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COMPARATIVE COSTS OF ELECTRICITY GENERATION: UPDATE 2000

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ABSTRACT

This paper provides an update to the 1998 NRCan paper "Comparative Costs of Electricity Generation: A Canadian Perspective"; it discusses the key factors impacting on the costs of nuclear, coal and gas-fired electricity and presents results from recent studies. The paper also presents a summary of a recent NRCan study which looks at the potential for nuclear energy in meeting Canada's CO2 emission targets. In light of the increased focus on environmental uncertainties (or externalities) surrounding the various options and the need to treat these in a common and consistent manner the paper examines the impact on comparative LUEC if one were to account for these uncertainties.

Electricity Production in Canada

Canada is fortunate to have a diversified energy base and large hydro resources; hydro accounts for about 60% of our electricity supply; nuclear accounts for about 15% and the remainder is primarily fossil. Fossil fuels, particularly natural gas, have been playing an increasingly important role in our electrical energy mix. The generally held view is that no significant baseload generating capacity is likely to be required until about the year 2010 which means that planning needs to start now for new capacity and decisions will have to be made in the next few years.

The electric power industry is also undergoing fundamental change towards a more competitive, deregulated market. The restructuring of electricity markets is expected to lead to a lowering of retail electricity prices over time, thereby increasing competitive pressures on generators to produce electricity at the lowest possible cost. Thus, when new capacity is required, average production costs per unit will be a significant investment criteria. At the same time, there is increasing concern about the environmental implications of various options and increasing focus on the need to account for environmental uncertainties. This, along with greenhouse gas emissions obligations under the Kyoto Protocol may constrain future generation choices.

Levelized Unit Energy Cost (LUEC) and Different Generating Sources

The Levelized Unit Energy Cost (LUEC) approach to the comparative analysis of the economics of various generating options takes into account the total discounted cost of producing the energy (capital, operating and maintenance and fuel costs) and the total amount of energy produced over the life of the plant, and distributes these costs over the anticipated operating life of the station. This all-in unit cost of producing electricity over the life of a power plant expressed in terms of cents or mills per kWh is one important measure of the relative attractiveness of each investment option.

Using LUEC, one can calculate generating costs over the expected operating lives of new baseload power plants using either established or new technologies. LUEC is also helpful in analysing major capital investments in existing plants to determine whether the plants are financially amenable to refurbishment and life extension. The LUEC methodology enables one to vary capacity factors, operating lives, interest (or discount) rates and other key factors to assess the impact of different assumptions on costs. Changes in fuel, capital and O&M costs also have varying effects on unit costs for different generating options.

While the LUEC approach is extremely useful for comparing various investment options, utilities do not make planning decisions solely on the basis of average unit production costs. LUEC provides only part of the information a utility needs in determining the optimum generating option(s). The utility must do a complete study of its options and the markets in which it operates including, supply-demand balances, price outlooks for fuels, potential timing and impacts of technology improvements, rates of return, payout periods, regulatory costs and other factors.

The fundamentals of nuclear costs have not changed since our 1998 study. Nuclear costs are much more sensitive to the discount rate, capacity utilisation factor and economic life than coal or gas-fired plants. Nuclear electricity costs, like hydro costs, are dominated by capital costs and are very sensitive to the time taken for plant construction, interest rates on borrowed funds, explicit or implicit return on equity, changes to the regulatory regime, and price changes for equipment, material and labour during the construction period. The high up-front capital costs result in greater investment risk if there are construction delays or cost overruns. During periods of low or uncertain load growth, the financial risk may be too substantial to order a large, high cost plant that will only come into service in five to ten years. The high up-front capital cost of hydro and nuclear plants is counter-balanced by the low fuel and water rental costs. Coal and gas-fired plants, which are less expensive to build, carry a higher risk on variable operating costs, such as fuel prices and availability of fuel.

Once built, nuclear plants are in principle relatively immune to inflationary pressures, but their cost efficiency over a 40 year lifetime will depend on their capacity utilization factor. A high level of power output is needed to provide adequate returns on investment. It is for this reason that the nuclear option is particularly suited to meeting base load demand. In many countries, including Canada, the performance record of nuclear power plants has been improving. Nonetheless, any lengthy shutdown, exposes reactor owners to financial exposure not faced by owners of low capital cost stations.

Ways and means of reducing the high investment cost of nuclear is getting considerable attention. A study released in 1999 by the Nuclear Energy Agency entitled "Reduction of Capital Costs of Nuclear Plants" shows that the capital cost of nuclear energy makes up about one half

to 80% of the total cost while for natural gas it ranges from 13% to about 40%. It discusses means to reduce the capital cost of nuclear energy to help keep nuclear competitive relative to natural gas. Table 1 is drawn form the recent NEA study. It shows the impact of a 25% reduction in the capital cost of nuclear and how it compares to coal and gas investment costs.

Table 1: Effects of a 25% Reduction in Specific Capital Cost of Nuclear (Total LUEC - US Mills/kWh (1996)

	5% Discount Rate	10% Discount Rate
Nuclear	21 to 51	32 to 68
Coal	25 to 56	35 to 76
Gas	24 to 79	24 to 84

Atomic Energy of Canada Limited (AECL) is currently working on its next generation product – the CANDU NG – which will benefit from much lower capital and other costs and shorter construction schedules. The costs and schedules of CANDU 6 and CANDU 9 are also benefiting through plant optimization and simplification.

Recent Studies

Canadian utilities, the Canadian National Energy Board (NEB) and Natural Resources Canada (NRCan) make use of LUEC, as do international energy organizations such as the Nuclear Energy Agency (NEA) of the OECD and the International Energy Agency (IEA). We focus on the results of recent LUEC studies by NRCan and the NEA/IEA. The studies differ in their assumptions, their scope, their purpose, the time at which they were done and the timing of the projects they consider. Consequently, they give somewhat different results. Nonetheless, some fundamental common trends emerge from these studies.

NRCan's specific interest in using the methodology is to better understand the factors impacting on costs of baseload generation options available in Canada in the medium term. It has used the model to run Canadian utility and AECL data, run reference cases using NRCan fuel price projections (for gas, coal, nuclear and hydro plants as well as renewable sources of energy) and run sensitivities to determine the impact on all plants of changes to discount rates, capital costs, capacity factor, fuel price and operating life. The NRCan study results at the 5% and 10% real discount rates for gas, coal, nuclear and hydro show that:

- There continue to be strong regional differences in Canada. Fossil-fired generation in western Canada, for instance, have the lowest LUECs.

- At the 5% real discount rate, LUEC for nuclear in Central Canada is lower than that for coal and natural gas.
- Preliminary cost estimates by AECL indicate that the CANDU NG would be competitive with coal and gas even at higher discount rates In Central Canada.

Table 2 presents LUEC data for three different technologies (nuclear (6 and 9), natural gas (combined cycle gas turbine or CCGT) and coal. It is assumed that both fossil stations would be located in Central Canada.

Table 2: LUEC at the 5% and 10% Real Discount Rate (CDN mills/kWh)

Unit Type	O&M	Fuel	Investment	LUEC
CANDU 9 (2x876 MWe)	9.5 (9.5)	3.4 (3.27)	21.1 (42.5)	34.0 (55.3)
CANDU 6 (2x676 MWe)	10.4 (10.4)	3.6 (3.47)	23.3 (47.0)	37.3 (60.9)
CC Gas Turbine (2x750 MWe)	2.7 (2.7))	32.0 (32.0)	11.1 (16.8)	45.8 (51.5)
Coal (4x750 MWe)	5.2 (5.2)	23.0 (23.0)	13.2 (23.8)	41.4 (52.0)

Note: 25 year life assumed for gas units; 85% capacity factor assumed for all units

Sensitivities were run to determine the impact of increases and decreases in capital cost, high and low capacity factors, fuel cost increases and decreases and different economic lives for plants. Nuclear and hydro were more sensitive to capital cost increases, discount rates, capacity factor and plant life than coal or gas, which are more sensitive to the cost of fuel. Lifetime extension impacts more heavily on the capital intensive nuclear plants. Capital cost decreases have a greater impact on LUEC than a lifetime extension for nuclear for a given plant, although in the comparison between existing and new plants, a life extension for an existing plant is generally more economic.

The NEA/IEA work is consistent with Canadian results. Its most recent comparative cost study was issued in 1998. The NEA used data provided by OECD and non-OECD countries and focus on baseload nuclear, fossil, renewable plants and new technologies pertaining to all fuel types; hydro is not considered as its costs tend to be site-specific. There are cost differences between regions and countries with respect to capital, O&M and fuel cost inputs. The studies require participants to use some common economic and technical variables for all types of stations; the 1998 study required participants to provide cost data for a 75% capacity factor, 5 and 10% real discount rates and a 40 year operating life.

The price of fuel is the key determining factor for coal-fired and gas-fired LUEC. Coal prices are expected to be in the $1.00 - $3.20 (U.S.) per GJ range in the year 2005 in OECD and non-OECD countries; the average real price escalation rate is estimated to be 0.3 per cent per annum. Delivered gas costs in the year 2005 are expected to be in the $1.60 US to $5.35 $US/Gjoule range and average real gas prices are expected to increase at about 1% annually over the plant life.

In OECD countries, the construction cost of nuclear plants is in the 1,500$ to 2,500 $US per kilowatt (kWe) while that for coal is in the 1,000$ to 1350$ US per kWe range. Natural gas capital costs are much lower (below 800$ US per kWe in most OECD and non-OECD countries).
The NEA/IEA study results show that the estimated real nuclear LUECs for plants to be in service about ten years down the road from the time of the study remain fairly steady for most countries. Coal-fired electriciy continues to be competitive because of low coal prices. Gas-fired LUECs have declined since the last study due to decreases in the estimated cost of natural gas, making gas-fired generation increasingly competitive. Natural gas LUECs are more competitive in regions or countries with access to large, low-cost natural gas supplies. Natural gas is an attractive near-term option because of low cost, simple construction, maintenance, low fuel cost projections and low environmental emissions relative to coal.

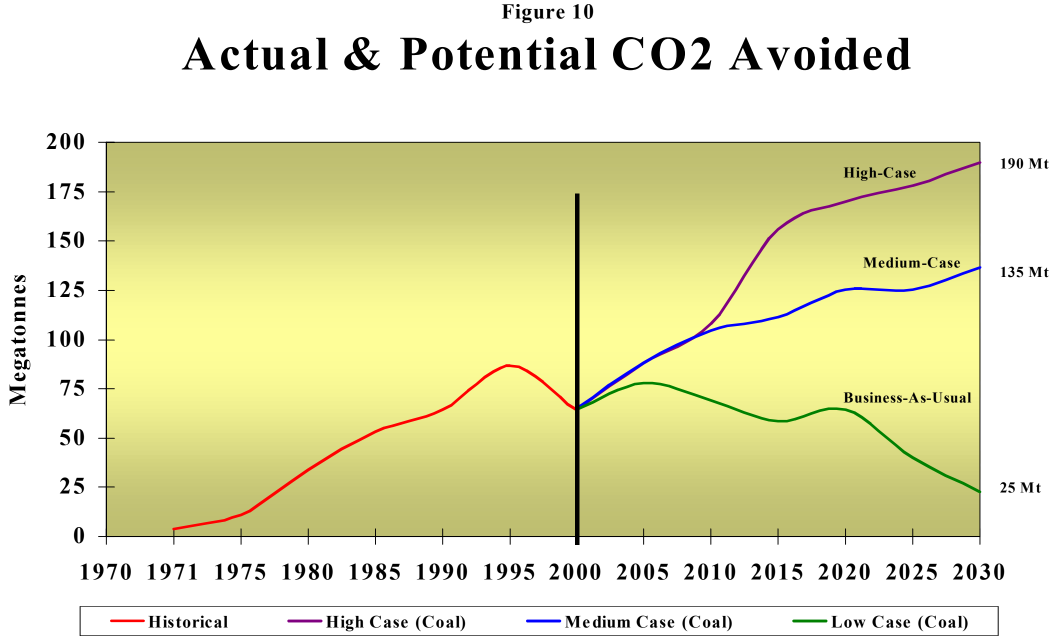
In the OECD study, at the 5 and 10% real discount rates, three countries, France, Japan and Korea, and Central Canada project generating costs lower for nuclear than for gas-fired plants. The LUEC for the CANDU 6 and the 9 are among the lowest in the OECD countries. This is due primarily to the lower fuel costs (no enrichment needed and on-line fuelling). Electricity costs in Canada, particularly gas-fired generation in western Canada, are among the lowest in the OECD countries.)

Avoided Emissions and Accounting for Environmental Costs

Emissions of greenhouse and sulphurous gases from fossil units have not been internalized as a LUEC cost although they are significant. NRCan studies show that nuclear energy has helped reduce electric utility emissions in Canada by about 50% since the first nuclear unit came on line in 1971. In other words, emissions were about 50% lower than they would have been if fossil fuels had been used instead of nuclear generation over the period 1971 to 1999. Over the period 1971-99, electricity generated by Canada's nuclear plants have avoided 1,417.7 million tonnes of carbon dioxide emissions alone.

NRCan has undertaken a separate study to illustrate the potential contribution of nuclear energy to climate change on the basis of three separate nuclear development or growth paths for Canada. The paths, reflecting a low (business as usual case), medium (maintain 18% share) and high case for nuclear growth show differing impacts on emissions. The results of the study are summarized in the Chart above. The results indicate that nuclear power could make a significant impact on emissions from the electricity sector. However, since these emissions only account for 16% of the total, it will be necessary to examine the potential for nuclear in other sectors (eg. Transport) in order to make a real impact on total emissions.

Figure 10



Source: NRCan, Nuclear Division.

Many utilities in North America and in countries of the OECD and international bodies, have begun integrating the costs of many impacts that were previously considered external to arrive at the least cost mix of resources within a sustainable development framework. The nuclear industry believes that it has largely internalized its safety, environmental and waste management costs and that this is reflected primarily in the relatively high capital costs for the stations. In other words, the cost of unaccounted "conventional" externalities are very small due to the large amount of resources devoted to the control of emissions, worker and public safety. At the same time, the debate surrounding the continues surrounding the large uncertainties such as nuclear accidents and how these compare to the health and environmental impacts of fossil fuels.

Valuation of these uncertainties is controversial. While there is no agreement on the monetary value of these externalities, translating them to a common unit for assessment purposes is nevertheless helpful in recognizing, valuating and comparing the impacts of different technologies. We have reviewed a range of studies, including those of the European Commission ExternE studies, which attempt to cost out externality costs for nuclear (which is primarily the cost of a severe accident) and fossil (costs of routine operation of plants on health due to respiratory diseases and particulates and on the environment). We have assumed, for illustrative purposes only and based on our review of studies to date, a conservative externality charge (based on routine plant operation only) of 15CDN mills kWh for coal, of 7.5 mills kWh for natural gas and of 1.5 mills kWh for nuclear. The impact is shown in Tables 3 and 4.

Table 3: LUEC at the 5% Real Discount Rate (CDN mills/kWh)

Unit Type	(5%)	Impact of Externality Charge
CANDU 9 (2x876 MWe)	34.0	35.5
CANDU 6 (2x676 MWe)	37.3	38.5
CC Gas Turbine (2x750 MWe)	45.8	53.3
Coal (4x750 MWe)	41.4	56.4

Note: 25 year life assumed for gas units; 85% capacity factor assumed for all units

Table 4: LUEC at the 10% Real Discount Rate (CDN mills/kWh)

Unit Type	(10%)	Impact of Externality Charge
CANDU 9 (2x876 MWe)	55.3	56.8
CANDU 6 (2x676 MWe)	60.9	61.4
CC Gas Turbine (2x750 MWe)	51.5	59.0
Coal (4x750 MWe)	52.0	67.0

Note: 25 year life assumed for gas units; 85% capacity factor assumed for all units

Outlook, Uncertainty and Externalities

What can these ongoing studies of LUEC tell us about future prospects for the nuclear industry in Canada and around the world?

Nuclear energy is holding its own in terms of absolute costs but the high capital cost remains a significant challenge. Lowering the impact of the investment costs, enhancing the economic life and performance will increase the relative attractiveness of the nuclear option. And with the current work that AECL is undertaking to lower capital costs and reduce construction schedules, nuclear power will become even more competitive for future CANDU designs such as the CANDU NG.

Coal and especially natural gas fired generation are still much more competitive at higher discount rates. In the case of coal this is largely due to the reduced cost of the fuel itself. In the case of natural gas, it is due to a combination of reductions in the cost of natural gas and of the escalation rate for those costs, and also to the lower cost and improved efficiency of the technology for generating electricity from gas, along with heat in some cases. Since our 1998 update, the cost of natural gas has actually increased by about 25% although the real price of the fuel is expected to remain flat over the next 20 years.

LUEC estimates help shed light on real world experiences. While they cannot predict what will happen in the real world, they can help decision-makers and planners understand the ramifications of business decisions they make. For example, you can be assured that significant delay in nuclear plant construction will incur massive capital cost overruns which in turn impact on the average cost of electricity and rates charged to consumers.

There are other limitations to the LUEC methodology in its inability to take into account the full costs and benefits of the options, many of which are difficult to quantify and estimate on a per kilowatt hour basis. For example, studies have not included federal government R&D infrastructure costs (these are minute on an LUEC basis), broader macroeconomic factors such as indirect impact on employment and, as previously noted, environmental externalities, such the contribution to climate change from the burning of fossil fuels.

CONCLUSIONS

The cost of generating electricity will be even more critical factor in the decision-making process for electric power utilities in the years ahead as plans for new capacity are made under the pressures of a more competitive, deregulated market. Technologies with low capital, fuel and operating costs, short construction schedules, capacity closely matched to load growth and minimal regulatory/public acceptance problems are generally more attractive.

From a cost perspective, the challenge for the nuclear industry in Canada is to ensure, in the short to medium term, that the existing plants at a minimum reach their full operating life,and that they operate consistently at high capacity factors. In the longer term, improvements which lower the capital costs of new nuclear plants, decrease construction times and increase capacity utilisation factors will enhance the competitiveness of the nuclear option.

As the LUEC studies show, natural gas plants require ready access to low-cost supply of natural gas in order to compete. In areas with access to large supplies of low cost natural gas, it is therefore quite likely that natural gas turbines will be chosen, perhaps in combined cycles, for the next round of capacity increases in order to minimize financial risks. Gas turbine plants are relatively quick to build, have a low capital cost and high thermal efficiency and can be written off over shorter periods of time. There is now a general expectation that natural gas's contribution to electricity supplies will increase in Canada and other OECD countries.

While natural gas plants are attractive, access to the fuel, the potential escalation of natural gas market prices due to geopolitical and other events, the release of methane into the atmosphere during extraction and transmission are additional factors to consider. Even though it is too early to evaluate the impact of the Kyoto Protocol, it is possible that it will drive up natural gas as well as coal LUECs.

Developing a solid public understanding of the risks (uncertainties) and the benefits of the various energy options will become an increasingly greater challenge in the years ahead as utilities start planning for new generation facilities. Translating the uncertainties associated with the various technologies into a common unit for assessment purposes will be helpful in recognizing, valuating and comparing the impacts of different technologies.