NUCLEAR POWER PLANT ELECTRICITY: A SIMPLE COSTING MODEL

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There has been much discussion about a nuclear revival, and how these types of facilities can have electricity generation costs that, while not too cheap to meter, will be competitive in the power market.

As we all know from the Enron debacle, there are a number of ways to calculate power generation costs that can involve a dizzying number of variables. However, I would like to lay out a simple model that will get us close enough to the truth, say within a penny or two of the cost of generating and delivering a kilowatt-hour (kWh) of electricity from a new nuclear power plant to the end consumer.

The usual first step in this type of analysis is to establish what the power plant will produce annually. Thus, if our hypothetical nuclear power plant is a Westinghouse AP1000 pressurized water reactor with a net rated capacity of 1115-MW[2] and a 90% availability factor, it will have a total generation of 8,672,400,000 kWh during the course of a year.

Next, we have to determine the various generation costs, which is a bit more difficult.

The first cost is the production cost, consisting of both the operating and maintenance (O&M) cost and the fuel cost. The Nuclear Energy Institute recently reported that production costs in 2007 came to 1.68 cents/kWh, so this is a good starting point[3]. Roughly adjusted for inflation[4], the 10-year production cost for nuclear power plants averaged 2.18 cents/kWh[5].

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[1] During my 29 year career in the energy efficiency and renewable energy arena, I have been involved with more than 100 projects, and two of these received the National Award for Innovation from the U.S. Department of Energy. My consulting duties have included business case and plan development, scenario analysis for various financial strategies, trending analysis, capital investment analysis, and due diligence investigations. I have also worked for a public utilities commission, a state energy agency, and as an appointive energy administrator for two governors.

[2] The Westinghouse AP1000 Advanced Nuclear Plant Description, see: http://www.ne.doe.gov/pdfFiles/AP1000_Plant_Description.pdf. The facility is projected to have a gross rating of 1200-MW. From that amount, you then have to subtract the parasitic losses for internal operations, running the pumps to the cooling towers and that sort of thing, to arrive at the net rated capacity to determine the amount of electricity that can be exported to the grid after the plant's parasitic requirements are accounted for.

[3] See: http://nei.org/newsandevents/newsreleases/setrecordhighs/

[4] See http://www.bls.gov/cpi/

[5] See: http://nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/graphicsandcharts/uselectricityproductioncostsandcomponents/

Also needing to be included in the production cost are the costs of the eventual decommissioning of the facility and the cost of disposing of the highly radioactive fuel rods. While the federal government already collects a fee for nuclear waste disposal,[6] the U.S. Department of Energy has a $7 billion liability for long-term waste management that is not included in current industry production cost estimates. Also, in addition to rising decommissioning costs, the nuclear industry is also installing new infrastructure (replacing the World War II-era gaseous diffusion technology used to enrich uranium with centrifuges) that will have to be paid for. Therefore, it is a reasonable expectation that overall production costs for nuclear electricity will increase.

One early reviewer of this paper noted that a median estimate of O&M cost would now be on the order of 3.00 cents/kWh, and that the enriched uranium fuel cost would add roughly another 1.50 cents/kWh. For discussion's sake, let's say that, all in, the future production costs for a new nuclear plant will be 4.50 cents/kWh.

The second cost item is accounting for the plant's capital costs. The loan lifetime and the interest rate for the borrowed money are the key factors. And, while there is no current data of the long-term borrowing rates by investor-owned utilities for building new nuclear power plants, a proxy will get us close.

For example, Bloomberg[7] shows that a 30-year triple-A rated, tax-exempt insured revenue bond has a current interest rate of 5.14%. Rural electrification loan interest rates[8] for a comparable period are now 4.75%. We know that the cost of borrowing money will unlikely be lower than these rates, but how much higher will they be?

> *"…nuclear ownership entails a special set of risks that require an owner to adjust the corporate capital structure, liquidity sources and risk management procedures to address the financial exposure. All else being equal, the large scale of individual nuclear plants, their high capital cost and fixed expenses, and stringent safety regulations cause these facilities to have a low incidence of failure but a high economic consequence of outage or failure. For this reason, nuclear ownership requires more conservative financial planning and greater financial liquidity than would be required of a generation company without nuclear exposure[9]."*

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[6] The fee, one mil (one-tenth of a cent) per kilowatt-hour of nuclear-generated electricity, is collected from utility customers. This money goes into the Nuclear Waste Fund. As of late 2007, payments and interest credited to the Fund totaled $27.2 billion.

[7] http://www.bloomberg.com/markets/rates/

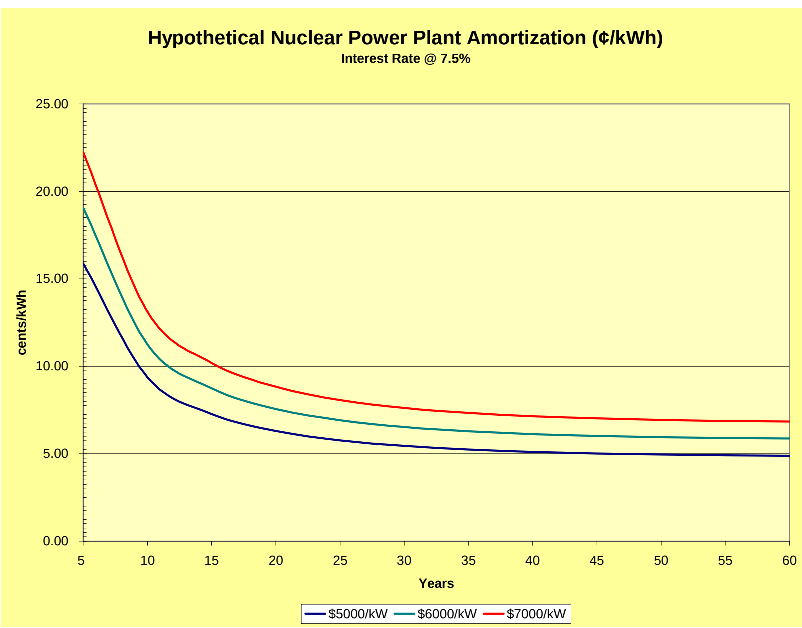
[8] http://www.usda.gov/rus/electric/rates.shtml

[9] Fitch Ratings. (2006) U.S. Nuclear Power: Credit Implications. See: http://www.fitchratings.com/corporate/reports/report_frame.cfm?rpt_id=300084

To begin our amortization exercise, let us assume that the interest rate will be 7.5% and that the project will be financed for a 30 year period.

What is the cost of building a new nuclear power plant? In this case, it was estimated using recent "turn-key" project cost estimates from Florida that indicated building two Westinghouse AP1100's reactors would cost a total of $14 billion. To make the math simpler, let's make that one reactor that costs $7 billion, a net installed capacity cost of $6,278/MW. While not all new plants may be as costly as these proposed units, it is more than likely that the installed costs for the four major reactor designs now under consideration will be substantially the same.

When these factors are entered into a simple loan spreadsheet[10], the annual note to the bank is calculated to be $592,698,650 /year. While this amount would be reduced by using a monthly repayment schedule instead on an annual loan repayment schedule, that's still a pretty big nut to cover[11].



Dividing the annual note due to the bank by the net kWh calculated above means that the break-even amortization cost is equal to 6.83 cents/kWh.

The chart provides the amortization curves for the nuclear power plant example based on three different cost levels[12]. The thing to note is that the amortization cost becomes asymptotic after 30 years, meaning that there is not a great deal of change. For example, if the time period of our example were extended to 60 years (a 100% increase), the amortization declines to only 6.13 cents/kWh, a

[10] Try this at home… a $7 billion project financed for a 30 year period at a 7.5% interest rate.

[11] The amortization assumes the project is financed with 100% debt. As the investor-owned utilities will likely have to have some skin in the game to get financed, this will only increase the amortization cost as their cost of capital is higher than a lending institution. For example, most electric utilities have a 10-15% return on shareholders equity.

[12] The announced costs by Progress Energy in Florida are already about 5% higher than the highest range ($6,000) projected by Moody's Investment Service last fall.

reduction of about 10%. This means that capital cost amortization is relatively inelastic with respect to time.

If you want to argue that the interest rate used in the amortization is too high, here you have to work on evaluating the project's risk profile. Do you really think that Wall Street will make a 60 year loan at a 4%-5% interest rate without the backing of the full-faith and credit of the federal government?

> *"Proposed federal guarantees of electric utility bonds, while possessing superficial attractiveness to the utilities and their regulators, would have numerous technical and substantive defects. Rather than increasing the amount of investment funds available to the economy, these guarantees would crowd out other borrowers, raising interest costs both to the government and to the private sector in the process[13]."*

The third cost that should be included is infrastructure if there were any electric grid upgrades necessary to support the new enterprise. In the Florida example, this was estimated to be a total of $3 billion for the two reactor project. Using the same process as above, I calculate this will have an amortization of around 1.84 cents/kWh.

Since the electric utility is a for-profit entity, you then have to add on their rate of return on top of the production costs. Let's assume this example has a regulated rate of return equal to 12%, which will add another 1.58 cents/kWh to the generation cost.

Given the assumptions, our total generation cost is now estimated to be 16.65 cents/kWh at the busbar. The busbar is the mythic point where the electrons get on the grid for their transmission and distribution to the end consumer.

The final cost that needs to be included is the transmission and distribution (T&D) of the electrons from the busbar to the end-consumer, which is quite dependent upon location and time of the year[14]. For some utilities[15], residential T&D averages about 9.50 cents/kWh. In others states, routine T&D costs are estimated to be in the 2.50-3.00 cents/kWh range. Let's just say that the transmission cost adds another 5.00 cents/kWh to the busbar generation cost, meaning that the delivered cost to the end consumer is roughly 19.75 cents/kWh.

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[13] The Case against Government Guarantees of Electric Utility Bonds, Murray L. Weidenbaum. *Financial Management*, Vol. 3, No. 3 (Autumn, 1974), pp. 24-30.

[14] NOTE: T&D should include the inevitable lines losses of electrons, which are routinely estimated to be in the 7%-9% range. Assuming an 8% line loss rate, this would mean the T&D in this example would be a minimum of 1.18 cents/kWh.

[15] See: http://www.bhe.com/residential/energymgr/lifestyle_elec.cfm

By logic, any conservation, efficiency or renewable energy technology placed on the customer's side of the meter that costs less than 19.75 cents/kWh should be deployed first, as those options will be more "cost-effective" than buying the electrons from the nuclear generation example just presented.

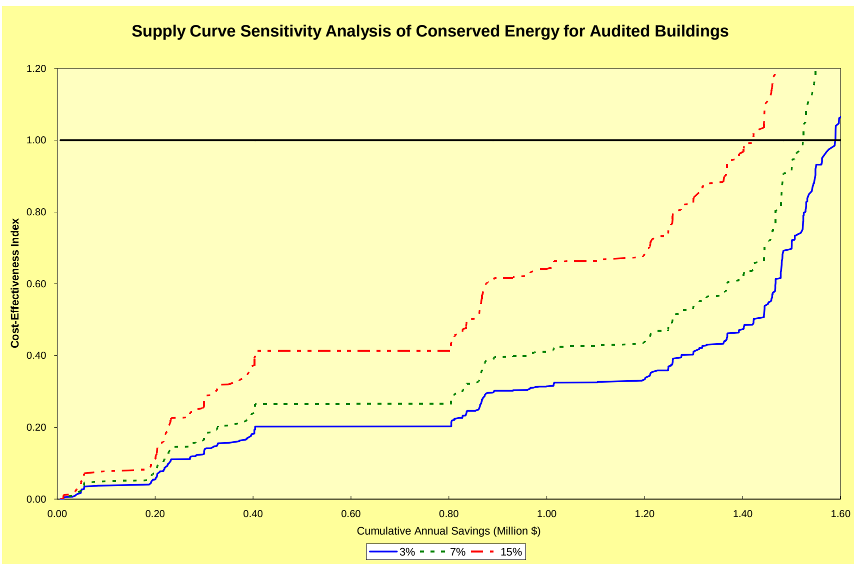
NUCLEAR POWER PLANT GENERATION COSTS (CENTS/KWH)	
Production	4.50
Amortization	6.83
Infrastructure	1.84
Profit	1.58
Sub-Total	14.75
Transmission and Distribution	5.00
TOTAL	19.75

What are some of the options costing less than new nuclear generation on the customer's side of the meter? They generally include energy efficiency measures, renewable energy resources such as solar and wind power, and decentralized power generators that produce electricity and heat water (combined heat and power or CHP) at the same time. Behind this is the assumption of consumer indifference with respect to energy form. What the consumer cares about are the services which energy provides, not the intrinsic value of a specific energy form. To rephrase one approach to consumer theory--the demand for characteristics--what people desire are services such as comfort, illumination, and so forth, and not nuclear-generated electricity.

Quite simply, energy efficiency is the quickest, cheapest, cleanest way to extend our energy supplies. And, despite three decades of focus, residential and commercial buildings still hold great potential for increased energy efficiency. For example, homeowners may be surprised to find that they could reduce their energy consumption by 20%-40% by sealing leaks around doors and windows, using more efficient appliances and windows, and by changing lightbulbs. As another example, Wal-Mart Stores, self-reportedly the biggest private user of electricity in the world, has proven technologies that will allow their new stores to be 25%-30% more energy efficient than today's. As a last example, unlocking the now hidden potential of CHP at existing industrial operations is estimated to have the potential of around 50 large power plants with roughly the same baseload capacity as nuclear.

While it is difficult to prescribe the specific measures that are more cost-effective than the nuclear power, the essence of evaluating any demand-side program is to develop a "supply curve"[16] of the options, so that rational decisions may be made when choosing between competing alternatives[17]. Such a schedule would allow us to rank choices in terms of their cost-effectiveness, since we do not wish to use those options that would increase the relative spending of our energy dollar.

Just to give one example how this is done, the chart is a "supply curve" of 460 of the 600 possible choices identified when energy audits were done for one sample population of institutional buildings[18]. The identified energy options included items such as lighting



upgrades, mechanical equipment such as more efficient chillers, or even renewable energy resources like a wood-fired boiler and solar water heating.

Of these, 439 measures were found to be cost-effective, which is the point where the rising blue line (3% discount rate) crosses over the 1.00 index, meaning that above the line it's no longer economically rational to continue to use more of them. Assuming that all of the options were actually procured, energy consumption for this sample population would have been reduced by almost 26%.

The other lines represent two sensitivity studies, where the discount rate is upped to adjust for investment risk. Using a higher discount rate reduces the number of options that would be employed, and reduces as well the cumulative annual savings resulting from their use. A 7% discount rate, an increase of 133 percentage points compared to the baseline, reduced cumulative savings by 4 percentage points. A 15% discount rate, an increase of 400 percentage points compared to the baseline, reduced cumulative savings by 11 percentage points. This

[16] The basic question regards the arcane economic concept of using the marginal vs. incremental cost when making the investment, words that are sometimes used interchangeably. However, when discussing electric power plants, the incremental cost is the delivered cost of new facilities to the end consumer. The marginal cost only relates to the utility's production cost.

[17] Meier, A; Wright, J; and Rosenfeld A. 1983. *Supplying Energy Through Greater Efficiency.* Berkeley and Los Angeles: University of California Press.

[18] Lusk, P. 1988. *Procuring Energy Efficiency in Public Buildings*. Master's Thesis. Also presented at International Symposium on Energy Options for the Year 2000: Contemporary Concepts in Technology and Policy, Wilmington, DE.

implies an inelastic relationship, at least through the range of discount rates likely to be used by the public sector.

If I were to do a follow-up on this story, I would call it "What Berkshire-Hathaway Saw", and it would be an investigative review of their short-lived nuclear power plant proposed in Idaho and their decision not to go forward with it because of poor economic merit. While Warren Buffett could not figure out how to make a few bucks on this deal in a state well-known for its atomic boosterism , you have to appreciate that his business strategy is based on managing the downside risks of any investment.

"If you take care of the downside risk, the upside benefit will take care of itself" is reportedly a favorite quotation of Mr. Buffet. To point out the downside risk, if we put all of our investment capital and social resources into fully developing the nuclear revival, that investment cannot be made and still fully develop the efficiency and renewable option because those choices will be crowded out of the market.

Substituting taxpayer liability with federal loan guarantees for ratepayer liability is only a transfer of those costs, which is even worse when we make them a contingent liability for future generations. Not only would the investment in nuclear power seem foolish from an investment perspective, one can also point out that forcing the public to invest in the nuclear revival through Construction Work In Progress type surcharges is the fiscal equivalent of reckless conduct on the part of utility commissions. "Reckless" conduct is conduct that exhibits a culpable disregard of foreseeable consequences to others from the act or omission involved, as any first-year law student knows.

With a minimal downside risk, there is a significant opportunity to increase the number of jobs and investments in the United States by using energy more efficiently and substituting cost-effective renewable energy. A new study[19] confirms the current United States renewable energy and energy efficiency industry is substantially larger than previously thought; and some argue the industry is poised to grow into one of the main economic drivers of the 21st century. This study found that by 2030 these industries could generate up to $4.53 trillion in revenue in the US, and create more than 40 million new jobs. To achieve this vision, however, policymakers must be committed to making the transition to a sustainable energy economy a national priority.

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[19] Bezdek, R. 2008. *Renewable Energy and Energy Efficiency: Economic Drivers for the 21st Century*. Management Information Services, Inc. for the American Solar Energy Society.