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The Costs of Reducing Greenhouse-Gas Emissions

Human activities around the world are producing increasingly large quantities of greenhouse gases, particularly carbon dioxide (CO_2) resulting from the consumption of fossil fuels and deforestation. Most experts expect that the accumulation of such gases in the atmosphere will result in a variety of environmental changes over time, including a gradual warming of the global climate, extensive changes in regional weather patterns, and significant shifts in the chemistry of the oceans.[1] Although the magnitude and consequences of such developments are highly uncertain, researchers generally conclude that a continued increase in atmospheric concentrations of greenhouse gases would have serious and costly effects.[2]

A comprehensive response to that problem would include a collection of strategies: research to better understand the scientific processes at work and to develop technologies to address them; measures to help the economy and society adapt to the projected warming and other expected changes; and efforts to reduce emissions, averting at least some of the potential damage to the environment and attendant economic losses. Those strategies would all present technological challenges and entail economic costs.

Reducing emissions would impose a burden on the economy because it would require lessening the use of fossil fuels and altering patterns of land use. This issue brief discusses the economic costs of reducing greenhouse-gas emissions in the United States, describing the main determinants of costs, how analysts estimate those costs, and the magnitude of estimated costs. The brief also illustrates the uncertainty surrounding such estimates using studies of a recent legislative proposal, H.R. 2454, the American Clean Energy and Security Act of 2009.

What Determines the Costs of Reducing Emissions?

The costs of reducing emissions would depend on several factors: the growth of emissions in the absence of policy changes; the types of policies used to restrict emissions; the magnitude of the reductions achieved by those policies; the extent to which producers and consumers could moderate emission-intensive activities without reducing their material well-being; and the policies pursued by other countries. (For a discussion of different concepts of cost, see Box 1.)

Emissions in the Absence of Policy Changes

In 2006, the United States emitted roughly 7 billion metric tons (MT) of greenhouse gases, measured in CO_2 equivalents (CO_2e, or the amount of CO_2 that would cause an equivalent amount of warming).[3] Eighty percent of domestic emissions consisted of CO_2 from the burning of fossil fuels in activities such as manufacturing, electricity generation, transportation, agriculture, and the heating and cooling of buildings. The remaining 20 percent—consisting of CO_2 emitted from sources other than fossil fuels, methane (CH_4), nitrous oxide (N_2O), and a variety of fluorinated gases—were produced by myriad processes and activities throughout the economy. Under current land-use patterns in the United States, forests and soils absorb nearly 900 million MT CO_2 every year,

1. For a discussion of expected effects, see Congressional Budget Office, *Potential Impacts of Climate Change in the United States* (May 2009), available at www.cbo.gov/ftpdocs/101xx/doc10107/05-04-ClimateChange_forWeb.pdf.

2. For a general discussion of the economics of climate change, see Congressional Budget Office, *The Economics of Climate Change: A Primer* (April 2003), available at www.cbo.gov/ftpdocs/41xx/doc4171/04-25-ClimateChange.pdf. For a general discussion of uncertainty and climate change, see Congressional Budget Office, *Uncertainty in Analyzing Climate Change: Policy Implications* (January 2005), available at www.cbo.gov/ftpdocs/60xx/doc6061/01-24-ClimateChange.pdf.

3. See Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2006* (April 15, 2008).

Box 1.

Measuring the Costs of Reducing Greenhouse-Gas Emissions

Economists characterize and measure the costs of reducing emissions in a number of related ways, each of which provides a useful perspective on how a program to control emissions would affect the economy.

Incremental Cost

Not all emissions of greenhouse gases are equally expensive to reduce. If emissions were restricted in a manner that allowed firms and households flexibility in how they met the restriction, the least costly reductions would tend to be undertaken first. If the restriction was tightened and people had to forgo increasingly highly valued activities to further reduce their emissions, each additional ton of reductions would be more expensive. For any amount of reduction, the incremental cost of cutting the last ton necessary—what economists call the marginal cost—reflects how much consumption of goods and services people would have to forgo to eliminate that last ton of emissions. If emissions were restricted using a cap-and-trade system, the incremental cost would determine the market price of allowances, even if most of the reductions were less expensive than the very last, incremental ton. If, instead, a tax was imposed on emissions, the incremental cost would equal the tax rate: People would make reductions that cost less than the tax; for the rest, they would simply pay the tax. Traditional command-and-control approaches are unlikely to mandate the least expensive ways of restricting emissions and therefore are likely to achieve any given reduction in emissions at greater cost than market-based approaches such as taxes or cap-and-trade programs.

Aggregate Cost

Researchers measure and report the aggregate cost of restrictions in a variety of ways. One common measure, the direct resource cost of restrictions on emissions, is simply the sum of all resources that society must give up to meet the restrictions—that is, the sum of all the incremental costs discussed above. However, significant restrictions would impose costs on the economy over and above the direct cost as economic effects rippled beyond markets directly related to emissions and into other parts of the economy. Such adjustments would include changes in aggregate spending, saving, investment, and nonpaid activities, such as childrearing, production of goods and services in the home, and leisure activities. Those broader impacts would depend not only on how emission restrictions were implemented but also on whether the program raised revenues for the government and how the revenues were used. An ideal measure of the overall effect of the policy on households' welfare would account for all such aspects of the policy as well as all the changes in behavior that might be triggered by the policy. Unfortunately, little information is available regarding the likely magnitude of many of those changes, so estimates of the overall economic burden of policies are highly uncertain. Most researchers avoid the difficulties associated with estimating that burden by focusing on the impacts of policies on less comprehensive but more readily estimated measures of aggregate economic activity, such as gross domestic product, personal consumption expenditures, or employment.

The Distribution of Costs

Some studies analyze how the costs of policies to reduce emissions would be distributed among households and among industries. Most policies would not only generate a cost to the economy as a whole but would also cause significant shifts of income among households. Such shifts would not involve net costs to the economy, since one household's gain would be another's loss, but the gains and losses clearly would matter for the well-being of the affected households. For example, if fossil-fuel producers were required to pay a tax per ton of emissions resulting from the burning of their products, the tax burden would be passed on to consumers in the form of higher prices and to some owners of capital in the form of reduced profits. The distribution of the tax revenues would depend on how the government used them either to reduce other taxes or to increase spending. By contrast, if the government instituted a cap-and-trade policy and gave away emission allowances, the recipients would receive the full value of the allowances. Such transfers would probably be significantly larger than the aggregate costs associated with a given policy, particularly in the initial years of the policy.

Distributional studies typically find that, ignoring the allocation of tax revenue or allowance value flowing from the policy, low-income households would bear lower costs than high-income households in absolute terms. However, the former group would bear higher costs measured as a fraction of their income because they consume a larger share of their income and because their consumption is more energy-intensive. Studies also conclude that the owners of fossil-fuel-producing or energy-intensive industries would bear a disproportionate share of producers' costs (ignoring any effects from the allocation of allowances or tax revenues). However, the allocation of allowances or revenues from the policy could greatly affect those distributional impacts.

putting net U.S. emissions in 2006 at about 6 billion MT CO_2e. U.S. emissions of CO_2 from the burning of fossil fuels accounted for one-fifth of global CO_2 emissions from such activities. However, net U.S. emissions of all greenhouse gases accounted for only about 12 percent of net global emissions.

Experts generally expect that, in the absence of policy changes to reduce them, domestic greenhouse-gas emissions will grow substantially in the next few decades, totaling roughly 330 billion MT CO_2e between now and 2050. However, long-term trends in emissions are notoriously difficult to project because they will be influenced by population and income growth, by advances in technology, and by the availability and price of fossil fuels; total emissions, therefore, could be substantially higher or lower than that central estimate.[4] The more rapidly that emissions are projected to grow without policy changes, the greater the changes that would be required and the greater the mitigation costs that would be incurred to keep emissions below any specific level.

The Types of Policies Adopted

The costs of reducing emissions would depend critically on the approach that policymakers adopted to achieve that goal. In particular, costs would depend on whether the policy worked primarily through conventional regulation or market-based approaches, on the stringency of emission reductions, and on other policy choices.

Conventional Regulation Versus Market-Based Approaches. A basic choice facing policymakers is whether to adopt conventional regulatory approaches, such as setting standards for machinery, equipment, and appliances, or to employ market-based approaches, such as imposing taxes on emissions or establishing cap-and-trade programs. Experts generally conclude that market-based approaches would reduce emissions to a specified level at significantly lower cost than conventional regulations.[5] Whereas conventional regulatory approaches impose specific requirements that may not be the least costly means of reducing emissions, market-based approaches would provide much more latitude for firms and households to determine the most cost-effective means of accomplishing that goal.

Alternative Market-Based Approaches. If a tax was imposed on emissions, people would make reductions that cost less than the tax, and the incremental cost would equal the tax rate. Proposals for such taxes generally specify rates that gradually rise year by year, with the aim of making emission-producing activities increasingly expensive. Cap-and-trade proposals, by contrast, explicitly restrict the quantity of emissions that can be produced over any given period. Under such programs, allowances to emit greenhouse gases would be allocated or sold, and then could be traded. Market forces would yield an allowance price equal to the incremental cost of meeting the cap. Cap-and-trade proposals generally specify caps that gradually decrease over time in absolute terms, so households and firms would incur gradually rising incremental costs to reduce emissions.

If policymakers had full and accurate information about the costs of reducing emissions, either taxes or caps could be used to achieve a given goal for emissions. Policymakers could set a cap and know what allowance price it would yield; or they could set a tax at that same allowance price and achieve the same reduction in emissions. Thus, policymakers could use either approach to balance the incremental costs of reducing emissions against the incremental benefits of doing so, thereby achieving the greatest possible net benefit.

However, policymakers face great uncertainty about the cost of reducing emissions. The two approaches therefore are likely to yield different outcomes: A tax on emissions would leave the resulting amount of emissions uncertain,

4. For example, in 2000, the Energy Information Administration (EIA) overpredicted the amount of energy-related CO_2 that would be emitted in 2006 by 350 million tons, or by about 6 percent, largely because it overpredicted manufacturing output. EIA has subsequently reduced its projection of such emissions in 2020 by about 18 percent, resulting in lower estimates of future incremental costs for meeting any given target. (EIA's projections of greenhouse-gas emissions are particularly important for analysts of climate policy because nearly every estimate of the costs of mitigating those emissions takes the EIA reference case as its baseline. For this reason and others, the range of estimates among analysts does not fully represent the actual degree of uncertainty about mitigation costs.)

5. For further discussion, see Congressional Budget Office, *Policy Options for Reducing CO_2 Emissions* (February 2008), available at www.cbo.gov/ftpdocs/89xx/doc8934/02-12-Carbon.pdf; and Congressional Budget Office, *How Regulatory Standards Can Affect a Cap-and-Trade Program for Greenhouse Gases,* Issue Brief (September 16, 2009), available at www.cbo.gov/ftpdocs/105xx/doc10562/09-16-CapandStandards.pdf.

whereas a cap would leave the resulting allowance price uncertain.

Most experts conclude that, in the face of such uncertainty, policies that set the year-by-year price of emissions to be consistent with the projected incremental benefits of reducing emissions (as with a tax) would probably yield higher net benefits than policies that specified year-by-year caps on emissions or even a cap on cumulative emissions over many years.[6] The cost of meeting a fixed emission cap is likely to vary substantially from year to year—depending on the weather, economic activity, and the price of fossil fuels. A tax would ensure that firms and households had an incentive to make all reductions that cost less to achieve than that expected incremental benefit. By contrast, a cap could easily generate incremental reductions that cost substantially more or less than the expected benefit.

Even if policymakers chose a target measured in terms of average global temperature or atmospheric concentrations (for example, staying under 450 parts per million CO_2e), meeting rigid year-to-year (or even cumulative) targets for emissions would be relatively unimportant. The uncertainty about how a given quantity of emissions would ultimately affect concentrations or temperatures is so great that little additional certainty would be gained from choosing fixed emission goals over price paths that were expected to achieve the same goal.

If policymakers chose cumulative emission targets, policies that offered firms and households greater flexibility as to when they reduced their emissions would achieve such targets at a lower cost than policies that afforded them less flexibility. Various provisions of a cap-and-trade program could provide greater flexibility in the timing of emission reductions.[7] One important provision of this sort would permit regulated entities to “bank” emission allowances in any given year for use in future years. Such provisions would tend to moderate the overall costs of the policy by giving firms flexibility to make larger emissions reductions when such reductions were less expensive. A related “borrowing” provision would enable firms to use allowances from future years (to be repaid with interest) during periods when particularly high demand led to spikes in allowance prices. A variant would create a “reserve pool” of allowances from future years that could be used only under certain circumstances (for instance, when allowance prices rose above a designated threshold). Another widely discussed provision—referred to as a “safety valve”—would allow firms to exceed annual caps if the market price for allowances rose above some specified value. That value, typically specified to rise over time, would determine the maximum incremental cost of reducing greenhouse-gas emissions in any given period. Proposals could also keep incremental costs above a minimum by specifying a “price floor.” A “price collar” would specify both a ceiling and a floor. Unlike banking, borrowing, and a reserve pool, a safety valve or a price collar would not guarantee that a given cumulative cap would be achieved. Policymakers might have to shift the price collar in order to ensure that a desired cap was met.[8]

Other Policy Approaches. Some proposals would augment basic cap-and-trade or tax provisions with subsidies for activities that reduced emissions or with regulations such as standards for machinery, equipment, and appliances. Some such approaches—subsidies for basic energy research, for example—would probably be useful and effective supplements to market-based approaches. Standards might also be effective when the nature of the emission-producing activities made caps difficult to implement and taxes difficult to levy (as would be the case with emissions associated with agricultural practices) or where

6. The greater efficiency of taxes arises because the incremental cost of reducing emissions is relatively sensitive to the quantity of emission reductions (especially within a given year), while the incremental benefit is expected to be relatively insensitive to the quantity of reductions (and errors in estimating incremental benefits and costs are not expected to be correlated). The latter is true primarily because scientists are very unsure about the extent to which additional reductions would alter future climate outcomes. For further discussion, see Congressional Budget Office, *Potential Impacts of Climate Change in the United States*, pp. 14–17; and Congressional Budget Office, *Limiting Carbon Dioxide Emissions: Prices Versus Caps*, Issue Brief (March 15, 2005), available at www.cbo.gov/ftpdocs/61xx/doc6148/03-15-PriceVSQuantity.pdf.

7. For a detailed description of cap-and-trade programs, see Congressional Budget Office, *Policy Options for Reducing CO_2 Emissions*.

8. For a discussion of potential outcomes associated with alternative design features that are intended to provide firms with greater flexibility in shifting emission reductions over time, see Statement of Douglas W. Elmendorf, Director, Congressional Budget Office, before the House Committee on Ways and Means, *Flexibility in the Timing of Emission Reductions Under a Cap-and-Trade Program* (March 26, 2009), available at www.cbo.gov/ftpdocs/100xx/doc10020/03-26-Cap-Trade_Testimony.pdf.

market forces did not convey appropriate incentives (for example, when a tax on energy would not spur landlords to make efficiency improvements if renters were responsible for paying the electricity bills and rents were not adjusted to reflect the energy efficiency of apartments). However, standards would tend to increase the costs of a cap-and-trade program if they supplanted the effective reliance on market forces—even though they would also tend to reduce the allowance price in the program by reducing emissions covered under the program.

Other types of government activity could also affect the costs of restricting emissions. Many experts believe that nuclear power could displace a significant amount of fossil-fuel use, but only if the regulatory framework was adjusted to allow for the greater use of nuclear power to generate electricity. Similarly, generators would be unlikely to adopt technologies for the capture of CO_2 and its sequestration in the ground unless an extensive regulatory structure was put in place to address issues involving property rights, rights-of-way for pipelines, and liability for emissions that escape from the ground.

Governmental activities not immediately related to the energy sector could affect the costs of reducing emissions as well. For example, the tax treatment of investment could influence the cost and availability of particular technologies. Similarly, existing land-use regulations and the continued construction of highways might hinder efforts to increase urban density and to foster the development of public transportation networks.

Coverage, Timing, and Stringency. Policymakers also face decisions about which types of emissions to control, and when and how much to reduce them.[9] Coverage (that is, the types of emissions subject to control) could sharply affect costs. Most recent policy proposals would control all or nearly all CO_2 emissions produced by the burning of fossil fuels and would cover at least some other emissions of CO_2 and non-CO_2 greenhouse gases. Because monitoring and measuring emissions from some sources would be difficult, no proposals include all emissions from all sources. Nevertheless, many cap-and-trade proposals provide incentives for reducing emissions from sources not covered under the cap-and-trade program. For example, many proposals would allow landowners to earn credits by planting trees that absorb CO_2 from the atmosphere—credits that could then be sold to entities covered by the cap-and-trade program, who might submit those credits in lieu of allowances. Proposals often limit the use of such "offsets" (which, in some proposals, could be purchased in foreign countries as well) to a fixed annual amount or a fixed fraction of the total quantity of emissions allowed. Greater latitude for the use of offsets could help moderate the costs of achieving a given emission target because inexpensive reductions by uncovered sources could then substitute for a larger share of costlier reductions that covered sources would otherwise have to achieve. However, difficulties in ensuring the credibility and permanence of offsets could at least partially undermine the effectiveness of policies at achieving their stated emission goals.[10]

Proposals vary as to where in the chain of production and consumption the restrictions on emissions would apply. For example, emissions from petroleum products could be restricted by limiting production at refineries or by limiting consumers' purchases at the gas pump; emissions from coal could be restricted by limiting shipments of coal from mines or by limiting emissions from coal-fired power plants. Such differences, however, would have only small effects on incremental costs or on the distribution of costs among producers or consumers: No matter where the restrictions applied, costs would be determined mainly by the characteristics of supply and demand in the markets for fossil fuels and other goods and services.[11]

Most recent proposals call for gradual reductions in emissions through 2050, a significant shift in focus from that in the 1990s, when policy proposals usually focused on establishing targets for the 2007–2011 period to be

9. A given quantity of reductions in greenhouse-gas emissions could be achieved at a lower cost if the cap covered more types of gases and more sources of emissions. (For example, although CO_2 from the burning of fossil fuels accounts for roughly 80 percent of domestic greenhouse-gas emissions, some cuts in emissions of other greenhouse gases, such as methane or nitrous oxide, could be achieved at a relatively low cost.) Policy proposals are often expressed in terms of reducing emissions by a certain percentage; and the greater the required percentage reduction, the greater the costs are likely to be. However, the percentage usually applies to covered emissions rather than to total emissions, and a given percentage target is likely to be more expensive to achieve if it covers more sources: For instance, a 90 percent reduction in CO_2 emissions from the burning of fossil fuels would not be as stringent as a 90 percent reduction in all greenhouse-gas emissions.

10. For further discussion of offsets, see Congressional Budget Office, *The Use of Offsets to Reduce Greenhouse Gases,* Issue Brief (August 3, 2009), available at www.cbo.gov/ftpdocs/104xx/doc10497/08-03-Offsets.pdf.

11. One important exception involves CO_2 capture and storage. Capture would occur mainly at power plants, so if a policy imposed caps at the point of production (at the minemouth for coal, for example), it would also have to provide additional allowances as credit for capture and storage.

incorporated in the 1997 Kyoto Amendment to the Framework Convention on Climate Change. Recent proposals typically would impose relatively modest tax rates or restrictions on emissions in the early years and then gradually raise rates or tighten caps over time. Gradually increasing levels of stringency would provide firms and households time to anticipate and adapt to rising costs by slowly replacing long-lived energy-using structures and equipment with newly developed, more energy-efficient or non-fossil-fuel substitutes. Such policies would cost a good deal less than policies that imposed severe restrictions all at once—even if they resulted in equivalent amounts of total emissions over time. Some recent proposals would limit cumulative emissions through 2050 (which are projected to total roughly 330 billion MT CO_2e) to less than 200 billion MT CO_2e, leading to annual emissions in 2050 that would be a fraction of today's. The more stringent the cuts, the higher the incremental and total costs eventually would be, other things being equal.

Allocation of Allowances and Use of Additional Government Revenue. If policymakers decided to adopt market mechanisms to control emissions, they would also face decisions about how to allocate allowances under a cap-and-trade program or how to use the revenues generated by taxes on emissions. No matter which approach they adopted, the resulting policy would almost certainly involve shifts of resources among households, in their capacity as consumers, workers, and owners or shareholders of firms. For example, a program that distributed allowances to firms for free would be giving those firms a valuable right to emit gases—a right they could then exercise or sell—while consumers would pay more for fossil fuels and fossil-fuel-intensive goods and services. Such a program and allocation would effectively shift income from consumers of fossil-fuel-intensive goods and services to recipients of allowances. Alternatively, the government could auction allowances to firms and use the revenue to provide new tax credits or rebates, reduce existing taxes, or finance government spending. (Revenue raised from a tax on emissions could be used in any of those ways as well.) Revenue-raising approaches would effectively shift income from consumers of fossil-fuel-intensive goods and services to the people who would benefit from the resulting spending increases or tax reductions.[12]

In a cap-and-trade system, policymakers' choices about the allocation of allowances and the uses of additional government revenue would affect both the overall economic cost of the program and the distribution of that cost. If allowances were given away in a manner that offset the increases in prices of fossil fuels (increases that would otherwise encourage households and businesses to reduce their consumption of such fuels), then a larger share of the overall reduction in carbon emissions would need to occur elsewhere in the economy. For example, some recent proposals would direct a portion of tax revenues or proceeds from the sale of allowances to households or businesses to help compensate for some of the loss in purchasing power they would experience under a climate policy. To the extent that such an allocation masked the price signals needed to alter behavior, it would raise the overall economic cost of meeting the cap. However, to the extent that the allocation did not mask price signals, the overall cost would not be affected by who received the allowances—although the distribution of that cost might be greatly affected.

If allowances were auctioned rather than freely allocated, and the revenue was used to reduce marginal rates on taxes on labor and capital, the economic cost of a cap-and-trade program would be reduced.[13] If the revenue from auctions was not used to reduce marginal rates, then decisions about who received that revenue would have little effect on the program's overall economic cost—although they could have important effects on the distribution of that cost.

The Response of the Economy

By gradually increasing the prices of fossil fuels and other goods and services associated with greenhouse-gas emissions, market-based policies would induce firms and households to change their practices—in the short run, by driving slightly less, adjusting thermostats, and switching fuels in the power sector; and in the long run, by buying more-efficient vehicles and equipment, building more-energy-efficient buildings in denser neighborhoods, and building power plants that used less (or no) fossil fuel or that captured CO_2 and sequestered it in the ground. Depending on the specifics of the policy, people might

12. See Congressional Budget Office, *The Economic Effects of Legislation to Reduce Greenhouse-Gas Emissions* (September 2009), available at www.cbo.gov/ftpdocs/105xx/doc10573/09-17-Greenhouse-Gas.pdf.

13. See Congressional Budget Office, *Trade-Offs in Allocating Allowances for CO_2 Emissions,* Issue Brief (April 25, 2007), available at www.cbo.gov/ftpdocs/89xx/doc8946/04-25-Cap_Trade.pdf.

also plant trees and change agricultural practices to absorb and sequester CO_2.

Rising costs of emission-intensive activities would tend to dampen overall economic activity by reducing the productive capacity of existing capital and labor; by reducing households' income (which, in turn, would tend to reduce consumption and saving); by reducing real (inflation-adjusted) wages and, thereby, the supply of labor; and by discouraging investment through increasing the costs of producing capital goods (which is a relatively energy-intensive process) and through diverting investment and research toward the production of less emission-intensive but more expensive sources of energy.[14] Taken together, those changes would affect the levels and composition of both gross domestic product (GDP) and employment and would thus influence households' economic well-being, although the effect on overall output would be modest compared with expected future economic growth. The more easily that producers and consumers can respond to price changes by altering their production techniques and behavior and by bringing low-emission fuels and technologies to market, the lower the costs of reducing emissions would be.

However, analysts have only a limited understanding of how easily such responses can occur—especially over an extended period—because energy use is important in so many economic activities and because such a wide range of activities besides energy use generate emissions. Uncertainty about how the economy would respond to price changes contributes importantly to the wide variation in estimates of the cost of achieving any particular emission target. For example, expert opinion varies considerably about which types of technologies are likely to be available at different points in the future or how emissions restrictions might shift the pace of their development and deployment. Some experts argue that nuclear energy is likely to dominate other alternatives to fossil fuels; others believe that CO_2 capture and storage shows greater promise; and still others believe that renewable energy sources could be most promising of all.

14. In addition, higher energy prices would interact with the distortions of economic behavior imposed by the existing tax system, tending to magnify those distortions in some cases but to offset them in others.

Efforts by Other Countries

The stringency of other nations' efforts to reduce emissions could strongly influence the costs of reducing them in the United States. As long as a significant percentage of the world's economy did not restrict greenhouse-gas emissions, a portion of any reductions achieved in the United States would probably be offset by increases in emissions elsewhere. For example, as U.S. consumption of oil declined, pushing down international oil prices, foreign consumption of oil would rise. In addition, energy-intensive production overseas (and exports of such products to the United States) would most likely grow as U.S. manufacturing costs rose relative to foreign costs. Such emissions "leakage" would lead countries that were controlling emissions to achieve smaller net reductions in global emissions and to incur greater costs than they would if all countries were controlling emissions simultaneously.

Leakage could be avoided if most countries restricted emissions at the same time. Even so, the policies used in other countries would influence costs in the United States. For example, demand for biofuels from many countries would raise biofuel prices more than would demand from the United States alone. Moreover, if a domestic cap-and-trade system was linked to similar systems in other countries, the United States might benefit from being able to buy low-cost foreign allowances—or it could find that prices for domestic allowances were driven up by foreign demand.

How Are Costs Estimated?

Researchers estimate the costs of reducing emissions using a variety of techniques. Those techniques range from detailed analyses of specific technologies—which can be termed "engineering estimates"—to highly aggregated analyses—which can be termed "economic estimates."

Engineering Estimates

Often referred to as bottom-up studies, engineering estimates typically analyze the net direct costs of installing and operating many specific types of equipment.[15] Engi-

15. A useful recent such study is McKinsey & Company, *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve* (McKinsey & Company, January 2009), available at https://solutions.mckinsey.com/ClimateDesk/default.aspx.

neering studies frequently yield low estimates of the cost of achieving particular emission targets and can yield estimates of negative costs for some applications—that is, energy savings appear to more than outweigh the capital costs of investing in certain types of equipment. Most economists conclude that such estimates generally do not represent the full costs of adopting the specific technologies, partly because they may not adequately consider all of the costs of installing new equipment or the costs of various impediments—such as borrowing constraints or the effort to acquire needed information about alternatives—that deter firms and households from making certain investments. Moreover, such estimates may not sufficiently account for all of the characteristics that users value in the equipment.

Economic Estimates

Economic estimates typically rely on aggregate data to project the cost of reducing energy use across broad classes of activities. Such studies often simulate the effects of policies using large-scale economic models that attempt to measure not only the full range of emission-producing activities that would be directly affected by restrictions on carbon emissions but myriad other economic activities that might be indirectly affected as firms and households adjust their behavior in response to the restrictions.[16] Most studies use so-called *general-equilibrium* models that simulate how idealized households and businesses would respond to policies by adjusting their consumption, saving, hours worked, and production behavior; simulations using those models often run for decades into the future. In many of the models used to analyze climate policies, however, households are assumed to have perfect foresight—that is, to take into account fully and accurately events far into the future. As a consequence, the modeled economies respond rather quickly to changes in policy. A smaller set of studies uses so-called *macroeconometric models*, which are designed to simulate gradual responses of consumer spending and investment to unexpected economic shocks over shorter time periods. Those models show how adjustments in behavior might result in lower aggregate economic activity.

Some economic estimates also include considerable engineering detail about different technologies used in the energy sector. One well-known example is the Energy Information Administration's National Energy Modeling System (NEMS), which integrates a highly detailed representation of the energy sector with a macroeconometric model of the U.S. economy. Some models include only cursory representations of international linkages, while others include the entire global economy. Nearly all modeling efforts in the United States rely on the EIA for baseline (reference) forecasts, and they draw on engineering estimates of abatement costs by the Environmental Protection Agency for nearly all types of greenhouse-gas emissions other than CO_2 resulting from the combustion of fossil fuels.

How Large Are Estimated Costs?

In recent years, a few legislative proposals for long-term emission reductions have been analyzed using several different models, providing an opportunity to compare cost estimates and to understand the sources of differences in estimates. Most recently, several groups have released estimates of the economic impact of H.R. 2454, the American Clean Energy and Security Act of 2009.[17] (For more information on those estimates, see Box 2.) That bill would create two cap-and-trade programs for greenhouse-gas emissions—a large one applying to CO_2 and most other greenhouse gases, and a much smaller one applying to hydrofluorocarbons—and would make further significant changes in climate and energy policy. The larger cap-and-trade program, on which most analyses focus, would restrict greenhouse-gas emissions from covered entities by requiring them to hold allowances or offset credits for their emissions. The annual allocation of allowances would fall to 83 percent of 2005 emission levels by 2020 and to 17 percent of 2005 levels by 2050. Fully phased in by 2016, the cap would cover roughly 85 percent of projected total U.S. greenhouse-gas emissions. The bill would allow for unlimited banking, and limited borrowing, of allowances. The bill also would allow covered entities to meet a significant portion of their compliance obligations by purchasing offset credits from domestic and international providers; in total, entities could use offset credits in lieu of reducing up to 2 billion tons of greenhouse-gas emissions annually (which would represent more than half of the annual emission reductions projected until about 2030).

16. Almost none of those models provide estimates of the economic effects of climate change or the benefits of averting climate damage, so they usually cannot be used to compare costs and benefits of different policies.

17. For a more detailed discussion of the studies reviewed in this section, see Congressional Research Service, *Climate Change: Costs and Benefits of the Cap-and-Trade Provisions of H.R. 2454*, CRS Report for Congress R40809 (September 14, 2009).

Box 2.

Recent Analyses of H.R. 2454, the American Clean Energy and Security Act of 2009

A number of analyses of different versions of the American Clean Energy and Security Act of 2009 have been published (some at the request of Members of Congress) by government agencies, academic institutions, and private organizations. The Congressional Budget Office published cost estimates for two versions of the bill, one as ordered reported by the House Committee on Energy and Commerce (available online at www.cbo.gov/ftpdocs/102xx/doc10262/hr2454.pdf) and another as amended and reported by the House Committee on Rules (available at www.cbo.gov/ftpdocs/103xx/doc10376/hr2998WaxmanLtr.pdf). In addition, CBO reported on other aspects of the bill in the following publications: *The Estimated Costs to Households from the Cap-and-Trade Provisions of H.R. 2454* (June 19, 2009), www.cbo.gov/ftpdocs/103xx/doc10327/06-19-CapAndTradeCosts.pdf; *The Economic Effects of Legislation to Reduce Greenhouse-Gas Emissions* (September 2009), www.cbo.gov/ftpdocs/105xx/doc10573/09-17-Greenhouse-Gas.pdf; *The Use of Offsets to Reduce Greenhouse Gases*, Issue Brief (August 3, 2009), www.cbo.gov/ftpdocs/104xx/doc10497/08-03-Offsets.pdf; and *How Regulatory Standards Can Affect a Cap-and-Trade Program for Greenhouse Gases* (September 16, 2009), www.cbo.gov/ftpdocs/105xx/doc10562/09-16-CapandStandards.pdf.

Analyses from other sources include the following:

Sergey Paltsev and others, *The Cost of Climate Policy in the United States,* Report No. 173 (Cambridge, Mass.: Massachusetts Institute of Technology, Joint Program on the Science and Policy of Global Change, April 2009), "Appendix C: Analysis of the Waxman-Markey American Clean Energy and Security Act of 2009 (H.R. 2454)," available at http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt173.pdf. To perform the analysis, the authors used the Integrated Global System Model, including the Emissions Prediction and Policy Analysis model (IGSM-EPPA).

Department of Energy, Energy Information Administration, Office of Integrated Analysis and Forecasting, *Energy Market and Economic Impacts of H.R. 2454, the American Clean Energy and Security Act of 2009*, SR/OIAF/2009-05 (August 2009), available at www.eia.doe.gov/oiaf/servicerpt/hr2454/pdf/sroiaf%282009%2905.pdf. The analysis was conducted using the National Energy Modeling System (NEMS).

Environmental Protection Agency, Office of Atmospheric Programs, *EPA Analysis of the American Clean Energy and Security Act of 2009, H.R. 2454 in the 111th Congress* (June 23, 2009), available at www.epa.gov/climatechange/economics/pdfs/HR2454_Analysis.pdf and www.epa.gov/climatechange/economics/pdfs/HR2454_Analysis_Appendix.pdf. The analysis was performed using the Intertemporal General Equilibrium Model of the U.S. (IGEM) and the Applied Dynamic Analysis of the Global Economy (ADAGE).

CRA International, *Impact on the Economy of the American Clean Energy and Security Act of 2009 (H.R. 2454)* (prepared for the National Black Chamber of Commerce, May 2009), available at www.crai.com/uploadedFiles/Publications/impact-on-the-economy-of-the-american-clean-energy-and-security-act-of-2009.pdf. The analysis was conducted using the Multi-Region National-North American Electricity and Environment Model (MRN-NEEM).

A few other organizations have reported estimates of the economic impact of H.R. 2454, but their estimates appear not to have incorporated key features of the bill, such as the full range of greenhouse gases covered and the potential for the banking of allowances and the extensive use of international offsets.

Estimates of the economic cost of this proposal vary because of differences in assumptions about a number of factors: future economic growth and emission trends, firms' and households' responses to the policy, the future cost and availability of various technologies, the climate policies pursued by other countries, and the availability and cost of credible international offsets. Moreover, no single model or scenario addresses the full complexity of the domestic and global economies or the full range of activities associated with greenhouse-gas emissions, and thus no framework provides a comprehensive treatment of all the potential effects of any climate policy. For example, few models include an explicit channel through which a climate policy would influence the pace of development of new technologies (although at least some effects of policies on technological development are included implicitly in the responses of consumers and producers of energy to changes in energy prices). In addition, none of the models incorporates the effect of climate change itself on economic activity or incomes. As a consequence, the results provide information about the costs of policies to reduce greenhouse-gas emissions but do not provide enough information to do cost-benefit analyses of such policies. Moreover, since most models use many similar assumptions, even the wide range of reported estimates does not illustrate the full degree of uncertainty regarding the costs of mitigating emissions.

All of the models used to estimate the effects of climate policies provide estimates of the annual prices of allowances and offsets necessary to achieve the specified levels of emissions. Most of those models also provide estimates of macroeconomic impacts, such as changes in inflation-adjusted gross domestic product and personal consumption expenditures. Very few, however, provide comprehensive estimates of changes in households' economic well-being—what economists refer to as welfare impacts or the economic burden.

Changes in Energy Use and Emissions

The qualitative findings of the leading models are similar. In nearly all of the reported scenarios, changes in the demand for energy and reductions in overall energy use are only modest in the near term—that is, roughly through 2025. Instead, emission reductions over that period would stem primarily from shifting the mix of fuels used in electricity generation away from coal and toward natural gas, and from domestic and international offsets (particularly the sequestration of carbon in forests). The heavy use of offsets predicted by the models presumes that offsets could be provided with only modest administrative and other costs; if offsets proved not to be available at modest cost, allowance prices and the economic costs of the proposal would be much higher.

Over the longer term, the use of domestic and international offsets would be constrained by the limits specified in the legislation, and reductions would come increasingly from the energy sector. Technological developments would play a critical role in that process, and some of the variation among results reflects a lack of consensus about which technologies would be adopted. Energy conservation and most renewable energy sources are projected to play relatively limited roles over the entire period, mainly because most kinds of renewable energy provide power intermittently. Instead, a substantial increase in the use of nuclear power plays a dominant role under some assumptions, while significant increases in the use of biofuels or carbon capture and sequestration play a much more important role under other assumptions.

All of the reported estimates that take into account the potential to bank emissions find that during the early years of the program, covered entities would reduce emissions and purchase offsets to a greater extent than necessary to meet the cap's specified for those years. They would thus accumulate a substantial quantity of allowances that they could use in later years. Those allowances, combined with the extensive purchase of offsets in later years, would allow covered entities to maintain levels of emissions that were much larger than the levels specified by the annual caps for those later years.

Allowance Prices

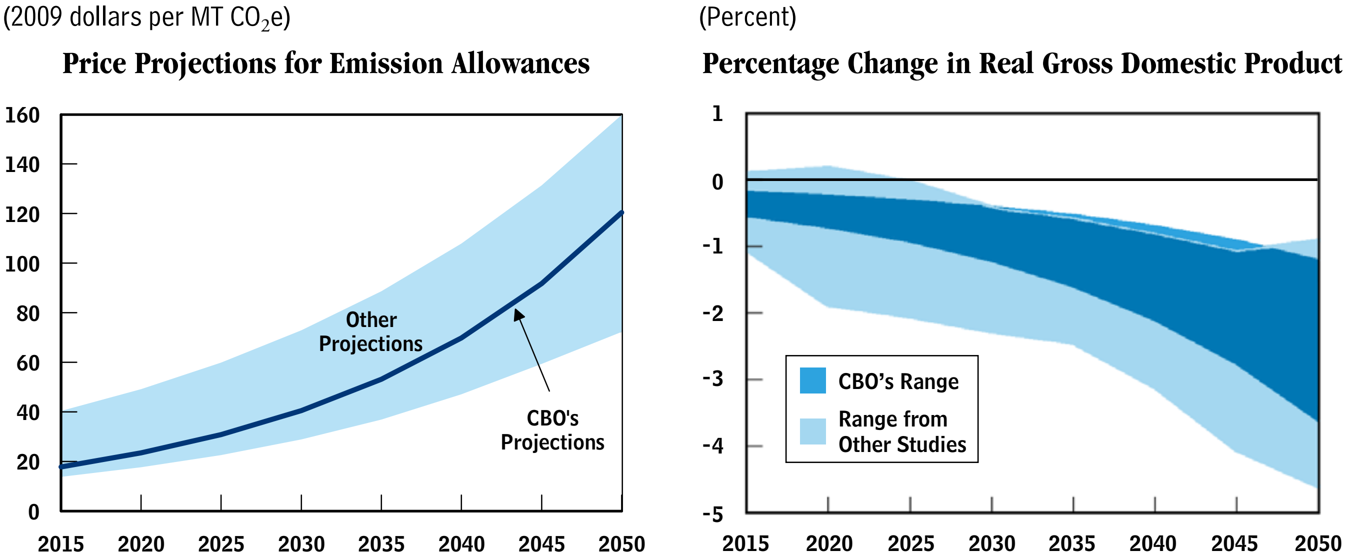
The left panel of Figure 1 illustrates the range of estimates of allowance prices required to induce the emission reductions specified by H.R. 2454 according to several prominent models; for comparability, all of the estimates are presented in constant 2009 dollars per metric ton of CO_2 equivalent.[18] The estimates shown in the figure all reflect the full range of greenhouse gases covered by the bill, the banking of allowances, and the extensive use of international offsets. However, the estimates incorporate varying assumptions about economic growth, policy implementation, households' and firms' responses, the development and cost of various types of technology over time, and the availability of offsets.

For 2020, estimates of the allowance price vary by nearly a factor of three, ranging from under \$18 to almost \$50. The allowance prices rise over time at rates that reflect modelers' assumptions about rates of return that firms would require to bank allowances; for 2050, allowance prices range from about \$70 to nearly \$160 per metric ton of CO_2 equivalent. (If offsets were assumed not to be

18. Somewhat confusingly, estimates are often provided in different years' constant dollars and in different physical quantities as well, such as metric tons of carbon—MTC—instead of MT CO_2e. Because of inflation, \$10 per MT CO_2e in constant 2009 dollars is equivalent to roughly \$8 per MT CO_2e in constant 2000 dollars; and because carbon dioxide is composed only partly of carbon, it is equivalent to roughly \$37 per MTC in constant 2009 dollars.

Figure 1.

Projections Under the American Clean Energy and Security Act of 2009



Source: Congressional Budget Office.

Notes: MT CO_2e = metric tons of carbon dioxide equivalent (or the amount of CO_2 that would cause an equivalent amount of warming).

The figures illustrate a range of estimates of the impacts of the emission reductions specified in the cap-and-trade portions of H.R. 2454, the American Clean Energy and Security Act of 2009. The estimates of allowance prices (shown in the figure on the left) reflect all greenhouse gases covered by the bill, the banking of allowances, and the extensive use of international offsets. The estimates of changes in real gross domestic product (shown in the figure on the right) reflect a wider range of assumptions about coverage, allowance banking, and the use of offsets. Both sets of estimates incorporate varying assumptions about economic growth, policy implementation, households' and firms' responses, the development and cost of various types of technology over time, and the availability of offsets. [Note revised on May 28, 2010]

The projections displayed in the figures were produced by the Energy Information Administration, the Environmental Protection Agency, CRA International, Massachusetts Institute of Technology, the Brookings Institution, and the Congressional Budget Office.

available, projected allowance prices would be substantially higher.) CBO's estimate of allowance prices lies near the middle of the range shown here, but it rises slightly faster than in most other estimates because CBO uses a rate of return for the banking of allowances that is slightly higher than that used by most other modeling groups.

Macroeconomic Impact

All of the models reporting macroeconomic impacts project that the emission reductions required by H.R. 2454 would slightly dampen the growth of GDP over the long term. (One model projects small increases in the early years of the program). Quantitative estimates of the losses in GDP and consumption vary among studies, depending in large part on differences in assumptions about the availability of offsets (reduced availability of offsets increases the emission reductions required in the energy sector and thus increases economic costs) and differences in assumptions about the sensitivity of energy use to changes in prices (reduced sensitivity increases the price increases required to reach emission targets and thus increases economic costs). On the basis of those estimates and its own analysis, CBO concluded that H.R. 2454 would slightly reduce real GDP—by roughly 0.25 percent to 0.75 percent in 2020 and by between 1.0 percent and 3.5 percent in 2050 (see the right panel of Figure 1).[19] By way of comparison, CBO projects that real GDP will be roughly two-and-a-half times as large in 2050 as it is today. Losses in consumption and overall well-being would probably be smaller than losses in GDP.

Unchecked increases in greenhouse-gas emissions would also tend to reduce output compared with a situation where climate change did not occur—especially later in

19. See Congressional Budget Office, *The Economic Effects of Legislation to Reduce Greenhouse-Gas Emissions.*

this century as emissions accumulated in the atmosphere. Nonetheless, CBO concludes that the net effects on GDP of restricting emissions in the United States—combining the effects of diverting resources to reduce emissions and moderating losses in GDP by averting warming—are likely to be negative over the next few decades because most of the benefits from averting warming are expected to accrue in the second half of the 21st century and beyond.

Impact on Employment

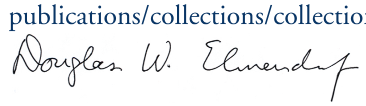
H.R. 2454 would cause a significant shift in the composition of employment over time. Production and employment would shift away from industries related to the production of carbon-based energy and energy-intensive goods and services and toward the production of alternative and lower-emission energy sources, goods that use energy more efficiently, and non-energy-intensive goods and services. Those shifts in employment would occur gradually over a long period, as the cap on emissions became progressively more stringent and the allowance price became progressively higher. The experience of the U.S. economy over the past half-century in adjusting to a sustained decline in manufacturing employment strongly suggests that the economy can absorb such long-term changes and maintain high levels of overall employment. As a result, CBO concludes that the cap would probably have only a small effect on total employment in the long run.

Nevertheless, the employment effects of H.R. 2454 could be substantial for some workers, families, and communities. Labor markets would take time to adjust to shifts in demand. Job losses would be concentrated in particular industries and in particular geographic regions. Some workers would probably end up working fewer hours or at lower wages than they did previously, and some might leave the labor force entirely. Involuntary job losses could significantly reduce the lifetime earnings of some affected workers. Several provisions of H.R. 2454 would subsidize the development and deployment of technologies that reduced emissions or would subsidize production by specific industries and firms, tending to dampen the bill's effects on employment—especially in industries and areas where they are expected to be most severe.

The Distribution of Costs

Few analysts have assessed how the costs and transfers associated with the cap-and-trade program established under H.R. 2454 would be distributed among groups of households. As a rough indication of those distributional impacts, CBO estimated the effect on households' purchasing power of the costs of complying with the policy (by reducing emissions and purchasing allowances and offsets) minus any associated compensation (such as freely allocated allowances, earnings from sales of allowances, and profits from producing offsets).[20] CBO concluded that under H.R. 2454 the loss of aggregate purchasing power would increase from about 0.1 percent in 2012 to 0.8 percent in 2050. Those losses would be distributed in ways that tend to benefit lower-income households. In 2020, households in the highest income quintile would see a loss in purchasing power of 0.1 percent of after-tax income, and households in the middle quintile would experience a loss equivalent to 0.6 percent. Households in the lowest quintile, by contrast, would see an average gain of 0.7 percent. By 2050, households in the highest quintile would see a loss in purchasing power of 0.7 percent of after-tax income, and households in the middle quintile would see a loss of 1.1 percent. Those in the lowest quintile would see a 2.1 percent increase.

This brief was prepared by Robert Shackleton of CBO's Macroeconomic Analysis Division. In addition to the reports mentioned in the text and footnotes of this brief, the following CBO publications focus on policy choices associated with climate change: *The Potential for Carbon Sequestration in the United States* (September 2007), *Evaluating the Role of Prices and R&D in Reducing Carbon Dioxide Emissions* (September 2006), and *Shifting the Cost Burden of a Carbon Cap-and-Trade Program* (July 2003). Those and other reports on climate policy are available at CBO's Web site, www.cbo.gov/publications/collections/collections.cfm?collect=9.



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20. See Congressional Budget Office, *The Economic Effects of Legislation to Reduce Greenhouse-Gas Emissions*.