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Nuclear power in a carbon-constrained world

History of science and technology has consistently taught us that scientific advances in basic understanding have sooner or later led to technical and industrial applications that have revolutionized our way of life. It seems to me improbable that this effort to get at the structure of matter should be an exception to this rule. What is less certain, and what we all fervently hope, is that man will soon grow sufficiently adult to make good use of the powers that he acquires over nature.

– Enrico Fermi, in 1953, the year before his death

I have spent nearly four decades in the utility industry grappling with the effort to "make good use" of the power man has acquired in learning to split the atom. I cut my teeth in private practice licensing the fleet of Commonwealth Edison, one of the nation's most nuclear-intensive utility companies. In my first CEO position, I worked to recover Central Maine Power's economically disastrous investments in the Seabrook plant while fighting referenda to shut down the productive and economical Maine Yankee station. When I later returned to Illinois, this time as CEO of ComEd, I led a dedicated team of nuclear professionals who turned the country's worst-performing fleet into the nation's best. This year I celebrated my 25th year as a CEO in the electric industry. Exelon Corporation, a successor company to ComEd and PECO (another nuclear utility), is the largest commercial nuclear operator in the United States and the third largest in the world.

The politics and economics of nuclear energy represent a nearly complete circle: a burst of building in the late 1960s and 1970s; public concerns and rising costs aggravated by the Three Mile Island accident of 1979; deteriorating economics due to high inflation, poor operating performance, and low-priced natural gas in the 1980s and early 1990s; and now, as of early 2009, 17 license applications filed with the Nuclear Regulatory Commission (NRC) for the construction of as many as 26 new reactors, including Exelon's application to build a two-unit plant in Texas. Traditional considerations – the low production costs of nuclear power, volatility in electricity prices because of a growing reliance on natural gas, projected electricity demand outstripping supply (a "shrinking reserve margin," in utility parlance) – are driving these ambitious proposals and plans. Increasingly, however, concerns about climate

change are also driving the so-called nuclear renaissance.

Dramatic economic growth and projected power demand in nations such as China and India have only accelerated the need for nuclear energy. Even more than in the United States, nuclear power is becoming a more attractive option globally. In a November 2008 survey of more than 10,000 respondents in 20 countries, Accenture found strong growing support for nuclear power as a way to reduce reliance on fossil fuels. Moreover, the strongest support came from respondents in India, China, the United States, and South Africa, in that order. Construction plans abroad are as bold as, and in many cases more real than, those in the United States. According to the International Atomic Energy Agency, 13 countries outside the United States are building 44 reactors, and an additional 108 are being planned. This is clearly a positive outcome from a climate change standpoint, but it raises concerns as well – not the least of which are about nuclear security and nonproliferation.

From my vantage point, this nation's energy and climate challenges pose three inconvenient truths (to borrow an already overworked phrase), rather than just one.

Inconvenient Truth #1: *Climate Change is Real*. Our planet is warming, at least in part due to human production of CO_2 and other greenhouse gases. The Intergovernmental Panel on Climate Change and the National Academy of Sciences have issued reports that persuade all but the most skeptical reader. Indeed, one must be almost obstinately skeptical to resist the weight of this analysis, the closest one gets to consensus among scientists.

These reports conclude that global temperatures are rising and that human activity – especially the burning of fossil fuels – is a major contributor to that warming. The reports are less sure about the long-term effects. Predicted outcomes range from comparative nuisance to complete catastrophe. However, our inability to predict the outcome must not be an excuse for inaction. Both governments and industry, including electric utilities, are obliged to make billion-dollar investment decisions in the absence of complete information. We must similarly deal with our climate challenge in a way that is both decisive and prudent.

Fortunately, President Obama and congressional leadership seem to agree there is a problem. As I write this in the spring of 2009, both branches of government are moving forward with proposals and legislation that will place a price on carbon emissions, either through a cap-and-trade system or a carbon tax, essential ingredients to encouraging low-carbon investments and discouraging high-carbon ones. We must ensure that this price signal is phased in gradually so as to avoid shocking a weak economy, to give it political stability, and to allow time for better technological solutions to develop. A predictable, economically sustainable price for greenhouse gas emissions is the *sine qua non* of addressing climate change. I believe that today we are closer to a comprehensive governmental policy on climate change than ever before.

Putting a price on carbon, however, creates another huge challenge. Because the essence of global energy policy has for years been founded on the consumption of low-cost fossil fuels, in a carbon-constrained world new sources and approaches to energy supply will be required.

Inconvenient Truth #2: *Energy Efficiency and Renewable Power Cannot Meet our Needs on Their Own*. The United States' appetite for electricity is projected to grow dramatically, even accounting for the impact of the current recession. Research by The Brattle Group based on the *Annual Energy Outlook 2008*, published by the Energy Information Administration (EIA) of the Department of Energy, concludes that the U.S. electric industry will need to build 214 gigawatts (GW) of new generating capacity in the next 20 years to meet projected demand.[1] This increase in generation is roughly 20 percent of the industry's current installed nameplate capacity. It is a stark reflection of the fact that as our nation has grown more prosperous and our standards of living have increased, so, too, have our power needs. Meeting these needs will be a stiff challenge for the utility industry, even absent the need to adapt ourselves to a low-carbon world.

Energy efficiency will be a critical – and in some ways the most creative – component of meeting that growing demand. Improved efficiency standards have been in vogue for years with policy-makers who have (wisely, in my view) passed laws requiring air conditioners that run on less power, toilets that flush with less water, and other similar measures. When Exelon renovated its headquarters in downtown Chicago, we designed our 10 floors of the 1970s-era building to meet LEED (Leadership in Energy and Environmental Design) Platinum standards. We changed our lighting, put advanced controls on our heating and cooling, and installed Energy Star-rated appliances. In doing so, we reduced our electricity consumption by 50 percent and achieved substantial cost savings. And efficiency is even penetrating the public consciousness. As electricity prices rose in recent years, consumers found themselves more willing to embrace the twists and curves of a compact fluorescent light bulb – even if it did not fit perfectly with their home decor.

Undoubtedly, efficiency is the best first step when it comes to meeting our future needs in the least carbon-intensive fashion. But how much of future demand can be mitigated by improved efficiency? The answer is not at all clear. Technology and the behavior of consumers are both too complicated to be characterized by a supply curve. The items that clearly pay for themselves, such as Exelon's office renovations, will be quickly adopted. Yet I believe that we are still far from the day when consumers will pay $20 for an LED bulb, even if it is more efficient than its compact fluorescent cousin. We must find a way to convince landlords to build the most efficient buildings possible when their tenants – not they – will pay the monthly bill. And we must realize that as our economy grows and our standards of living become ever higher, we will find new technologies, like mobile phones and flat-screen televisions, that will use more power, not less. We will not and cannot all live simpler lives consuming less and still providing for ourselves.

The Brattle Group study estimates that in the most realistic case, 38 percent of the projected growth in generating capacity can be eliminated through improved efficiency and conservation. In the best-case scenario – which assumes that we can (and will) change our behaviors and pay the still-unknown costs – 48 percent of projected growth in generating capacity could be eliminated. That is certainly meaningful progress toward meeting our needs in a low-carbon fashion, but assuming the best-case efficien-

cy scenario, we still must build 111 GW of new generation over the next 20 years.

Renewable generation sources – primarily wind, which is the most mature of the alternatives – have also caught the imagination of the public and policy-makers. Subsidies and governmental mandates fueled a wind construction boom in recent years, aided by rising electricity prices (largely due to volatile natural gas supplies) and concerns about dependence on foreign energy sources. According to the American Wind Energy Association, over 5 GW of wind capacity were installed in 2007, and approximately 7.5 GW were projected for 2008. (The previous annual high-water mark for new installed wind capacity was in the neighborhood of 3 GW.) There is something appealing to the public about a form of electric generation that requires no fuel and passively harnesses nature.

But how much generating capacity can renewables achieve? The Brattle Group and the EIA conclude that we can expect to obtain roughly 39 GW of generating capacity from wind and other renewable sources. This amount is roughly the same in the reasonable and best-case scenarios, reflecting current knowledge about the technologies involved. These 39 GW come with a significant cost, though. Exelon's internal economic analysis places the unsubsidized cost of avoiding carbon emissions with wind at between $50 and $90 per metric ton.[2] A recent article in *The Economist* cites a study that places the cost of avoided carbon emissions with renewables at between $70 and $140 dollars per metric ton. This translates into wholesale power price increases between 3 and 14 cents per kilowatt-hour (depending upon the market), which could easily double a consumer's monthly bill. And these figures do not count the attendant investments that must come with renewable power. The most promising regions in the United States for wind development are in the Southwest and Great Plains, far from the population centers that would need the power the most and necessitating the construction of costly transmission lines. A February 2009 report by the Lawrence Berkeley National Laboratory summarizing more than 40 existing transmission studies estimates that the average additional cost for transmission – on top of the higher cost of wind energy – is between 1.5 and 2.5 cents per kilowatt-hour.

Moreover, renewable power sources are intermittent. According to a 2007 study by the engineering firm Black & Veatch, the newest and most efficient wind turbines have a 35 percent capacity factor (defined as the amount of energy produced over a given time divided by the unit's total energy potential). We would still need to build backup generation from traditional sources, most likely quick-starting natural gas facilities, to ensure reliability of the grid and that the lights come on whenever customers flip the switch, regardless of whether those wind resources are producing power. As for solar power, the same issues about transmission and reliability apply, but the technology is even less mature, and so the costs, according to Exelon's internal analysis, are as much as 10 times higher than the cost of wind.

We can and must invest in wind, solar, and other emerging technologies. But even in the most optimistic of scenarios, we face a shortfall of 75 to 100 GW of power. And it is critically important to remember that this is merely the generation required to meet projected demand. It does not address replacement of any part of the existing and aging carbon-intensive coal-generation infrastructure, which accounts

for roughly 50 percent of power generated today and the vast majority of the industry's CO_2 emissions.

Inconvenient Truth #3: *We Need Low-Carbon Base Load Power, a Substantial Amount of Which Will Have to be Nuclear.* We have three options to fill the gap in our country's future power needs in a low-carbon fashion: natural gas, clean coal, and new nuclear plants. Each has disadvantages and complications.

More natural gas-fired generation is a certainty. The capital investments are manageable for companies the size of the average U.S. utility. It can be dispatched quickly, making it the ideal complement to intermittent renewables, and it is relatively attractive from the standpoint of carbon emissions. Current economic conditions, stresses on the ability of utilities to make large capital investments, and today's low commodity prices all but ensure another "dash to gas." In today's environment, natural gas is second only to energy efficiency as a way to provide electricity at the lowest avoided cost for carbon emissions. But we should be wary of the unintended consequences of such a dash. Most significantly, a further build-out of gas generation would lead to an increasingly undiversified generation portfolio. According to the energy data provider Ventyx, approximately 375 GW of nameplate generating capacity have been brought on line in the United States since 1990; more than 85 percent of that capacity is gas-fired. As the percentage of gas-fired generation increases, the volatility in its price will become an even larger problem. The potential volatility was perfectly illustrated in 2008: natural gas prices stood at $7 per MMBtu at the beginning of the year, rose to almost $14 per MMBtu in the summer, and fell to $5 per MMBtu at year's end. By early 2009, it had fallen even further, to less than $4 per MMBtu. Future oscillations in price will translate into power price volatility, and that volatility will become more pronounced as the dash to gas progresses. This outcome is good neither for power generators, whose revenues and cash flows will ride the peaks and troughs of the commodity cycle, nor the customers they serve, who will quickly become frustrated by the uncertainty about what their electricity bill will cost.

Coal, which accounts for roughly 50 percent of the electricity generated in the United States, is a second option. We will not retire existing plants overnight, making coal-fired electricity a reality for many years to come, even in the unlikely event that we never build another new coal plant. Accordingly, we must pursue clean coal technology. Yet this, too, has limitations. Since my first day as a utility CEO, I have been told that the revolution in clean coal is imminent. While we have had success in removing the sulfur and nitrous oxides from the emissions, the challenge currently lies in confronting carbon emissions. Carbon capture and sequestration technology may work; however, it has not yet been proven on a large scale. The most significant project that would do so – the FutureGen project in downstate Illinois – has been in limbo due to tenuous governmental funding and industry support. The technology must be proven on a large scale and made available for both new plants and as retrofits to existing plants. We must understand the cost of coal with carbon capture, which Exelon's analysis estimates to be the most expensive of any base-load generating option, at roughly $150 per metric ton of CO_2 avoided. And the public must understand and become comfortable with the risks of

sequestration. The process involves injecting a large amount of carbon dioxide into a geological repository, where it must stay for the duration of human existence. If those repositories burp, our planet will have a problem.

The third option is new nuclear power. Today, nuclear is the predominant low-carbon base-load generating source. The EIA estimates that in 2007 nuclear accounted for approximately 74 percent of the electricity derived from sources that emit no greenhouse gas. And as an industry, we have made progress on many of the concerns that reared their heads during the 1980s.

- *Improved safety and reliability.* We have made great progress since the partial meltdown at Three Mile Island Unit 2. According to the NRC, the number of "significant events" at U.S. plants has fallen from an average of 1 in 1989 to somewhere in the neighborhood of between 0.04 and 0.07 in recent years. Capacity factors across the industry are substantially improved as well. At the time of the Three Mile Island incident, the average nuclear reactor in the United States generated power at only 60 percent capacity; today that capacity factor is 91 percent. At Exelon we have had 6 straight years with capacity factors in excess of 93 percent.
- *Improved public support.* The public perception of nuclear power is improving, due in no small part to efforts by the industry to win back the public's trust through the safety and reliability improvements mentioned above, as well as an increasing recognition of the cost and environmental impacts of other fuel options. A poll by Bisconti Research commissioned by the Nuclear Energy Institute in March 2009 found that 70 percent of Americans supported nuclear power, up from roughly 50 percent in the early 1980s. Among those who view nuclear as a low-carbon option, the support level increases to 75 percent. Of those who have a plant within 10 miles of their home, 82 percent view nuclear power favorably. Lest one suspect some bias in the polling based on who commissioned it, an independent poll by Zogby International conducted in June 2008 shows that two-thirds of Americans favor the construction of new nuclear plants.
- *Plentiful, stable, and secure fuel source.* Nuclear power offers advantages over gas from the standpoint of fuel security. The Organisation for Economic Co-operation and Development (OECD) noted in its *Nuclear Energy Outlook*, published in October 2008, that identified uranium supplies could support an expansion of nuclear generating capacity until 2050 without the need for reprocessing; additional suspected reserves could provide enough supply for "several hundreds of years." Moreover, the OECD points out that uranium comes from diverse sources and regions, with the key suppliers operating in politically stable countries. The high energy density of uranium means that its transportation is less vulnerable to disruption, and the storage of reserves is easier. Finally, Goldman Sachs states in its January 2008 report, "Reacting to Climate Change: Considering Nuclear Options," that uranium costs represent only about 10 percent of the overall production cost. This compares to roughly 77 percent for coal and 93 percent for gas, according to data provided by Ventyx. This means that even when uranium prices become volatile, as was the case in the past several years, nuclear power is substantially less vul-

nerable to price shocks. In the United States, investments are beginning to be made in conversion, fabrication, enrichment, and other parts of the fuel cycle. This strengthened fuel supply chain will support new nuclear facilities as they come on line.

- *Spent fuel.* Sadly, we are not much closer to a consensus solution on spent fuel than we were when I first became a CEO. The government and the industry have spent approximately $9 billion and countless man-hours over a 20-year period on a permanent repository at Yucca Mountain, Nevada. The Nevada congressional delegation has exerted a comparable amount of effort to thwart it. Recent policy pronouncements indicate that the game is over, and Nevada has won. Nevertheless, current storage provisions at existing nuclear generating sites are safe. The NRC has certified on-site storage for the 60-year life of the plant plus another 30 years afterward during decommissioning, and the amounts of fuel are relatively compact in physical size. The nuclear industry has paid the federal government $20 billion since its plants entered operation to fund the government's obligation to take possession of spent fuel. Progress is beginning on alternatives to a permanent geological repository. Secretary of Energy Steven Chu plans to assemble a blue ribbon commission to determine the best options for managing spent fuel and the back end of the nuclear fuel cycle. I believe that the most likely outcome will be several regional, above-ground interim storage sites, which will serve as a bridge to further development of the technology and a national consensus on the solution. However, all options must be on the table, including developing advanced, safe reprocessing methods to close the fuel cycle.
- *Competitive economics.* Nuclear generation from existing sources enjoys the lowest production cost of any major form of base load generation in the United States. According to the EIA, production costs in 2007 amounted to 1.8 cents per kilowatt hour for nuclear generation, compared to 2.5 cents for coal, and 6.8 cents for natural gas. Exelon's 17 reactors had an average production cost of 1.5 cents, well below the national average. In terms of new-build economics in the long-term, nuclear is competitive with gas and coal even without a price on carbon emissions. Goldman Sachs estimates that the construction cost of new nuclear plants is roughly 6.3 cents per kilowatt hour, equal to that of natural gas and scrubbed coal.[3] Their analysis assumes a long-term natural gas price of $7 per MMBtu, a long-term coal price of $65 per ton, and a new-build cost for nuclear of $6,000 per kilowatt (in nominal dollars). It also ignores any production tax credit benefit nuclear would enjoy under the provisions of the Energy Policy Act of 2005. Were that to be included and were there to be a $20 per metric ton carbon cost, nuclear would be advantaged over natural gas and far more attractive than scrubbed coal. Other studies provide different conclusions in terms of absolute generating costs but not in relative ordering.

While nuclear is far from being "too cheap to meter," neither is it too expensive to contemplate.[4] At the same time, there are three important caveats to this economic analysis to bear in mind.

- *Construction risk remains.* The U.S. nuclear supply chain has atrophied, and no major project will proceed without sig-

nificant engineering and construction support from French or Japanese partners. The industry and the NRC have designed processes to avoid many of the regulatory and design delays that plagued the last cycle of construction, but several projects will need to be completed on-time and on-budget to instill confidence that we truly have learned to avoid our past mistakes.

- *Financing risk is more acute than ever.* A two-unit nuclear plant is a massive capital investment, greater than the book equity of Exelon, the largest company in the industry. While oil companies can and do regularly undertake capital projects of this size, building a new nuclear plant may be a task too large for the U.S. electric industry in its current state. A few utilities in traditionally rate-based regulatory environments with cooperative state utility commissions might be able to build a plant with the costs and risks borne by their ratepayers through construction-work-in-progress (CWIP) rate increases, allowing them to recover the costs from their customers even before the plant is placed in service. The federal loan guarantee program is designed to provide additional assistance, offering attractive debt financing for up to 80 percent of the project's costs. For companies like Exelon that operate in competitive markets without the backstop of ratepayers, loan guarantees are essential. Congress, however, has underfunded the loan guarantee program. The allocated $18.5 billion cannot adequately support more than 5 or 6 of the 26 proposed units, which will dramatically curtail construction plans. Whether through CWIP or loan guarantees, ultimately all utilities will need some form of assistance until the construction risk diminishes in the minds of investors and a price on carbon translates into power prices that can support a project of this size.
- *Current economic conditions are unfavorable.* It takes serious courage, if not sheer audacity, to begin a project of this size in the midst of the worst economic downturn since the Great Depression. Electricity demand has fallen in the near term and reserve margins are not as tight, creating uncertainty about the revenues of a new project. More significant is the collapse in the price of natural gas. It has reduced the marginal price of electricity dramatically, and at $4 per MMBtu, gas-fired generation is by far the preferred low-carbon base load option. None of this addresses the concerns about energy security, price volatility, and diversity in generation, but the prospect of low gas prices for several years to come may be as powerful as the Sirens' call to Odysseus.

Finally, the U.S. nuclear industry has made progress on proliferation. Our plants have security plans and well-trained security forces in place. These in-depth security measures are designed both to protect public health and safety in the event of a terrorist attack and to safeguard fissile materials. We are confident in our ability to protect against either possibility.

In a larger sense, the industry is ready to contribute to crafting a policy response to concerns about proliferation, but we are only a small part of that response. When a rogue state contemplates building a nuclear weapon, spent fuel sitting in Clinton, Illinois, or Pottsville, Pennsylvania, probably doesn't occur to them as their first or best option. In addition

to storage at generally remote locations, the plutonium is mixed with highly radioactive elements that make handling spent fuel dangerous and reprocessing complicated. Nevertheless, we need a comprehensive solution that covers the nuclear power industry and others with potential weapons-making capabilities. The solution needs to be led by public policy-makers who are cognizant of all the issues and competing interests. And the solution needs to be global, accounting for not only the U.S. sources of potentially fissionable material, but also those sources around the world. The American nuclear power community stands ready to contribute to the debate on that solution, and will work to ensure that the ultimate nonproliferation regime is effective.

Nuclear power is inescapably part of the answer to addressing climate change. We face a growing need for power; every available option to meet that demand has its limitations. Energy efficiency is valuable but too limited in its scope to meet all of our future needs without radically changing the way we live. Renewables are too expensive and too unreliable at the current or near-term state of technological advancement. Coal is too dirty, and carbon capture and sequestration is too hypothetical. Natural gas is too volatile. And nuclear, while significantly more attractive today than 20 years ago, still has unresolved issues related to construction, economics, and spent fuel. Nothing is perfect, and none of these solutions is compelling on its own. All of them taken together give us a realistic chance of meeting our future energy needs and adapting our current generation mix for a carbon-constrained world. But construction of new nuclear plants has to be on the table with all of the other options.

Which brings me to one final inconvenient truth: when this nuclear renaissance comes, it will come not only to the United States and Europe, but also to Asia, Africa, and the Middle East. Barring a breakthrough on carbon sequestration for coal, there is no other way to meet the needs of the world's fastest growing economies in a low-carbon fashion. This clearly creates new challenges for nonproliferation regimes. Despite past stumbles and a couple of near-calamities, the nuclear community in the United States, Europe, and Japan has by and large managed to be, in Fermi's words, "sufficiently adult to make good use" of the power to split the atom. The realities of a warming climate and growing energy needs now force us to address Fermi's challenge amid a new, larger international nuclear-generating community.

ENDNOTES

[1] Other studies suggest different figures, but the Brattle and EIA scenario is a good enough approximation to illustrate the task before us.

[2] Exelon conducted a comprehensive economic analysis of carbon abatement opportunities as part of *Exelon 2020: A Low Carbon Roadmap*. *Exelon* 2020 is our plan to reduce, offset, or displace more than 15 million metric tons of greenhouse gas emissions (our 2001 carbon footprint) per year by 2020. The report, along with the supply curve showing the various costs of avoided emissions, can be found on our website, www.exeloncorp.com.

[3] Production costs consist of operations and maintenance charges plus the cost of nuclear fuel. This is contrasted to construction costs, which include the capital expenditures and expenses incurred up to the point of a unit's commencement of commercial operations. In this context, construction costs are quoted in nominal dollars and include a substantial amount of interest incurred during the lengthy construction period.

[4] "Too cheap to meter" is an old chestnut from Rear Admiral Lewis L. Strauss, the particularly controversial head of the Atomic Energy Commission from 1953–1958. All too often it has been attributed to a utility executive.