A COMPARITIVE COST BENEFIT ANALYSIS OF NUCLEAR ELECTRICAL POWER GENERATION FOR COMMERCIAL APPLICATIONS

Cost benefit analyses of nuclear and other power generating technologies for commercial applications have many distinct challenges associated with them that must be evaluated and explained before any meaningful review of options within the industry can be performed.

In an often-cited paper from 1971, Donald E. Watson, M.D. of the Lawrence Livermore Laboratory's Biomedical Division summarized the fundamental challenge as follows: "Since the major benefits of electrical power generation are the same regardless of the ultimate source, comparison of cost-benefit considerations of nuclear and fossil-fueled power plants reduces to a problem of cost comparisons alone. In fact, if there were only one source of energy, cost-benefit analysis would not even be necessary, since the benefits of electrical power production so far outweigh the costs of production, including environmental costs."[1]

Dr. Watson's analysis pre-dated two significant changes in economic, scientific and popular understanding of environmental impacts of electric power production: the growing awareness of the impact of greenhouse gasses on the Earth's climate, and the human and economic costs of nuclear power generation accidents at Three Mile Island and Chernobyl.

In the United States and abroad, the commercial impact of the 1979 Three Mile Island accident on the nuclear industry was profound. In a 2004 Brookings Institution policy brief, Pietro S. Nivola wrote: "Before 1979, it took an average of seven years for plants to go on line. By 1990, the average lag from groundbreaking to operation had reached twelve years. The delays, in turn, have been widely attributed to a ratcheting up of regulatory requirements for health, safety, and environmental reasons following episodes such as the Three Mile Island

(TMI) accident in 1979. One estimate imputed to the post-TMI standards as much as 60 percent of capital costs for plants completed after 1979."[2]

These rising regulatory costs and the related heightened political sensitivities associated with nuclear power led to widespread cancellations of nuclear power plant orders. Nivola explained: "Following Three Mile Island, the building of nuclear plants and fuel production facilities ground to a stop in many countries. The development of nuclear energy is stalled in Germany, Belgium, Holland, Sweden, and Italy. In some of these places — Germany, for instance — the change of heart has come in spite of extant safety regulations that sometimes have required more redundancy and inspections than has been the case in the United States."[3]

The far more environmentally catastrophic 1986 Chernobyl accident in the Soviet Union had an even more far-reaching impact on costs associated with the nuclear industry. "When reactor number four at Chernobyl spewed radiation levels 100 times as strong as Hiroshima's fallout, plans for new plants were shelved across the globe and many politicians, particularly those in Europe, pushed to phase out nuclear power," wrote Lionel Beehner of the Council on Foreign Relations in 2006. "But Chernobyl served as a wakeup call within the nuclear industry, experts say. The World Association of Nuclear Operators was established shortly afterward to serve as the industry's self-policing watchdog and to write confidential safety reviews on nuclear plants. The United States and other Western countries have also spent hundreds of millions of dollars to improve the safety of the dozens of other Chernobyl-era reactors in the former Soviet Union."[4]

As the memories of Three Mile Island and Chernobyl fade, as the world's nuclear power generating facilities are run to more stringent safety standards, and as the need to reduce carbon emissions becomes more urgent, the nuclear power generation industry is experiencing renewed interest—though more so abroad than in the United States to date. There have been a growing number of cost-benefit analyses performed to assess nuclear power both in general terms as a world-wide resource, and for specific national applications. The three recent cost-benefit analyses selected for review in this paper are:

1. “Nuclear Power Generation Cost Benefit Analysis,” Department of Trade and Industry (United Kingdom), 22 February 2007, hereafter referred to as “DTI.”
2. “Cost-Benefit Analysis: Replacing Ontario’s Coal-Fired Electricity Generation,” Ontario Ministry of Energy (Canada), April 2005, hereafter referred to as “OME.”
3. “The New Economics of Nuclear Power,” World Nuclear Association, December 2005, hereafter referred to as “WNA.”

DTI and OME are regionally specific, assessing nuclear power generation options in the United Kingdom and Ontario, respectively. WNA offers a more omnibus approach, creating a comprehensive cost-benefit analysis that incorporates the research and findings from seven subsidiary analyses conducted between 2003 and 2005 in the United States, France, Finland, the United Kingdom and Canada.[5]

These cost-benefit analyses of nuclear power generation can be evaluated using two structural filters: first, the basic steps of a Cost-Benefit Analysis as defined in *Cost Benefit Analysis: Concepts and Practice (Third Edition)* by Anthony E. Boardman, David H. Greenberg, Aidan R. Vining, and David L. Weimer. (Hereafter referred to as BGVW), and second, by comparison to a clear and comprehensive standard list of pertinent costs associated with nuclear power generation that were ably and conveniently summarized by Joseph Gonyeau in his article “Cost Comparison for Nuclear vs. Coal,” from *The Virtual Nuclear Tourist*.

BGVW defined the basic steps of a Cost-Benefit Analysis as follows:

1. Specify the set of alternative projects.
2. Decide whose benefits and costs count (standing).
3. Catalog the impacts and select measurement indicators.
4. Predict the impacts qualitatively over the life of the project.
5. Monetize (attach dollar values to) all impacts.
6. Discount benefits and costs to obtain present values.
7. Compute the net present value of each alternative.
8. Perform sensitivity analysis.
9. Make a recommendation.[6]

Gonyeau defined the key costs that must be considered when evaluating nuclear power generation to other sources as follows:

1. Fuel costs
2. Capital costs
3. Operation and Maintenance costs
4. Waste-related costs
5. Decommissioning Costs[7]

For the most part, all three of the selected cost-benefit analyses adhere to Watson's 1971 dictum that benefits of power generation are equal, regardless of which method is chosen, leaving the key analytical effort to focus on costs associated with various approaches. The one significant difference from this viewpoint is an attempt to value the reduction of carbon emissions and other pollutants as a health and environmental benefit, generally measured by the reduction in fossil fuels consumed in a nuclear power station compared to a conventional gas or coal fired power station.

The following matrix offers an overview of the three analyses when evaluated against the BGVW criteria listed above, noting whether and how each complied with the guidelines.

	DTI	OME	WNA
1. Specify alternatives	Yes: Nuclear vs. a "do nothing" scenario in which needs for new capacity are diverted to gas fired plants in lieu of nuclear plants.	Yes: A status quo base case, an all gas option, an option for replacing gas plants with nuclear, and a "stringent controls" option using existing power stations.	Yes: Looks at comparative costs and benefits for constructing new nuclear, gas and coal fired power plants.
2. Define standing	Yes: Costs to be borne by constructing and operating agent, be it government or private sector, benefits accrue to the operator and to society at large, through estimates of global benefits of reducing carbon emissions. Appears to be UK specific otherwise.	Vague: Not explicitly stated, though the capital costs are generally applied to Ontario Ministry of Energy and Ontario Power Generation, the operating costs will be borne by "ratepayers" and the environmental benefits are generally with regard to Ontario's citizens.	Vague: Due to application of data from multiple nations, unclear exactly how costs and benefits will be borne within the omnibus model used in the final analysis.
3. Catalog impacts	Yes: Reduction in costs of producing electricity, reduction in carbon emissions, reduced likelihood of fuel supply interruptions, offset by possibility of nuclear accidents, which are not quantified, as they are considered to be within the range of sensitivity.	Yes: Air pollution, costs of generating electricity in each scenario, other health impacts on the citizenry including acute premature morbidity associated with accidents, other environmental impacts and damages.	Yes: Focus is less on environmental impacts, more on economic benefits, and world capacity to meet growing energy demands. Varies from others by not factoring in economic benefits of energy security and reduction in global carbon emissions, instead focusing strictly on "nuclear economics examined in isolation."[8]
4. Predict impacts over life of project	Yes: Looks at costs and benefit streams over a 40 year life cycle after completion of a plant.	Yes: looks at costs and benefits streams over a 22 year operating window.	Yes: Looks at expanding world power generation requirements for a 25 year period, and evaluates all three options in light of meeting emergent needs driven by global energy consumption.
5. Monetize impacts	Yes: Extensive analysis of baseline and "do nothing" options, looking at costs from licensing through to decommissioning.	Yes: Offers summary, executive level over-view of projected costs of each impact over the life of the project.	Yes: Uses a baseline built on current operating nuclear power plant capabilities and performance, and assesses the economic ability of each type of new plant to compete in increasingly liberalized international power markets.

	DTI	OME	WNA
6. Discount to obtain present values	Yes: Discounting at the UK Social Time Preference Rate of 3.5% for the first 30 years, and 3.0% thereafter.	Vague: Does not define discount rate, but notes "standard economic principles have been used to derive estimates of the total present value of these costs expressed in 2004."[9]	Yes: Creates its omnibus international standard using various discount rates applied by its subsidiaries for their own national markets. The cited discount rates range from 2.5% to 10.0%
7. Compute net present values	Yes: Calculated for baseline and "do nothing" scenarios over a 40 year life cycle.	Yes: Computes net present value for all four options.	Yes: Computes net present values for all options, and breaks them down in real US$, $Canadian, euros and pounds.
8. Perform sensitivity analysis	Yes: Several analyses included to reflect variations in nuclear and fossil fuel prices, as well as risk aversion factors associated with nuclear accidents.	Yes: Notes that the net economic benefits were most sensitive to social discount rate and economic value placed on preventing premature mortality from air pollution.	Yes: Explains impacts of varying discount rates and capital costs, and notes that nuclear will be competitive as long as overnight capital costs are below $1400/kW.
9. Make a recommendation	Yes: "Nuclear generation is likely to be justified in a world where there is a continued commitment to carbon emissions reduction and gas prices are at or above 37 pence/therm" and "Economic risks associated with keeping the nuclear door open would appear to be limited."[10]	Yes: "The results of this analysis suggest that [the nuclear/gas option] is likely to yield the greatest net benefit of the four parameters analyzed. This conclusion is insensitive to the values assigned to key parameters."[11]	Yes: "New nuclear power plants are robust, secure long-term investments as part of a portfolio of environmentally conscious technologies that make the world less dependent on damaging carbon emissions," and "The economic case favouring new nuclear builds is now virtually universal."[12]

Because all three of these cost-benefit analyses generally follow the Watson criteria of treating the benefits of electricity as equivalent for all options, the emphasis within each analysis is firmly on the life-cycle costs of nuclear generating stations when compared to other alternatives. To compare and contrast these analyses in a meaningful way, it is important to establish whether or not they are all incorporating the same elements of this industrial life cycle, using the Gonyeau criteria defined above. The following table evaluates each analysis against these five cost criteria, explaining whether and how they are incorporated.

	DTI	OME	WNA
1. Fuel Costs	Yes: Notes that the analysis is relatively insensitive to raw costs of uranium, since they are a small portion of the overall costs associated with enriching it to levels needed for power generation applications.	Vague: Uses historic data from the Ministry of Energy and Ontario Power Generation, but does not specifically ad-dress the issue of uranium enrichment, or whether Ontario has the industrial infrastructure needed for enrichment.	Yes: Looks at the full cycle of fuel costs from raw uranium through enrichment, and includes radioactive waste management as part of the cost of using nuclear fuel.
2. Capital Costs	Yes: Notes a high degree of uncertainty in capital costs due to significant variations in construction costs, construction times, and costs of capital. Also includes pre-operational development costs associated with site selection and preparations and licensing.	Yes: Uses historic data provided by the Ministry of Energy and Ontario Power Generation. As noted above, it is unclear whether these costs include any needed capital costs to support uranium enrichment.	Yes: Notes that construction costs in the aftermath of TMI and Chernobyl were high compared to what is possible today. Includes engineering, equipment and labor. Uses "overnight costs," i.e. without interest charges and financing costs.
3. Operations and Maintenance Costs	Yes: Evaluates both system-wide costs per MWh and overall operational costs for a single generating station.	Yes: Uses historic data provided by the Ministry of Energy and Ontario Power Generation. As noted above, it is unclear whether these costs include any needed capital costs to support uranium enrichment.	Yes: Addresses differences in regulatory regime and the efficiency of the plant operator. Notes that the liberalization of power markets has forced increased efficiency among power suppliers on a global basis.
4. Waste-related Costs	Yes: Assumes wastes are stored in a deep geological repository with a long-term cost stream associated with legacy wastes.	Vague: Puts a high level of emphasis and value on reductions in air pollution, but does not specifically address the environmental or financial costs associated with long-term storage of spent nuclear fuel.	Yes: Includes waste disposal as an integral element of the fuel production cycle, as noted above.
5. Decommissioning Costs	Yes: Calculates a cost for decommissioning and decontaminating the site based on varying sizes of power generation stations.	No: Does not include costs associated with decommissioning for any of the options considered. Nuclear decommissioning is dramatically more expensive than it is for a gas-fired plant, so this model likely under-estimates this cost.	Vague: Recognizes need to assess decommissioning costs in the analysis, but several of the subsidiary reports cited do not explicitly include such costs. Not clear what is used in the overall case.

From the standpoint of robust economic analysis, DTI clearly offers the strongest model. While WNA makes its case based on power generation "in isolation," (i.e. absent any stated benefits associated with reducing carbon emissions or ensuring a stable fuel supply), its ambiguity with regard to decommissioning costs would indicate that it may be understating the overall life cycle costs by an equal or greater amount than it is understating benefits associated with reduced carbon emissions. The OME model is the least robust of the three surveyed: it places the heaviest emphasis on the benefits associated with environmental improvements, but potentially understates the costs associated with waste management and decommissioning. Given the high degree of uncertainty associated with these models, the safest and most sound methodology would be to maximize costs and minimize benefits: DTI is the only one the three that takes such a conservative approach to evaluating the net present value of its options.

In presenting their final financial conclusions in summarized numerical formats, each one of these cost-benefit analyses takes a fundamentally different approach to supporting the same overall, consistent conclusion: that nuclear power will be a cost-effective means of meeting regional and global energy requirements through the first half of the 21st Century. Given the different approaches taken and various currencies used in each of the three analyses, there is no simple way to tabulate them in an apples-to-apples fashion. Their bottom line financial conclusions and methodologies, as their authors present them, are each described below, with explanatory remarks and evaluations on each table.

DTI Model: Calculates a nuclear generation welfare balance under alternative gas price, carbon price and nuclear cost scenarios, net present value over forty years in millions of UK pounds per gigawatt capacity, summarized in the following table:[13]

Carbon Price (Euro/ton of CO2	Low Gas Price	Central Gas, High Nuclear	Central Gas Price	Central Gas, Low Nuclear	High Gas Price
0	-2100	-1400	-400	**900**	**1400**
15	-1500	-900	**200**	**1400**	**2000**
25	-1100	-500	**600**	**1800**	**2400**
36	-700	0	**1000**	**2300**	**2800**

Scenarios highlighted in bold in the table above represent cases where DTI believes nuclear is the preferred option. Based on DTI's assumed high-probability outcomes for gas and nuclear fuel prices, they express optimism that the real world scenario over the next 40 years would fall into one of the bold, pro-nuclear outcomes.

OME Model: Calculates a net present value of the total cost of generation for each scenario, with subsidiary reports on financial costs (i.e. the actual physical costs of building and operating plants), costs of health damages and costs of environmental damages, presented in 2004$MCanadian; the table on the following page summarizes results.[14]

	Do Nothing (Keep Current Plants)	New Plants, All Gas	New Plants, Nuclear and Gas	Stringent Controls on Current Plants
Financial Costs	985	2,076	1,529	1,367
Health Costs	3,020	388	365	1,079
Environmental Costs	371	141	48	356
Total Cost of Generation	4,377	2,605	1,942	2,802

OME's model is especially sensitive to the human and environmental costs of its meeting Ontario's power generation requirements. Virtually the entire financial case for doing something other than the “do nothing” scenario hinges on the extremely high health costs associated with continuing to operate the Province’s current power generation stations.

WNA Model: Calculates ranges of net present values of generating costs in US$ per megawatt hour at both five and ten percent discount rates to give a wide range of sensitivities, and to demonstrate that nuclear is the cost preferred option in a variety of scenarios.[15]

	5% Discount Rate	10% Discount Rate
Nuclear	21to 31	30 to 50
Coal	25 to 50	35 to 60
Natural Gas	37 to 60	40 to 63

WNA’s model provides the widest range of options, though its stated conclusions are generally based on the low end of the nuclear ranges in the table above; with a 5% discount rate, there are scenarios where coal would be the cost effective option, and at the 10% discount rate there are scenarios where both coal and natural gas would fare better from a cost benefit analysis standpoint.

Taken in aggregate, these three reports provide a solid body of economic evidence that there may be net social benefits to be gained by an increased use in nuclear power generation over the next 50 years. However, given the complexity associated with nuclear power generation, the severe consequences associated with accidents or weaponization of highly enriched uranium from commercial plants, and the highly toxic and hazardous waste streams that will last longer than the sum total of recorded human history to date, Governments and utilities would be well advised to ensure that their own very specific national or regional needs and opportunities were fully assessed before blindly re-embracing nuclear power as their primary form of electrical generation based on analyses conducted to meet another nation’s needs.

END NOTES

[1] Watson, M.D., Donald E. "Goals of Cost-Benefit Analysis in Electrical Power Generation." University of California, 1971.

[2] Nivola, Pietro S. "The Political Economy of Nuclear Power in the United States." Brookings Institution, 2004.

[3] IBID

[4] Beehner, Lionel. "Chernobyl, Nuclear Power, and Foreign Policy." Council on Foreign Relations Backgrounder, April 25, 2006.

[5] "The New Economics of Nuclear Power." World Nuclear Association, December 2005, pages 24-29.

[6] Boardman, Anthony E., David H. Greenberg, Aidan R. Vining, and David L. Weimer. *Cost Benefit Analysis: Concepts and Practice (Third Edition)*. Pearson/Prentiss Hall, 2006. Pages 7-17.

[7] Gonyeau, Joseph. "Cost Comparison for Nuclear vs. Coal," *The Virtual Nuclear Tourist*, 2006.

[8] "The New Economics of Nuclear Power," World Nuclear Association, December 2005. Page 6.

[9] "Cost-Benefit Analysis: Replacing Ontario's Coal-Fired Electrical Generation," Ontario Ministry of Industry, April 2005. Page 7.

[10] "Nuclear Power Generation Cost Benefit Analysis," UK Department of Trade and Industry, February 22, 2007. Page 6.

[11] "Cost-Benefit Analysis: Replacing Ontario's Coal-Fired Electrical Generation," Ontario Ministry of Industry, April 2005. Page 8.

[12] "The New Economics of Nuclear Power," World Nuclear Association, December 2005. Pages 5 and 22.

[13] "Nuclear Power Generation Cost Benefit Analysis," UK Department of Trade and Industry, February 22, 2007. Page 32.

[14] "Cost-Benefit Analysis: Replacing Ontario's Coal-Fired Electrical Generation," Ontario Ministry of Industry, April 2005. Page 6.

[15] "The New Economics of Nuclear Power," World Nuclear Association, December 2005. Page 20.