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ROUNDTABLE

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Nuclear power and climate change

In Progress: 5 September 2007

When considering ways to limit carbon dioxide emissions, experts argue that all options should be considered—including nuclear power. But with nuclear power comes concerns about proliferation, waste disposal, and cost. R. Stephen Berry, the former Special Advisor to the Director of Argonne National Laboratory for National Security, Amory B. Lovins (PDF, 35 KB), the chairman and chief scientist of the Rocky Mountain Institute, and Peter A. Bradford, a former member of the U.S. Nuclear Regulatory Commission, consider the feasibility of nuclear power as a remedy to climate change in the Bulletin Online's inaugural roundtable.

Tomorrow's nuclear power will be different than yesterday's nuclear power

Response: 5 September 2007
Posted by: R. Stephen Berry

Amory is correct that the sort of nuclear power last built in the United States is much more expensive than other major sources of electric power. The construction costs of the most recent nuclear plants were about $10,000 per kilowatt (kW). But this figure is misleading when considering the cost of future plants. For example, the Japanese plant at Onagawa (completed in 2002) cost approximately $2,400/kW, and a Chinese plant built at Yonggwang in 2004-2005 cost $1,800/kW, according to a May 2006 presentation given at the University of Paris by Paul Joskow. The Keystone and MIT studies estimate the next plants built in the United States will cost $3,600-$4,000/kW. These are "first-of-a-kind" reactors, too, meaning they're sure to be more expensive than later plants. Much of the cost reduction comes from changes currently being made in the regulatory structure. These changes will allow reactor licensing of a single design to be done almost in one step. Previously, each new reactor had to undergo a full licensing procedure--regardless of whether similar plants had been licensed. Significant improvement in reactor designs is also another important factor in reducing capital costs, as new reactors are cheaper and easier to build.

This brings us to safety. Of the major forms of electric power generation now used globally (I don't include wind power because I haven't found data on its safety), *the most deadly is hydroelectric power*! And this is on the basis of deaths per terawatt of electricity generated. The Keystone report cites three sources for its data, the most recent from 2001. However, we came to the same conclusion in a 1979 study: People build towns in the floodplains below dams, and the dams sometimes break. The second most deadly by far is coal--simply because of accidents, as deaths from emphysema weren't included. Nuclear power is the safest by a significant margin. Plus, Chernobyl can be removed from the equation because no one will build that type of reactor again, making it absolutely clear that nuclear power wins on safety. To my knowledge, a study of accidents or mortality from micropower has yet to be done.

(Incidentally, the rest of the world, as recognized by Google, thinks of micropower as items such as power supplies for computers and hand tools. It might be useful if Amory found a different word.)

Returning to costs: When taking into account the value of the large land areas needed for wind farms, it's far from clear that wind power is economically competitive with coal, gas, and nuclear everywhere. Of course, in arid regions with no high-value uses for land, wind power makes great sense--so long as the windmills don't spoil the environment. For example, I'd hate to see wind farms at Capitol Reef National Park in Utah, and some in the Northeast have objected to local offshore wind farms on environmental and aesthetic grounds.

Amory's argument for generating electric power locally with small-scale sources certainly has a range of validity. I'd be thrilled if towns in western Colorado generated their own electricity; in fact, Telluride still does at the Ames hydroelectric plant, the world's first commercial alternating current power station. But that power goes into the nationwide net; so does the power generated with solar panels. The time will come when individuals can afford to install solar panels that collect enough energy for their domestic power and heating needs, but not for many generations.

As for the Chinese approach to supplying electricity, the Three Gorges Dam project, which is supposed to supply large amounts of electric power in China, has been one of the biggest environmental disasters of modern times. This is well recognized by the roughly one million people displaced from their homes and farms because of the dam *and* knowledgeable people with scientific understanding of the dam's issues. Not to mention, this project runs concurrent with the program to build an average of 1 gigawatt coal-fired power plant per week.

The gains from Beijing's renewables program are miniscule when compared to the impact of its hydroelectric- and coal-based electric power supplies. If China can replace a significant fraction of its planned coal-fired plants with nuclear plants, especially at the low cost of about $1,800/kW cited above, the global impact of China's electricity needs could be significantly lessened. Safety might influence that policy, too. Days after the Utah mine collapse, which trapped six miners, a collapse occurred in a Chinese mine, trapping 180 miners.

I want to end this discussion on a positive note. Amory has been very successful in communicating his ideas to significant and influential people. But there is one effort he could expand that would give his efforts a new level of long-term impact. The Rocky Mountain Institute (RMI) has a kids' program, which features some interesting points. Yet, this is small potatoes compared to what RMI might do. I suggest that they work with teachers, beginning in the Roaring Fork Valley where RMI is located, to create an in-school program to educate students about energy and climate issues. It could be done at several age levels, starting with first and/or second graders. It will take considerable experimentation and careful evaluation to find what approaches work. After all, the concept of energy is subtle: We see it as a single natural phenomenon even though it appears in a remarkable variety of forms. An exciting curricular unit could be built just on what energy is, how we get and use it, and the type of care we need to exert when working with it.

So, Amory, here's a challenge for you! If you decide to try such a program and if I can help, let me know. I'll be happy to do what I can.

Negawatts and micropower are market winners, while nuclear is a market loser
Response: 27 August 2007
Posted by: Amory B. Lovins

Steve Berry undoubtedly supports energy efficiency, on which he did good work in the past. But his understanding of it is so minimal that he thinks it "barely lowered the slope" of China's energy demand. In fact, "barely" averaged 70 percent during 1980-2001.

In his world, cheap, fast, profitable, privately financed market winners that provide the majority of the world's new electrical services (negawatts and micropower, in roughly equal measure) are inevitably too slow and small. Instead, he urges that we should subsidize a costly, slow, unprofitable, tax-funded market loser that has only a few percent market share and actually *lost* net capacity last year. (The International Atomic Energy Agency reports that global nuclear capacity shrank 0.43 gigawatts (GW) in 2006, while even the smallest and costliest renewable--photovoltaics--installed 1.74 new GW.) Yet he never explains why this perverse shift is necessary or desirable.

I agree that "no single approach" can *entirely* power a climate-safe, prosperous global economy. Yet energy efficiency, in its myriad forms, comes closer than all other energy options combined.

Steve's appeal to "provide energy" to people without clean water or electricity is valid but irrelevant: For those mainly rural people without wires or money, an efficiency-and-distributed-renewables portfolio is the only practical solution today, while nuclear power is the most exorbitant and unsuitable.

Steve claims that China plans "to build roughly one nuclear plant per month"--five times the actual rate in the 2006 official target (40 GW by 2020). China's 7 GW of nuclear capacity is struggling to reach 10 GW by 2010. Yet, in 2005, China led the world with 42 GW of installed renewable capacity excluding big hydro (in which it was number two); it tied Germany for the lead in renewable investments; and it ranked number five (just after India) in wind-power additions. Its wind-power target rivals its nuclear target but is far likelier to be achieved.

True, China has been building about 1 GW of coal plants a week, two-thirds of them unauthorized by Beijing. But many of these will be idled as the "coal rush" collides with reinvigorated efficiency efforts and burgeoning micropower. Similar trends are clear in India. In both countries, efficiency and renewables are starting to become flourishing private enterprises, thanks to gradually more transparent and competitive power markets.

Steve's central basis for his nuclear fixation is his claim that efficiency can't level off China's or India's total electric or energy needs. Why not? Their rapid economic growth comes from constructing millions of buildings, appliances, factories, and vehicles that can be designed properly the first time; if they're not, supply-side investments will eat the budget, stalling development. Even in the United States, which is several times more efficient and has already built most of its infrastructure, efficiency grew faster than the economy last year. A poorer, more populous nation with faster economic growth needs efficiency even more and has more of it left to buy at lower cost.

Even if efficiency could only drastically reduce demand growth and not eliminate it, a logical investor would seek the cheapest, fastest supply-side portfolio to meet the remaining needs. Micropower, lately adding an order of magnitude more capacity each year than nuclear and at far lower cost, seems the obvious place to look.

Of the four studies Steve cites, only the Keystone and MIT studies properly examined real data when comparing the costs of coal and nuclear power. The MIT study found nuclear uncompetitive with coal and gas; the Keystone study examined only nuclear and found it around 8-45 percent costlier per kilowatt-hour (kWh) than MIT had said four years earlier. The Keystone report's capital costs (actually measured in dollars per kilowatt, not dollars per kWh) are quoted as if to imply that U.S. plants cost more than foreign plants; actually, the cited foreign costs (for seven Asian units completed during 1994-2005) are "overnight" costs in 2002 dollars, while the U.S. costs look higher because they include interest during construction, are in 2007 dollars, and reflect rapid actual capital-cost escalation.

However, coal-versus-nuclear costs are irrelevant because both have proven grossly uncompetitive against negawatts and micropower. In 2006, micropower surpassed nuclear power's total global output and added roughly 34 GW of global net capacity, 15 GW of it from wind power. Why is micropower winning? Well, as Lawrence Berkeley National Laboratory's 2007 wind review (PDF) found, the median price of power provided by new U.S. wind farms added during 1999-2006 was 3.4 cents per kWh in 2004 dollars, while the cheapest cost less than 2 cents. If you take the higher median price, "firm" that variable wind power to make it fully dispatchable whether the wind is blowing or not, and take away its 0.86 cent Production Tax Credit (far less than nuclear's subsidies), it still costs less than half of what Keystone found new nuclear plants would cost. Wall Street understands this arithmetic.

In 2006, distributed renewable power sources worldwide got $56 billion of private risk capital; nuclear projects got zero. As Peter Bradford rightly notes, recent industry efforts to entice the U.S. Treasury to give it $50 billion are a desperate response to private capitalists' unwillingness to finance plants they consider too costly and too risky.

Steve urges us not to "abandon" nuclear power. But he doesn't mean benign neglect; he means putting this moribund technology in an extremely costly intensive care unit. Paying ever vaster subsidies to a market loser incurs a grave opportunity cost: we get 2-10 times less climate solution per dollar, slower, than if we bought market winners instead, and we harm rather than help global security and development.

Why Steve insists this inversion of market outcomes is desirable remains a mystery. As an empirical scientist who takes market economics seriously, I'm unmoved by nuclear theology. Show me the numbers.

Follow the money
Response: 1 August 2007
Posted by: Peter A. Bradford

In the months since this exchange began, one episode after another has established that the nuclear power surge emerging from Washington is not the benign version that its more idealistic proponents envision. These episodes include: President George W. Bush hauling the Nuclear Regulatory Commission (NRC) chairman (an ostensibly impartial regulator) to the reopening of the Brown's Ferry I plant to order him to speed up the licensing process; Bush's enthusiasm at Brown's Ferry for reprocessing, a technology he and Russian President Vladimir Putin then hailed in Kennebunkport--despite dangers vastly outweighing its questionable benefits; and a few days ago, the administration's undermining of the little nonproliferation resolve remaining in the U.S.-India nuclear agreement.

Another unedifying episode is the astonishing rush to the trough that has accompanied the Energy Department's effort to promulgate the rules governing the loan-guarantee program set forth in the 2005 Energy Policy Act.

Remember that the act's incentives were intended to apply to a few "first mover" nuclear units, to demonstrate the viability of new reactor designs and the revised NRC licensing process. (Never mind that the oft-vilified "old" NRC licensing process licensed more plants than the next four countries combined without turning down a single applicant.)

Nonetheless, Congress authorized $4 billion in loan guarantees for "new" low-carbon technologies, including nuclear power. However, the debate now raging over the administration's implementation of the loan-guarantee program reveals that the amount sought by nuclear power alone will approach $50 billion. The 2005 plea for limited support for "first-mover" units has become yet another multibillion dollar nuclear cost underestimate.

Representatives of major lenders and investors have said that unless the industry gets its way, the "nuclear renaissance" will be stillborn because "there is not going to be any financing." (See "Nuclear Power, Banks Link Up in Bid to Get Better Financing.") They also say that they want to "avoid another Shoreham," a praiseworthy sentiment of mystifying relevance, since bondholders didn't lose a penny over Shoreham, and loan guarantees wouldn't have made a difference to any aspect of that project.

What is one to make of this, as nuclear proponents claim that the new designs are cheaper and more foolproof? That the licensing problems have been fixed? That the industry's excellent safety and operating record in recent years has made Three Mile Island irrelevant to judging future plants?

Apparently, Wall Street doesn't accept these conclusions. Instead, it threatens not to advance money unless the risks are borne by taxpayers, or perhaps customers. Since risk drives the cost of capital, such a shift will make capital-intensive nuclear plants look cheaper than their competitors, an especially crucial feature in the competitive power markets that now encompass more than half of the electricity sold in the United States.

But the plants will not actually be cheaper. The risks will simply have been off-loaded, a zero-sum game unlike real savings in construction or operating costs. If the price of uranium or concrete falls, nuclear power becomes cheaper in a real sense, but if risk is shifted from one party to another, it does not.

To appreciate that risk equals real money, consider the possible implications of loan guarantees in four (among many) illustrative real-world situations--Three Mile Island, the municipal bond catastrophe that accompanied the Washington Public Power Supply System nuclear construction fiasco in the 1980s, the bankruptcy of Public Service Company of New Hampshire as it struggled to complete the Seabrook plant, and the recent indefinite shutdown of a seven-plant Japanese nuclear site due to an earthquake. In the likely event that any of these events resulted in inadequate bond repayment in competitive markets or otherwise, the money would come from taxpayers, as it would have if the stranded investment threat of the mid-1990s had materialized.

Investors studying such situations know that risk isn't abstract, that it will take the form of multibillion-dollar impacts unmitigated by a faster NRC licensing process or by improved reactor designs. Such exposure is much greater for nuclear power than for energy efficiency or other low-carbon energy sources, which is why the nuclear industry is objecting vociferously to having a fraction of the debt of these plants not be guaranteed, perhaps to assure that private investors will still perform their expected risk assessment and management functions in deciding where to put their money.

This spectacle shows again that nuclear power seeks a remarkably privileged status among the energy resources that we have discussed and that the industry fears head-to-head competition with the other ways of reducing greenhouse gas emissions.

It's been a dismaying year for principled nuclear power proponents. We haven't seen a similar year since the early 1970s, and we know where that exuberance led.

Keep all options on the table
Response: 5 July 2007
Posted by: R. Stephen Berry

Amory has the impression that I'm not a strong supporter of energy efficiency. In fact, as he knows, I've worked on energy efficiency since 1969, well before the 1973 oil "crisis." My colleagues and I developed what is now known as "life cycle analysis," beginning with the study Margaret Fels and I did of the automobile as a manufactured article (See the December 1993 issue of the *Bulletin of the Atomic Scientists*; available as a PDF from berry@uchicago.edu.) We sought to identify steps in processes that would be good targets for technological innovation.

This led to investigations of other areas by our group and others. We then moved into more basic questions--whether and how one could use methods of thermodynamics and optimization to design more efficient systems and processes. (See our book *Thermodynamic Optimization of Finite-Time Processes*.) I applaud the work Amory does to propagate the distribution and use of energy-efficient technologies and lifestyles. That subject is in no way the basis of our differing viewpoints.

My point is that no single approach will accomplish the goals of *reducing* the impact we have on the environment, improving the living standards of people throughout the world, and providing the basis of a sustainable human society.

We certainly need to move to energy-efficient technologies, but we also need to provide energy to people who don't have clean, reliable water supplies, adequate (or even any) electricity or motor transportation. We need to recognize that India and China are on growth trajectories that make our energy growth curve look flat. China is planning to build roughly one nuclear plant per month, while building one coal-based generating station every *week*! It's impossible for the efficient technologies that Amory correctly advocates to be available on a timescale or size scale that could accomplish what the Chinese power plants will provide.

Yes, China improved its energy efficiency, but this barely lowered the slope of its energy demands. Efficiency can't bring the total electric power needs or overall energy needs of China or India to a constant, level line in time.

Another point that we haven't really discussed: alternative sources of energy and carbon sequestration. Some of these such as combustibles derived from cellulose will probably be moderately important in our lifetimes. But the public discussion has carefully neglected "little" problems--for instance, ethanol absorbs water too readily to be shipped by pipeline. So presumably we would distribute it by trucks, using up the very fuel they carry! This problem has to be included in the overall assessment of the effectiveness of ethanol as fuel.

As for carbon sequestration, underground storage chambers for carbon dioxide under high pressures are known to explode. Hydrogen is popular in some circles, but we must recognize that it is a form of energy storage, not an energy source on our oxygen-rich planet. If we can find ways to generate hydrogen from energy sources that don't produce greenhouse gases, such as solar photodriven electrolytic cells or electrolysis at very high temperatures, then perhaps we could justify hydrogen as a fuel for some purposes.

The relative costs of coal and nuclear power have been studied in several recent, extensive studies: "Nuclear Power Joint Fact-Finding June 2007" (The Keystone Report); "Projected Costs of Generating Electricity, 2005 Update," International Energy Agency, OECD; "The Economic Future of Nuclear Power," University of Chicago (2004); and "The Future of Nuclear Power," MIT (2003). The Keystone Report indicates that the cost of constructing modern nuclear plants has been about $2,000-$3,000 per kilowatt-hour (kWh) in countries where such plants have been built recently; the projection of this study for the United States is $3,600-$4,000 per kWh.

The costs of supplying coal versus nuclear power depend sensitively on whether there is a carbon tax; some models discussed in these studies indicate that the delivered cost per kWh of nuclear power could easily be about the same as coal if there were some type of carbon tax. The relative costs of coal and nuclear power are changing as technology and regulation evolve. A study by the Secretary of Energy's Nuclear Energy Task Force ["Moving Forward with Nuclear Power: Issues and Key Factors" (PDF 388 KB)] argues that some form of financial aid and inducement will be needed to stimulate nuclear power in this country

We will need careful cost and cost-benefit analyses that account for externalities, examine varieties of scenarios, and recognize the ranges of uncertainties in order to choose the proper path. However, it would be a serious mistake to close off potentially important contributors to our overall energy program. Therefore, abandoning nuclear power would be as foolish as halting efforts toward energy efficiency.

Nuclear remains a slow, expensive option
Response: 25 June 2007
Posted by: Amory B. Lovins

I asked Stephen Berry what he thinks energy efficiency and low- or no-carbon energy sources can do, how fast, and at what cost--giving him concrete examples of their successful implementation. His reply is simply: "Amory is always delightfully optimistic about the rates of diffusion and acceptance of new technologies." That hardly seems responsive. I wasn't referring to new technologies but to well-understood, widely available efficiency and distributed-generation techniques that have become much cheaper in the past decade. As usual, I was using empirical data.

My 2006 Royal Academy of Engineering lecture (PDF, 3.7MB) mentioned that from 1982 to 1985, when California let all options compete fairly, its utilities bought or were firmly offered 23 GW of savings; 13 GW of new capacity (mostly renewable) bought plus 8 GW more on firm offer **;** and further such supplies increasing by another 9 GW *per year*. Since the 1984 peak load was only 37 GW, this four-year experiment yielded low- or no-carbon alternatives totaling 143 percent of total peak demand. Twenty years later, these alternatives are even bigger, cheaper, and faster to deploy via their far more mature market structure.

Second, my white paper on energy efficiency for the InterAcademy Council (PDF, 344KB) (a consortium of 90 national academies of science) notes: "In 1983-1985, 10 million people served by Southern California Edison Company were cutting its decade-ahead forecast of peak load by 8 1/2 percent per year, at around 1 percent the long-run marginal cost of supply. In 1990, New England Electric System signed up 90 percent of a pilot market for small-business retrofits in two months. In the same year, Pacific Gas and Electric Company (PG&E) marketers captured one-fourth of the new commercial construction market for design improvements in three months, so in 1991, PG&E raised the target--and got it all in the first nine days of January." And although

48 of the country's 50 states reward utilities for selling more electricity and penalize them for cutting customers' bills, in 2006, the United States cut electric intensity 3 percent and primary energy intensity 4 percent.

"Mighty Mice," (PDF, 680KB) my *Nuclear Engineering International* cost comparison of nuclear *versus* efficiency and micropower, and its backup paper (PDF, 476KB) summarize extensive empirical data showing that saving electricity costs an order of magnitude less than producing and delivering it from new nuclear plants and that "micropower" is also walloping nuclear in the global marketplace. The 2005 data (the latest available) posted at www.rmi.org in publication E05-04 showa remarkable contrast: micropower--cogeneration plus renewables minus big hydro--added four times as much electrical output and eleven times as much capacity in 2005 as nuclear power did, while "negawatts" were of comparable size. Germany, Spain, and India *each* add about 2 GW of wind power per year (as will China within a year or so)--about as much net capacity as the *world* adds in nuclear power each year.

Thus, Berry thinks we must divert far more investment into new nuclear plants, which added only 4 percent of the world's new 2005 capacity, even though they'd cost 2-10 times as much per delivered kilowatt-hour as the winning competitors that added more than 50 percent. He apparently thinks this small, costly increment is vital because we need everything. Sorry, but I don't see why. Pursuing an expensive, slow option instead of a big portfolio of cheap, fast options will make climate change worse, not better. And though I agree with his call for pricing carbon, doing so will equally advantage efficiency and renewables and partially advantage cogeneration, so carbon pricing won't relieve nuclear power's profound uncompetitiveness.

Developing countries see the same economic imperatives. Energy efficiency is China's top national development priority because without it, China can't develop. (China already spends three times the fraction of gross domestic product on electricity that the United States spends.) In the quarter-century through 2001, China cut its energy intensity faster than any other country. India is the world's fourth largest wind power installer; China ranks just behind. By 2010, India is predicted to have 11-12 GW of wind power (up from 6.3 GW at the end of 2006); China will have far more than 5 GW (versus 2.6 GW in 2006).

I predict that the emerging successes of efficiency, wind, small hydro, other renewables, and cogeneration will lead China to stop building those big, but uneconomic, coal plants just as it recently abandoned coal-to-liquids. Because building more central stations requires about 10,000 times more capital than saving electricity, it reduces prosperity in all countries. The United States can't afford such squandering of capital; China and India , even less.

Prioritize all options first
Response: 13 June 2007
Posted by: Peter A. Bradford

Stephen Berry confronts Amory Lovins with rebuttals more applicable to new nuclear power plants than to Lovins's alternatives. Consider the statement, "We can't afford to bet on only one roulette number." Surely the current Washington strategy of hugely disproportionate subsidy of new nuclear power plants is closer to betting unaffordable amounts on a single roulette number than equally backing the many variants of energy efficiency and renewables. In fact, governmental betting on mature energy technology is a well-demonstrated way to waste public money.

Lovins, Berry and, I seem to agree on the desirability of incorporating a carbon cost in the price of the fuels of the future. But Berry's assertion that this will make fossil fuels equal in cost to new nuclear power assumes several propositions as to which none of us knows anything meaningful.

No one knows the future cost of carbon reduction, of natural gas and coal, or of new nuclear units. Yet Berry asserts at least the relative positions of all three in a single breathtaking prophecy: "If we were to internalize the cost of fossil fuels . . . nuclear power will immediately be at least as cheap as fossil-generated power."

But maybe not. Maybe the necessary carbon reductions will come from transportation, efficiency, coal sequestration, and renewables. Maybe natural gas prices will decline, as they did in the 1980s. Maybe regulating as if nuclear power is safe because it is needed will once again bring cost increases, as events contradict judgments. Maybe nuclear construction costs will more nearly approximate Areva's current cost overruns and delays in Finland than the optimism of today's vendor cost estimates. Maybe proliferation resulting from encouraging the casual spread of reprocessing and enrichment to less stable nations will discredit nuclear technology altogether.

The differences among the three of us lie largely in the way that we deal with these uncertainties.

Many people of good faith are buying into a need for nuclear power because they believe that they know more than they really do about the future. They assume a regime in which nuclear power's problems are solved before they manifest themselves in real world dangers, and in which the alternatives are less capable than nuclear power of scaling up fast enough.

But the nuclear power that we have invariably gotten from the Washington sausage machine doesn't conform to this idealized version. That process demands licenses without an impartial licensing process, public acquiescence without public involvement, spent fuel without a waste repository, multibillion dollar projects without analysis of alternatives, nearly separated plutonium (per the Global Nuclear Energy Partnership) without adequate safeguards--in short, a renaissance without masterpieces.

Even the apparently reasonable assertion that "we must pursue all the plausible paths" invites disappointment. Such assertions were a centerpiece of now discredited nuclear industry refutations of Lovins in the 1970s. Pursuing all plausible paths costs too much, and some activities are inconsistent with others. The builder of a 1500 MW nuclear plant must oppose efficiency investments sufficient to reduce the price for the plant's output.

Prioritization is needed. A wise society will look first to markets (adjusted for externalities) to prioritize. Beyond that will come research and commercialization packages arranged according to speed, size, cost-effectiveness, and the absence of unacceptable side effects.

I don't think Berry disagrees with this, but I do think that he misunderstands the extent to which real world nuclear technology refuses to live by these rules, and perhaps cannot do so. I'm willing to use the nuclear units that emerge from such prioritization as part of a climate change strategy.

But I want those asking me to buy into their renaissance to submit to a meaningful prioritization exercise first. Otherwise, we'll continue our "sentence first, verdict later" energy policy making, an expensive and ineffectual process less analogous to roulette than to pin-the-tail-on-the-donkey, a contest in which the apparent deciders are blindfolded and spun dizzy by those really in charge.

Energy efficiency alone won't work
Response: 24 May 2007
Posted by: R. Stephen Berry

Amory is quite correct that there are many ways to reduce energy use and retain at least the same level of services we have now. And it is very sensible to try to adopt such means. But Amory is always delightfully optimistic about the rates of diffusion and acceptance of new technologies.

In the real world, when a new technology requires major changes in our manufacturing and distribution system, it's adopted slowly. One circumstance can change that--a major crisis. When an event such as World War I comes along, then we always find a way to implement innovation, i.e., airplanes!

The problem we face today is vividly exposed in a new Proceedings of the National Academy article, "Global and Regional Drivers of Accelerating CO2 Emissions." The authors show that the anthropogenic carbon dioxide levels in the atmosphere are actually rising faster than the highest predictions made in the late 1990s by the Intergovernmental Panel on Climate Change.

We simply can't afford to pursue the adiabatic path of an optimum, equilibrium-model economy. We're living in a dangerously dynamic situation and must pursue all the plausible paths we know. At present, nuclear power *is* more expensive than fossil fuels. But if we were to internalize the costs of fossil fuels, instead of leaving them as externalities, we would apply taxes, "cap and trade," or some other ingenious method to make us pay the real costs of using fossil fuels. If we do that, nuclear power will immediately be at least as cheap as fossil-generated power. Moreover, the next generation of light water reactors, the type of reactors that power companies are planning to build as soon as they get licenses, will be cheaper, safer, and more reliable than the reactors we're using now.

Just one other specific concern with Amory's idealistic vision: Whatever we do in the United States in the coming decades to adopt more energy-efficient devices, it's hard to believe that developing nations will go along with it. No matter what kind of micropower we invent, China will build large electric power generating stations to supply power to its growing cities and power-starved rural population. The future of the world will be in much less jeopardy if those power stations use nuclear power instead of coal power.

Multiple pathways and a flexible choice of options are the keys to maximizing stability. We can't afford to bet on only one roulette number.

Nuclear is uneconomic
Response: 25 April 2007
Posted by: Amory B. Lovins

My friend Steve Berry "posits" a supposed need for major nuclear expansion, unsupported by any analysis. To understand and test his conclusion, one must know what he thinks energy efficiency and low- or no-carbon energy sources can do, how fast, and at what cost. With basic citations at Rocky Mountain Institute's website (PDF) and basic publications at our nuclear energy library, here's my view:

Existing technologies for more efficient end-use can save three-fourths of U.S. electricity at an average cost of around 1 cent per kilowatt-hour--cheaper than running a coal or nuclear power plant, let alone building one. Scores of utilities have demonstrated and implemented at scale, rapid, large, predictable, and extremely cheap "negawatts" (saved electricity). California's per-capita use of electricity has been flat for 30 years while per-capita real income rose 79 percent. Firms like DuPont, Dow, and IBM are saving billions of dollars by cutting energy intensity, sometimes as fast as 6-8 percent a year.

My household saves 90 percent of electricity and 99 percent of space and water heating energy with a 10-month payback using 1983 technology. My team's redesign of some $30 billion worth of facilities in 29 sectors normally finds energy savings of 30-60 percent in retrofits (paying back in about 2-3 years) and 40-90 percent in new installations (typically with lower capital cost). A detailed road map for eliminating U.S. oil use by the 2040s, led by business for profit ("Winning the Oil Endgame"), shows how to save half of U.S. oil and gas at average costs one-fifth and one-eighth of current prices. Implementation is already underway. And each of the 60-80 known obstacles to implementing energy efficiency can be turned into a business opportunity.

On the supply side, "micropower"--small-scale generation that emits little or no carbon dioxide--provided one-sixth of the world's electricity and one-third of its new electricity in 2005, meeting from one-sixth to more than one-half of all electrical needs in 13 industrial countries. The smaller of micropower's components, distributed renewable sources of electricity, was a $56 billion global equipment market in 2006, while the larger, combined-heat-and-power, was probably even larger. Micropower added four times the electricity and 8-11 times the capacity that nuclear power added globally in 2005, now produces more electricity than nuclear power does, and is financed by private risk capital. Micropower plus "negawatts," which are probably about as big, now provide more than half of the world's new electrical services.

Nuclear power is unnecessary and uneconomic, so we needn't debate its safety. As retirements of aging plants overwhelm construction, global capacity and output will decline (as they did slightly in 2006). Most independent analysts doubt the private capital market will finance any new nuclear plants. Even in the United States, where new subsidies would roughly repay the next six units' entire capital cost, Standard & Poor's said this wouldn't materially improve the builders' credit ratings. I expect this experiment will be like defibrillating a corpse: It'll jump, but it won't revive.

Nuclear power's market meltdown is good for global development: Saving electricity needs around 1,000 times less capital and repays it about 10 times faster than supplying more electricity. Shifting capital to saving electricity can potentially turn the power sector (now gobbling one-fourth of global development capital) into a net funder of other development needs. Further, an efficient, diverse, dispersed, and renewable energy system can make major supply failures, whether caused by accident or malice, impossible by design rather than (as now) inevitable by design.

The nuclear phaseout will also speed climate protection, because buying negawatts and micropower instead will save 2-10 times more carbon per dollar, and will do so more quickly. And it can belatedly stem nuclear proliferation, too, by removing from commerce a vast flow of ingredients of do-it-yourself bomb kits in civilian disguise.

This would make bomb ingredients harder to get, more conspicuous to try to get, and far costlier politically if caught trying to get, because the motive for wanting them would be unmasked as unambiguously military. Focusing intelligence resources on needles, not haystacks, would also improve the odds of timely warning. All this wouldn't make proliferation impossible, but it would make things far more difficult for both recipients and suppliers.

Thus, acknowledging and accepting the market collapse of nuclear power is an important step toward a fairer, richer, cooler, and safer world.

Nuclear is more reliable, safer than before
Response: 10 April 2007
Posted by: R. Stephen Berry

There is every reason to pursue increased energy efficiency. There are even justifications for subsidizing capital investments in energy-efficient technology. After all, the discount rates used by corporate managers who choose those investments are, in effect, considerably larger than the discount rates implicit in governmental decisions. The former are based on near-term returns and stock prices, while the latter are based on a society's long-term sustainability.

But, despite some beliefs to the contrary, all of our past experience and evidence tells us that we'll need to generate more energy in the coming years. If the standard of living rises in underdeveloped countries, this is an absolute certainty globally--regardless of the efficiency in the United States, Europe, and even China and India. It's also terribly dangerous to the sustainability of humanity as we know it to allow the concentrations of human-generated greenhouse gases to grow at even a moderate fraction of their current rates--Oklahoma Republican Sen. James Inhofe notwithstanding. Hence, our response to the sustainability challenge must include better energy generation methods than those we rely on today--both in terms of their impact on climate and human life.

There are probably places where wind power is reliable and not harmful to the environment, increasing its usefulness. Biofuels provide a "break-even" means of slowing greenhouse gas concentrations, but they don't help reduce those concentrations. And biofuels only make sense if they're made from plants that don't double as food. Hydropower is virtually saturated and (perhaps surprisingly) the deadliest source of electric power because people live in the floodplains below dams, which occasionally break. Direct solar power, either as heat or electricity, is a marvelously attractive goal that we currently can't achieve at a cost that would make it available to a large part of the population. There's plenty of motivation for us to invest in solar power research, making it a realistic component of the overall energy picture. But that's not going to happen for many years.

Nuclear power has become more and more reliable and increasingly safe. While no energy source is risk-free, nuclear power probably represents the safest electricity source in overall costs of human life--and also the most reliable. Nuclear reactors now perform at about 90 percent of their theoretical limits; 20 years ago, it was roughly 60 percent. New designs of conventional light water reactors will be safer still, because they'll have inherent, gravity-driven self-quenching that won't require active steps by operators if something goes wrong.

The direct cost of nuclear power now is indeed higher than that of coal-, oil-, or gas-generated electric power. But this wouldn't be the case if the indirect costs of environmental damage from greenhouse gases were formulated into the cost, which would happen if a carbon tax were introduced. Even without a carbon tax, at least one extensive economic study found that the cost of nuclear reactors will drop after the first three or four new nuclear reactors are built, making nuclear competitive with fossil-fueled generating plants.

The emotional reaction to resist nuclear power is an interesting analogue to the emotional reaction to deny the likelihood of human-generated climate change. The two positions have remarkable similarities, at opposite ends of a common scale. Let's hope there's enough rationality for us to make our way in a healthy, sustainable manner between those emotional extremes.

Nuclear is not an essential solution
Response: 23 March 2007
Posted by: Peter A. Bradford

A sensible approach to climate change would put a significant price on fuels according to their carbon content. It would offer nondiscriminatory, governmental support to technologies according to their ability to achieve reductions rapidly, economically, and acceptably to the public. It would insist that any nuclear power growth occur in ways that diminish the association between nuclear power and proliferation.

Instead, too many nuclear proponents have turned to their old playbook-- pushed power plants; postponed problems. Nuclear power's asserted comeback in the United States rests not on newfound cost competitiveness, but on an ancient formula: licensing shortcuts, risks borne by customers and taxpayers, political muscle, and ballyhoo. Climate change has replaced oil dependence as the bogeyman from which nuclear power can save us.

Those who assert, "Nuclear energy just may be the energy source that can save our planet from catastrophic climate change," "It could save the Earth," or "Clean, green atomic energy can stop global warming," are inviting us into a dangerous la-la land in which nuclear power will be oversubsidized and underscrutinized while more promising and quicker responses to climate change are neglected.

Nuclear power may not even be an essential part of the solution to global warming. A widely noted paper (PDF, 1 MB) by Princeton professors Stephen Pacala and Robert Socolow introduces the useful concept of a "wedge," defined as any measure that would lead to a global reduction of 25 billion tons of carbon dioxide emissions relative to business-as-usual over the next 50 years. Under optimistic assumptions, some seven wedges are needed to avoid dangerous climate change; this number could increase significantly under less optimistic assumptions.

The study provides a list of 15 measures involving technologies that exist today and could be scaled up to become one or more wedges. Energy efficiency comprises three wedges, alternatives to business-as-usual transportation account for another four, and increasing natural sinks provides two wedges. Generating electricity in less carbon intensive ways contributes four wedges. Of the latter, *a worldwide tripling of nuclear power would contribute one wedge at most,* and that's if the new plants replace only coal and old nuclear units.

In addition, a nuclear wedge requires fuel enrichment (perhaps an additional 15 plants), waste repositories (perhaps the equivalent of 14 Yucca Mountains), and possibly reprocessing plants.

Nothing resembling such a massive scaling up of nuclear construction is underway. Indeed, when retirements are netted against new nuclear plants, the worldwide annual megawatt growth rate is about 5 percent, far under the 15 percent that a wedge will require.

Nuclear power is more expensive and controversial than other ways of generating electricity and other ways of cubing carbon emissions, so this trebling can only be done through substantial governmental assistance. The subsidies enacted by the U.S. Congress in 2005 are limited to a few plants. Many successful years of construction and operation will have to pass before these few plants can become a basis for a stream of privately financed orders.

A nuclear ramp up necessary to provide a wedge will not be some idealized future in which the problems are solved before the plants are built. Massive construction commitments will have to be made long before present waste and proliferation problems are resolved.

Proliferation is a particularly troublesome prospect. Aspects of civilian nuclear power programs have been implicated in every recent proliferation example, but particularly India, Pakistan, and potentially, Iran. Given a trebling of worldwide nuclear capacity, other countries of proliferation concern will have nuclear power programs. (For example, see Richard Beeston's *Times Online* article, "Six Arab States Join Rush to Go Nuclear.") International Atomic Energy Agency safeguards are not adequate for separated plutonium, which is directly useable in nuclear weapons. Two Bush administration initiatives--the Global Nuclear Energy Partnership and the nuclear arrangement with India--contain elements that undermine aspects of the already strained nonproliferation regime.

Nuclear power plants are made safe by combinations of vigilance and careful engineering and construction. If, in an effort to improve their dubious economics, we again freight the technology with unrealistic demands and expectations this safety can be seriously compromised.

Asserting that nuclear power answers climate change is like asserting that invading Iraq answers 9/11. This is policy making built on distraction, bolstered by deception, burdened by debt, and bound for disillusion. Both nuclear power and the country deserve better.

Nuclear can help
Response: 22 March 2007
Posted by: R. Stephen Berry

Given Earth's inevitable and imminent climate change and the rapid development of previously underdeveloped nations, humanity faces a novel challenge. Whether the climate will change slowly enough that we can respond at familiar rates or the change will happen so abruptly that we need new modes of adaptation, we don't know. Whether China, India, and other fast-developing nations can find pathways to sustainable lifestyles is another unanswered question, but one that perhaps we can help guide.

At the very least, given that we now live with these uncertainties, we can identify things that we recognize as *necessary*. But we certainly can't tell whether they're *sufficient* to enable humanity as we know it to survive and continue improving. The core issue is to find a way to use nature's resources that allows us to improve the human condition globally. Naturally, the first resource on our list is energy.

The most obvious, universally accepted--but not universally adopted--action we can take is to use energy more efficiently. Here, the problem is not whether to follow such a path but how to make it happen. So another given is that we will somehow discover and adopt creative ways to use energy efficiently.

The next problem is based on the unavoidable course that we've adopted to improve our lives (nationally and globally) by using considerably more energy *per capita*. Whether it's inevitable that per capita energy consumption will rise in developed nations is open, even controversial. But there's no arguing the global need, if the human condition is to improve everywhere.

From there, we move to the question of how to meet that need, which relates directly to the efficiency of how much or how little we will need to supply. Perhaps it would be better to phrase that question in terms of how much energy is needed if certain levels of efficiency were attained--and if certain levels of improved living conditions were our goal.

Suppose we're able to make a rough prediction of how much energy we'd need to supply in

2015, 2025, and 2050. Suppose we're even able to set rough upper and lower limits on these estimates. We'd then be in a position to rationally decide what energy source to choose. We have a list already, including all of the available sources:

- Coal, oil, and gas (with some means of avoiding carbon emissions);
- Hydroelectric (with safe and environmentally acceptable dams);
- Solar;
- Environmentally acceptable wind;
- Environmentally acceptable geothermal;
- Possibly tidal;
- Safe and secure nuclear.

But when would we have the information to make a well-guided, information-based decision? The difficult problem now is that the world is changing faster than we can generate the information needed to make well-guided decisions.

A kind of negative benefit-cost analysis could help deal with this dilemma. That is, we can estimate benefits and costs of different pathways in the conventional way, and then go a step further by estimating the costs of choosing a pathway *and making a mistake*. For example, we can ask what the costs of pumping carbon dioxide into underground storage wells would be if the wells were safe *and* if the wells sometimes exploded. Likewise, we can estimate the costs of accidents at nuclear plants if we made an incorrect assumption about their safety level. Such an analysis gives us an "insurance" perspective to help guide choices.

This leads me to posit that the mix of energy sources for the next many, many years *must* include a significant component of nuclear power--and much more than we have now. The nuclear power issue divides naturally into a near- and long-term aspect. The near-term addresses the question of how to reduce carbon emissions relatively soon (say in 10 or 15 years) in a way that's at least as safe as the ways we provide energy now. The present generation of light water reactors (LWRs) has proven more durable, efficient, secure, and safe than the LWRs from the 1960s and 1970s. We will need to build many more LWRs during the next 20 or 30 years, while finding ways to safely deal with their waste.

The long-term problem combines dealing with nuclear wastes and making more efficient use of potentially fissionable nuclear materials. This is the challenge of reducing the volume of nuclear wastes by orders of magnitude and increasing the energy derived from uranium by an equal amount.

At present, there is a potential pathway to do this that looks very promising, but it's still far from realization. This pathway would combine recycling nuclear fuel with reactors using fast neutrons. (Our current reactors use slow, "thermal" neutrons.) This will require years of research and development and takes into account safety and security from proliferation. In my view, this makes nuclear power one of those necessary, but not sufficient, components of our energy future in the near and long terms.
