allowances in the trading market crashed from 30 euros per metric ton of CO_2 to a low of 3 euros, as every EU member but the United Kingdom reported that their emissions were not as high as their too-generous allocations. The resulting mess has stymied investment. Companies that had made plans to install carbon controls that were economical at prices of 25-30 euros per metric ton of CO_2 found themselves unable to justify the cost at the lower prices. The temptation for governments to manipulate emissions estimates used for permit allocations may be an intrinsic problem with cap-and-trade.

Some observers have argued that the best bet for promoting reductions in CO_2 emissions is for government to establish renewables portfolio standards (RPSs), which mandate that electricity distributors must rely on specific renewable energy sources to provide a set percentage of power supplied to their customers. Twenty U.S. states have enacted some form of RPS, with quotas that range from 1% to 30% of electric power.

RPSs are not without drawbacks, however. Although achieving "energy renewability" is loosely correlated with the objective of reducing carbon emissions, it is not the same thing. An RPS is a policy instrument with many objectives. Recent RPS debates have cited numerous goals, including reducing air pollutants, keeping down fluctuating prices of fossil fuels, encouraging energy independence and diversity of fuel supply, promoting resource sustainability, and creating jobs. Although this kitchen sink approach may make it politically easier to pass RPSs than more focused regulations, there are significant cost penalties. One penalty is that some of the renewable sources encouraged or mandated by an RPS produce electric power only intermittently, making poor use of expensive capital investments. Another is that set-asides and subsidies for sources such as solar photovoltaic, which are now much more expensive than wind, conservation, or new carbon-controlled fossil and uranium energy sources, significantly increase the cost of power provided to consumers.

Given such considerations, we believe that the best method to promote reductions in carbon emissions is for individual states, which typically regulate energy matters, to adopt a carbon emissions portfolio standard (CPS). Under such a strategy, each supplier of electricity would be responsible for assuring that it meets an overall constraint on its carbon emissions. The company must supply the mandated fraction of low-carbon power, from wherever it is purchased. A CPS avoids the thorny problem of allocating permits because it requires distributors to buy a set amount of low-carbon power but allows them to seek the most inexpensive suppliers. Moreover, a CPS can be written to allow trading among those jurisdictions that have similar rules. A CPS can send a clear market signal to generators and provide a robust incentive to make long-term investments in generation technologies with low- or no-carbon emissions.

To complement state adoption of CPSs, the federal government should guarantee loans for construction of advanced generating plants that emit significantly less CO_2 than current facilities. Such loan guarantees may be critical to obtaining financing from investors who have demanded risk premiums to compensate for the uncertainty of electric competition, lowering the bond rating of most investor-owned utilities.

Technology options

Technologies to produce electric power with low-carbon emissions already are in use at various scales. These sources include nuclear, hydroelectric, biomass, geothermal, wind, and solar power. Together they account for roughly 28% of all U.S. electric power production, with nuclear representing the majority (20%), followed by hydroelectric (7%). However, demand for power is increasing, driven by increased population and per capita demand. If the current rates of electric generation construction are maintained, by 2020 the percentage of low-carbon sources is projected to fall to 21% of total production.

Clearly, the nation will need to develop—or, in some cases, simply adopt—other power-generating technologies that use coal, an abundant resource, but greatly reduce CO_2 emissions or control their dispersal. (See sidebar.) Studies presented at the International Energy Agency's Greenhouse Gas Technology Conferences have shown that if the electric power industry adopts technologies to greatly reduce CO_2 emissions, the wholesale cost of power would rise by roughly two to three cents per kilowatt-hour for fossil-fuel, wind, and nuclear options, four to five cents for geothermal, and more than 20 cents for solar.

Based on available estimates of the likely cost of future low-carbon options, we have estimated that the cost of eliminating most CO_2 emissions from the electricity system would reach a range from 0.4% to 0.9% of the U.S. gross domestic product (GDP) as the proportion of low-carbon power is increased over the next four decades, provided the transition is achieved in a gradual and orderly manner. Although this is a significant amount of money—roughly $60 billion to $125 billion per year—it is certainly manageable. Despite dire predictions, the nation's economy thrived while spending 1.5% of GDP to reduce air pollution discharges in the 1970s and 1980s.

BEGINNING NOW WITH MEASURES SUCH AS CARBON PORTFOLIO STANDARDS AND LOAN GUARANTEES FOR LOW-CARBON PLANTS WOULD REDUCE THE LONG-RUN COST OF CONTROLLING CARBON.

If the United States waits to encourage low-carbon technologies, foreign companies may seize the early market advantage. Both Shell and GE are working hard on coal gasification, but Shell has ready markets close to home in Europe. The benefits to the economy of taking the leading market share can be very large.

Cost of regulatory uncertainty

The electric power industry is well aware of the possibility that the federal government will impose carbon constraints, perhaps in the near future. The chief executive officer of Exelon, one of the nation's largest electric power producers, said that he is in favor of a carbon tax, but would also support the idea of tradable CO_2 emissions permits with a cap. The CEO of Duke Energy came out in favor of a carbon tax in April 2005. Cinergy's CEO wrote to shareholders in December 2004 that "we eventually will operate our business in a carbon-constrained world and it is our responsibility to prepare for that likelihood."

Power producers and distributors could make better planning decisions if the government was clearer about its regulatory timetable. If companies were certain that the government will require specific reductions in levels of CO_2 emissions by certain dates, they would make decisions accordingly. A power plant has a life of many decades (13 coal plants from the 1920s are still operating). If a carbon constraint costing, say, \$50 per ton of emitted CO_2 were to come into force 10 years into a plant's 40-year planned lifetime, managers could easily calculate whether it was in their interest to install low-carbon technology.

In the real world, however, the timing and stringency of pollution constraints remain uncertain. In this climate, companies will likely continue to build conventional high-carbon-emissions plants, because they are cheaper. Indeed, uncertainty may encourage utilities to rush now to build conventional plants in the hope that they will be grandfathered under any new regulations, which would increase total costs by imposing more stringent emission constraints for plants built later. For this reason, state legislatures and public utility commissions (PUCs) would be wise to make it clear that investors, not rate payers, will bear future regulatory costs if conventional plants are built today without at least leaving space to later add postcombustion capture and storage of CO_2.

Retrofits of this sort have been done for years for other pollutants, and lessons learned in those applications can help to avoid some costs in retrofitting for CO_2 capture and storage. For example, one lesson from retrofits for controlling emissions of sulfur dioxide and nitrogen oxides has been that allocating space for postcombustion capture units during construction can reduce retrofit costs significantly. Retrofits have total costs greater than those of a purpose-built low-carbon plant but allow the decision to be postponed until it becomes mandatory. The public would bear the extra costs of this decision in the form of higher electricity bills; the total bill would be more than if a low-carbon plant had been built from the start. The company is making a rational decision, ensuring its survival by not expending too much capital when the carbon tax is still uncertain.

The decision to build from the start with a low-carbon technology or to retrofit will depend, in part, on the scale of the extra costs that are imposed by the retrofit. The higher the extra retrofit costs, the more likely the tendency to install a low-carbon technology before the carbon-control details are clarified. For example, Joule Bergerson of the University of Calgary and Lester Lave of Carnegie Mellon University have determined that building an integrated gasification combined cycle (IGCC) coal-fired plant—one of the promising technologies becoming available—and then later adding the capability to capture CO_2 and sequester it deep underground costs 50% more than building in CO_2 capture and storage at the beginning. In addition, they determined that a company would be better off building in carbon capture at the start only if they believe a $100-per-ton CO_2 penalty will happen within seven years of the plant's commissioning. If they believe the $100 penalty will occur later than year 13, they would be more likely to build a conventional coal-fired plant with retrofit capability for capturing and storing CO_2.

In another study, Peter Reinelt of the State University of New York at Fredonia and David Keith of the University of Calgary have quantified the costs of regulatory uncertainty in a simplified dynamic model. They find that if it is technically feasible to retrofit a plant for later CO_2 capture and storage, uncertainty in carbon regulation may increase the social cost of controlling carbon emissions by 10% to 30%, whereas if retrofits are not feasible and if natural gas pri commercial use in other settings, it is even more important to begin to build full-scale plants and thus move upward on the learning curve. As a recent editorial in Nature declared, “Bringing carbon sequestration into a fast track

CO_2 and mercury allowances, to compute the value of such options. She found that in the absence of a carbon price, only if the owners have a planning horizon longer than 20 years would they replace a conventional coal-fired plant with a high-performance unit; otherwise, they would install SO2 and NOx controls on the existing plant. Without a carbon price, installing advanced technology would not be profitable.

Moreover, even in an era when CO_2 allowances in a cap-and-trade system cost an average of $30 per ton of CO_2

Whatever is done, the nation must start soon. There are three penalties for delayed action on carbon control. First, a 15% discount rate (which many companies use for investment decisions) lowers the present discounted cost of a $100-per-ton CO_2 emission tax or allowance cost imposed in 2030 to $3-

controls. But they will not do so until we take the lead and show how it can be done in an efficient and affordable way.

Beginning now with measures such as CPSs and loan guarantees for low-carbon plants can make later actions much less costly. A CPS is the least-cost national solution, and has many of the benefits espoused by proponents of RPSs. But there is no escaping the conclusion that effective control of carbon in the U.S. electric power industry requires regulators to act quickly to set a clear timetable for emission reductions.

Low-Carbon Technologies

Conventional coal-fired plants, which burn pulverized coal in boilers, emit more CO_2 per kilowatt-hour than any other method of producing electricity. High-performance coal plants, called supercritical plants, and very high-performance plants, called ultra supercritical plants, are more efficient than even the newest pulverized-coal generation plants. Replacing an old, inefficient coal plant with a supercritical or ultra supercritical plant can reduce CO_2 emissions by a third.

Emissions can be reduced much more by chemically capturing the CO_2 produced during combustion and injecting it deep underground, a process called CO_2 capture and deep geological sequestration. The technologies required to capture CO_2 from all types of pulverized-coal plants, transport it long distances by pipeline, and inject it into underground reservoirs exist at commercial scale today.

A few pilot coal-fired plants use a method in which coal is burned, but in the presence of a much higher percentage of oxygen than is present in ordinary air (95% instead of 20%). This “oxyfuel” method produces an exhaust gas with much higher concentration of CO_2, making capture more efficient than with a conventional boiler.

At 130 coal-burning facilities around the world, including some plants that produce electricity, coal is used in a very different fashion. Instead of being burned in open flames, it is fed into a refinery vessel along with oxygen. The process results in exhaust streams of CO_2, hydrogen gas, sulfur powder, and a glassy slag containing various other impurities. The CO_2 gas stream can be injected deep underground instead of being released into the atmosphere, reducing emissions by 85%. When used to produce electricity, these plants are called integrated gasification combined cycle (IGCC) plants.

Among other current low-carbon energy sources, nuclear power is the largest deployed technology. But the capital cost of building a nuclear station is considerably larger than that of a coal-fired plant with conventional pollution control. If nuclear power is to keep its present 20% share of electricity production—from 103 plants now operating—30 new nuclear plants must be brought into service by 2020 to keep up with increasing demand. After 2020, many existing nuclear plants may have to close because of age, and construction will have to reach very high levels if market share is to be maintained.

Hydroelectric power is the second major source of low-carbon electricity.(Hydro produces only small amounts of CO_2 as a byproduct of dam construction and operation, but in some cases may produce significant amounts of another greenhouse gas, methane.) Fifty years ago, hydroelectric power made up a third of all electric generation. But almost all potential domestic large water power sites are already in use, and environmental and social costs make a significant increase in hydropower unlikely in North America, although small scale projects may continue to be built.

For a time in the 1990s, electricity generation was switching from coal to natural gas. (Gas plants emit about half as much CO_2 per kilowatt-hour produced as do coal plants.) The supply of North American natural gas is limited, however, and imports will be minor until huge fleets of liquefied natural gas tankers ply the seas. The inevitable result of increased demand arising from the switch to natural gas was a fourfold increase in gas prices, and investment in new natural gas-electric generators has virtually ceased. In any case, conventional natural gas does not provide the deep cuts in CO_2 emissions that are likely to be required by future regulations.

Biomass currently is used to produce just less than 1% of the nation's electricity. This fraction can be increased, both in advanced biomass plants and by blending biomass with other fuels in power generators. Some studies indicate that biomass may be an important transportation fuel, and (typically coal or gas) emits CO_2. However, because the fuel cost for wind is zero, the total cost per kilowatt-hour is roughly competitive with other low-carbon sources, such as new nuclear power plants.

The amount of solar energy that reaches the United States each year is equivalent to approximately 4,000 times the nation's total electric power needs, but tapping that energy is expensive. Costs for solar photovoltaic (PV) power are five to 10 times higher than those of other low-carbon technologies, and the average power produced at even the best sites is less than a quarter of the energy produced at noon on a sunny day. Significant research efforts are under way in basic science to improve the performance of PV cells, which may lead to cost reductions in the future.

Energy conservation and demand reduction also represent ways to reduce CO_2 emissions. Experience in Vermont and California shows that aggressive policies can significantly reduce the growth of electricity demand. California's per capita consumption grew by just 5% during the past 25 years, markedly less than the 35% national per capita growth.(Some of the decline may have been due to large electricity consumers relocating outside the state.) The cost of such measures, however, is hotly debated. Also, population increases have continued to boost overall electricity consumption. And given that the nation must achieve deep reductions in emissions while the population and economy continue to grow, there is clearly a limit to how large a role conservation and demand management can play in meeting the carbon challenge.

Recommended reading

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