Climate Change and Electricity R&D: Preparing for the Future

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I would like to talk about how a serious attempt to deal with the climate change problem would affect the future of world electricity supply, and what we should doing today to prepare this future.

[VIEWGRAPH 1: Objective of the FCCC]

The objective of the Climate Convention is to stabilize concentrations of greenhouse gases at a level that would prevent dangerous interference with the climate system.

The Convention does not define “dangerous interference,” and the panel of experts assembled to advise the parties to the Convention—the Intergovernmental Panel on Climate Change (IPCC)—has not rendered a judgment about the level of greenhouse gases that would prevent dangerous interference with the climate system.

After studying the available evidence on how climate might respond to increasing greenhouse gas concentrations, and how natural systems and national economies might respond to changes in climate, I believe that the stabilization goal should not be higher than an equivalent doubling of carbon dioxide.

According to the IPCC, the current “best guess” is that a doubling of CO_2 would increase the global-average surface temperature by 2.5 °C, and that the increase could be as low as 1.5 degrees or as high as 4.5 degrees. The wide range is mostly due to uncertainties about how clouds and ocean currents will respond—whether they will change in ways that amplify or diminish the warming.

[VIEWGRAPH 2: Average surface temperature from 100 Myr BP to 2200 AD]

An increase of 2 or 3 degrees may not sound like much, but it is large when compared to historical changes. The increase of 0.5 °C that has been observed over the last hundred years, and which is probably due to increased greenhouse gas concentrations, makes this the warmest period since at least the 14th century, and one of the warmest in the last 10,000 years.

Even small changes in temperature have been associated with significant changes in climate. Six thousand years ago, when the average temperature was about 1 °C warmer than at present, the tropic experienced floods 4 to 10 times larger than today and the temperate latitudes were significantly drier. The Little Ice Age, which began in about 1300 AD, when average temperatures fell by 0.5 to 1 °C, was accompanied by violent storms and floods and crop failures.

Looking further back in history, we see that average temperature varied by about 5 degrees as the Earth shifted between glacial and interglacial periods. These temperature increases have sometimes been very rapid, and have been accompanied by dramatic changes in ocean circulation. A change in temperature of 5 °C is at the upper end of the estimates for a doubling of CO_2, but it cannot be ruled out.

Economists generally have downplayed the economic impact of climate change. a doubling of carbon dioxide. Estimates center around 2 percent of GWP. Although a small fraction, this would amount to perhaps two to four trillion dollars per year in the second half of the next century. Such estimates also fail to take into account damage to ecosystems, increases in climate variability, or the possibility of very rapid climate change.

Of course, there are huge uncertainties in estimates of climate change and its impacts. It is unlikely that the range of uncertainty will be narrowed substantially in the next twenty years. In order to stabilize at an equivalent doubling, however, we will have to take decisive action within the next twenty years.

One way to develop a strategy in the face of uncertainty is to construct reasonable scenarios based on the information we have today, and ask what we should be doing now if these scenarios were to become reality. So let's explore the implications for the future of world electricity supply of adopting a stabilization goal of an equivalent doubling of CO_2.

[VIEWGRAPH 3: Carbon Emissions to Achieve Stabilization]

If we take into account other greenhouse gases, such as methane, nitrous oxide, and halocarbons, and equivalent doubling would require that CO_2 concentrations be stabilized at about 450 ppm—certainly no higher than 500 ppm. For comparison, CO_2 concentrations have risen from 280 to 360 ppm during the last 150 years, so we already are about half-way toward a goal of 450 ppm.

In order to achieve stabilization at an equivalent doubling, emissions of carbon dioxide must peak within the next ten to twenty years. After peaking, emissions must decline to levels below the current rate by 2050, and below half the current rate by 2100. These conclusions hold regardless of assumptions and uncertainties. Note, however, that the level at which emissions peak is much less important than the rate of emission in the second half of the next century. So we are free to increase emissions for another ten or twenty years, but what comes up must come down.

This scenario has profound implications for energy supply, and particularly for electricity production. Today, fossil fuels supply 85 percent of the world's commercial energy and 60 percent of the world's electricity. Electricity production is responsible for about 30 percent of global carbon emissions.

[VIEWGRAPH 4: Projections of energy demand]

The demand for energy will grow substantially over the next fifty years, driven by increases in both population and per-capita consumption in developing countries. Even if steady progress is made in improving the efficiency of energy production and use, overall demand for energy is likely to at least double, and perhaps triple, by 2050. The demand for electricity will grow even faster. But if greenhouse gases are to be stabilized at an equivalent doubling, traditional fossil fuels could not supply more energy in 2050 than they supply today.

[VIEWGRAPH 5: Required non-CO2-emitting energy supply]

Thus, over the course of the next 50 years, energy sources that do not emit CO_2 will have to go from 15 to over 50 percent of total energy supply, from less than 2 TW of primary energy today to 20 TW in 2050—an average growth rate of about 5 percent per year. The production of electricity from sources that do not emit CO2 will have to go from less than 5,000 to 25,000 TWh/yr or more. (A TWh is a billion kWh.)

How will all this electricity be produced? Only five sources are capable of supplying the large amounts of electricity that will be required in this time frame without emitting significant amounts of CO_2: solar, fission, decarbonized coal, and perhaps wind and biomass.

Other alternatives are too limited or too immature. Hydroelectric production might be doubled at most, from 2500 to 5000 TWh/yr. Hot-water geothermal might be expanded by a factor of five to ten, from 80 today to 400–800 TWh/yr. Hot-rock geothermal, ocean thermal and wave energy, and nuclear fusion are unlikely to be technically or economically feasible in this time frame.

Each of the remaining five sources has significant economic and environmental liabilities. It is too early to pick winners and losers, and the options are so few, and the stakes so high, that we cannot fail to ignore or dismiss any of these. I believe that we need a balanced and greatly enhanced research and development effort on all five, so that affordable and acceptable alternatives will be available for large-scale deployment 15 to 20 years from now.

Solar photovoltaic, nuclear fission, and decarbonized coal have the greatest potential promise, and could benefit most from intensified research and development.

Since my time is limited, let me concentrate on fission. Of the major alternatives, fission is the only one that today produces large amounts of electricity—about 2,300 TWh in 1996, or 19 percent of total consumption. Fission is , of course, experiencing major difficulties, particularly in the United States, and it is far from certain that additional research and development would prove useful in resolving these difficulties. But because fission is the only one of the major alternatives that has been proven capable of generating large amounts of electricity at costs competitive—or nearly competitive—with coal, it would be irresponsible not to try.

The list of fission's difficulties is well known: the perceived risk of reactor accidents; the problem of disposing of high-level radioactive wastes; the potential link between the spread of nuclear power and the spread of nuclear weapons; and the generally high cost of nuclear-generated electricity.

It is my perception that most people in the nuclear energy community do not believe that any of these problems are real, in the sense that they regard them as political, not technical, problems. In their view, and, they might say, in the view of any reasonable and informed person, current reactor designs are very safe, waste-disposal risks are infinitesimal, proliferation risks are purely theoretical and can be managed, and costs are inflated by licensing delays. The nuclear community believes that sound technical solutions are already in hand: advanced light-water reactors in the near-term and liquid-metal breeder reactors in the longer term. They fear that the current lack of interest in fission might atrophy the industry in this country so much that they won't be able to deliver these solutions 20 years from now. They favor R&D, but on well-developed concepts in an effort to keep the industry alive.

It is also my perception that most people in the anti-nuclear community believe that the liabilities of nuclear energy are so great, and so intractable, that no amount of R&D could possibly solve them to their satisfaction. For them, fission is simply "beyond the pale." Any government-sponsored research on fission is money that could be better spent on renewables, and would only serve to prop up an industry that otherwise is headed toward extinction, and which has already been heavily subsidized by government.

These are caricatures, of course, but not unfair ones, I think. The rigidity of these opposed groups combines to inhibit innovative thinking about the future of fission.

The Clinton administration and the Republican-controlled Congress seem to agree that fission either does not deserve or does not require government support for research and development. Federal funding for fission-energy R&D will decline from nearly $2 billion in FY78 to a mere $46 million in FY98, with no funds for allocated for new reactor concepts. Industry spending has also declined greatly.

I believe that, if fission is to make a major contribution to stabilizing greenhouse-gas concentrations, it will have to be reinvented—reinvented in ways that address concerns about accidents, waste disposal, and proliferation. Reducing the cost of fission is less important, I think, because the costs of non-CO_2-emitting alternatives are also likely to be higher, but the cost should be made more predictable.

In this regard, I largely agree with the recommendations of the PCAST Report of the Energy Research and Development Panel, which was discussed in an earlier session today. The Panel argued that fission is a potentially valuable contributor in the effort to stabilize greenhouse gases, and that is important to pursue R&D designed to make it a more attractive option.

The key recommendation is that DOE should establish a Nuclear Energy Research Initiative, initially funded at $50 million per year and increasing to $100 million per year in FY2002, to fund R&D on new, safer, and lower-cost reactor designs, new waste-disposal techniques, and proliferation-resistant fuel cycles.

I agree with the focus of the proposed program, but the scale of the effort is too modest. For comparison, the Panel recommends that fusion energy—a source which almost certainly cannot make a significant contribution for 50 years, when the need is greatest—be funded at $320 million in FY2002. That's three times the level of fission, an energy source which could make a major contribution to stabilizing greenhouse gases if it's problems could be solved.

As another point of comparison, fission today generates over $100 billion per year in revenue. The $100 million that PCAST recommends is less than 0.1 percent of revenues. This is well below the level for most other energy sources, even assumed a proportional increase in industry support.

If funding is increased, what sorts of R&D should be supported? My recommendations would parallel those of the PCAST panel.

First, I would support R&D on reactor designs that are immune to operator error or equipment failures. Current designs are safe if they are built and operated properly, and advanced versions of these designs are even safer, but people are worried—justifiably so, I think—that they won't be operated properly. Unfortunately, stories of poor management are not hard to find, from the United States to Canada, from Japan to Eastern Europe and the former Soviet Union.

The goal should be to build reactors that cannot produce off-site fatalities, no matter what happens inside the plant. The Westinghouse AP 600, which is nearing design certification, might meet that standard, but we shouldn't put all our eggs in this one basket. There should be room in an expanded energy R&D program to support industry-government partnerships on additional advanced designs, such as the Simplified BWR, the HTGR, or the Safe Integral Reactor. The concept of small (50 MW) factory-built modular reactors with lifetime cores in especially interesting.

I would not give a high priority to R&D efforts designed to extend the life of currently operating reactors. It is often noted that extending the life of current plants will significantly reduce U.S. carbon emissions, but what we do in the next twenty years doesn't matter nearly so much as what we do after that time. If keeping current plants operating would make it much easier to build new nuclear plants, then that would be a better reason to keep them going.

[VIEWGRAPH 6: Uranium usage in high-growth nuclear scenario]

I would not fund any research on breeder reactors for at least the next twenty years. Breeder reactors will be economically attractive only if the price of uranium becomes so high that their increased efficiency of uranium use compensates for their increased capital cost. But known low-cost uranium resources are sufficient to support a very large increase in fission energy over the next century. Indeed, if uranium can be extracted from seawater for less than $250 per kilogram, which seems possible with additional R&D, then breeding my never be needed.

[VIEWGRAPH 7: Cost of uranium from seawater]

In general, I think that the nuclear community has made a huge mistake by linking its long-term growth to reprocessing and breeder reactors. If I listen to one more talk that links the demise of nuclear in this country to the Carter administration's decision to forgo reprocessing, I think I'll scream. It was the right decision, it remains the correct policy, and the failure of Japan, France, and the United Kingdom to come to the same conclusion is a triumph of inertia over reason.

Second, I would support work alternative fuel-cycle concepts designed to minimize proliferation risks in a world with many more reactors, and with reactors in many more countries. This would include novel reactor concepts, such as lifetime cores; new reprocessing techniques that do not involve the separation of pure plutonium; fuel cycles that minimize the production of high-quality plutonium, such as the thorium fuel cycle; and the indefinite use of seawater uranium on a once-through fuel cycle.

Third, I would support work on alternative waste disposal concepts. Right now, we have all our eggs in one basket—deep geologic disposal—and the U.S. has all its eggs in one site—Yucca Mountain. Fission probably will not grow unless the waste-disposal problem is resolved. We need backups to Yucca Mountain, both short-term backups, such as interim storage, and long-term backups, including disposal in granite and in the deep sea bed.

In conclusion…