Myths of the Nuclear Renaissance

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More than thirty years ago, my now-deceased colleague David Comey was asked to make a presentation before the annual meeting of the Atomic Industrial Forum, then the major trade association backing expansion of nuclear power worldwide.[1] He was asked to deliver that speech because he had built credibility with the press and with key decision makers by being scrupulously careful with his facts and analyses. The industry understood that its reputation—particularly with the media—was poor, and they wanted to understand how David did it. In Comey's view, there was an easy explanation—the nuclear industry regularly exaggerated and misled.

In the intervening years, not much has changed. The industry still seems to prefer the sound of a splashy argument to a defensible case. Popular articles in the press, some opinion leaders and politicians, and even some environmentalists have bought the notion of a nuclear renaissance. Among other things, we hear that:

1) nuclear power is cheap;
2) learning and new standardized designs solve all past problems;
3) the waste problem is a non-problem, especially if we'd follow the lead of many other nations and "recycle" our spent fuel;
4) climate change makes a *renaissance* inevitable;

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1. David Comey was executive director of the Chicago-based organization, Citizens for a Better Environment. In that role and with Business and Professional People in the Public Interest (BPI), he was an early leader among skeptics of nuclear power.

5) there are no other *large* low-carbon "*baseload*" alternatives;
6) there's no particular reason to worry that a rapidly expanding global industry will put nuclear power and weapons technologies in highly unstable nations, often nations with ties to terrorist organizations.

In summer 2006, the Colorado-based Keystone Center convened a panel of about 25 experts from all sides of the compass to investigate the possibility of a major nuclear revival. Participants included representatives from the utility industry (e.g., Southern Company, American Electric Power, and Florida Power & Light), the environmental community (e.g., Natural Resources Defense Council, Environmental Defense, National Wildlife Federation, and Pew), two former commissioners of the Nuclear Regulatory Commission, and others. We were asked to look at economics, safety and security (in light of TMI, Chernobyl, and 9/11), waste, and proliferation. The report was released in June 2007 and is relatively sober and free of misleading one-liners.[2]

I. COSTS OF NEW PLANT CONSTRUCTION

Few people question the economics of existing nuclear plants. Many are twenty to thirty years old, and anything depreciated over such a period ought to be cheap. New plants, however, are not cheap, despite a number of studies that make that claim. The Keystone group looked at the studies, and discarded nearly all of them. They are typically based on vendor projections; reference each other; do not include owner's costs (contingency for unexpected delays or scope changes, construction management, land, interest costs); and are extremely optimistic with respect to construction time, capital cost, regulatory support, and many other factors. These aren't assumptions so much as a wish list.

The last time the United States tried to build a number of reactors, costs rose spectacularly, particularly for those plants built during the inflation-plagued 1980s. Whether built in the early or later years, US nuclear reactors—on average—exceeded their original construction budgets by factors of between two to four.[3]

Today, the industry says, "Give us a chance. Trust us. There's a lot we've learned, and we'll learn more if we build lots of new plants." There have been improvements in nuclear construction practices, based on recent experience in Japan and South Korea. But we also see current evidence of construction delays—at Olkiluoto-3 in Finland—that is

2. THE KEYSTONE CENTER, NUCLEAR POWER JOINT FACT-FINDING (2007), *available at* http://www.keystone.org/spp/documents/FinalReport_NJFF6_12_2007(1).pdf.

3. MARK GIELECKI AND JAMES HEWLETT, US ENERGY INFORMATION ADMINISTRATION, COMMERCIAL NUCLEAR POWER IN THE UNITED STATES: PROBLEMS AND PROSPECTS (1994), *a*vailable at http://tonto.eia.doe.gov/ftproot/features/hewlett1.pdf.

reminiscent of problems we had before.[4] Construction started before engineering designs were complete; design drawings were not consistent with current regulatory requirements; inexperienced contractors and crews made expensive mistakes; skilled labor was in short supply; and procurement often took longer than expected.[5]

Two decades ago, in the US, we had 400 nuclear suppliers and 900 holders of N-stamp certificates from the American Society of Mechanical Engineers (essentially verification of a nuclear quality control program). Today we have 80 US suppliers and 200 N-stamp holders.[6] Only two companies in the world—Japan Steel and Creusot Forge—can do the heavy forgings for pressure vessels, steam generators, and pressurizers.[7] We also have six-year lead-times for reactor cooling pumps, diesel generators, and control and instrumentation equipment.[8] These pinch points lead to delay and potential monopoly pricing throughout the supply chain.

The Keystone group started with limited (but real) recent Asian experience and escalated costs to 2007. After a period of relatively stable construction costs, we have seen a steep rise in all of the materials that go into a nuclear reactor—steel, concrete, copper, zinc, and other raw materials. The effect began in 2002 and, if anything, has worsened over the last few years. Some refer to this as the "China effect," and the consequences are particularly acute for long lead-time, capital intensive technologies like nuclear power. The Keystone Center panel concluded that new reactors were probably two to three times costlier than recent studies and government estimates. Capital costs were not $1500–2000/kW, but $3000–4000/kW.[9] Since the release of that study, other similar estimates have emerged. Standard & Poor's estimated $4000/kW.[10] Moody's estimated $5000–6000/kW.[11] Florida Power & Light estimated that a two-unit project would cost $12–18 billion, or more than

4. Jenny Weil, *Supply Chain Could Slow the Path to Construction, Officials Say*, NUCLEONICS WEEK, Feb. 15, 2007, at 13.

5. Ariane Sains and Ann MacLachlan, *Lack of Complete Design Blamed for Problems at Olkiluoto 3*, NUCLEONICS WEEK, May 17, 2007, at 4; Ann MacLachlan, *Areva Official Says Olkiluoto-3 Provides Lessons for Future Work*, NUCLEONICS WEEK, May 3, 2007, at 7.

6. Weil, *supra* note 4, at 13.

7. *Id.*

8. *Marketplace: A Missing Generation of Nuclear Energy Workers*, (NPR radio broadcast, Apr. 26, 2007) *available at* http://marketplace.publicradio.org/shows/2007/04/26/PM200704265.html; Mark Hibbs and Ann MacLachlan, *Vendors' Relative Risk Rising in New Nuclear Power Markets*, NUCLEONICS WEEK, Jan. 18, 2007, at 1.

9. THE KEYSTONE CENTER, *supra* note 2, at 33–34.

10. *Which Power Generation Technologies Will Take the Lead in Response to Carbon Controls?* STANDARD & POOR'S VIEWPOINT, May 11, 2007.

11. MOODY'S GLOBAL CREDIT RESEARCH, NEW NUCLEAR GENERATION IN THE UNITED STATES: KEEPING OPTIONS OPEN VS. ADDRESSING AN INEVITABLE NECESSITY, Oct. 2007.

$8000/kW on the high end.[12] All of these studies estimate much shorter (five to six year) construction times than the US industry achieved decades ago. None could be called "worst case."

The sheer magnitude of the capital investment (e.g., $12–18 billion for a two unit plant) is larger than the book value of many medium-sized electric companies. Finance, cash flow, liquidity, and rate shock will be big challenges. In terms of life cycle cost (inclusive of fuel, operations and maintenance, decommissioning, etc.), these higher capital costs translate into roughly 11–17 cents/kWh "levelized" over the life of the plant.[13] First year costs are nearly twice these values. In real (inflation adjusted) terms, it takes about six years of construction plus 13 years of operation for reactor costs to reach their life cycle levelized cost. These numbers make nuclear power a very indigestible resource for smaller utilities, large utilities unable to put construction work in progress into rate base, any utility with electricity-intensive, price-sensitive industrial loads, any entity building plants in a deregulated market environment, or any entity that sees substantial near-term improvements in costs of renewable technologies. In essence, it is a "bet the company" investment.

While the industry talks about a renaissance, simply keeping pace with planned retirements would require eight new plants per year in this decade and twenty new ones per year in the following decade. Of course, governments can try to subsidize new reactors, as the US did with the federal loan guarantee provisions of the 2005 Energy Policy Act. Loan guarantees are also available for renewable technologies. Even with strong federal support, the Energy Information Administration projects a US nuclear industry in 2030 barely larger than the one that exists today.[14] And it will take heroic efforts to solve the fuel problem.

II. FUEL SUPPLY PROBLEMS

Current uranium consumption in existing reactors is about 50% higher than uranium production, and one wonders how that can be. The answer is that current fuel supplies are supplemented by finite but inexpensive inventories from surplus Russian weapons uranium, cancelled and shutdown plants, and other government inventories—all driving prices down and mines and enrichment plants out of business since the late 1980s.

Today, utilities have long-term contracts for uranium and enrichment, typically with price ceilings. These contracts fall off

12. Pam Radtke Russell, *FPL says cost of new reactors at Turkey Point could top $24 million*, NUCLEONICS WEEK, Feb. 21, 2008, at 3.

13. Levelization is often used in the utility industry to compare resources with very different capital and fuel cost profiles. Annual cash flows are discounted and averaged over the lifetime production of the plant.

14. THE KEYSTONE CENTER, *supra* note 2, at 26–27.

substantially in the next two years and most are over in five years. With price ceilings in contracts and a relatively small spot market, mining companies aren't raking in huge profits or expanding rapidly. The same holds true for enrichment companies. Meanwhile, the spot market uranium prices have soared—seven times higher today than five years ago.[15]

Utilities will soon have to enter that market, and it will not be a friendly one, as the mines, mills, and enrichment plants needed to deliver these products and services do not exist today. Nuclear fuel has been cheap—about 0.5 cents/kWh. But current spot prices will soon be reflected in new longer term contracts, resulting in nearly a three-fold increase in fuel price, at best.[16] Mining and enrichment operators have a very strong hand: a nuclear plant owner would pay almost any price to avoid shutting down. Heroic measures will be needed merely to meet near term demand, and prices for both products will rise—perhaps spectacularly.

The historical answer to high uranium prices has been chemical reprocessing of nuclear fuel, to extract unburned uranium 235 and plutonium 239 that can be used in existing reactors as a substitute for natural uranium. But reprocessing capacity is limited and the cost is enormous. So too is the cost of fabricating this type of fuel. Moreover, most current reactors cannot use a full core of reprocessed fuel without physical modification. With reprocessing, nuclear fuel cycle costs are higher by 2.5–3 times (3.5–4.5 cents/kWh). One might expect parts of the nuclear industry—especially the utility operators—to recoil at such numbers. One three-fold fuel price increase for plants trying to survive in a more competitive wholesale market may be unavoidable and painful, but a nine-fold increase—relative to the historical 0.5 cents/kWh level—would challenge some existing operators.

III. WASTE DISPOSAL CHALLENGES

Capital cost and fuel supply are major challenges facing the industry, but so too is the waste problem. The US approach to waste storage—the Yucca Mountain repository in Nevada—is also in jeopardy. It can take no more waste from the civilian nuclear industry than that industry has generated to date without exceeding its statutory volume limit.

Meanwhile, the Bush administration has invented a preposterously silly answer to the Yucca problem—GNEP, or the Global Nuclear

15. Thomas Neff, Dynamic Relationships Between Uranium and SWU Prices: A New Equilibrium (paper presented at the World Nuclear Association Annual Symposium, 2006), *available at* http://www.world-nuclear.org/sym/2006/neff.htm; Thomas Neff, Uranium and Enrichment—Supply, Demand, and Price Outlook (presentation to the Winter Energy Conference, Banff, Jan. 2007).

16. THE KEYSTONE CENTER, *supra* note 2.

Energy Partnership.[17] On the domestic side, the proposal is to reprocess the waste, and store two of the hottest and most dangerous products (Cesium 137 and Strontium 90) on the surface for hundreds of years, so that more waste can be crammed into Yucca Mountain. As mentioned earlier, this approach vastly increases nuclear fuel cost. It also relies on unproven technologies and increases the risks of waste storage. Abroad, nuclear power would be free to expand, but countries without either enrichment or reprocessing capacity would be forced to rely on the superpowers for fuel supply. Too many countries will reject this proposal in the near term, and turn to highly proliferative enrichment and reprocessing technologies as forms of self protection.

IV. LIMITS AND RISKS TO WORLDWIDE EXPANSION OF CAPACITY

Worldwide expansion capacity is very limited. The Western European and Russian industries have been essentially moribund since Chernobyl. But the Keystone group took a look at what it might take to achieve a climate "stabilization wedge." Princeton scientists Stephen Pacala and Rob Socolow studied portfolios of emissions reductions strategies, each component of which they termed a "wedge." They proposed fifteen possible wedges, covering all sectors of the economy, as a way to reduce climate change risks over the next fifty years.[18] Seven full wedges would be needed to stabilize atmospheric concentrations of CO2 at 500 parts per million—a little less than twice pre-industrial levels (280 ppm). One of the possible wedges involved nuclear power, essentially doubling current capacity from 370 GWe to 700 GWe over fifty years.

Because all existing reactors will be retired over this period, about 1070 GWe of new capacity (i.e., more than twenty reactors per year) must be built to achieve a wedge. Quite a few nuclear fuel cycle facilities would either be required, or need to be considered, including:[19]

- 23 new centrifuge enrichment plants[20]
- 18 new fuel fabrication plants
- 10 new repositories the size of the proposed Yucca Mountain facility in Nevada
- 36 new spent fuel reprocessing plants, if all spent fuel were reprocessed

17. *See* Global Nuclear Energy Partnership, U.S. Department of Energy, http://www.gnep.energy.gov/ (last visited Apr. 8, 2008).

18. S. Pacala and R. Socolow, Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies, 305 SCIENCE 968–72 (2004).

19. THE KEYSTONE CENTER, *supra* note 2, at 23.

20. The value of 23 enrichment plants is consistent with them all being centrifuges of current average size. These are rough estimates that assume future fuel cycle facilities are about equal in capacity to those in operation today.

A recent analysis by the International Energy Agency estimates a 2030 reference case of 415 GWe capacity worldwide, implying a growth rate of 2 GWe per year, far below the 20 GWe pace required to reach a full wedge over 50 years. The agency identifies "several constraints, such as limits to global capacity to build major components of nuclear power plants, for example pressure vessels and valves, especially for very large reactors. Similar to other industries, short-term constraints that may limit new construction include the cost of raw materials, the difficulty of finding engineering, procurement, and construction contractors, and the shortage of key personnel."[21]

Interestingly, of IEA's projected net global increase of 48 GWe, 47 GWe occurs outside the Organisation for Economic Co-operation and Development (OECD) (including Japan and Korea) and Russia: in China, India, other Asian nations, the Middle East and Latin America.

In an alternative case, 74 GWe of net capacity is added, 90% of it in China and India. Despite large increases, nuclear's share of total generation rises from a modest 2% to a still modest 6% in China and from 2% to 9% in India. Neither nation has a good record of meeting its past nuclear expansion targets.

The US Energy Information Administration also forecasts global electricity demand, and projected nuclear capacity by nation and region. Estimates for 2030 generally fall between IEA's Reference and Alternative Policy scenarios, with a total of 481 GWe projected for that year.[22]

In essence, from 2007 to 2030, forecasts for OECD plus Russia show almost no net growth in nuclear capacity. Retirements are roughly offset by additions. In base cases, 72–100% of net growth occurs elsewhere, mainly India and China. Even so, by 2030, nuclear represents from 3–6% (from 2% today) of electric generation in those two nations. By 2030, net additions are at best about 1/7th of one wedge.[23] The pace of retirements quickens rapidly in later years, however, requiring more than a quadrupling of annual additions to achieve a full wedge by the late 2050s.

In other words, it will be very difficult to achieve a full wedge by mid-century without expanding nuclear power on a huge scale to many nations that have very limited internal capacity, financial wherewithal, or necessary safety culture (e.g., Turkey, Mexico, Venezuela, Yemen, Vietnam, Egypt, Nigeria, Saudi Arabia, Iran, and Indonesia). Setting aside safety culture, internal capacity, and proliferation, there isn't much of a business case for vendor investments in most of those nations. It pays

21. INTERNATIONAL ENERGY AGENCY, ENERGY TECHNOLOGY PERSPECTIVES IN SUPPORT OF THE G8 PLAN OF ACTION: SCENARIOS AND STRATEGIES TO 2050 (2006).

22. ENERGY INFORMATION ADMINISTRATION, INTERNATIONAL ENERGY OUTLOOK 2007, *available at* http://www.eia.doe.gov/oiaf/ieo/.

23. Seven full wedges are needed over 50 years to stabilize atmospheric concentrations of CO2 at twice pre-industrial levels. Pacala and Socolow, *supra* note 19, at 968.

to recall Enron's unpleasant experience with a large gas combined cycle plant built in India. Officials wanted the plant and got it, but would not approve the rates necessary for Enron to recover its costs.

There are also proliferation risks associated with this scenario. Reactors themselves are not major proliferation risks. But bulk fuel handling facilities (e.g., uranium enrichment, reprocessing, and mixed oxide fuel fabrication plants) either routinely process or can be easily modified to make weapons-usable uranium or plutonium that can be diverted without detection.

V. TWO ALTERNATIVES—RENEWABLES AND EFFICIENCY

While the outlook for nuclear power falls well short of what could reasonably be called a renaissance, the electricity and climate future is not all bleak. Renewable resources are growing very rapidly today. Energy efficiency can be improved everywhere, at costs that are a small fraction of the cost of any new resource. Contrast, for example, per capita electricity use for the US as a whole with California, where lower per capita use has meant 22 fewer reactors since 1970. While this is oversimplified (i.e., not adjusted for weather, less industrial capacity, high rates, etc.), it is clear that strong standards, utility programs, and cultural values can make a huge difference.

Some people argue that efficiency is a limited resource, and that we've already grabbed the low-hanging fruit. But consider the example of the refrigerator. Since 1970, US refrigerators, large then, have gotten 10% bigger. Efficiency improvements have cut electricity use by 75%, and the cost of the larger, more efficient fridge has fallen 60%. In short, the cost of this efficiency improvement is negative, and the slope continues to impress. The same basic story applies to industrial electric motors and lighting.

Finally, we are also beginning to see truly exciting news in solar technology, with one example being the California firm Nanosolar, started by Google's two founders, and backed by, among others, Swiss Re. The company has built two 430 megawatt per year production facilities in California and Germany over the last year, using a non-silicon material and a production process they compare to newspaper printing. Those two plants increased global solar cell production capacity by nearly 50%, and began shipping—profitably at $0.99/watt—late last year. With reasonable, but low installation and balance of system costs, decent insolation and financing, photovoltaics are getting very close to current nuclear cost estimates.[24] First Solar, Miasole, Applied Materials, and

24. Insolation is a measurement of solar intensity, usually measured in kWh per square foot. Balance of system costs include inverters to convert photovoltaic power from direct to alternating current.

others are also in the chase. Twenty years from today, light water reactor technology will be about the same as it is today.

Myths survive for thousands of years throughout all our cultures, because they bring practical significance and inspiration to our lives. The nuclear renaissance is not even a myth; it is instead a story based on a stack of fallacies, unsupported by past experience or future promises. This story seems to be getting a second re-telling, but it does not deserve a third.