate.

Congressional Research Service

Carbon Control in the U.S. Electricity Sector: Key Implementation Uncertainties

Paul W. Parfomak
Specialist in Energy and Infrastructure Policy

December 23, 2008

Congressional Research Service
7-5700
www.crs.gov
R40103

CRS Report for Congress
Prepared for Members and Committees of Congress

Summary

Congress has been debating a range of potential initiatives for reducing atmospheric CO_2 from U.S. sources. Legislative proposals would seek to limit U.S. CO_2 emissions to historical levels through emissions caps, carbon taxes, or other mechanisms. In the 110th Congress, the most prominent CO_2 proposals sought reductions of nationwide CO_2 emissions to 1990 levels or lower by 2030. President-elect Barack Obama has proposed cutting carbon CO_2 emissions to 1990 levels by 2020, and by an additional 80% by 2050.

A fundamental question arising from carbon control proposals is how the CO_2 reduction targets can be achieved in the electricity industry, which is responsible for nearly 40% of U.S. CO_2 emissions. It appears from the policy research and technical studies that substantially reducing CO_2 emissions in the U.S. electricity sector over the next few decades would likely require every key carbon mitigation measure at the nation's disposal. However, it is also clear that significant uncertainty exists about the potential of individual measures to achieve their hoped-for carbon impact:

- **Energy efficiency**—Can the United States overcome socioeconomic barriers to achieve four times more potential savings than ever before?
- **Renewable energy**—Will there be enough transmission for wind power? Is there enough land to grow the needed biomass?
- **Nuclear power**—Could the United States build new plants fast enough to matter?
- **Advanced coal power**—Will banks fund them and regulators approve them?
- **Carbon capture and sequestration**—Will the technology be commercially deployable in 10 years, 25 years, or never?
- **Plug-in hybrid electric vehicles**—How much "low carbon" electricity would be available to charge their batteries?
- **Distributed energy resources**—Would carbon costs change distributed energy economics enough to spur deployment?

As the nation's CO_2 mitigation policies develop, the inherent uncertainty associated with specific carbon measures may be a critical concern. Commitments to specific carbon emissions targets over time, or to a specific schedule of carbon costs (whatever form they may take) may be greatly affected by the success of the underlying measures relied upon to achieve them. Notwithstanding the best efforts of federal policy makers, it is possible that, given the uncertainties each faces, few if any of the major measures proposed to moderate U.S. carbon emissions will achieve their anticipated impacts in a 20-year time frame. As Congress considers implementing CO_2 policies, keeping a close eye on the technology and market developments associated with every key measure could be a priority. Balancing responses to energy market volatility and unexpected structural changes against the need for a predictability in R&D and private capital investment may be essential to maintaining the nation on course to meaningful atmospheric CO_2 reduction.

Contents

Figures

Contacts

Federal policymakers have long been concerned about the impact of manmade carbon dioxide (CO_2) emissions on global climate change. To address these concerns, Congress has been debating a range of potential initiatives for reducing atmospheric CO_2 from U.S. sources. Legislative proposals would seek to limit U.S. CO_2 emissions to specific (historical) levels through emissions caps, carbon taxes, or other regulatory mechanisms. Many of these proposals dictate or anticipate a declining long-term trajectory for annual U.S. carbon emissions. In the 110th Congress, the most prominent CO_2 proposals sought reductions of nationwide CO_2 emissions to 1990 levels or lower by 2030.[1] President-elect Barack Obama has proposed carbon reduction targets as well, intending to cut CO_2 emissions to 1990 levels by 2020, and by an additional 80% by 2050.[2]

A fundamental policy question which arises from carbon control proposals is how the CO_2 reduction targets can be achieved. Numerous analysts have been examining this question and identifying specific measures to reach particular targets—especially in the electricity industry, which is responsible for nearly 40% of U.S. CO_2 emissions. In the electricity sector, these measures typically include some combination of energy efficiency, renewable energy, nuclear power, advanced fossil-fuel power generation, carbon capture and sequestration, plug-in hybrid electric vehicles, and distributed energy resources. **Figure 1** illustrates the CO_2 abatement potential of these measures in the electricity sector as estimated in a widely cited analysis by the Electric Power Research Institute (EPRI). In the EPRI example, overall CO_2 emissions associated with the electricity sector would be reduced below 1990 levels by 2030. Other studies have generated their own projections, with alternative targets and assumptions leading to distinct trajectories for CO_2 emissions and different contributions from the various abatement measures.[3]

Analyses like that in **Figure 1** are important for understanding the potential opportunities and limitations of specific technological measures which may be needed to meet CO_2 abatement goals. However, with their focus on technical potential, such studies often have difficulty conveying in a straightforward way the key infrastructural, environmental, regulatory, or operational uncertainties which might affect how much of that potential could practically be achieved.[4] These uncertainties, nonetheless, are of critical concern to legislators overseeing existing carbon-related programs or considering future CO_2 abatement policies. In addition to their technical aspects, Congress faces a need to gauge the overall viability of specific CO_2 abatement measures—what are their prospects for helping to achieve CO_2 targets in the electricity sector. Legislators also face a need to assess the time frame over which such measures could be expected to work, and how these measures may fit together to achieve overall CO_2 abatement goals under a national carbon policy.

---

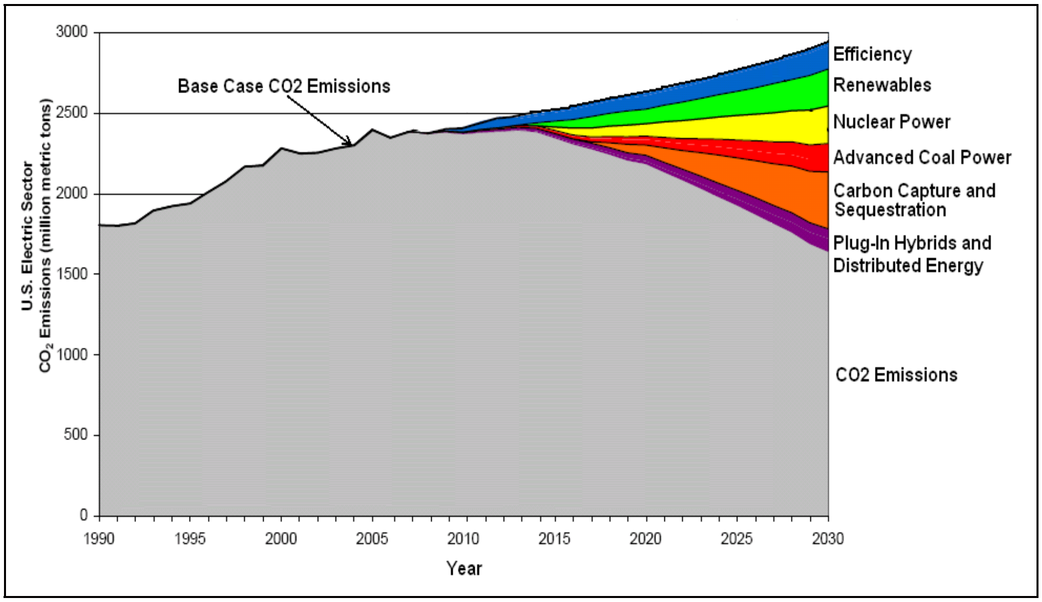
[1] World Resources Institute, "Comparison of Legislative Climate Change Targets," (Washington, DC: June 18, 2008): 3.

[2] President-elect Barack Obama, Remarks before the Governor's Global Climate Summit, Beverly Hills, California (November 18, 2008).

[3] For another prominent analysis, see also: S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science*, Vol. 305, No. 5686 (August 13, 2004): 968 - 972.

[4] See, for example: Seung-Rae Kim, Klaus Keller, and David F. Bradford, "Optimal Technological Portfolios for Climate-Change Policy Under Uncertainty: A Computable General Equilibrium Approach," Presented at the 10th International Society of Computational Economics Conference on Computing in Economics and Finance (Amsterdam: July 8-10, 2004).

Figure 1. Potential CO_2 Reductions in Electric Power



Source: Adapted from Barbara Tyran, Electric Power Research Institute, "The Power to Reduce CO_2 Emissions: The Full Portfolio," Slide presentation (May 15, 2008): 7. http://www.iea.org/Textbase/work/2008/roadmap/2a_Tyran_EPRI%20Roadmaps.pdf

This report examines key uncertainties associated with the CO_2 emissions abatement measures identified in **Figure 1**. The report briefly describes each measure and discusses expectations for its potential in the context of past experience, technical challenges, infrastructure requirements, or other factors which may inform performance expectations. For each measure, it identifies and discusses a critical uncertainty which may influence its overall viability. The report concludes with a discussion of the implications of these uncertainties in the context of the congressional carbon control debate.

Energy Efficiency and Conservation

When an energy conversion device, such as a household appliance or automobile engine, undergoes a technical change that enables it to provide the same service (e.g, cooling, lighting, motor drive) while using less energy it is said to have increased "energy efficiency." The energy-saving result of the efficiency increase is often called "energy conservation." The energy efficiency of buildings can likewise be increased through the use of certain design changes such as more insulation, thermal windows, improved ventilation, and solar orientation.[5] Energy efficiency is often viewed as interchangeable with energy supply options like electric generation, oil, or natural gas. Energy efficiency can also reduce energy resource use and associated environmental impacts—like CO_2 emissions from power plants.

[5] Strictly speaking, "conservation" means "avoiding waste," but the term is typically used interchangeably with "efficiency" in the energy policy context, as it is in this report. "Efficiency" and "conservation" contrast with "curtailment" or "load management" which decrease output (e.g., turning down the thermostat) or services (e.g., driving less) to decrease energy use at specific times. Curtailment is often employed as an emergency measure.

Electricity-Efficiency Potential

Baseline improvements in energy efficiency occur over time as an economic response to changes in energy prices, the availability of new technology, turnover in end-use equipment, and other factors. However, conservation studies since the OPEC oil embargoes of the 1970s have identified substantial potential for energy efficiency improvements above baseline levels. One seminal analysis in 1976 stated

> technical fixes in new buildings can save 50 percent or more in office buildings and 80 percent or more in some new houses.... [B]y 1990, improved design of new buildings and modification of old ones could save a third of our current total national energy use—and save money too.[6]

A 1981 study by the Solar Energy Research Institute[7] likewise found that "through energy efficiency, the U.S. can achieve a full-employment economy and increase worker productivity, while reducing national energy consumption by nearly 25 percent."[8] The study further concluded that "the consumption of electricity can be reduced to a point where, on a national basis, demands through the end of the [twentieth] century can be met with generating equipment now operating or in advanced stages of construction."[9]

More recent studies continue to identify significant electricity conservation potential. The "Five Lab Study" in 1997 estimated a technical electricity savings potential of approximately 23%, and a maximum "achievable" potential of 15% among residential and commercial buildings, assuming aggressive policies promoting conservation and a $50/metric tons (1993 dollars) carbon cost.[10] A 2004 meta-analysis by the American Council for an Energy-Efficient Economy of several regional studies reported a technical electricity conservation potential of 33%, and an achievable potential of 24% over a 5 to 15 year time horizon, depending upon the study.[11] The U.S. Department of State's 2006 *Climate Action Report* concludes that "by using commercially available, energy-efficient products, technologies, and best practices, many commercial buildings and homes could save up to 30 percent on energy bills."[12]

---

[6] Amory B. Lovins, "Energy Strategy: The Road Not Taken?" *Foreign Affairs*, Vol. 55 No. 1 (October 1976).

[7] Now the National Renewable Energy Laboratory.

[8] Solar Energy Research Institute (SERI), *A New Prosperity: Building a Sustainable Energy Future*, Brick House Publishing (Andover, MA: 1981): 1.

[9] Ibid: 2.

[10] Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy-Efficient and Low-Carbon Technologies by 2010 and Beyond*, (1997) :3.3-3.4. http://enduse.lbl.gov/projects/5lab.html The five laboratories are Oak Ridge National Laboratory, Lawrence Berkeley National Laboratory, Pacific Northwest Laboratory, Argonne National Laboratory, and the National Renewable Energy Laboratory.

[11] Steven Nadel, Anna Shipley and R. Neal Elliott, "The Technical, Economic and Achievable Potential for Energy-Efficiency in the U.S. – A Meta-Analysis of Recent Studies," *Proceedings of the 2004 ACEEE Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy (Washington, DC: 2004).

[12] U.S. Department of State, *U.S. Climate Action Report—2006* (July 2007): 40.

Impacts from Electricity-Efficiency Initiatives

Both federal and state agencies have implemented a multitude of electricity efficiency initiatives over the last 40 years to capture energy efficiency potential in the electricity sector. These initiatives have included appliance, equipment, and building efficiency standards; electric utility-administered conservation incentives;[13] consumer information campaigns; and other initiatives. Notwithstanding these efforts, the levels of incremental electricity conservation actually achieved since the 1970s have been more modest than the 25%-30% suggested in conservation potential studies. A 2004 analysis examining a comprehensive range of both federal and utility-sponsored conservation and energy efficiency programs (including federal efficiency standards) administered through 2000 concluded as follows:

> [P]rograms for which *ex post* quantitative estimates of energy savings exist are likely to have collectively saved up to 4.1 quads of electricity annually. These estimates typically reflect the cumulative effect of programs (e.g., all appliance efficiency standards, past and present) on annual energy consumption. This total energy savings represents about 6% of annual nontransportation energy consumption....[14]

A study of California's 2001 energy demand reduction initiative (promoted heavily as an emergency measure to avoid blackouts during the state's electricity crisis) reported 6% reduced electricity usage compared to the prior year, although only 25%-30% of this reduction was "attributable to savings from energy efficiency or onsite generation projects ... likely to persist for many years."[15] Consistent with these studies, a 2008 analysis by EPRI projected a "realistic" U.S. electricity savings potential of 7% beyond baseline levels which would occur without additional market intervention.[16]

Uncertainty about the Efficiency Opportunity

Taken together, the studies of technical conservation potential and actual conservation impacts suggest a perpetual opportunity for incremental electricity conservation on the order of 25%—more than four times the savings such programs have actually realized. Moving beyond the 5% to 7% electricity savings range has been a persistent challenge to conservation proponents, primarily because of the diffuse nature of the efficiency opportunity and the economic complexity of decision making and capital investment by electricity consumers.

> Students of end-use markets have long been puzzled by the lack of adoption of ostensibly cost-effective energy efficiency technologies. A rich literature has developed around this

[13] Commonly referred to as "demand-side management" or "DSM" programs.

[14] Kenneth Gillingham, Richard G. Newell, and Karen Palmer, *Retrospective Examination of Demand-Side Energy Efficiency Policies*, Resources for the Future, RFF DP 04-19 REV (June 2004; revised September 2004): 63-64.

[15] Charles A. Goldman, Joseph H. Eto, and Galen L. Barbose, *California Customer Load Reductions during the Electricity Crisis: Did they Help to Keep the Lights On?*, Lawrence Berkeley National Laboratory, LBNL-49733 (May 2002): iii, 20.

[16] Michael Howard, Senior Vice President, "Electric Power Research Institute, Energy Efficiency: How Much Can We Count On?" Presented at the Edison Foundation Conference, Keeping the Lights On: Our National Challenge, (April 21, 2008): 14. http://www.edisonfoundation.net/events/2008-04-21/EPRIPresentation.pdf

> question, and evidence for various barriers to adoption of efficiency technologies is widespread.[17]

Among the barriers to energy efficiency analysts have identified are–

- limited market availability of new efficiency measures,
- incomplete consumer information about efficiency options,
- insufficient capital for efficiency investments,
- fiscal or regulatory policies discouraging efficiency investments,
- builder focus on first costs vs. lifecycle costs,
- lack of consumer focus on energy costs relative to other costs, and
- energy prices not reflecting the full social costs of energy supply.[18]

Conservation advocates and federal policy makers have proposed a range of additional policy approaches to further overcome these barriers, but there is limited consensus on which policies would be effective and how much additional conservation they might achieve. As a study of conservation barriers from Lawrence Berkeley National Laboratory concluded–

> Although these rationales provide a basis for some type of intervention, we acknowledge that they do not justify any particular intervention.... [W]e suggest that differences of opinion about the appropriateness of public policies stem not from disputes about whether market barriers exist, but from different perceptions of the magnitude of the barriers and the efficacy and (possibly unintended) consequences of policies designed to overcome them....[19]

There have been numerous legislative proposals to promote electricity efficiency and conservation.[20] The key uncertainty faced by all of them, and future conservation proposals, is whether, as a whole, they may cost-effectively capture much more of the "latent" electricity conservation potential than such programs have done in the past. Carbon control studies which project electricity efficiency savings on the order of 5% to 10% over a 20-year time frame appear consistent with U.S. conservation program experience, and may be aided by any future costs of CO_2 emissions if they are reflected in electricity prices. Unlike large physical infrastructure, however, such as power plants or electric transmission lines, conservation impacts do not necessarily "scale up" to achieve greater impacts simply by increasing the size or funding of a given conservation program. Efficiency potential is also extremely diffuse—existing literally at the individual light socket level in nearly every household. Consequently, policy makers seeking large conservation impacts may need to try alternative or more aggressive policies (e.g., very

[17] J.G. Koomey, C.A. Webber, C.S. Atkinson, and A. Nicholls, "Addressing Energy-Related Challenges for the U.S. Buildings Sector: Results from the Clean Energy Futures Study," Energy Policy, Vol. 29, No. 14 (November 2001): 1211.

[18] Howard Geller and Sophie Attali, "The Experience with Energy Efficiency Policies and Programmes in IEA Countries: Learning from the Critics," International Energy Agency, IEA Information Paper (August 2005): 23.

[19] William H. Golove and Joseph H. Eto, *Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency*, LBL-38059, UC-1322, Lawrence Berkeley National Laboratory (March 1996): xii-xiii.

[20] For further analysis of conservation proposals, see CRS Report RL33831, *Energy Efficiency and Renewable Energy Legislation in the 110th Congress*, by Fred Sissine, Lynn J. Cunningham, and Mark Gurevitz.

strict building efficiency codes) with little track record upon which to base projections of future effectiveness.

Renewable Energy

Renewable energy supplies in the electricity sector typically include the following types of power plants: geothermal, solar, wind, biomass, and municipal solid waste/landfill gas.[21] Many carbon control advocates and federal policy makers have high expectations for the potential of renewable generation to help reduce CO_2 emissions in the United States. The widely publicized Pickens Plan, for example, announced by T. Boone Pickens in July, 2008, envisions deploying enough wind generation in the Great Plains states to produce 20% of U.S. electricity by 2018.[22] The Obama-Biden presidential campaign similarly pledged to establish a federal Renewable Portfolio Standard requiring that 25 percent of electricity consumed in the U.S. be "derived from clean, sustainable energy sources, like solar, wind, and geothermal" by 2025.[23] Some groups have advocated even more aggressive targets for U.S. renewable power development.[24] Others are less optimistic. EPRI, for example, assumes renewable sources (excluding hydroelectric generation) could contribute 9% of electricity production in the electric power sector by 2030.[25]

According to the Energy Information Administration (EIA), biomass and wind generation are the two types of renewable power with the greatest overall economic potential, and therefore, the greatest potential to reduce CO_2 emissions.[26] Biomass and wind power are inherently different technologies, however, so they face distinct uncertainties related to their potential expansion under a national program of carbon control. They are discussed, in turn, in the following sections.

Wind Power

Wind power does not consume fuel and produces no CO_2, so it is an extremely attractive technology for CO_2 mitigation in the electricity sector.[27] Wind generation technology is also fairly mature. It has been deployed commercially throughout the United States—albeit with federal assistance in the form of renewable energy production tax credits and state renewable energy

[21] This report excludes hydroelectric power generation from the renewables category because of environmental constraints and associated limits on potential new hydro capacity.

[22] T. Boone Pickens, *The Plan*, Internet page (August 7, 2008). http://www.pickensplan.com/theplan

[23] Obama-Biden, *Barack Obama and Joe Biden: New Energy for America*, Fact sheet (August 3, 2008). http://www.barackobama.com/pdf/factsheet_energy_speech_080308.pdf; A 2004 Illinois state senate bill cosponsored by Senator Barack Obama (SB2321, 93rd General Assembly) excluded new construction hydroelectric power from its proposed state RPS.

[24] See, for example: American Council On Renewable Energy, The Outlook on Renewable Energy in America Volume II: Joint Summary Report (Washington, DC: March 2007).

[25] Barbara Tyran, Electric Power Research Institute, (May 15, 2008): 7.

[26] U.S. Energy Information Administration, *Annual Energy Outlook 2008* (June 2008): 70.

[27] For a more comprehensive analysis of wind power, see CRS Report RL34546, *Wind Power in the United States: Technology, Economic, and Policy Issues*, by Jeffrey Logan and Stan Mark Kaplan.

portfolio standards.[28] Wind plants accounted for just over 1% of U.S. electricity generation in 2008.[29]

A 1991 study of available U.S. wind resources by Pacific Northwest Laboratory concluded that "the wind electric potential that could be extracted with today's technology ... across the United States is equivalent to about 20% of the current U.S. electric consumption."[30] A 2003 analysis by the National Renewable Laboratory similarly concluded that "by 2050, wind could account for about 25 percent of all generation in the U.S."[31] Consistent with these technical assessments, the Department of Energy (DOE) recently examined the practical possibility of 20% wind power production in the United States by 2030 (a longer time frame than either the Pickens or Obama-Biden campaign proposals). The DOE report concluded that a "20% Wind Scenario in 2030, while ambitious, could be feasible."[32]

Transmission Requirements

Although studies have identified substantial untapped wind power potential for the United States, the rapid expansion of U.S. wind generation faces significant challenges. According to the DOE, these challenges are related to the integration of intermittent wind power into regional electricity control areas, cost reduction and efficiency improvement for wind turbine technology, and wind facility siting issues.[33] The principal challenge the DOE identifies, however—and, according to many experts, the principal uncertainty facing wind power—is "investment in the nation's transmission system."[34]

As **Figure 2** shows, the nation's most abundant wind resources tend to be located far from population centers where the electricity is needed. Consequently, wind generators require a robust transmission grid to move power to the market. But the U.S. transmission network is constrained, significantly limiting the availability of transmission capacity to new wind farms. Transmission owners, in agreement with the DOE, have pointed to transmission grid constraints as the single greatest impediment to aggressive wind power expansion.

> Although there is sufficient evidence showing that wind generation can be reliably integrated into the electricity system, ... obstacles to new generation sources continue to exist due to the lack of adequate transmission system access. The remoteness of wind sources, an underinvested transmission infrastructure, and lack of workable transmission investment policies all hinder the development of wind power in the US.[35]

---

[28] Federal tax credits are provided for under the Energy Policy Act of 1992 (P.L. 102-486 § 1914) and subsequent statutes.

[29] U.S. Energy Information Administration, *Electric Power Monthly*, DOE/EIA-0226 (2008/10) (October 28, 2008): Tables 1.1 and 1.1a. This figure is year to date through July.

[30] D. L. Elliott, L. L. Wendell, G.L. Gower, *An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States 1991*, Pacific Northwest Laboratory, PNL-7789 (August, 1991): iii.

[31] Walter Short and Nate Blair, The Long-Term Potential of Wind Power in the U.S., *Solar Today* (November/December 2003): 29.

[32] U.S. Department of Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, DOE/GO-102008-2567 (July 2008): 1.

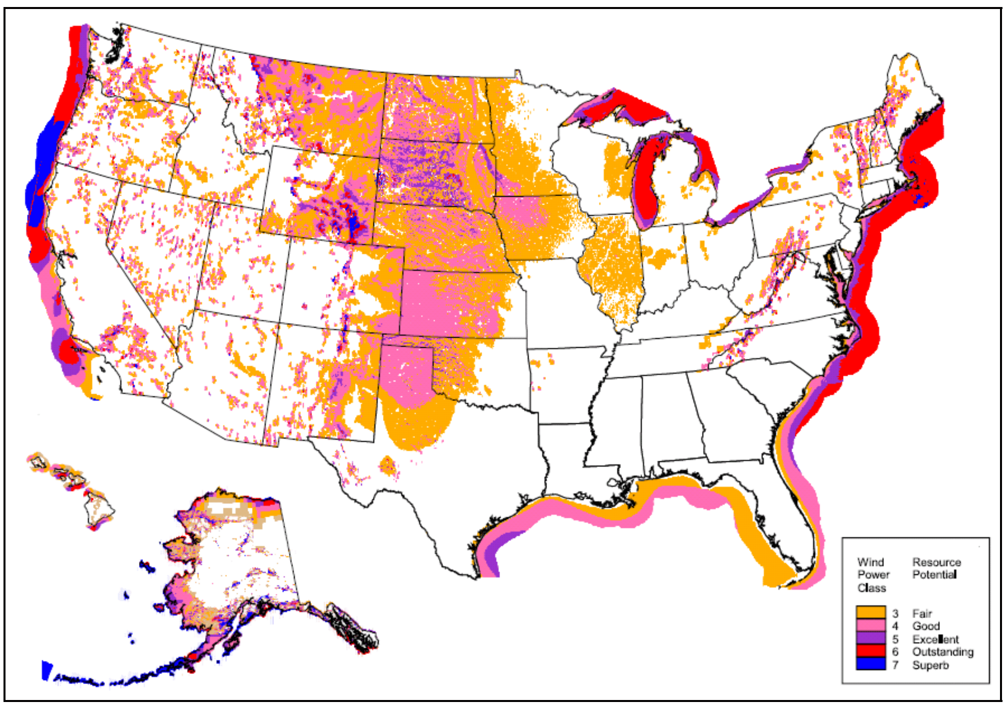
[33] U.S. Department of Energy (July 2008): 14.

[34] Ibid.

[35] National Grid Corp., *Transmission and Wind Energy: Capturing the Prevailing Winds for the Benefit of Customers* (Westborough, MA: September 2006): 9. http://www.nationalgridus.com/non_html/c3-3_NG_wind_policy.pdf

The DOE study estimates that to achieve 20% wind energy in the United States would involve building "more than 12,000 miles of additional transmission, at a cost of approximately $20 billion in net present-value terms."[36] A similar conceptual transmission plan by the American Electric Power Company (AEP) to integrate 20% wind energy estimated that 19,000 miles of new 765 kV transmission lines would be needed, with a net present value of $26 billion.[37] While such plans put a needed focus on some of the specific requirements for a U.S. transmission upgrade, marshaling the level of investment to expand transmission capacity quickly could stress the supply and price of materials, labor, and other resources. Any wind power project requiring the construction of extensive new transmission infrastructure from remote to populated areas also could face concerted community opposition to the siting of those transmission lines. Public challenges to electric transmission projects have long been considered among the most serious and most intractable challenges in the U.S. energy sector.[38] With wind projects in mind, Congress included provisions increasing federal authority to approve interstate electric transmission projects in the Energy Policy Act of 2005 (P.L. 109-58 § 1221). Nonetheless, challenges continue to delay or prevent new transmission development in some regions.

Figure 2. Wind Power Resources in the United States



Source: National Renewable Energy Laboratory (2008).

[36] U.S. Department of Energy (July 2008): 95. This compares to 200,000 miles of existing transmission lines operating at 230 kV and above.

[37] AEP, "Interstate Transmission Vision for Wind Integration," *Electricity Today* (September 2007): 30-37.

[38] Shalini P. Vajjhala, "Siting Difficulty and Transmission Investment,"*IAEE Energy Forum* (International Association for Energy Economics: 2nd Quarter 2008): 5-7; North American Electric Reliability Council, *2006 Long-Term Reliability Assessment* (October 2006): 22-23.

Transmission Grid Uncertainty

If U.S. wind power is beginning to face transmission constraints at only 1% of total U.S. electricity production, analysts raise concerns about the practicality of transmitting 20 times that amount of wind power in the near term. In its 2007 wind program plans, for example, the DOE itself states that large wind power deployment projections "seem too good to be true."[39] A 2008 *New York Times* assessment makes the point more strongly: "Experts say that without a solution to the grid problem, effective use of wind power on a wide scale is likely to remain a dream."[40] The key uncertainty for wind power then, is whether the electric grid, after decades of under-investment, will expand sufficiently to support a rapid expansion of wind power.

Biomass Power Generation

Biomass power plants are combustion power plants that effectively recycle the CO_2 they emit through carbon sequestration in the crops grown (continuously) for fuel. Crops take up carbon dioxide from the air via photosynthesis as they grow and release it to the air when they are burned, so they cause no net increase in atmospheric CO_2.[41] Currently, most biomass power plants are fueled with waste materials from farming, forestry, and manufacturing (e.g., paper mill byproducts), although future expansion of biomass generation is expected to rely increasingly on dedicated fuel crops, such as poplar and switchgrass. Biomass power plants accounted for 1.3% of U.S. electricity generation in 2008.[42]

Biomass Fuel Supply

The principal factor which constrains the potential expansion of biomass power in the United States is the availability of biomass fuel. Biomass crops dedicated for power generation require land to grow—potentially in competition with food crops, lumber, and other traditional crops. Up to a point, such competition may not be a significant barrier to growth, since biomass power producers can use more waste from existing agricultural production (e.g., corn stalks) or grow fuel crops on U.S. lands not currently in agricultural production. A 2002 analysis by the Energy Information Administration concluded that U.S. biomass power generation capacity could increase by a factor of ten (from approximately 7 GW to 70 GW) through 2020 and not conflict with land requirements for existing crop production.[43] A 2005 analysis by the Department of Agriculture similarly concluded that forestland and cropland had the potential to support a seven-fold increase in the amount of biomass consumed for "bioenergy and biobased products."[44]

[39] U.S. Dept. of Energy, *Wind Energy Multiyear Program Plan For 2007–2012*, DOE/GO-102007-2451 (August 2007): 8.

[40] Matthew L. Wald, "Wind Energy Bumps into Power Grid's Limits," *New York Times* (August 27, 2008).

[41] Additional CO_2 is emitted by combustion of fossil fuels used to produce and process fuel crops, but those emissions are small compared to power plant combustion emissions.

[42] U.S. Energy Information Administration, *Electric Power Monthly*, DOE/EIA-0226 (2008/10) (October 28, 2008): Tables 1.1 and 1.1a. This value is year-to-date through July 2008.

[43] U.S. Energy Information Administration, *Biomass for Electricity Generation* (2002). http://www.eia.doe.gov/oiaf/analysispaper/biomass/ The study excludes biomass and coal co-firing.

[44] U.S. Department of Agriculture, *Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, (April 2005): 34.

Biomass Fuel Uncertainty

While studies like those above seem to support the potential expansion of biomass power production, others contradict them, raising critical questions about the limits of biomass fuel supply in the United States. As a 2008 RAND report states, "the cost and supply of future biomass feedstocks are highly uncertain factors."[45] This uncertainty is exacerbated by the possible expansion of biomass demand for transportation fuels such as ethanol and biodiesel—also motivated by CO_2 abatement objectives, but in the transportation sector. To the extent that biomass for power and biomass for liquid fuels are pursued aggressively and concurrently, overall competition for U.S. agricultural resources may become a serious concern.

> The significant resulting increase in biomass usage would require harvesting various energy crops at a scale that vastly exceeds current practice. Greatly increased biomass production could be accompanied by adverse environmental and economic impacts due to land conversion.[46]

Adverse impacts limiting biomass production for electric power could include increases in food prices. Some analysts, for example, have argued that corn price increases could be partly linked to the diversion of U.S. corn crops from food and feedstock supply to fuel ethanol production.[47] Biomass crops could also compete for land with forest carbon sequestration, the latter likely to increase in importance as a source of valuable CO_2 emissions offsets under future carbon control policies.[48] Some analysts have suggested that biomass fuel or food crops could be imported to alleviate domestic land constraints, but such imports would raise other concerns about U.S. energy and food supply independence. A 2007 MIT study concluded,

> If we restrict USA biofuels to those produced domestically, as much as 500 million acres of land would be required in the USA for biofuels production.... The result would be that the USA would need to become a substantial agricultural importer. This suggests that the idea that biomass energy represents a significant domestic energy resource in the USA is misplaced.[49]

Carbon release from previously untilled lands and from agricultural processing are other factors which may reduce the life cycle CO_2 benefits, and therefore the economic potential, of rapid biomass crop expansion.

Nuclear Power Generation

Nuclear power has been a significant part of the U.S. electricity sector for decades. The U.S. nuclear power industry currently comprises 104 licensed reactors at 65 plant sites in 31 states and

[45] Michael Toman, James Griffin, and Robert J. Lempert, *Impacts on U.S. Energy Expenditures and Greenhouse-Gas Emissions of Increasing Renewable-Energy Use,* RAND Corp. (2008): 38.

[46] Michael Toman, et al. (2008): xiii.

[47] For further analysis of renewable fuels issues, see CRS Report RL34265, *Selected Issues Related to an Expansion of the Renewable Fuel Standard (RFS)*, by Brent D. Yacobucci and Tom Capehart.

[48] U.S. Environmental Protection Agency, *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*, EPA 430-R-05-006 (November 2005): 4-12.

[49] John Reilly and Sergey Paltsev, "Biomass Energy and Competition for Land," MIT Joint Program on the Science and Policy of Global Change, Report No. 145 (April 2007):16.

generates about 20% of the nation's electricity.[50] Although no nuclear power plants have been ordered in the United States since 1978, and more than 100 reactors (all ordered after 1973) have been canceled, nuclear power is receiving renewed interest, prompted by a spike in fossil fuel prices, new federal subsidies and incentives—and possible CO_2 mitigation policies. As of September 30, 2008, the Nuclear Regulatory Commission had received, or anticipated receiving, license applications for 20 new nuclear reactor projects comprising 30 reactors in total.[51]

Because nuclear power generation is an established technology and produces virtually no direct CO_2 emissions, an expansion of U.S. nuclear power is viewed by many as essential for reaching long term CO_2 mitigation goals.[52] For example, in recent remarks before the Governor's Global Climate Summit, President-elect Obama stated that "we will tap nuclear power" as one way to help "build a clean energy future."[53] Likewise the Intergovernmental Panel on Climate Change *Fourth Assessment Report* states that "[n]uclear energy ... could make an increasing contribution to carbon free electricity and heat in the future."[54] EPRI proposes a 64% net increase in U.S. nuclear generating capacity, over four times the capacity addition in EIA's reference forecast, by 2030.[55] A 2003 study by MIT postulates a 300% net increase in U.S. nuclear power capacity by 2050.[56]

Nuclear Power Construction Uncertainty

Although nuclear energy proponents have high hopes for growth in this sector, not all groups concerned about climate change favor nuclear power as a key element of U.S. carbon control. The Natural Resources Defense Council, for example, argues that nuclear power may be too costly relative to clean energy alternatives, and may present unacceptable risks of nuclear proliferation and environmental damage from radioactive waste.[57] Other analysts raise questions about long-term nuclear fuel supply constraints, plant safety and security, and public acceptance.[58] These are all vital questions, any one of which could influence the viability of a U.S. nuclear resurgence. Perhaps a more fundamental uncertainty, however, even if these questions were resolved, is whether nuclear power plants could be constructed quickly enough to significantly reduce U.S. carbon emissions in a 20-year (or longer) time frame.

[50] U.S. Nuclear Regulatory Commission, *Information Digest 2008-20098*, NUREG-1350, Vol. 20 (August 2008): 32.

[51] U.S. Energy Information Administration, *Status of Potential New Commercial Nuclear Reactors in the United States* (October 9, 2008): Table 1. http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/com_reactors.pdf

[52] Processes related to nuclear generation, such as the mining, processing, and transportation of nuclear fuel, do generate CO_2 emissions. The levels of these emissions are the subject of debate. See Kurt Kleiner, "Nuclear Energy: Assessing the Emissions," *Nature Reports: Climate Change* (September 24, 2008).

http://www.nature.com/climate/2008/0810/pdf/climate.2008.99.pdf

[53] President-elect Barack Obama (November 18, 2008).

[54] Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007: Mitigation, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press: 2007): 253.

[55] Barbara Tyran, Electric Power Research Institute, (May 15, 2008): 7.

[56] Massachusetts Institute of Technology (MIT), *The Future of Nuclear Power* (2003): 3.

[57] Natural Resources Defense Council, *Nuclear Facts*, (February 2007): 1. http://www.nrdc.org/nuclear/plants/plants.pdf

[58] IPCC (2007): 253; MIT (2003): 21-24.

Uncertainty arises about the possible pace of U.S. nuclear expansion because nuclear power plants are large, complex, and must go through a lengthy and rigorous siting approval process. Furthermore, global capability to construct nuclear plants has diminished since the 1980s. A 2001 DOE analysis concluded that, because of limited growth in the nuclear sector over many years, there had been a "gradual erosion" in important nuclear infrastructure elements, such as qualified personnel in nuclear operations, qualified suppliers of nuclear equipment, and contractors with the necessary skills for nuclear design, engineering, and construction.[59] Little has changed since that report was released. Nuclear plant construction in the United States remains constrained by time, access to critical construction resources, and the availability of qualified engineering and construction firms.

Given the decline in U.S. nuclear infrastructure, there is ongoing debate among nuclear analysts about the prospect for rapid nuclear power expansion. A 2008 analysis by the Organisation for Economic Co-operation and Development (OECD) concluded that, based on historical experience from the 1970s and 1980s, and more recent growth in the world economy, "the capability could be rebuilt to construct 35-60 1000 GWe reactors per year" worldwide by 2030, and "[b]y 2050, capability could grow to 70-120 reactors per year."[60] Roughly consistent with this assessment, a 2008 study by the DOE's Nuclear Energy Advisory Committee concluded that, with additional infrastructure, it would be "plausible," albeit "a major challenge," to build 30 new U.S. reactors by 2030.[61] The latter rate of construction is substantially lower than that during the peak period of U.S. nuclear development, from 1963 to 1985, during which time 77 nuclear reactors were ordered, constructed, and began commercial operation.[62]

Others are more pessimistic about the potential for a rapid expansion of nuclear power in the United States. For example, one analyst concludes that "contrary to the public's perception and the industry's efforts, nuclear power will continue [a] long-term decline rather than move toward a flourishing future revival."[63] The debate is complicated by the need to replace U.S. nuclear plant capacity retiring in the near future simply to maintain nuclear power's current electricity supply contribution. Referring specifically to such construction limitations, another expert concludes that "nuclear energy will remain an option among efforts to control climate change, but given the maximum rate at which new reactors can be built, much new construction will simply offset the retirement of nuclear reactors built decades ago."[64] Observing that "the nuclear capability of the U.S. has atrophied in the 30 years since the last nuclear plant was ordered," Secretary of Energy Samuel Bodman has remarked more bluntly: "let's not kid ourselves about the challenges here." [65] In its 2008 report, the National Intelligence Council likewise states–

[59] U.S. Department of Energy, *A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010: Volume 1 Summary Report* (October 31, 2001): 7.

[60] Organisation for Economic Co-operation and Development (OECD), *Nuclear Energy Agency, Nuclear Energy Outlook 2008*, NEA No. 6348(2008): 316. GWe=Gigawatt-electric.

[61] Nuclear Energy Advisory Committee, *Nuclear Energy: Policies and Technology for the 21st Century* (November 2008): 8.

[62] Compiled from the Energy Information Administration (EIA) Reactor Status List, available at http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactsum.html.

[63] Mycle Schneider, "2008 World Nuclear Industry Status Report: Global Nuclear Power," *Bulletin of the Atomic Scientists*, Web edition (September 16, 2008). http://www.thebulletin.org/web-edition/reports/2008-world-nuclear-industry-status-report/2008-world-nuclear-industry-status-rep

[64] Sharon Squassoni, *Nuclear Renaissance: Is It Coming? Should It?* Carnegie Endowment for International Peace (October 2008): 2.

[65] U.S. Secretary of Energy Samuel Bodman, Remarks before the Nuclear Energy Summit: *Renewing America's* (continued...)

> expansion of nuclear power generation by 2025 to cover anywhere near the increasing demand would be virtually impossible. The infrastructure (human and physical), legal (permitting), and construction hurdles are just too big. Only at the end of our 15-20 year period are we likely to see a serious ramp up of nuclear technologies[66]

Faced with these divergent assessments, experts disagree on the ability of nuclear power to help meet CO_2 mitigation goals.

> Members of the Nuclear Power Joint Fact Finding (NJFF) reached no consensus about the likely rate of expansion for nuclear power in the world or in the United States over the next 50 years. Some group members thought it was unlikely that overall nuclear capacity would expand appreciably above its current levels and could decline; others thought that the nuclear industry could expand rapidly enough to fill a substantial portion of a carbon-stabilization "wedge" during the next 50 years.[67]

Consequently, congressional policy makers face a key uncertainty as to the achievable pace of nuclear power industry expansion, and therefore, the potential contribution nuclear generation may make to near-term CO_2 reduction.

Advanced Coal-Fired Power Generation

One set of technologies that may help to reduce CO_2 emissions from coal power plants is advanced coal-fired power generation. Advanced coal technologies include ultra-supercritical pulverized coal plants and integrated gasification combined cycle (IGCC) units, the latter of which convert coal into a synthetic gas prior to combustion. Compared to conventional coal-fired power plants, which typically operate at around 33% efficiency, advanced technologies under development or demonstration could improve coal plant efficiency to 46% or more.[68] Because they use coal more efficiently, advanced coal plants could yield proportionate reductions in CO_2 emissions per unit of electricity output compared to conventional coal plants. If carbon capture and sequestration technology (discussed in the next section) could be added to these plants their CO_2 emissions could be further reduced.

Some analysts and policy makers anticipate that advanced coal generation, either in the form of new coal-fired plants or upgrades to certain existing plants, will make a significant contribution to U.S. carbon reduction goals. They argue that, until carbon capture and storage technology is commercialized, advanced coal plants will be a cost-effective option for meeting future electricity demand growth while limiting CO_2 emissions growth compared to its current rate of growth. EPRI, for example, proposes CO_2 reductions from advanced coal plants on par with those from customer energy-efficiency programs through 2030.[69]

(...continued)

Nuclear Power Partnership For Energy Security and Economic Growth, Convened at the U.S. Department of Commerce (October 8, 2008).

[66] National Intelligence Council, *Global Trends 2025: A Transformed World*, NIC 2008-003 (November 2008): 45.

[67] Keystone Center, *Nuclear Power Joint Fact-Finding* (June 2007): 10.

[68] Massachusetts Institute of Technology (MIT), *The Future of Coal* (2007): 115, 124.

[69] Barbara Tyran, Electric Power Research Institute, (May 15, 2008): 7.

Uncertainty in Coal Plant Financing and Approval

While power plants employing advanced coal-fired generation technology face important questions about technological readiness and cost-effectiveness, the key uncertainty is whether they can be built—that is, whether the capital markets will finance them and whether regulators will permit them. Although they are more efficient than traditional coal plants, advanced technology coal plants still burn coal and—absent carbon capture technology—still release large volumes of CO_2 to the atmosphere. Once constructed, they may remain in service for 40 years or more. Hence they may not satisfy regulatory objectives for carbon control and may face financial risks stemming from future policies imposing costs on CO_2 emissions. Furthermore, industry arguments that these plants will be retrofitted with carbon capture technology when it becomes available are assuming the availability of that technology, which faces uncertainties as discussed in the following section.

Due to the potential carbon-related risks faced by new coal generation projects, major financial institutions are imposing greater requirements on developers seeking capital for new coal plant investments.[70] Regulatory agencies also have begun withholding regulatory approval from advanced coal project proposals. For example, in August 2007, the Minnesota Public Utilities Commission rejected a developer's proposal to construct a new IGCC power plant in the state as "not in the public interest."[71] The Sierra Club reports that at least 30 other proposed IGCC or supercritical coal generation projects have been cancelled across the country over the last several years due to financial and carbon emissions concerns.[72] In November, 2008, the Environmental Protection Agency's (EPA) Environmental Appeals Board ruled that an EPA region could not issue a permit for proposed coal-fired power plant without considering whether the "best available" CO_2 controls should be required for such a plant.[73] According to industry analysts, the EPA ruling would place a "freeze on the construction of as many as 100 new coal-fired power plants around the U.S."[74] The EPA Administrator has subsequently overruled the board's decision, apparently clearing the way for numerous coal plant permit applications to proceed, but raising new questions about future regulatory treatment of coal plant emissions under the next administration.[75]

[70] Citi, JPMorgan Chase and Morgan Stanley, "Leading Wall Street Banks Establish The Carbon Principles," Joint press release (New York: February 4, 2008).

[71] Minnesota Public Utilities Commission, *Order Resolving Procedural Issues, Disapproving Power Purchase Agreement, Requiring Further Negotiations, and Resolving to Explore the Potential for a Statewide Market for Project Power under Minn. Stat. § 216b.1694, Subd. 5*, Docket No. E-6472/M-05-1993 (August 30, 2007):15.

[72] Sierra Club, "Stopping the Coal Rush," Internet database (December 16, 2009). http://www.sierraclub.org/environmentallaw/coal/plantlist.asp

[73] U.S. Environmental Protection Agency, Environmental Appeals Board, *In re: Deseret Power Electric Cooperative PSD Permit No. PSD-OU-0002-04.00*, PSD Appeal No. 07-03 Order Denying Review in Part and Remanding in Part (Decided November 13, 2008).

[74] Kate Sheppard, "Is That a Bonanza in Your Docket?," *Gristmill*, Internet blog (November 14, 2008). http://gristmill.grist.org/story/2008/11/13/165551/28

[75] Stephen L. Johnson, Administrator, U.S. Environmental Protection Agency, *EPA's Interpretation of Regulations that Determine Pollutants Covered By Federal Prevention of Significant Deterioration (PSD) Permit Program*, Memorandum (December 18, 2008).

Carbon Capture and Sequestration

Another approach to mitigating atmospheric carbon emissions is direct sequestration of carbon dioxide: capturing CO_2 at its source and storing it indefinitely to avoid its release to the atmosphere. Carbon capture and sequestration (CCS) is of great interest because potentially large amounts of CO_2 emitted from the industrial burning of fossil fuels in the United States could be suitable for sequestration. In theory, carbon capture technologies are seen as potentially removing 80%-95% of CO_2 emitted from an electric power plant or other industrial facility. Power plants are the most likely initial candidates for CCS because they are predominantly large, single-point sources, and they contribute approximately one-third of U.S. CO_2 emissions from fossil fuels.

Many analysts and policy makers have high hopes for CCS technology to help meet future CO_2 reduction goals in the U.S. electricity sector and worldwide. For example, one expert has testified before Congress that "[c]apturing and sequestering CO_2 emissions from coal-fired power plants and eventually all fossil combustion is a foundational technology component of any emissions reduction plan" seeking to stabilize atmospheric CO_2.[76] In the International Energy Agency's 2007 forecast CCS is "widely-deployed" under global CO_2 stabilization assumptions and accounts for 21% of avoided CO_2 emissions by 2030.[77] In EPRI's analysis, CCS makes the single greatest contribution to reduced CO_2 emissions among all measures by 2030.[78]

CCS Technology Uncertainty

Developing technology to capture CO_2 in an environmentally, economically, and operationally acceptable manner—especially from coal-fired power plants—has been an ongoing interest of the federal government for a decade. Nonetheless, the technology on the whole is still under development: no commercial device is currently available to capture carbon from coal plants. (Technology is currently available for capturing CO_2 from certain industrial processes, such as ammonia production, or natural gas processing, but the volumes of CO_2 emitted from coal-fired power plants dwarf any current industrial process in use today.) Various new CCS technologies have been tested successfully in laboratories, and some are being demonstrated in limited capacity field trials, but they are costly and face technical challenges to reaching commercial scale. Consequently, analysts disagree as to whether, when, and how CCS technology might be widely available in the United States at a cost competitive with commercially available technologies for generating electricity—particularly natural gas turbines.[79] Policies that impose costs on generators for CO_2 emissions, such as carbon taxes or cap-and-trade programs, presumably, would benefit CCS competitiveness, but they, too, are highly uncertain and constrained by other economic factors. As one study notes, "[t]he success of a cap-and-trade

[76] Raymond J. Kopp, Director of the Climate Policy Program, Resources for the Future, Testimony before the Senate Energy and Natural Resources Committee (June 25, 2008).

[77] International Energy Agency (IEA), *World Energy Outlook 2007* (2007): 208.

[78] Barbara Tyran, Electric Power Research Institute, (May 15, 2008): 7.

[79] For discussion of specific carbon capture technologies and analysis of the potential costs implications of carbon capture relative to other generation technologies, see CRS Report RL34621, *Capturing CO2 from Coal-Fired Power Plants: Challenges for a Comprehensive Strategy*, by Larry Parker, Peter Folger, and Deborah D. Stine.

program in spurring widespread CCS deployment depends on a wide range of factors that cannot be controlled or even predicted in advance."[80]

A review of recent studies reveals a broad range of opinion as to how quickly CCS could be commercially deployed on large scale. An analysis from Imperial College, London, sees initial commercial deployment of CCS technology in the 2015-2020 period.[81] DOE officials reportedly have stated that the agency hopes to have carbon capture technology "in a deployable position within a decade."[82] A 2008 study by McKinsey & Company projected that early commercial CCS projects would be built "around 2020."[83] The World Business Council for Sustainable Development believes CCS technology will enter commercial deployment by 2025.[84] The Intergovernmental Panel on Climate Change 2005 report on CCS technology states that "many integrated assessment analyses ... foresee the large-scale deployment of CCS systems within a few decades from the start of any significant regime for mitigating global warming."[85] A coalition including Greenpeace, Friends of the Earth, and other public interest groups asserts that "the best-case scenario is that [CCS] technology would be ready by 2030."[86] Referring to IEA's long term projections for carbon control, the OECD states that "there must be significant doubt as to whether or not it is feasible to achieve the assumed contribution from CCS by 2030."[87]

Given the range of expectations for CCS technology readiness, policy makers may not be able to establish to their satisfaction the contribution this technology may make to CO_2 emissions abatement. As one former DOE official reportedly has cautioned, "[p]eople's conception of how much [CCS] can deliver is probably wildly overrated. So I'm hopeful that carbon capture and storage could be part of the solution, but ... one just has to put a big question mark on it."[88] Echoing this view, Nobel laureate Steven Chu, Director of the Lawrence Berkeley National Laboratory and nominee for Secretary of Energy, reportedly has remarked, "it's not guaranteed we have a solution for coal."[89] Accordingly, the key uncertainty for policy makers regarding CCS is if and when the technology might be available for widespread deployment.

---

[80] Ken Berlin and Robert M. Sussman, *Global Warming and The Future of Coal*, Center for American Progress (May 2007): 34.

[81] J. Gibbins and H. Chalmers, "Preparing for Global Rollout: a 'Developed Country First' Demonstration Programme for Rapid CCS Deployment," *Energy Policy*, Vol. 36, No. 2 (2008): 501-507.

[82] Acting Deputy Energy Secretary Jeffrey Kupfer quoted in "Bush DOE Transition Head Sees Commercial Carbon Capture In 10 Years," *EnergyWashington* (December 2, 2008).

[83] McKinsey & Company, Inc., *Carbon Capture & Storage: Assessing the Economics* (September 22, 2008): 18.

[84] World Business Council for Sustainable Development, *Pathways to 2050: Energy and Climate Change* (December 7, 2005): 5.

[85] Intergovernmental Panel on Climate Change (IPCC), Special Report: *Carbon Dioxide Capture and Storage*, 2005 (2005): 341

[86] Greenpeace, "Tell Congress To Keep Carbon Capture and Storage Out Of Energy Legislation," Internet page (Washington, DC: May 6, 2008) http://members.greenpeace.org/action/start.php?action_id=189; "Public Interest Groups Oppose Carbon Capture Scam," *It's Getting Hot in Here*, Internet blog (May 6, 2008). http://itsgettinghotinhere.org/2008/05/06/public-interest-groups-oppose-carbon-capture-scam/

[87] OECD (2008): 133.

[88] Joseph Romm, Center for American Progress, as quoted in "Coal's Carbon Capture in Question," *Living on Earth*, Public Radio International, audio transcript (February 8, 2008).

[89] Keith Johnson, "Steven Chu: 'Coal is My Worst Nightmare'," *Wall Street Journal, Environmental Capital*, Internet blog (December 11, 2008).

http://blogs.wsj.com/environmentalcapital/2008/12/11

Plug-in Electric Hybrid Vehicles

A recent development in advanced vehicle technologies is the potential introduction in the next few years of plug-in hybrid electric vehicles (PHEVs). PHEVs, like commercially available hybrid electric vehicles (HEVs), would combine an electric motor and battery pack with an internal combustion engine to improve overall fuel efficiency. PHEVs would use a much higher-capacity battery pack than a typical HEV, however, and would be able charge the vehicle on grid power rather than solely by the combustion engine during operation. With their larger batteries, PHEVs could achieve an all-electric range of 20 to 40 miles (the average commuting distance). By using grid electricity rather than gasoline in this way, PHEVs could lower overall fuel-cycle pollutant emissions—including CO_2 emissions—from vehicles.[90] Accordingly, many analysts and policy makers believe PHEV's offer substantial opportunities to reduce the nation's overall CO_2 emissions. A 2007 joint EPRI-Natural Resources Defense Council (NRDC) study, for example, concluded that, through the widespread adoption of PHEV technology, "cumulative [CO_2] savings from 2010 to 2050 can be large."[91] The Obama-Biden presidential campaign pledged to "[p]ut 1 million plug-in hybrid cars ... on the road by 2015."[92]

While PHEVs are an innovative technology, there are important questions about the impact PHEVs may have on CO_2 emissions over the next 20 ot 30 years. One key uncertainty is whether such vehicles would be purchased in sufficient numbers (approximately 50% of new car sales by 2025, according to the EPRI/NRDC study)[93] to have a significant carbon impact despite their high cost. PHEVs are projected to retail for over $40,000 per vehicle in the near-term compared to approximately $28,000 for an HEV and $23,000 for a conventional vehicle.[94] As a point of reference, conventional HEVs accounted for 2.4% of new vehicle sales in the United States through November 2008.[95] Of greater uncertainty, perhaps, are the projected carbon emissions of power plants operating to supply PHEV electricity. As a general rule, PHEVs only reduce net carbon emissions if the power plants supplying them produce relatively little carbon per kWh. But some studies show that, if the U.S. generation portfolio does not significantly reduce its overall carbon intensity, widespread adoption of PHEVs through 2030 may have only a small effect on, and might actually increase, net CO_2 emissions.[96] Thus, the carbon abatement potential of PHEVs is largely dependent upon the concurrent implementation of renewables, nuclear power, and CCS—each of which face great uncertainties of their own as discussed above.

[90] While these emissions reductions, technically, affect the transportation sector, they are linked to emissions in the electricity sector and so are often assessed in both contexts.

[91] Electric Power Research Institute and Natural Resources Defense Council, *Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 1: Nationwide Greenhouse Gas Emissions* (July 2007): 5-10.

[92] Obama-Biden, *Barack Obama and Joe Biden: New Energy for America*, Fact sheet (August 3, 2008). http://www.barackobama.com/pdf/factsheet_energy_speech_080308.pdf

[93] Electric Power Research Institute and Natural Resources Defense Council (July 2007): 4-8. This value is for the "Medium PHEV fleet penetration case."

[94] Andrew Simpson, *Cost-Benefit Analysis of Plug-In Hybrid Electric Vehicle Technology*, National Renewable Energy Laboratory, NREL/CP-540-40485 (November 2006): 10.

[95] Green Car Congress, *US Sales of Hybrids Down 50% in November*, Web page (December 9, 2008). http://www.greencarcongress.com/2008/12/us-sales-of-hyb.html#more

[96] See, for example: Stanton W. Hadley and Alexandra Tsvetkova, *Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation*, Oak Ridge National Laboratory, ORNL/TM-2007/150 (January 2008): 68; Constantine Samaras and Kyle Meisterling, "Life Cycle Assessment of Greenhouse Gas Emissions from Plug-in Hybrid Vehicles: Implications for Policy," *Environmental Science and Technology*, Vol. 42, No. 9. (2008): 3170-3176.

Distributed Energy Resources

Distributed energy resources are small-scale power generation technologies located near homes or businesses to provide an alternative to, or an enhancement of, conventional grid power. Distributed resources include technologies such as rooftop photovoltaics, natural gas-fired microturbines, wind turbines, and fuel cells. The category also includes combined heat and power (CHP) systems, which make productive use of "waste" heat from electricity generation, thereby increasing the total useful energy extracted from electric generation fuels.[97] Distributed energy resources (DER) offer potential benefits to customers in terms of energy costs, power reliability, and power quality. DER technologies also can help mitigate CO_2 emissions because some use renewable energy sources, or, as in the case of CHP systems, they make more efficient use of fossil fuels than the utility power generation they displace.[98]

Among DER technologies, CHP is the most widespread, accounting for nearly nine percent of U.S. electric generating capacity in 2007.[99] CHP is also viewed as having the greatest near-term potential to reduce CO_2 emissions. A 2008 report from Oak Ridge National Laboratory concludes that, by achieving 20 percent generation capacity from CHP by 2030 (an "aggressive target"), the United States could avoid 60 percent of the projected increases in CO_2 emissions during that time.[100] A 2007 study by McKinsey & Company further concludes that much of this added capacity could be installed at negative marginal cost.[101] Nonetheless, CHP, along with other DER technologies, has not been implemented to its potential due to technical and utility infrastructure barriers.

> CHP, or cogeneration, has been around in one form or another for more than 100 years; it is proven, not speculative. Despite this proven track record, CHP remains underutilized and is one of the most compelling sources of energy efficiency that could, with even modest investments, move the Nation strongly toward ... a cleaner environment.[102]

Other DER technologies, such as photovoltaics and fuel cells, likewise face barriers limiting their implementation. As a United Kingdom government study stated,

> The complexity and novelty of some of the technologies, together with their need to be integrated into the built environment, often by players new to the energy business, means there is a significant gap between potential and delivery. Moreover, many of the technologies are not yet cost-competitive at their current state of development and with current fuel and carbon prices.[103]

---

[97] CHP systems are also commonly referred to as "cogeneration" systems.

[98] S.W. Hadley, J.W. Van Dyke, W.P. Poore, III, and T.K. Stovall, *Quantitative Assessment of Distributed Energy Resource Benefits*, Oak Ridge National Laboratory, ORNL/TM-2003/20 (May 2003): 23.

[99] Oak Ridge National Laboratory, *Combined Heat and Power: Effective Energy Solutions for a Sustainable Future*, ORNL/TM-2008/224 (December 1, 2008): 4.

[100] Oak Ridge National Laboratory, (December 1, 2008): 21.

[101] McKinsey & Company, Inc., *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?*, (December, 2007).

[102] Oak Ridge National Laboratory, *Combined Heat and Power: Effective Energy Solutions for a Sustainable Future*, ORNL/TM-2008/224 (December 1, 2008): 3.

[103] United Kingdom, Department for Business Enterprise and Regulatory Reform, *UK Renewable Energy Strategy: Consultation Document* (2007): 135.

(continued...)

Analysts also question whether policies imposing costs on CO_2 emissions would substantially increase DER adoption due to the existing alignment of carbon reduction and cost reduction objectives, even without carbon costs, and the fundamental economics of renewables.[104] Thus, DER faces a key uncertainty similar to that faced by energy efficiency. The key question is whether new programs and the imposition of carbon costs would enable the electricity sector to capture substantially more DER potential than it does today.

Policy Issues for Congress

Policy research and technical studies show that substantially reducing CO_2 emissions in the U.S. electricity sector over the next few decades likely requires successful deployment of every major carbon mitigation measure at the nation's disposal. However, it is also clear that significant uncertainties cast doubt on the potential of individual measures to achieve their hoped-for carbon impact. For the measures discussed in this report, the key uncertainties can be summarized as follows:

- **Energy efficiency**—Can the United States overcome socioeconomic barriers to achieve four times more potential savings than ever before?
- **Renewable energy**—Will there be enough transmission for wind power? Is there enough land to grow the needed biomass?
- **Nuclear power**—Could the United States build new plants fast enough to matter?
- **Advanced coal power**—Will banks fund them and regulators approve them?
- **Carbon capture and sequestration**—Will the technology be commercially deployable in 10 years, 25 years, or never?
- **Plug-in hybrid electric vehicles**—How much "low carbon" electricity would be available to charge their batteries?
- **Distributed energy resources**—Would carbon costs change distributed energy economics enough to spur deployment?

Policy makers and interest groups recognize these uncertainties, and have put forth numerous proposals to address them. It is beyond the scope of this report to examine each of these proposals, but they include the broadest range of policy instruments at government's disposal: higher efficiency standards, new regulatory authorities, tax incentives, direct subsidies, research and development (R&D) grants, environmental rules, public information campaigns, and a host of other policy instruments. Specific examples include calls for more federally-funded CCS demonstration projects and proposals for federal preemption of state siting authority to promote new transmission development.[105] While they run the gamut, it remains to be seen which

(...continued)

http://renewableconsultation.berr.gov.uk/consultation/chapter-5/executive-summary/

[104] Ryan Firestone and Chris Marnay, "Distributed Energy Resources for Carbon Emissions Mitigation," Conference paper for The European Council for an Energy Efficient Economy 2007 Summer Study, (La Colle sur Loup, France: June 4-9, 2007): 5.

[105] Union of Concerned Scientists, *Coal Power in a Warming World* (October 2008): 3-4; Testimony of Joseph (continued...)

proposals may be pursued by Congress and what effects they would have. Consequently, the overall success of a multi-measure CO_2 mitigation scheme such as that proposed by EPRI in **Figure 1**, and its economic underpinnings, is inherently unpredictable.

> The cost of building and operating coal plants with and without CCS systems, the cost of natural gas, nuclear power and renewable sources of power, the cost of emissions offsets from outside the utility sector, and ultimately the market price of CO_2 itself are all variables that will dictate the decisions of future power plant developers. These variables are all highly uncertain from today's perspective and may create a set of economic drivers dramatically different from those anticipated by policymakers.[106]

Possible Outcomes for Carbon Control

Identifying key uncertainties for carbon abatement measures is not the same as predicting their ultimate success or failure. This report does not independently assess the likelihood of particular measures meeting any specific CO_2 reduction target. The whole point of this report's focus on uncertainty is that CO_2 outcomes are not known, and expert opinions vary as to what the future will be. It is, therefore, entirely possible that a portfolio of CO_2 measures such as those in **Figure 1**, implemented under the optimum subset of policies currently under debate, could achieve the types of carbon reductions projected. Indeed, EPRI has characterized its CO_2 scenario as "very aggressive, but potentially feasible."[107] Other CO_2 abatement analyses have also been developed in good faith with a similar belief in their practicality. Successfully reducing U.S. carbon emissions to 1990 levels, say, by 2030 would validate the overall policy approach as well as the specific measures comprising it. Such an outcome would not be conclusive, as deeper CO_2 cuts would arguably need to follow, but the intervening years would probably provide greater clarity on the best policy options to 2050 and beyond.

Underperformance of Individual CO_2 Measures

Although successful implementation of all carbon abatement measures is the goal, it is also entirely possible that, under a multi-measure strategy like EPRI's, one or more measures would fall short of meeting expectations for CO2 reduction. Nuclear industry expansion, for instance, could easily fail to materialize, or the transmission grid could expand too slowly for sustained wind power development. In such a case legislators might need to revisit both the enabling policies for the underperforming measures and for the carbon strategy as a whole.

One obvious solution could be to rely on more successful measures to compensate for the underperforming ones. As the OECD study posits, "if CCS and/or end-use efficiency fail to achieve the required targets, it follows that other technologies, including nuclear power, will need to make bigger contributions to fill the gap."[108] But based on a review of the relevant research cited in this report, such an approach may simply not be realistic. Since the CO_2 targets of the

(...continued)

Kelliher, Chairman of the Federal Energy Regulatory Commission, before the Senate Energy and Natural Resources Committee (July 31, 2008). http://www.ferc.gov/EventCalendar/Files/20080731102123-Chairmantestimony.pdf

[106] Ken Berlin and Robert M. Sussman (May 2007): 34.

[107] Barbara Tyran, Electric Power Research Institute, (May 15, 2008): 7.

[108] OECD (2008): 133.

individual measures are already viewed by some analysts as “ambitious,” “aggressive,” or “ a major challenge,” and there are questions as to whether the initial targets can be achieved, increasing those targets may stretch credibility and sharply increase the uncertainty of the overall CO_2 mitigation effort. Alternatively, legislators could revisit measure-specific policies to see if more intervention could improve their particular prospects. Larger tax credits for renewable energy, for example, could potentially improve the competitiveness of biomass generation, thereby encouraging biomass investment. Such an approach might still encounter difficulty making up for early underperformance of a measure in the out years, as CO_2 emissions are cumulative, but any improvement would arguably be helpful. A third option would be to increase the level of any future carbon costs with the expectation that an increase would benefit carbon-mitigating technologies across the board. Such an action, however, could have broad implications for energy prices, reliability, and availability.

Failure of the CO_2 Mitigation Portfolio

Notwithstanding the best efforts of federal policy makers, it is possible that, given the uncertainties they face, that few if any of the major measures proposed to moderate U.S. carbon emissions would achieve their anticipated impacts in a 20-year time frame. In its 2008 report, the National Intelligence Council suggests just such an outcome:

> [A]ll current technologies are inadequate for replacing the traditional energy architecture on the scale needed, and new energy technologies probably will not be commercially viable and widespread by 2025.... Even with a favorable policy and funding environment for biofuels, clean coal, or hydrogen, the transition to new fuels will be slow.[109]

Under such a scenario, legislators may face different policy alternatives, each with distinct but potentially significant implications. Congress might increase future carbon emissions costs even higher than under the previous scenario—to a level that virtually guarantees the targeted CO_2 reductions—although the effects of very high carbon prices on electricity costs might be detrimental to specific industries (e.g., coal) or to the economy as a whole. Alternatively, Congress might refocus its efforts on a single measure (e.g., CCS or nuclear power) restructuring its policies to expand the implementation of that specific measure far beyond its original targets. Congress could also reset its national CO_2 targets, deferring reduction goals until they are more in line with the maturation and implementation of the key CO_2 reduction technologies. In this case, legislators would signal acceptance that near-term targets could not be met and hope for greater success later in the century. This alternative risks unacceptable implications, however, and might violate future international emissions treaties. Finally, Congress could abandon its focus on CO_2 reduction altogether, instead directing resources at mitigating the effects of global warming and adapting to a hotter climate.

Conclusion

Reducing U.S. emissions of manmade CO_2 is a priority of both the President elect and leaders in Congress. Comprehensive policies have been proposed to achieve these reductions. Most envision aggressive implementation of a portfolio of major carbon reduction measures, with the

[109] National Intelligence Council, *Global Trends 2025: A Transformed World,* NIC 2008-003 (November 2008). http://www.dni.gov/nic/PDF_2025/2025_Global_Trends_Final_Report.pdf

goal of reducing U.S. CO_2 emissions to 1990 levels by 2020 or 2030. Numerous studies support the potential of specific measures to lower CO_2 emissions, but also identify key implementation uncertainties which may impact their overall viability. Congress is considering policies to address these uncertainties, but which policies may be implemented and how effective they may be cannot be known at this time.

As the nation's CO_2 mitigation policies continue to develop, the inherent uncertainty associated with specific carbon measures may be a critical concern. Commitments, either domestic or international, to specific carbon emissions targets over time, or to a specific schedule of carbon costs (whatever form they may take) may be greatly affected by the success of the underlying measures relied upon to achieve them. The reverse is also true; a schedule of carbon costs may also influence the success of CO_2 abatement measures. Therefore, policy makers may benefit from a complete and integrated understanding of measure-specific uncertainties and the range of carbon outcomes they imply. As one study has concluded, "explicitly including uncertainty in both technical change and in climate damages is important for understanding the relationship between technical change, climate change, and policy.... [O]ptimal policy is different ... when uncertainty is taken into account.[110]

As Congress considers implementing CO_2 policies, keeping a close eye on the technology and market developments associated with every key measure may be an oversight priority. Success or failure of any particular measure may be apparent early on in its implementation, affording an opportunity through quick action to make policy adjustments to improve a measure's chances for success, or to abandon it in favor of more promising options. Perhaps more importantly, given the complexity and scale of the carbon control problem, Congress may also find it useful to expect the unexpected in the electricity sector. Apart from the measures discussed in this report, new technologies, consumer behavior, or infrastructure developments (e.g., a rush to natural gas) may emerge rapidly and unexpectedly to change fundamental aspects of the nation's carbon emissions trajectory. One way or another, electricity supply will balance with demand—but perhaps in unanticipated ways. The recent volatility in global oil prices is a relevant example of unexpected structural changes in energy markets. Balancing responses to energy market volatility and unexpected structural changes against the need for a predictability in R&D and private capital investment may be essential to maintaining the nation on course to meaningful atmospheric CO_2 reduction.

Author Contact Information

Paul W. Parfomak
Specialist in Energy and Infrastructure Policy
pparfomak@crs.loc.gov, 7-0030

[110] Erin Baker, Leon Clarke, Jeffrey Keisler, and Ekudayo Shittu, "Uncertainty, Technical Change and Policy Models," University of Massachusetts, Boston, College of Management, UMBCMWP 1028 (July 2007): 3-4.