Center for American Progress Action Fund

The Self-Limiting Future of Nuclear Power

Joe Romm
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Executive Summary

Nuclear power generates approximately 20 percent of all U.S. electricity. And because it is a low-carbon source of around-the-clock power, it has received renewed interest as concern grows over the effect of greenhouse gas emissions on our climate.

Yet nuclear power's own myriad limitations will constrain its growth, especially in the near term. These include:

- Prohibitively high, and escalating, capital costs
- Production bottlenecks in key components needed to build plants
- Very long construction times
- Concerns about uranium supplies and importation issues
- Unresolved problems with the availability and security of waste storage
- Large-scale water use amid shortages
- High electricity prices from new plants

Nuclear power is therefore unlikely to play a dominant—greater than 10 percent—role in the national or global effort to prevent the global temperatures from rising by more than 2°C above preindustrial levels.

The carbon-free power technologies that the nation and the world should focus on deploying right now at large scale are efficiency, wind power, and solar power. They are the lower-cost carbon-free strategies with minimal societal effects and the fewest production bottlenecks. They could easily meet all of U.S. demand for the next quarter -century, while substituting for some existing fossil fuel plants. In the medium-term (post-2020), other technologies, such as coal with carbon capture and storage or advanced geothermal, could be significant players, but only with a far greater development effort over the next decade.

Progressives must also focus on the issue of nuclear subsidies, or nuclear pork. Conservative politicians such as Sen. John McCain (R-AZ) and other nuclear power advocates continue to insist that new climate legislation must include yet more large subsidies for nuclear power. Since nuclear power is a mature electricity generation technology with a large market share and is the beneficiary of some $100 billion in direct and indirect subsidies since 1948, it neither requires nor deserves significant subsidies in any future climate law.

The High Cost of Nuclear Power

For three decades, no new nuclear power plants have been ordered in the United States. Now a number of utilities are proposing to build nuclear power plants, in large part because of the escalating cost of electricity from new fossil fuels plants and the federal government's promise of production tax credits and loan guarantees for investments in new nuclear power capacity.

Nuclear power has reemerged as a major issue in the policy and political arenas in large part because of the growing recognition that the nation and the world must make significant reductions in greenhouse gas emissions. The combustion of fossil fuels is the primary source of carbon dioxide, which is the main greenhouse gas.

The threat of catastrophic global warming means that no carbon-free source of power can be rejected out of hand. The very serious possibilities that sea levels will rise several inches each decade for many centuries, and a third of the planet will undergo desertification are far graver concerns than the very genuine environmental concerns about radiation releases and long-term waste issues.

The issue of whether we should invest in nuclear power has typically been fought on classic partisan grounds, with progressives being skeptical and conservatives being enthusiastic. Conservative Sen. John McCain (R-AZ) has repeatedly said that nuclear power is the centerpiece of his climate strategy, and that the United States should emulate the French, who get 80 percent of their power from nuclear. Newt Gingrich has recently proposed a similar commitment to nuclear power. [1] Progressives counter that this plan would require building several hundred more new nuclear power plants and several Yucca Mountain-sized nuclear waste storage sites by 2050 at a total cost of more than $4 trillion.[2]

Nuclear power is hampered by a variety of problems that limit its viability as a climate strategy absent massive government subsidies and mandates, especially in the near term. As a 2003 interdisciplinary study by the Massachusetts Institute of Technology on "The Future of Nuclear Energy" concluded, "The prospects for nuclear energy as an option are limited … by four unresolved problems: high relative costs; perceived adverse safety, environmental, and health effects; potential security risks stemming from proliferation; and unresolved challenges in long-term management of nuclear wastes."[3]

New nuclear power now costs more than double what the MIT report assumed in its base case, making it perhaps the most significant "unresolved problem." It is easily the most important issue and is the source of much confusion in the popular press. Consider this recent interview between *Newsweek*'s Fareed Zakaria and Patrick Moore, one of the cofounders of Greenpeace and now a strong nuclear advocate. Zakaria says, "A number of analyses say that nuclear power isn't cost competitive, and that without government subsidies, there's no real market for it." Moore replies, "That's simply not true. … I know that the cost of production of electricity among the 104 nuclear plants operating in the United States is 1.68 cents per kilowatt-hour. That's not including the capital costs, but the cost of production of electricity from nuclear is very low, and competitive with dirty coal. Gas costs three times as much as nuclear, at least. Wind costs five times as much, and solar costs 10 times as much."[4]

Moore's answer states a common misconception—that you can ignore capital cost when calculating the cost of energy. His statement would be like saying, "My house is incredibly cheap to live in, if I don't include the mortgage." If you don't include the capital costs, then wind and solar are essentially free—nobody charges for the fuel, and operation is cheap. Compare this to nuclear plants, which are probably the most capital-intensive form of energy there is; also, they run on expensive uranium and must be closely monitored minute by minute for safety reasons.

Moore is comparing old nuclear plants that have already been paid off with new coal, gas, wind, and solar plants. Why? Because the price of new nuclear power has risen faster than any other form of power. Comparing new nuclear plants would be no contest—they are easily the most expensive kind of electricity plant to build today.

Consider an index of coal, gas, wind, and nuclear power capital costs from Cambridge Energy Research Associates.[5] From 2000 to October 2007, nuclear power plant construction costs—mainly materials, labor, and engineering—have risen by 185 percent.[6] That means a nuclear power plant that cost $4 billion to build in 2000, cost $11.4 billion to build last October.

The cost issues have reached such a high level for the industry that one of its trade magazines, *Nuclear Engineering International*, headlined a recent article, "How much? For some utilities, the capital costs of a new nuclear power plant are prohibitive."[7]

As the article related, the U.S. Energy Information Administration projected in 2005 that a nuclear plant's "overnight capital costs"—the industry's term for the construction cost if the plant could be built overnight, absent interest and financing costs, and assuming no cost overruns—would total about $2,000 per kilowatt. A typical current plant size is 1 gigawatt, or 1 million kW, which would total $2 billion under this formula.

Marvin Fertel, chief nuclear officer at the Nuclear Energy Institute, tried to convince the Senate that the assumptions made on new nuclear plant construction were "unrealistically high, and inflated." Fertel said the EIA assumed that new nuclear plants would experience the same delays, lengthy construction periods, and high costs experienced by some of the plants built in the 1980s and 1990s," when in fact designs were now standardized and construction techniques improved.

Yet as the *Nuclear Engineering International* article detailed, costs are now far beyond $2000/kW. By mid-2007, a Keystone Center nuclear report funded in part by the nuclear industry and NEI estimated overnight costs at \$3000/kW, which equals \$3600 to \$4000/kW with interest. The report notes, "the power isn't cheap: 8.3 to 11.1 cents per kilo-watt hour." In December 2007, retail electricity prices in this country averaged 8.9 cents per kwh.

At the end of August, 2007 *Tulsa World* reported that American Electric Power Co. CEO Michael Morris was not planning to build any new nuclear power plants. He was quoted as saying, "I'm not convinced we'll see a new nuclear station before probably the 2020 timeline," citing "realistic" costs of about \$4,000/kW, he said. [8]

Nuclear is simply not a near-term, cost-effective solution to our climate problem—especially if the \$4,000/kW cost last year was already starting to price it out of the marketplace. The prices utilities are quoting for nuclear have since soared 50 percent to 100 percent.

Florida Power & Light presented a detailed cost estimate for new nuclear plants to the Florida Public Service Commission in October of last year.[9] FPL is "a leader in nuclear power generation in the United States" with "one of the most active and current utility construction programs in the U.S." FPL concluded that two units totaling 2,200 megawatts would cost between \$5,500 and \$8100 per kW—\$12 billion to \$18 billion total—and that two units totaling 3,000 MW would cost \$5,400 to \$8,000 per kW—\$16.5 billion to \$24 billion total. [10] (These are the actual costs, not adjusted for inflation.)

Lew Hay, chairman and CEO of FPL, said, "If our cost estimates are even close to being right, the cost of a two-unit plant will be on the order of magnitude of \$13 to \$14 billion. That's bigger than the total market capitalization of many companies in the U.S. utility industry and 50 percent or more of the market capitalization of all companies in our industry with the exception of Exelon. … This is a huge bet for any CEO to take to his or her board."

An October 2007 Moody's Investors Service report, "New Nuclear Generation in the United States," concluded, "Moody's believes the all-in cost of a nuclear generating facility could come in at between \$5,000–\$6,000/kW."

In January 2008, MidAmerican Nuclear Energy Co said that prices were so high, it was ending its pursuit of a nuclear power plant in Payette County, Idaho, after spending \$13 million researching its economic feasibility. Company President Bill Fehrman said in a letter, "Consumers expect reasonably priced energy, and the company's due diligence process has led to the conclusion that it does not make economic sense to pursue the project at this time."[11]

MidAmerican is a company owned by famed investor Warren Buffet. When Buffet pulls the plug on a potential investment after spending \$13 million analyzing the deal, it should give everyone pause.

In mid-March, Progress Energy informed state regulators that the twin 1,100 MW plants it intends to build in Florida would cost \$14 billion, which "triples estimates the utility offered little more than a year ago." That would be more than \$6400/kW. The whole cost is even higher; "The utility said its 200-mile, 10-county transmission project will cost \$3-billion more." It looks like renewables are not the only source of electricity that requires new power lines. Factoring that cost in, the price would be \$7,700/kW.[12]

The utility, however, won't stand behind the tripled- cost for the plant. In its filing with state regulators, Progress Energy warned that its new $17 billion estimate for its planned nuclear facility is "nonbinding" and "subject to change over time."

The picture for Florida ratepayers is a harsh one. As the *St. Petersburg Times* reported, Florida passed a law that allows utilities to recoup some costs while a nuclear plant is under construction.[13] In short, "customers will start paying for the plant years before it goes into service." How much? The current estimate is about $9 per month starting as early as next year. That means the customers of Progress Energy will each pay more than $100 per year for years and years before they get a single kilowatt-hour from these plants.

Georgia Power said in early May that it planned to spend $6.4 billion for a 46 percent interest in two new reactors proposed for the state's Vogtle nuclear plant site. The *Wall Street Journal* noted, "Utility officials declined to disclose total costs. A typical Georgia Power household could expect to see its power bill go up by $144 annually to pay for the plants after 2018."[14]

This would seem to be a case of history repeating itself. According to the same *Wall Street Journal* article, "The existing Vogtle plant, put into service in the late 1980s, cost more than 10 times its original estimate, roughly $4.5 billion for each of two reactors."

How expensive have nuclear plants become? Duke Power has been refusing to reveal cost estimates for a nuclear plant for the Carolinas, saying it would reveal trade secrets. The *Charlotte News & Observer* reported in late April that, according to Duke attorney Lawrence Somers, "If Duke is requested to disclose the cost today, it will undermine the company's ability to get the lowest cost for its customers … In light of the testimony today, the public advocacy groups want the cost of this plant to go up."[15]

In other words, he is attacking public advocacy groups for trying to learn the cost of the plants before supporting them—and then preemptively blaming them for future cost overruns. Duke testified that if everyone knew the plant's cost, that would "give tactical advantage to vendors and contractors during sensitive negotiations." What Duke seems to be saying is that if suppliers knew just how expensive the plant is, they would want a bigger piece of the pie.

In March, Peter Bradford, former Commissioner of the Nuclear Regulatory Commission, former president of National Association of Utility Regulatory Commissioners, and member of the Keystone Panel, testified to South Carolina Public Service Commission on the Duke Power's request to "Incur Nuclear Generation Pre-Construction Costs," saying, "I then explain why Duke cannot establish the prudence of its decision to incur preconstruction costs of $230 million between now and the end of 2009 without providing reliable evidence of the likely cost of the unit and the impact of that cost on the rates to be paid by South Carolina electric customers."[16]

While this may seem obvious, North Carolina regulators ended up agreeing with Duke that the estimated cost is a "trade secret" under state law. Interestingly, while North Carolina's consumer advocate agreed with Duke, South Carolina's didn't. C. Dukes Scott, South Carolina's consumer advocate, who represents the public in utility rate cases, said, "If you want the ratepayers to pay for something, are you going to tell them it's none of their business?"

Back in February, Duke Energy CEO Jim Rogers told state regulators that the plant would cost $6 billion to $ 8 billion, but a mere two months later said the estimate was "dated and inaccurate." Scott wondered, "If the cost wasn't confidential in February, how is it confidential in April?"

Bradford also testified about yet another typically undisclosed cost of new nuclear plants—the storage of nuclear waste:

> Unless the law is changed to expand Yucca Mountain, that proposed repository will not be able to store all of the waste from the existing plants, to say nothing of new ones. Furthermore, the Department of Energy does not have the same obligation to take the waste from new plants, such as the unit proposed by Duke in this proceeding, that it has under the contracts with the existing plants. Therefore, the waste from this plant is not assured of a place in any repository. Indeed, there is no assurance that it can be moved off site at all.
>
> The only prudent assumption is that the waste from this plant may have to be stored on site for a long time. Dry cask storage makes this technically feasible, but Duke and its customers may be responsible for the costs of that indefinite storage because, unlike the existing spent fuel, it is not covered by a contract that subjects the U.S. government to an obligation to take it.

Bradford notes that it is possible to reprocess the spent nuclear fuel—extract the plutonium and run it in special reactors. But that doesn't actually reduce the waste problem, and it adds another 1.5 cents to 3.0 cents per kilowatt hour, or kWh, or more to the price of the nuclear electricity.

A detailed discussion of reprocessing is beyond the scope of this paper, but many conservatives hold views similar to ones expressed by John McCain in May, when he said, "Jimmy Carter decided back in '77 or '78, I don't remember exactly what year it was, but he said that we wouldn't reprocess spent nuclear fuel. That was a huge setback."[17]

Those interested in the issue should read former Clinton science adviser and Princeton nuclear physicist Frank N. von Hippel's article in the recent *Scientific American*, "Nuclear Fuel Recycling: More Trouble Than It's Worth."[18] Von Hippel is one of the country's top experts on the subject, and he explains the three big flaws of reprocessing: "extraction and processing cost much more than the new fuel is worth"; "recycling plutonium reduces the waste problem only minimally"; and separated plutonium can be used to make nuclear bombs if it gets into the wrong hands, which means that a lot of effort has to be expended to "keep it secure until it is once more a part of spent fuel."

As an important aside, the recent troubles the industry is having are not limited to this country. The first of the advanced reactor designs to be built in the West has been under construction in Finland since mid-2005. It is already 25 percent over budget and two years behind schedule because of "flawed welds for the reactor's steel liner, unusable water-coolant pipes, and suspect concrete in the foundation."[19]

Bloomberg notes, "The June commercial startup of China's Tianwan project came more than two years later than planned. The Chinese regulator halted construction for almost a year on the first of two Russian-designed reactors while it examined welds in the steel liner for the reactor core.... In Taiwan, the Lungmen reactor project has fallen five years behind schedule. Difficulties include welds that failed inspections in 2002 and had to be redone."

By mid-May, the *Wall Street Journal* was reporting that after "months of tough negotiations between utility companies and key suppliers … efforts to control costs are proving elusive." How elusive? According to the *Wall Street Journal*, "Estimates released in recent weeks by experienced nuclear operators—NRG Energy Inc., Progress Energy Inc., Exelon Corp., Southern Co. and FPL Group Inc.—'have blown by our highest estimate' of costs computed just eight months ago, said Jim Hempstead, a senior credit officer at Moody's Investors Service credit-rating agency in New York."

That is, Moody's is saying actual costs have "blown past" their earlier $6,000/kW estimate.

So what would be the cost of electricity from new nuclear plants today? Jim Harding, who was on the Keystone Center panel, was responsible for its economic analysis, and previously served as director of power planning and forecasting for Seattle City Light, emailed us in early May that his own "reasonable estimate for levelized cost range ... is 12–17 cents per kWh lifetime, and 1.7x times that number [20 to 29 cents per kWh] in first year of commercial operation."

In a 2008 presentation to the Wisconsin public utility Institute seminar, he noted that Puget Sound Energy had quoted a capital price as high as $10,000/kW.

One very good source of apples-to-apples comparisons of different types of low- and zero-carbon electricity generation is the modeling work done for the California Public Utility Commission on how to comply with the AB32 law, California's Global Warming Solutions Act.[20] AB32 requires a reduction in statewide greenhouse gas emissions to 1990 levels by 2020, something the entire country will have to do if we are to get off the path toward catastrophic warming.

The research for the CPUC puts the cost of power from new nuclear plants at more than 15 cents per kWh before transmission and delivery costs. These cost estimates lead directly to the final two economic problems for nuclear power:

1. The world needs thousands of gigawatts of zero-carbon electricity by 2050—and this country needs several hundred gigawatts—to avert catastrophic climate outcomes. Such increased demand would probably drive up nuclear costs even higher, while either having a much smaller cost effect on alternatives or actually reducing their cost.

2. Many large-scale alternative sources of carbon-free electricity are today either considerably cheaper or more competitive.

Nuclear Bottlenecks

To avoid the grave risks posed by global temperatures rising more than 2°C above preindustrial levels, we must stabilize atmospheric concentrations of carbon dioxide below 450 parts per million.[21]

As of the end of 2007, atmospheric CO_2 concentrations were already at 385 ppm. The concentration has been rising at a rate of 2 ppm a year since 2000, which is a 40 percent higher rate than the previous two decades. Global carbon dioxide emissions are more than 8 billion metric tons of carbon—29 billion metric tons of CO_2—and have been rising some 3 percent per year. To stay below 450 ppm, the latest analysis from the IPCC says that we should average under 5 billion tons of carbon a year for the entire century. So we need to peak in emissions globally in the 2015 to 2020 timeframe and return to 4 billion metric tons of carbon or less by 2050.

The Challenge of Building Plants Fast Enough

Reducing emissions to the necessary levels will require some 14 (modified) "stabilization wedges," the term coined by Princeton's Robert Socolow and Stephen Pacala for an "activity that reduces emissions to the atmosphere that starts at zero today and increases linearly until it accounts for 1 GtC/year [one billion tons of carbon] of reduced carbon emissions in 50 years." Since the time for action is so short, the wedges probably need to be modified so that they are squeezed into about four decades.[22]

The most comprehensive report ever done on what one wedge of nuclear power would require is the 2007 Keystone Center Report, "Nuclear Power Joint Fact-Finding," which was supported by the utility and nuclear industries.[23] The report notes that achieving a wedge of nuclear power by mid-century would require building approximately 1,000 1-GW nuclear plants, which requires adding globally:

- An average of 14 new plants each year for the next 50 years, as well as approximately 7.4 plants a year to replace those that will be retired.
- 11-to-22 additional large enrichment plants to supplement the 17 existing plants.
- 18 additional fuel fabrication plants to supplement the 24 existing plants.
- 10 nuclear waste repositories the size of the statutory capacity of Yucca Mountain, each of which would store approximately 700,000 tons of spent fuel.

In short, we need five decades of building nuclear plants at a rate only previously achieved for one decade—20 GW/year during the 1980s.

In fact, since we really need to deploy all this low-carbon power in 40 years, we should build 25 GW of nuclear plants a year.

Any individual wedge has a scale problem. One wedge of coal with carbon capture and storage will require storing the emissions from 800 large coal plants (80 percent of all coal plants in 2000). This represents a flow of CO_2 into the ground equal to the current flow of oil out of the ground. That would require recreating the equivalent of the planet's entire oil delivery infrastructure. One wedge of wind is 2,000 GW of nominal wind capacity. Last year the world installed 20 GW of wind.

Nuclear has a number of unique problems of scalability. Siting and building that many large waste repositories will not be easy, particularly given the difficulty that the United States has had siting a single one. On the other hand, reprocessing all the spent fuel would require 36 reprocessing plants, and add another 1.5 to 3 cents per kWh to the cost of nuclear electricity.

Nuclear Building Supplies Are Limited and Expensive

Then there are the industry bottlenecks. Twenty years ago the United States had 400 major suppliers for the nuclear industry. Today there are about 80. Only two companies in the whole world can make heavy forgings for pressure vessels, steam generators, and pressurizers that are licensed for use in any OECD country: Japan Steel Works and Creusot Forge.

Japan Steel is "the only plant in the world … capable of producing the central part of a nuclear reactor's containment vessel in a single piece, reducing the risk of a radiation leak."[24] In a single year, they can currently only make "four of the steel forgings that contain the radioactivity in a nuclear reactor." They may double capacity over the next two years, but that won't allow the huge ramp up in nuclear power that some are projecting for the industry.

According to Mycle Schneider, an independent nuclear industry consultant near Paris, the math just doesn't work given Japan Steel's limited capacity. Japan Steel caters to all nuclear reactor makers except in Russia, which makes its own heavy forgings. "I find it just amazing that so many people jumped on the bandwagon of this renaissance without ever looking at the industrial side of it," Schneider said.

At the same time, that capacity increase represents a gamble that the nuclear renaissance is here to stay, even in the face of rapidly escalating prices.

These supply bottlenecks, coupled with soaring commodity prices, have resulted in enormous price increases, even though new reactors have only been coming online at an average rate of about four to five per year in the past decade.[25]

Uranium Is Becoming Harder to Find and Must Be Imported

Uranium supply is also an issue. Most major carbon-free power sources have no fuel concerns since they are renewable sources that ultimately draw their power from the sun, or they are energy-efficient technologies.

Uranium production, however, has had difficulty keeping up with demand. From 1989 through 2003, the industry average uranium spot price was in the $10 to $15 a pound range. It soared to over $135 a pound in 2007 and now is back down around $60 a pound as of mid-May.[26]

There is a great deal of controversy as to whether "peak uranium" exists, a point at which production maxes out and then declines.[27] The subject is beyond the scope of this paper, except to say that adding and sustaining one full wedge of nuclear power requires a near tripling of nuclear power generation and hence greatly increasing uranium demand. An article in the April 2008 *Environmental Science & Technology* concluded, "Given the broad coverage of uranium exploration globally over the past 50 years, any new deposit discovered is most likely to be deeper than most current deposits." What's more, "the long-term trend over the past five decades has been a steady decline in most average country ore grades.… In terms of major production capacity for any proposed nuclear power program, it is clear that these larger-tonnage, lower-grade deposits would need to be developed."[28]

The other related issue for the United States is where we get our uranium from. In 2006, we imported 84 percent, or 56 million pounds, of our uranium. In February, the Bush administration signed a deal to boost U.S. imports of Russian uranium: "The new agreement permits Russia to supply 20 percent of U.S. reactor fuel until 2020 and to supply the fuel for new reactors quota-free."[29] Given that Russia has used its energy exports in the past for leverage against neighboring countries, this certainly raises energy security concerns for America.

If the United States were to significantly expand its use of nuclear power, doubling or tripling (or more) from current levels, our dependence on foreign sources of uranium and our trade deficit in uranium would likely grow significantly. If we seek to satisfy a significant portion of this increased demand from domestic uranium deposits, we run the risk, indeed the likelihood, given the sorry state of regulating U.S. uranium mining operations, of repeating the environmental debacle of the uranium boom that accompanied the buildout of the U.S. nuclear arsenal and the first wave of nuclear power plant construction. Of course, for uranium mined in places like Russia, Kazakhstan, and Uzbekistan, we may surmise that there is no effective enforcement of environmental standards whatsoever, resulting in the likely extensive pollution of drinking water and agricultural aquifers with heavy metals and mining chemicals such as sulfuric acid, as well as lasting damage to the health of workers and surrounding populations.

Water Shortages Will Hamper Growth and Increase Costs

Finally, we have water consumption. As a 2008 Department of Energy report on wind power noted, "few realize that electricity generation accounts for nearly half of all water withdrawals in the nation." At the same time, "existing nuclear power stations used and consumed significantly more water per megawatt hour than electricity generation powered by fossil fuels," as a 2002 report by the Electric Power Research Institute found.[30]

Yet as a comprehensive 2006 Department of Energy report, "Energy Demands on Water Resources" noted, "Some regions have seen groundwater levels drop as much as 300 to 900 feet over the past 50 years because of the pumping of water from aquifers faster than the natural rate of recharge. A 2003 General Accounting Office study showed that most state water managers expect either local or regional water shortages within the next 10 years under average climate conditions. Under drought conditions, even more severe water shortages are expected."[31]

Climate change is expected to drive drought, desertification, and water shortages (from the loss of the inland glaciers that feed major rivers) throughout the nation and the world. A 2006 analysis by the UK's Hadley Center for Climate Prediction and Research found that on our current emissions path, we may see desertification of one-third of the planet and drought over half the planet by the end of the century.[32]

A 2007 study published in *Science* warned of a permanent drought by 2050 throughout the Southwest—levels of aridity comparable to the 1930s Dust Bowl would stretch from Kansas to California.[33] The Dust Bowl occurred due to a sustained decrease in soil moisture of about 15 percent, which is calculated by subtracting evaporation from precipitation. In some climate scenarios, soil moisture will decline 30 percent to 40 percent over much of the South and Southwest.

Clearly, future power plants need to be designed to use very little water. Nuclear power can be designed with dry (air) cooling driven by giant fans, but that increases capital costs and lowers the net electrical output of the plant. The 2006 Department of Energy report noted, "In total, dry-cooled systems impose a cost penalty ranging from 2 to 5 percent to 6 to 16 percent for the cost of energy compared to evaporative closed-loop cooling. These ranges reflect the fact that the cost penalty is highly dependent on the value placed on the energy that is not generated and must be replaced when the weather is hot and demand is high."

So, again, nuclear power can deal with the water issues, but only at a price penalty. As of 2002, "dry cooling had been installed on only a fraction of 1 percent of U.S. generating capacity, mostly on smaller plants."

Nuclear power will have great difficulty filling out even one of the 14 wedges needed to stabilize carbon dioxide concentrations below 450 ppm. Indeed, merely replacing most of the existing reactors here and around the world by 2050 will be a great and costly challenge. And given a long-time lag for deploying reactors and rebuilding the industry, and the urgent need to reverse U.S. and global greenhouse gas emissions growth by 2020 and then sharply reduce emissions through 2050 and beyond, we must look seriously at carbon-free sources that might be deployed faster, cheaper, and with less accompanying problems.

The Near-Term Competition to Nuclear

The three most plausible ways to reduce emissions from power plants today are energy efficiency, wind power, and solar power. By "plausible," we mean capable of delivering large amounts of power affordably and quickly, which means having no obvious production bottlenecks.

Coal with carbon capture and storage technology may some day be commercial and affordable, but given the immature state of that technology from the perspective of wide-scale deployment, and given the current price of coal plants, it would be pure speculation to say that coal with CCS will be a low-cost option by 2025. Advanced geothermal could be a major source of power post-2020, as a comprehensive 2007 M.I.T. report concluded, but that would take a decade of significant public and private investment.[34]

Efficiency

Energy efficiency is the cheapest alternative to nuclear by far. California has cut annual peak demand by 12 GW, and total demand by about 40,000 GWh, through a variety of energy-efficiency programs over the past three decades. Over their lifetime, the cost of efficiency programs has averaged 2-to-3 cents per kWh. If every American had the per capita electricity of California, we'd cut electricity use about 40 percent. If the next president aggressively pushes a nationwide effort to embrace efficiency and change regulations to encourage efficiency, then we could keep electricity demand close to flat through 2020.[35] That is particularly true if we include an aggressive effort on behalf of cogeneration, which is the simultaneous generation and use of electricity and heat, a very efficient process.

A May presentation of the California Public Utilities Commission modeling results shows that energy efficiency could reduce electricity consumption up to 36,000 GWh by 2020—that is the equivalent of more than 5 GW of baseload generation operating 80 percent of the time.[36] At the same time, the state could build 1.6 GW of cogeneration plants smaller than 5 MW and 2.8 GW of cogeneration plants larger than 5 MW. So that is nearly 10 GW of efficiency by 2020. If this were reproduced nationwide, efficiency would deliver more than 130 GW by 2020, which is more than enough energy savings to avoid the need to build any new power plants through 2020 and beyond. This means any new renewable plants built could displace existing fossil fuel plants and begin to reduce U.S. carbon dioxide emissions from the utility sector.

Wind

A major new report issued in May by the Bush administration finds that for under 2 cents a day per household in total extra cost, Americans could get 300 GW of total wind capacity by 2030.[37] The report found that wind power should cost 6 to 8.5 cents per kWh, even without the current tax credit, including the cost of transmission to access existing power lines. And the cost of integrating the variable wind power into the U.S. grid would be under 0.5 cents/kWh.

The carbon dioxide savings alone would come to 7.6 billion metric tons cumulatively by 2030, at which point wind would be cutting annual emissions by 825 million metric tons a year. That is the equivalent in emissions reduction of taking two-thirds of all U.S. passenger vehicles off the road. That much wind would also reduce natural gas use by 11 percent.

The study notes that by 2030, wind would be cutting water consumption by 450 billion gallons a year, of which 150 billion gallons a year would be saved in the arid Western states, where water is relatively scarce—and poised to get even scarcer thanks to climate change. In addition, this wind effort would generate a half a million jobs, of which nearly a third would be high-wage workers directly employed in the industry.

To achieve this level of wind power, the industry only needs to continue growing for the next several years at the rate that the industry has seen in the past decade. From 2000 to 2007, the industry increased fivefold. Last year, $36 billion in wind investments were made around the world, and a total of 20 GW of new capacity was installed—enough to power 6 million homes—with $9 billion invested in U.S.-based projects. In 10 years, the wind industry is expected to nearly quadruple in size. Since 2000, Europe has added 47 GW of new wind capacity, but only 9.6 GW of coal, and a mere 1.2 GW of nuclear.

Wind power is a variable resource, with new plants providing power only about 35 percent of the time, compared to perhaps 90 percent for a nuclear plant (so 300 GW of wind capacity only delivers as much electricity as about 120 GW of nuclear). Fortunately, several sources of flexible generation can complement wind's variability, such as hydropower, natural gas, demand response, and soon, a significant amount of concentrated solar thermal power. Many regions in Europe integrate well beyond 20 percent wind power successfully. Iowa, Minnesota, Colorado, and Oregon already get 5 to 8 percent of their power from wind. And as we electrify transportation over the next two decades with plug-in hybrids, the grid will be able to make use of far larger amounts of variable, largely nighttime low-carbon electricity from wind. So post-2030, wind power should be able to grow even further.[38]

Solar

Two forms of solar energy are ready to deliver large quantities of cost-effective electricity: solar photovoltaics, or solar PV, and concentrated solar power, or CSP. The best-known form of solar is PV, direct conversion of sunlight to electricity. PV has historically been quite expensive, but its costs have been coming down for decades, and sales have been growing at some 50 percent per year recently. Last year, global PV installations surpassed 2,800 MW of new capacity, which represents growth of more than 60 percent from 2006 levels.[39]

It is difficult to compare PV costs with nuclear because, on the one hand, PV delivers power only about 20 percent of the time. On the other hand, PV can be installed directly on the roofs of buildings. PV therefore avoids transmission and distribution costs and associated losses, while providing power directly to retail customers when it is typically most expensive—during the sunny days of the summer.

Because it is a modular, low-maintenance consumer product, PV can make use of innovative financing strategies whereby the customer does not own the equipment, but merely purchases the power. SunEdison company is a leader in providing such solar energy services with no upfront costs. In a recent interview, Jigar Shah, the company's chief strategy officer, explained that his company could deliver Florida more kilowatt-hours of power with PV—including energy storage so the power was not intermittent—for less money than Progress Energy has said its nuclear plants could cost. And PV would have no risk of price escalation in the face of construction delays or rising prices for uranium.[40]

Shah projects that by 2015, solar PV will be able to provide electricity directly to the customer for $.12 per kWh unsubsidized. PV could provide 100,000 MW of U.S. capacity in 2020, and 350,000 MW by 2030.

After more than a decade of neglect, concentrated solar power has begun rapid growth with more than a dozen providers building projects in two dozen countries. [41] In 2006, the Arizona Public Service Company dedicated the first new CSP plant in the United States in two decades—a 1 MW-concentrated solar trough system with an engine used for decades by the geothermal industry. In June 2007, Nevada Solar One, the state's first CSP plant, went online. On 275 acres near Boulder City, it provides 64 MW of electricity from 98 percent solar power and 2 percent natural gas. And in California, PG&E has created deals with three major CSP companies to generate electricity for the Golden State. Another 10 plants are in the advanced planning stages in the Southwest, along with nine plants in countries that include Israel, Mexico, and China.

Utilities in the Southwest are already contracting for power at 14 to 15 cents per kWh. The modeling for the California Public Utilities Commission puts California solar thermal at 12.7 to 13.6 cents per kWh (including six hours of storage capacity), and at similar or lower costs in the rest of the West. A number of players are adding low-cost storage that will delivers peak power when demand actually peaks, rather than just delivering a constant amount of power around the clock. Thermal storage is far less expensive with a much higher round-trip efficiency than electric storage.

Equally important, CSP has barely begun dropping down the experience curve as costs drop steadily from economies of scale and the manufacturing learning curve.[42] The California Public Utilities Commission analysis foresees the possibility that CSP could drop 20 percent in cost by 2020.

A 2006 report by the Western Governors Association, "projects that, with a deployment of 4 GW, total nominal cost of CSP electricity would fall below 10¢/kWh."[43] It also asserts that deployment will likely occur before 2015. Indeed, the report noted that the industry could, "produce over 13 GW by 2015 if the market could absorb that much." The report also notes that 300 GW of CSP capacity can be located near existing transmission lines.

As an aside, wind power is a very good match with CSP in terms of their ability to share the same transmission lines, since a great deal of wind is at night, and since CSP, with storage, can be dispatched in a controllable manner.

A new report from Environment America, "Solar Thermal Power and the Fight Against Global Warming," explains how the United States could achieve 80 GW of CSP by 2030.[44] A number of industry and academic experts recently discussed the possibility of 10,000 solar GW globally by 2050 at an energy forum in Hanover, Germany.[45]

CSP plants can also operate with a very small annual water requirement because they can be air-cooled. CSP has some unique climate-friendly features. It can be used effectively for desalinating brackish water or seawater. That is useful for many developing countries today, and it's a must-have for tens, if not hundreds of millions, of people if we don't act in time to stop catastrophic global warming and, as a result, dry out much of the planet. Such desertification would, ironically, mean even more land ideal for CSP.

The technology has no obvious bottlenecks and uses mostly commodity materials—steel, concrete, and glass. The central component, a standard power system routinely used by the natural gas industry today, would create steam to turn a standard electric generator. Plants can be built in a few years—much faster than nuclear plants. It would be straightforward to build CSP systems at whatever rate industry and governments needed, ultimately 50 to 100 GW a year growth or more.

Nuclear Pork

What should our federal policy be to get the needed technologies into the market as fast as possible? The United States seems likely to pass some sort of cap-and-trade system for greenhouse gas emissions in 2009 or 2010. That might establish a price for carbon dioxide by 2015, if not sooner. Such a price will benefit all carbon-free sources of power equally. Every \$50 per ton of carbon (\$14 per ton of CO_2) would add 1.5 cents per kWh to a traditional coal plant without carbon capture and storage. Once the price exceeds about \$100 a ton, most carbon-free generation options probably won't need more government subsidies, at least those with more than 1 percent of the market.

Until then, we should extend the production tax credit for wind power and the investment tax credit for solar power. But what should we do about nuclear? That mature source of power has benefited disproportionately from government support to date.

From 1948 to today, nuclear energy research and development exceeded \$70 billion, whereas research and development for renewables was about \$10 billion.[46] From 2002 to 2007, fossil fuels received almost \$14 billion in electricity-related tax subsides, whereas renewables received under \$3 billion.

The Price-Anderson Nuclear Industries Indemnity Act caps the liability for claims arising from nuclear incidents. It reduces the insurance nuclear power plants need to buy and requires taxpayers to cover all claims in excess of the cap. The benefit of this indirect subsidy has been estimated at between $237 million and $3.5 billion a year, which suggests that it has been worth many billions of dollars to the industry.[47] It could be argued that the value is considerably larger than that, since the industry might not have existed at all without it: "At the time of the Act's passing, it was considered necessary as an incentive for the private production of nuclear power … because investors were unwilling to accept the then-unquantified risks of nuclear energy without some limitation on their liability.

One can make a case that such insurance was reasonable for a new, almost completely unknown technology in 1957. Extending it through 2025 is harder to justify. If investors aren't willing to accept the risks of nuclear energy now, without taxpayers liable for any major catastrophe, perhaps the technology no longer deserves government support.

Some argue, as Sen. McCain did in May, that "As a result of Three Mile Island and Chernobyl, we set in place a regulatory process that sometimes means it takes 10 to 15 years before we're able to get a nuclear power plant in operation."[48] There are two flaws in that argument. First, as we've seen, nuclear power plants face delays in other countries, most often because of quality problems related to construction. Second, as long as a catastrophic failure of the nuclear plant would have such devastating consequences—costs that the American taxpayer is ultimately on the hook for—the government must enforce the strictest safety standards. If power plants continue to take six to10 years to build, that is most likely because the industry has failed to develop and standardize a limited set of simple, modular, fail-safe reactor designs that could tap into economies of scale from mass production. In the American market alone, there is now not one new design, but at least five undermining the prospect of significant cost savings from standardization and mass production, although presumably some of these savings could still materialize at the subsystem and component level, particularly for items that are shared between reactor types.

There are $13 billion in subsidies and tax breaks in the Energy Policy Act of 2005, not even counting the value of the Price-Anderson act extension. It includes "Unlimited taxpayer-backed loan guarantees for up to 80 percent of the cost of a project" and "Production tax credits of 1.8-cent for each kilowatt-hour of nuclear-generated electricity from new reactors during the first 8 years of operation for the nuclear industry"[49]—the same tax credit wind gets, even though wind provides one-twentieth of the power of nuclear.

Nonetheless, on top of all this pork, Sen. McCain put another $3.7 billion in federal subsidies for new nuclear plants into his most recent climate bill, even though that bill creates a cap-and-trade system that would establish a price for carbon dioxide, which already benefits nuclear power and all low-carbon energy sources.

Yet last fall, when *Grist* magazine asked McCain, "What's your position on subsidies for green technologies like wind and solar?" he said, "I'm not one who believes that we need to subsidize things. The wind industry is doing fine, the solar industry is doing fine. In the '70s, we gave too many subsidies and too much help, and we had substandard products sold to the American people, which then made them disenchanted with solar for a long time."[50]

He reiterated his support for nuclear subsidies over renewable subsidies again in May.[51]

This suggests passing a climate bill may require satisfying conservatives who demand more subsidies for nuclear power. Given that such subsidies seem unwarranted at this point—and the subsidies would unlikely do more than build a few new heavily subsidized plants—progressives should insist on the needed subsidies for efficiency and renewables.

Conclusion

Nuclear power's many limitations—especially its escalating price—will constrain its growth in America, particularly in the near term. Nuclear power is unlikely to contribute even 10 percent of all of the low-carbon energy we need nationally or globally to keep total temperatures from increasing more than 2°C above pre-industrial levels.

Merely maintaining the percentage of generation provided by nuclear in this country through 2050 and beyond will require building on the order of 75 large replacement reactors, which itself is likely to pose challenges unless new nuclear plants can be built for under $4,000/kW total cost and provide electricity to the grid at $0.10 per kW or less.

As long as prices remain so high, we all need to focus on other, more consequential energy and climate efforts. The carbon-free power technologies that the nation should focus on deploying right now at large scale are efficiency, wind power, and solar power. They are the low-cost carbon-free strategies with minimal societal effects and the fewest production bottlenecks. They could easily provide the vast majority of new generation for the next quarter century and beyond, while at the same time providing enough generation for replacing some existing fossil fuel plants and supporting a reduction in overall greenhouse gas emissions. In the medium-term (post-2020), other technologies, such as coal with carbon capture and storage and advanced geothermal, could be big players, but only with a far greater development effort over the next decade.

Nuclear power is a mature technology, providing some 20 percent of U.S. power generation. It has been the beneficiary of nearly $100 billion in direct and indirect subsidies since 1948. Such a technology should be the focus of reduced subsidies, not increased ones.

A U.S. cap-and-trade system with a rising price for carbon dioxide advantages all low-carbon energy resources, including nuclear. After 50 years of development and federal government support, if new-build nuclear can't compete in this new low-carbon environment, then frankly it doesn't deserve to be in it. Even if a rising carbon price ultimately rescues nuclear power financially, the nuclear fuel cycle has other environmental and international security drawbacks, not dealt with in this paper, that strongly suggest we should turn to it only when we have exhausted the supply of energy services available at equal or lesser cost from truly sustainable sources, within the timeframe that the best science tells us is required to avert climate disruption. We are a very long way from having exhausted the potential of such resources today, beginning with massive potential electricity savings from least-cost energy efficiency. The present focus should be on accelerating sustainable emerging power generation technologies down the cost curve with a federal renewable electricity standard and multiyear tax credits that sunset by the end of the next decade. At the same time, the federal government should work closely with the states to adopt the best practices for utility regulations that promote energy efficiency.

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