Maintaining Flexibility: Ontario's Electricity Supply Gap and Implications for the Supply Mix

For Ontario Power Authority's Call for Submissions in Response to the Minister's Request for Advice on the Electricity Supply Mix

Executive Summary

In July 2005, the Ontario Power Authority (OPA) solicited public comment on the supply mix of Ontario's electricity generation resources with particular attention to baseload, intermediate, and peaking availability of energy. In response, Atomic Energy of Canada Limited (AECL) has conducted a 20-year, deterministic analysis of the demand for, and supply of, electricity in Ontario using techniques and data from the Independent Electricity System Operator and other third parties.

When considering the potential of new supply resources, the analysis assumes that large amounts of hydroelectric, wind, and gas-fired generation would be implemented in the next 5 to 10 years, itself an undertaking without precedent in Ontario. The analysis assumes more than 1,400 MW of new small hydro development within Ontario to supplement large, inter-provincial supplies. An additional 1,000 MW of wind generation, almost triple the amount put under contract by Ontario's Renewables I RFP, were also assumed. Assumptions of large amounts of new cogeneration (1,000 MW) and new gas-fired peaking supplies contribute to an aggressive and challenging program for new supply sources.

AECL also assumed a substantial refurbishment program for Ontario's 30-year old CANDU fleet. By the end of the study period in 2025, the majority of Ontario's 20 reactors are assumed to be refurbished and placed back into service.

Even with these new sources of supply, the analysis indicates that a gap between Ontario's electricity demand and its supply resources opens by 2014-2015 and widens dramatically through 2025. This gap is dominated by a shortfall in baseload resources (~5,700 MW by 2025) with some peaking resources (~1,200 MW) required to meet annual peak demands. The baseload gap alone constitutes 7% of Ontario's supply mix in 2015, growing to 14% by 2025.

An assessment of candidate supply technologies for filling this baseload gap was conducted against criteria that included cost, diversity-of-supply, and availability. In a particular comparison between new nuclear generation and combined cycle gas turbines, the cost and diversity-of-supply benefits of nuclear power over gas-fired generation were evident. By 2010, the analysis indicates that gas-fired generation will grow to 31% of the supply mix from its current level of 16%. Using additional gas-fired generation to fill the emerging baseload gap will create an over-reliance on the supply of natural gas and expose Ontario's electricity ratepayers to the volatile and rising prices of this widely used fuel. In contrast, filling the 5,700 MW of baseload gap with new nuclear generation will return the nuclear share of the mix to its historical level at lower costs and, if implemented with AECL's CANDU technology, with greater economic benefit to Ontario.

Third party comparisons of the environmental impact of supply technologies further reinforce the role of new nuclear in filling the 5,700 MW shortfall in Ontario's baseload

supply. Compared with gas-fired generation, more than 800 million tonnes of CO_2 equivalent can be avoided in the first 30 years of operation of the CANDU plants. Aside from assisting Canada to meet its Kyoto Protocol obligations, such massive emission reductions could widen the cost advantage of new nuclear generation over an equivalent amount of gas-fired resources.

Although new nuclear power generation will minimize electricity costs and price volatility, increase the diversity of fuel supply, and lower environmental impacts, the assessment acknowledges a 9- to 10-year period to plan, approve and construct a new CANDU plant. A foreign reactor technology, on the other hand, is likely to undergo a more protracted and uncertain licensing process due to unfamiliarity of Canada's licensing body with the technology.

To maintain the *option* of beginning plant construction in 2009 (to meet the 2014/2015 shortfall in baseload supply), decision-makers are advised of the urgency to initiate an environmental assessment for construction of a new CANDU nuclear plant.

Maintaining the option to construct new nuclear generating plants will ensure that Ontario's citizens and industries enjoy an inexpensive, secure, and environmentally friendly supply of electricity far into the future.

Introduction and Scope

In its July 4th Call for Submissions, the OPA invited comments on the Minister's specific requests and on four "issue areas". Within this suggested framework, AECL has addressed the Ministers request for:

> "Recommendations with respect to the appropriate mix of electricity supply sources to satisfy the remaining expected demand in Ontario, after conservation and renewable sources have been taken into account, and with particular attention to baseload, intermediate and peak availability of energy"[1]

In this submission, AECL has also addressed two of the issue areas identified in the OPA Call for Submissions:

- Assessment of different supply technologies, and
- Appropriate methods to assess the impact of the supply options on the natural environment.

In the recent past, Ontario's mix of electricity supply resources has provided it's residents and businesses with reliable, low cost electricity. This has been a competitive advantage for Ontario over neighboring jurisdictions for attracting investment. However, the confluence of four factors has resulted in a need for new generation in the province:

- Growth in electricity consumption,
- A dearth of investment in new generation over the last two decades,
- Normal aging of Ontario's existing resources, and

[1] Letter from Energy Minister Dwight Duncan to the Ontario Power Authority, May 2, 2005.

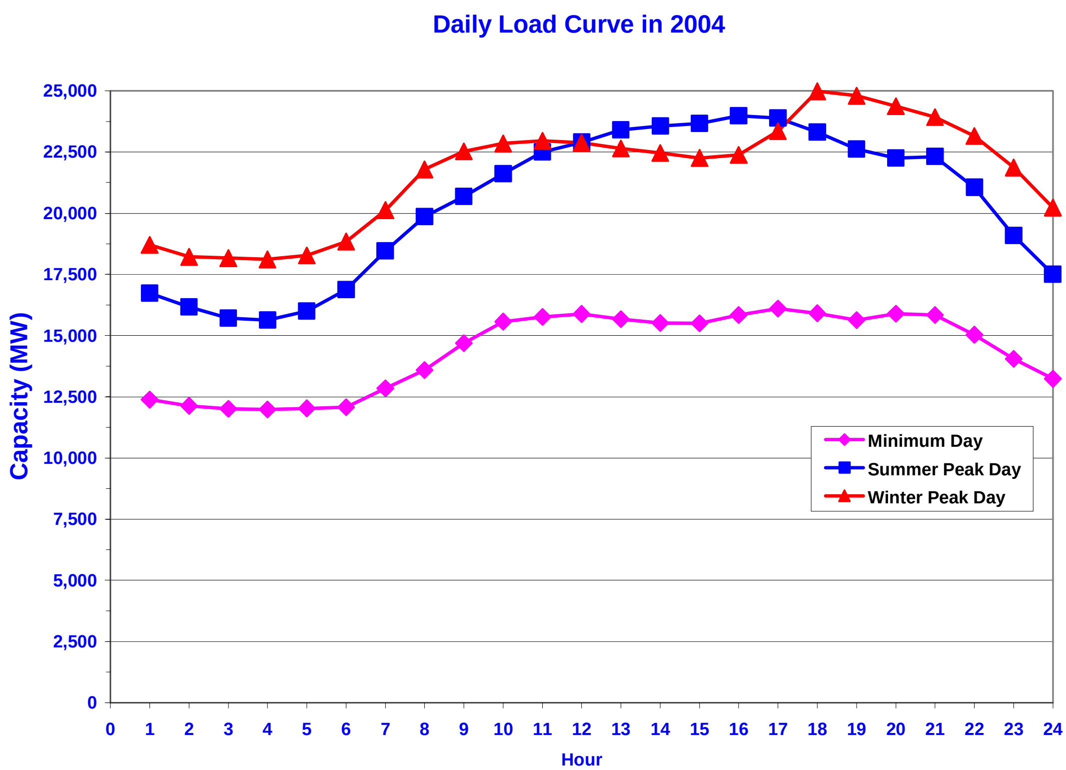
- o A government initiative to improve air quality by phasing out coal-fired generation in Ontario.

It is this need for new sources of generation that raises the question "What should Ontario's future mix of electricity supply be?" To better understand the range of possibilities for Ontario's supply mix, one must consider the future gap between electricity supply and demand while distinguishing between peak and non-peak demand.

The Need for Electricity Generation: a Baseload Perspective

The demand for electricity in Ontario varies from season to season, by the time of day, and by day of the week. This is evident in the daily demand curves presented[2] in Figure 1. This figure also illustrates the baseload, intermediate and peak demand experienced during the day; the lowest point on each curve representing the baseload demand for that day. In the morning hours (hours 6 to 9), intermediate demand begins and persists throughout the day until demand begins to drop off later in the day. The peak periods typically occur around the late afternoon (hour 16 to 20). Figure 1 also illustrates that baseload demand can vary by 2,500 MW between winter and summer periods.

Figure 1 – Daily Electricity Demand in Ontario



Source: Acres Management Consulting Limited

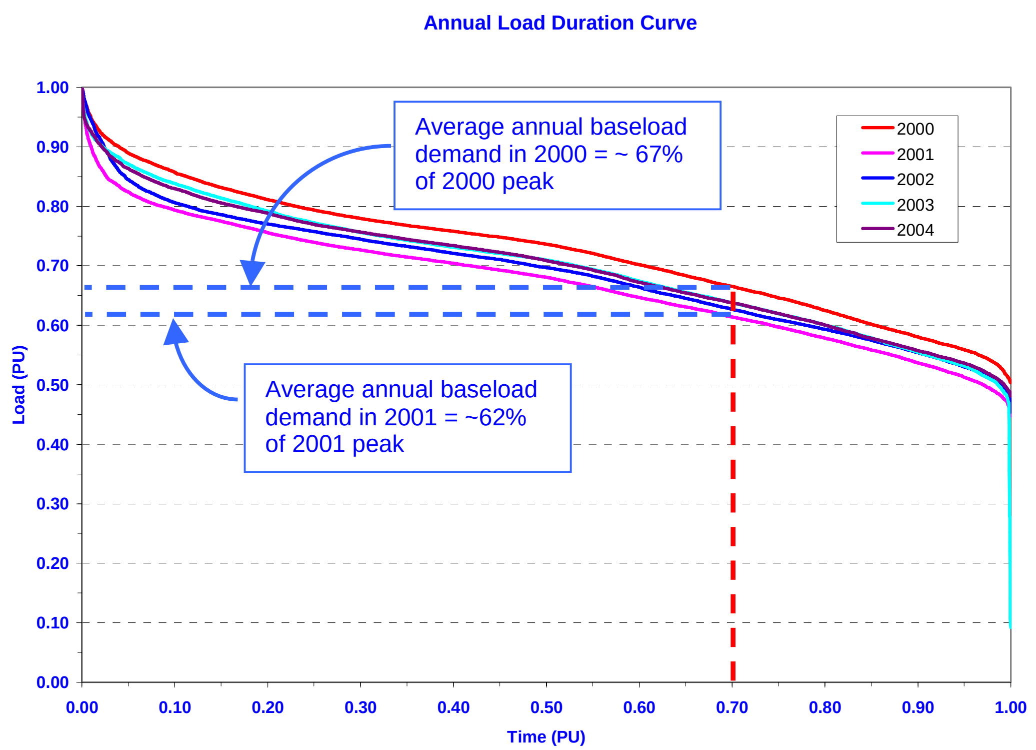
[2] To assist in its analysis of Ontario's baseload supply and demand, AECL retained Acres Management Consulting Limited, a firm with extensive domestic and international experience in power system planning. The planning presented in this paper is a simplified "deterministic" model intended to show broad trends.

The central importance of baseload demand is also apparent from the daily demand curves above. As the level of demand that exists "around the clock", baseload demand provides the foundation of the system and is preferably met by the least cost sources of generation.

Determining A Baseload Demand for Planning

Since the minimum daily demand fluctuates considerably from season to season, planning for baseload requires a manageable number of demand targets against which planned generating resources can be compared for many years into the future. A common definition of baseload is "the demand that exists at least 70% of the time"[3]. To determine this baseload target requires the development of "load duration curves", which plot the power demand against the number of hours in which the demand was equal to or greater than that level of demand. To enable comparison across years with different peak demands, planners utilize "Proportional Units" (PU) where demand is expressed as a proportion of the peak and duration is expressed as a proportion of the total time. Load Duration Curves for Ontario for the period 2000 to 2004 appear in Figure 2, below. In the figure below, one can see that the baseload demand in 2001 was approximately 62% of the peak while in 2000, the baseload was approximately 67% of the peak for that year, illustrating the variability introduced by weather and economic activity.

Figure 2 – Annual Load Duration Curves for Ontario, 2000 to 2004



Source: Graph by Acres Management Consulting Limited

[3] For example, this definition of baseload was utilized in the last long-term plan for Ontario's electricity supply; *Providing the Balance of Power*, issued in 1989 by Ontario Hydro. See pp. A-9.

An examination of the seasonal differences between load duration curves led to the selection of two baseload demand targets for each year; one for each of the winter and summer seasons:

- A summer baseload demand equal to 61.7% of the annual peak, and
- A winter baseload demand equal to 68.2% of the annual peak.

These targets can then be plotted against the forecast annual peaks to provide an upper and lower bound for the baseload demand of that year.

Providing for Reserves

An important component of any electricity supply system is the availability of resources held in reserve. At demand levels near the annual peak, the reserve resources are "standing by", ready to be pressed into service if a generator is forced offline by an unforeseen event at the station or along the transmission line that connects it to the grid. The level of reserve is established probabilistically to meet system reliability goals and is typically ~15% of the peak demand. In addition to these operating reserves, an additional reserve is required for regular planned maintenance of generating stations, de-ratings due to environmental conditions, or other planned events that prevent generators from servicing a load. Typically, about 10% of the installed resources are not available during the time of peak demand. One notable exception is the treatment of wind generation where the assumption of Ontario's Independent Electricity System Operator (IESO) was adopted; at the time of the peak demand, 10% of the installed capacity would be available[4].

When servicing a baseload demand, resources designed to serve intermediate and peaking loads can be brought on line in the event of a baseload generator going offline unexpectedly. Therefore, only "maintenance reserves" need be accommodated for baseload. For these reserves, AECL has assumed a reserve of 881 MW during the winter (i.e., allowing the equivalent of one reactor at Darlington Generating Station (GS) to be in planned maintenance during winter) and 1,360 MW during the summer (i.e., allowing one reactor at Bruce GS and one reactor at Pickering GS to be in planned maintenance during the summer). This is an illustrative scenario only; station operators will schedule actual maintenance outages based on many factors.

Installed Capacity Targets to Serve Peak and Baseload Demand

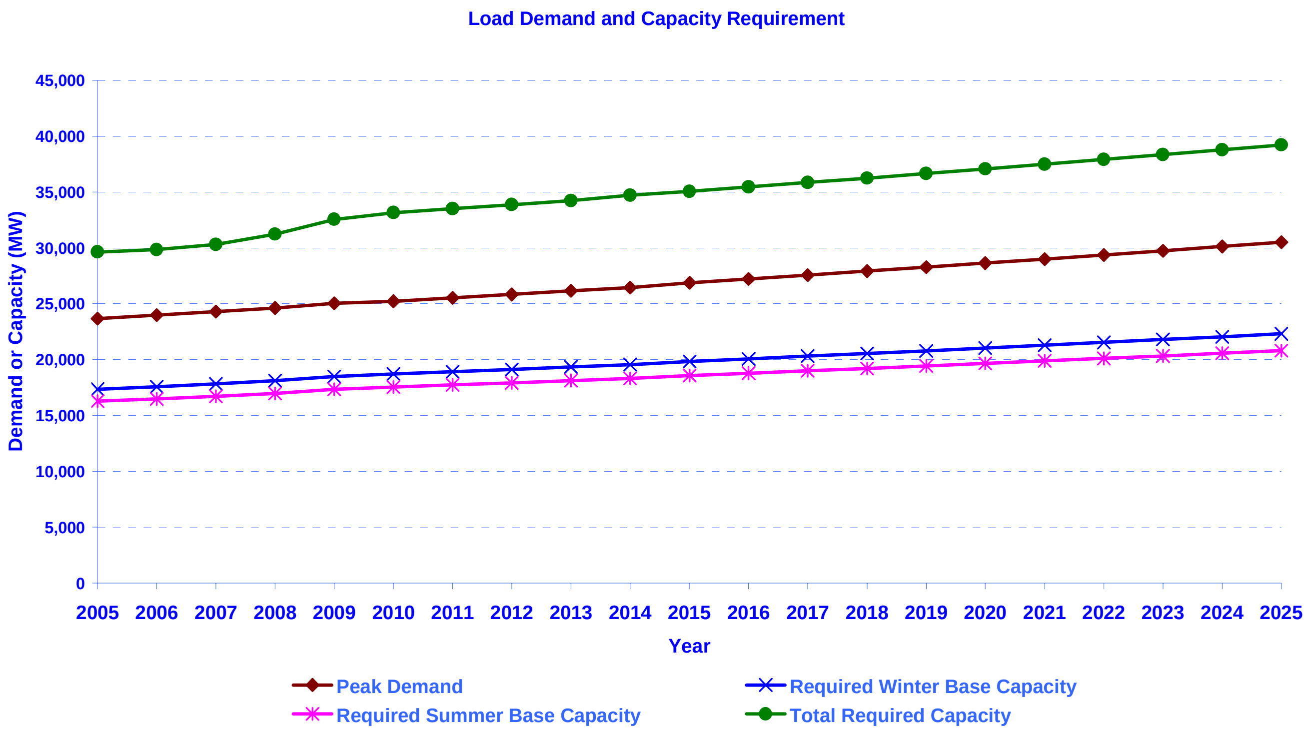
The preceding approach requires a forecast of the peak annual demand over the planning period. The IESO publishes an annual 10-year forecast of demand, the latest[5] of which forecasts peak demand under various growth and weather scenarios. For this analysis, AECL has selected the median growth, normal weather forecast of peak demand. The annual summer peak demand[6] during the period 2006 to 2015 begins at 23,991 MW in 2006 and increases steadily to 26,874 MW in 2015, an average annual

---

[4] IESO's *An Assessment of the Adequacy of Generation and Transmission Facilities to Meet Future Electricity Needs in Ontario From January 2006 to December 2015* (V2) published on August 15, 2005 is available from the IESO website at www.ieso.ca. See page 7 of 76.
[5] IESO's *Ontario Demand Forecast From January 2006 to December 2015* was issued on July 8, 2005 and is available from the IESO website at www.ieso.ca.
[6] Ibid. see Table 4.4 on page 27 of 38.

growth rate of 1.3%. This growth rate was used to extrapolate the annual peak demand for an additional 10 years to encompass the timeframes to plan and implement major power projects. The resulting forecast of peak demand was then utilized to generate Figure 3, a forecast of the total installed capacity required to meet the peak (including operating reserves averaging 14.7% and maintenance reserves) and the installed capacity required to meet the summer and winter baseload demands in each year.

Figure 3 – Peak and Baseload Installed Capacity Requirements



Conservation

The Ontario government has initiated a number of programs to foster a "culture of conservation" in the province. When speaking of "conservation", it is important to distinguish between load shifting and reductions in total electrical energy consumption.

Load shifting initiatives seek to modify consumer behaviour to use electricity during off-peak hours rather than during peak hours, thus avoiding the need to build generation capacity that serves only peak load. Examples of load shifting initiatives are:

- Time-of-day metering, where consumers are charged higher prices during peak periods, motivating them to reduce demand (e.g., by running major appliances in the late evening), and
- Price Sensitive Demand, whereby large industrial users that pay market prices enter contracts to curtail their demand when electricity prices reach a threshold. For some firms, high electricity prices means their marginal costs exceed the prices for their products.

While successful load shifting initiatives reduce the need for peaking resources, they have negligible effect on baseload demand (intuitively, load shifting may actually increase baseload demand slightly).

Reduction of total electrical energy consumption, by technological innovation or other means, can reduce both peak and baseload demand, depending upon the appliance or equipment load. Implementing conservation of this type is typically a slow process, since electricity consumers would normally upgrade their equipment or appliances only at the end of its useful life.

Assumed Resources to Meet Baseload and Peak Demand

Types of Generating Assets

Assessing the adequacy of electricity supply resources by service type requires an allocation of existing and future resources to baseload, intermediate, and/or peak service. Ontario currently has a broad range of resource types at its disposal to serve these different types of demand. The allocation[7] of these resources appears in Figure 4, below.

Figure 4 – Types of Generating Resources in Ontario

Resource Type	Dispatchable?	Typically servicing …		
		Baseload	Inter-mediate	Peaking
Hydroelectric (run-of-river)	Yes	√	√	√
Hydroelectric (w. storage)	Yes		√	√
Gas – Simple Cycle	Yes			√
Gas – Combined Cycle	Yes	√	√	
Gas – Cogeneration	Limited[8]	√		
Coal	Yes	√	√ [9]	
Nuclear	Yes	√	√ [10]	
Wind	No	√		
Wood waste	Limited[11]	√	√	

Source: AECL staff

[7] AECL was assisted in this allocation by Acres Management Consulting Limited

[8] The operation of cogeneration installations (also known as Combined Heat and Power) is typically governed by the need to provide steam to an industrial "steam host" and, as such, cogeneration is a "price taker" in the marketplace.

[9] While coal-fired generation is utilized for baseload service in many jurisdictions, Ontario's coal-fired stations have serviced mostly intermediate demand due to voluntary emission restrictions adopted by the operator.

[10] Although nuclear generation is typically regarded as a baseload technology, new designs (including those by AECL) incorporate the ability to "load follow", allowing them to increase output to service intermediate demand when called upon.

[11] Same as cogeneration. See Note 9.

Resource Assumptions

AECL has adopted, as a starting point, the resource assumptions of the IESO's "Coal Replacement Scenario" in their latest 10-year forecast[12]. The IESO begins with existing installed resources in 2005, as listed in Figure 5, below.

Figure 5 – Existing Installed Generation Resources per IESO

Resource Type	Total, MW	Percentage of Total, %	# of Stations
Nuclear	10,882	36.1	5
Coal	6,434	21.4	4
Oil / Gas	4,976	16.5	20
Hydroelectric	7,756	25.8	67
Miscellaneous	66	0.2	2
Total	30,114	100.0	98

Source: IESO 10-year outlook, August 15, 2005. Table 2.1

Except as noted below, all of the resources in Figure 5 are assumed to be in service throughout the 20-year study period.

Ontario's existing hydroelectric stations provide a great deal of flexibility to system operators to service baseload, intermediate and peaking demand. To determine the amount of hydroelectric capacity available to serve baseload, AECL commissioned a plant-by-plant review of operational data and assumed the allocation in Figure 6, below. The baseload contribution of each baseload plant was determined by multiplying the capacity factor by the nameplate capacity of the plant.

A similar exercise was conducted for Ontario's existing gas fired and cogeneration plants with the result also tabulated in Figure 6.

Figure 6 – Assumed Service Duty for Ontario's Existing Hydroelectric and Gas-fired Generating Resources

	Hydroelectric Resources	Oil/Gas-fired or Cogen Resources
Contribution to Baseload Demand	3,424 MW[13]	595 MW
Contribution to Intermediate/Peaking Demand	3,299 MW	3,588 MW
De-ratings (e.g., due to water/head constraints)	1,033 MW	793 MW
Total Existing Installed Resources	7,756 MW	4,976 MW

Source: AECL staff

[12] *op. cit*., see footnote 4.

[13] The construction of the Niagara Tunnel (completion before 2010 peak) will increase the baseload contribution of the Sir Adam Beck Generating station by approximately 200 MW by raising its capacity factor. See AECL Supplementary Assumptions – Large Hydroelectric Resource Development Assumptions

Like that of the IESO, AECL's analysis also assumes that committed and contracted generation resource additions will come into service on the dates indicated in Figure 7.

Figure 7 – Committed and Contracted Generation Resource Additions and Demand Side Projects per IESO

Project	Zone	Fuel Type	Installed Capacity MW	Connection Applicant's Estimated I/S Date
Pickering Unit 1	Toronto	Uranium	515	2005-Q3
Greater Toronto Airports Authority	Toronto	Gas	117	2005-Q4
Kingsbridge Wind Power Project	Southwest	Wind	40	2005-Q4
Melancthon Grey Wind Project	Southwest	Wind	68	2005-Q4
Prince Wind Farm	Northeast	Wind	99	2006-Q1
Erie Shores Wind Farm	Southwest	Wind	99	2006-Q2
Loblaws Properties	distributed	Demand	10	2006-Q2
Blue Highlands Wind Farm	Southwest	Wind	50	2006-Q3
Umbata Falls Hydroelectric	Northwest	Water	23	2007-Q1
Greenfield South Power Project	Toronto	Gas	284	2007-Q4
Greenfield Energy Centre	West	Gas	1,015	2007-Q4
St. Clair Power	West	Gas	688	2008-Q1
Greenfield North Power Project	Toronto	Gas	330	2009-Q2
Total			3,338	

Source: IESO 10-year outlook, August 15, 2005. Table 2.2

In this analysis, AECL has adopted all of the IESO assumptions associated with the Coal Replacement Scenario:

- Lambton and Atikokan units will be removed from service at the end of 2007,
- Coal-fired generation at Thunder Bay will be replaced with cleaner generation by the end of 2007. AECL assumed that the 310 MW station will be converted to natural gas in time for the 2009 peak and will be servicing intermediate demand loads,
- Bruce A Unit 3 will be removed from service at the end of 2009 (see also AECL's Supplementary Assumptions below),
- Pickering B Units 5,6, and 7 will be removed from service at the beginning of 2014 (see also AECL's supplementary assumptions below),
- Bruce Unit 6 will be removed from service in 2015 (assumed to come out of service before the 2015 peak, see also AECL's Supplementary Assumptions below),
- No price responsive demand beyond the 10 MW shown in Figure 7 was assumed until 2009 when an additional 250 MW of demand side measures are assumed to be implemented,
- Wind generation is assumed to provide a capacity contribution of 10% at the time of the annual peak (AECL has modeled this assumption by placing 90% of the wind capacity into the peak reserve),
- The second renewables RFP attracts 1,000 MW of wind generation, in service by 2009,
- Bruce GS Units 1 and 2 return to service in 2009,
- Additional power is procured for downtown Toronto (500 MW) and western GTA (1,000 MW) before the end of 2008. AECL assumed that

this capacity would be implemented with gas-fired generation serving an intermediate load.

- Cogeneration amounting to 1,000 MW is assumed to come into service in 2008. AECL assumed an average capacity factor of 60% for this generation which would translate into 600 MW of additional baseload contribution and 400 MW of intermediate demand service,
- Potential hydroelectric development of 380 MW is assumed to come into service starting in 2009 (additional small hydro development was assumed by AECL, see also AECL's Supplementary Assumptions below), and
- Nanticoke GS as assumed to be shut down over the period 2008 to 2009. AECL assumes it is taken out of service before the 2009 annual peak.

AECL's Supplementary Assumptions

For its analysis of baseload and peaking generation adequacy, AECL has adopted supplementary assumptions for conservatism, and in consideration of the 20-year timeframe of its analysis, especially regarding nuclear refurbishments and hydroelectric developments.

Nuclear Refurbishment Assumptions

A 20-year analysis must consider ageing of Ontario's nuclear fleet beyond the assumptions adopted by the IESO. AECL's assumptions regarding the retiring or refurbishment of Ontario's 20 reactors appear in Figure 8, together with the assumed return-to-service date, if applicable. The refurbishment assumptions are presented as an illustrative scenario only and are not intended to reflect the actual or forecast condition of the units. Refurbishment decisions are the responsibility of the unit owner/operator and will depend upon many factors including market conditions and the actual condition of the unit.

Figure 8 – AECL Supplementary Assumptions Regarding Refurbishment of Nuclear Resources

N.B. – The dates below are presented for illustrative purposes only and are not intended to reflect the actual or forecast condition of the units. Refurbishment decisions are the responsibility of the unit owner/operator.

Unit	Out-of Service	Returned to Service
Bruce Unit 1	n/a	2009 per IESO
Bruce Unit 2	n/a	2009 per IESO
Bruce Unit 3	2010 per IESO	2012
Bruce Unit 4	2016	2018
Bruce Unit 5	2015	2016
Bruce Unit 6	2016	2018
Bruce Unit 7	2017	2019
Bruce Unit 8	2019	2020
Pickering Unit 1	2017	n/a
Pickering Unit 2	Not in service throughout period	
Pickering Unit 3	Not in service throughout period	
Pickering Unit 4	2025	n/a
Pickering Unit 5,6,7	2014 per IESO	not refurbished
Pickering Unit 8	2019	not refurbished
Darlington Unit 1	2020	2022
Darlington Unit 2	2021	2023
Darlington Unit 3	2022	2024
Darlington Unit 4	2023	2025

Source: AECL staff

Small Hydroelectric Resource Development Assumptions

The latest IESO forecast ("Coal Replacement Scenario") contemplates that an additional 380 MW of unidentified hydroelectric generation development is placed into service in 2009. While there is much debate around the amount of untapped hydroelectric development within Ontario, AECL assumed an additional 1,000 MW of small, run-of-river hydro development and further assumed that these resources come into service in 2010, bringing the total new small hydro to 1,403 MW (including the 23 MW Umbata project identified in Figure 7). Each of these run-of-river developments is assumed to contribute, on average, 50% of its capacity to baseload demand.

When combined with the 1,356 MW of new wind capacity forecast by the IESO, these new hydroelectric developments would bring Ontario's total portfolio of new renewable and new small hydro capacity to 2,759 MW, assisting the government to achieve its Renewable Portfolio Standard target[14] of 2,700 MW by 2010.

[14] Details of the Ministry of Energy's Renewable Portfolio Standard target may be found at http://www.energy.gov.on.ca/index.cfm?fuseaction=english.renewable

Large Hydroelectric Resource Developments Assumptions

Two noteworthy hydroelectric projects have the potential to impact a 20-year analysis of Ontario's electricity supply; the 1,380 MW Conawapa development in Manitoba and Ontario's 945 MW share of its Lower Churchill development proposal in Labrador. Also, the construction of the Niagara Tunnel will impact the baseload contribution of the Sir Adam Beck generating station at Niagara Falls.

For this analysis, AECL has assumed that the Conawapa project will be implemented in time to serve the 2017 peak, consistent with public pronouncements by Manitoba Hydro[15]. AECL assumed that Conawapa would be operated in a "5-16" mode (i.e., 16 hours per day, 5 days per week) resulting in 20% of its capacity serving baseload demand in Ontario.

The Lower Churchill opportunity[16] consists of a 2,000 MW development at Gull Island and an 824 MW project at Muskrat Falls. These projects will operate essentially in a "run-of-river" mode at approximately 67% capacity factor. After accounting for the share of other partners in the project, the Lower Churchill Project could provide Ontario with approximately 635 MW of baseload service capacity. However, given the transmission infrastructure issues and a need to negotiate complex "wheeling" agreements between provincial governments, AECL's analysis assumes that the Lower Churchill project in Labrador will not come into service prior to the 2025 peak.

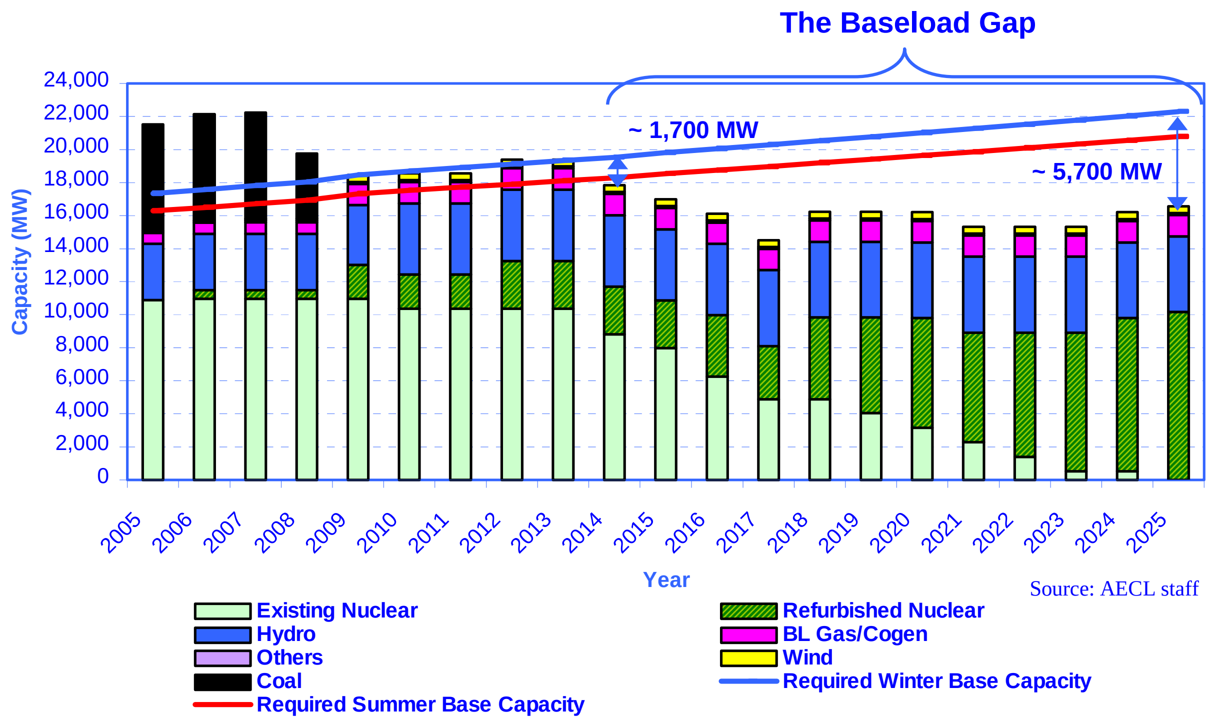
The Niagara Tunnel project[17] at the Sir Adam Beck Generating Station in Niagara Falls is designed to deliver more water to the turbines rather than increase the stations power capacity (which would require the installation of more or larger turbines). Thus, after the tunnel is completed (assumed prior to the 2010 annual peak), this run-of-river station will experience a higher capacity factor, a larger proportional contribution to baseload demand, and a reduction in the station de-rating. This has been implemented in the analysis by increasing the baseload contribution from existing hydroelectric resources by 200 MW in 2010 with an equivalent reduction in the station de-rating. The Niagara Tunnel project will have no effect on the ability of Ontario's electricity system to meet peak demand, however.

Comparison of Supply and Demand – The Baseload and Peak Gaps

The baseload demand and baseload supply assumptions above illustrate the magnitude and timing of the baseload gap in Ontario's electricity system as presented in Figure 9. The analysis indicates a baseload gap of ~1,700 MW in 2014 growing to 5,700 MW by 2025.

[15] Information on the Conawapa project, including in-service dates may be found on Manitoba Hydro's website at http://www.hydro.mb.ca/issues/transmission_projects/transmission_projects.shtml#conawapa
[16] For a technical description of the project, see http://www.gov.nl.ca/lowerchurchill/pdf/exphydro.pdf
[17] For additional information on the Niagara Tunnel Project see http://www.opg.com/ops/niagaratunnel.asp.

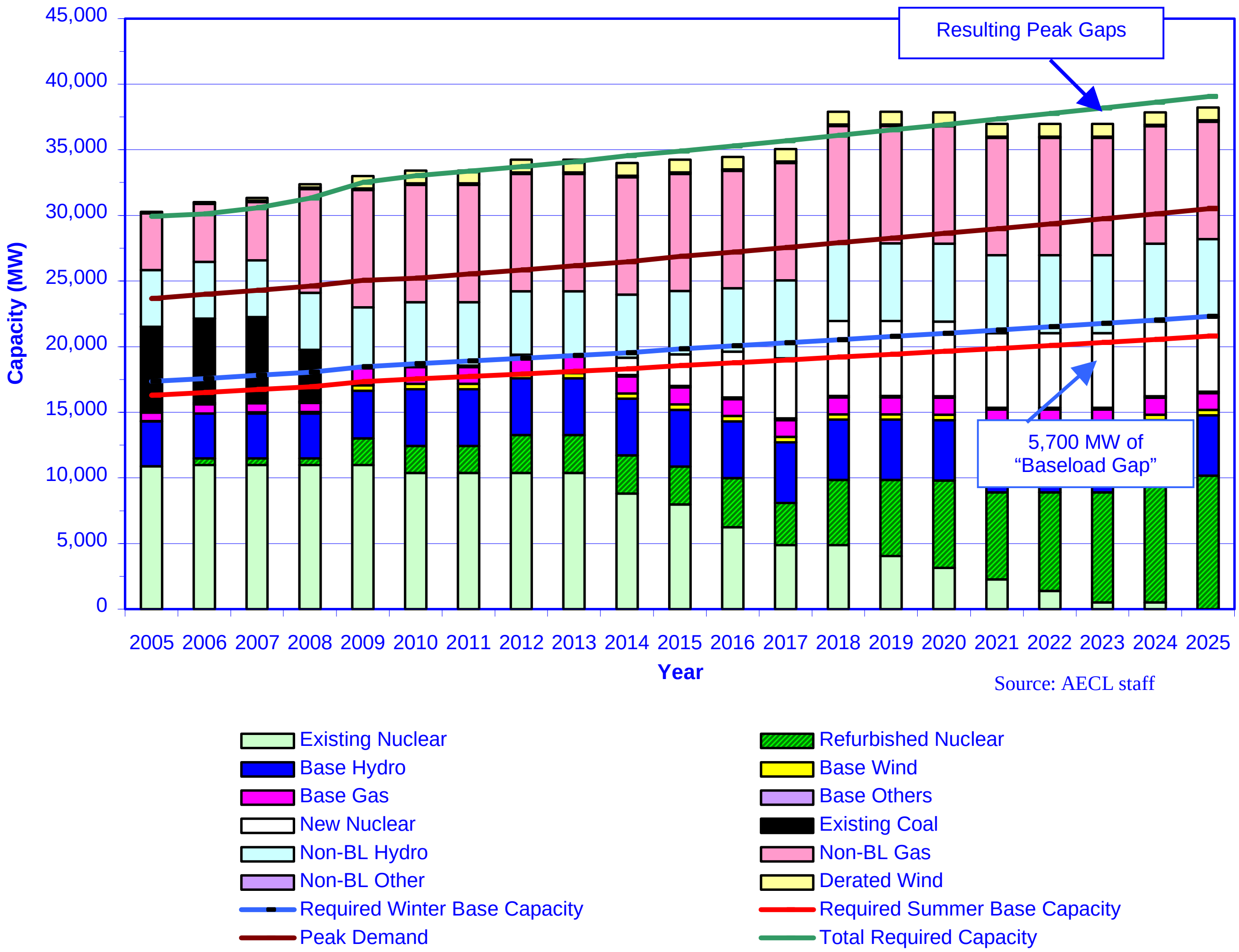
Figure 9 – Required Baseload Capacity versus Assumed Installed Baseload Capacity



With the further assumption that these baseload gaps from 2015 to 2025 are filled by a gradual buildup of 5,700 MW of baseload capacity, the adequacy of peaking resources can then be assessed. This analysis is summarized in Figure 10, below.

The comparison of peak demands with the resources available to meet the peak suggests that, after baseload gaps are addressed, only modest gaps remain in the peaking resources. Filling these “peak gaps” would require the installation of ~1,200 MW of new peaking service, introduced in stages over the period from 2014 to 2025. For the purposes of the supply mix, AECL assumes that this peak gap would be filled with gas-fired generation.

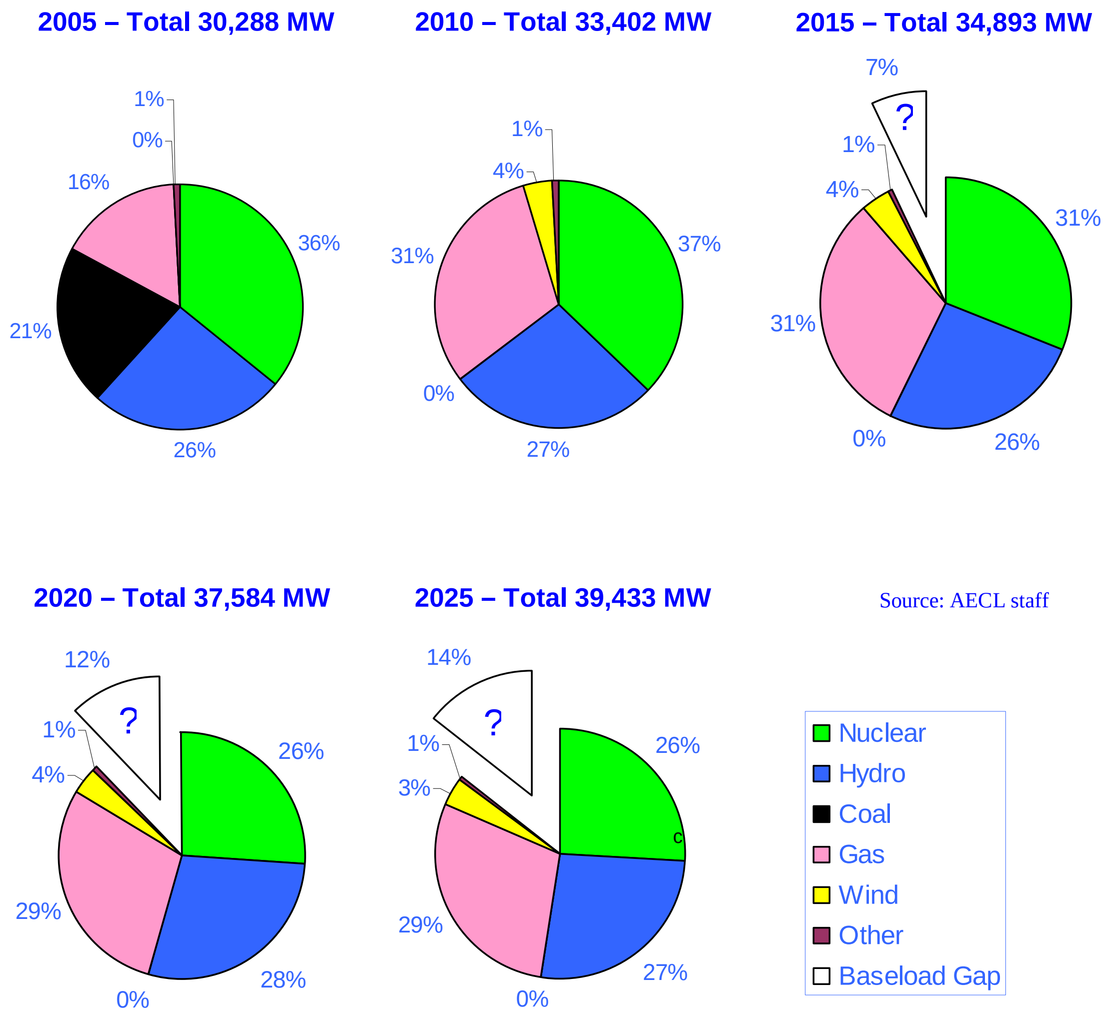
Figure 10 – Required Peak Capacity versus Installed Peak Capacity (after addition of 5,700 MW to fill Baseload Gap)



Implications for Ontario's Supply Mix

The analysis above indicates that Ontario will experience a shortfall in generating resources after 2014 and that these "gaps" should be filled primarily with baseload resources. The cumulative effect of the new generation and retirements at key dates is illustrated in Figure 11, below.

Figure 11 – Supply Mix of Installed Supply Resources with Assumed Additions and Retirements



Source: AECL staff

Figure 11 illustrates that, as coal-fired generation is removed, the proportion of gas-fired generation to the supply mix almost doubles; from 16% in 2005 to 31% in 2010. The pie chart for 2015 illustrates the opening of a baseload supply gap of 7% of the supply mix. By 2025, the baseload gap has increased to 14% of the supply mix while the share of nuclear generation has dropped to 26% of the supply mix.

The baseload generating technologies that are chosen to fill this 14% gap will determine not only the supply mix, but also the prosperity and security of Ontario's electricity consumers. A discussion of these technologies appears in the next section.

Assessment of Different Supply Technologies

Assessment Criteria

The technologies available to Ontario power system planners must be screened against a range of criteria. The considerations developed during the last long-term electricity supply plan[18] (appearing in bold typeface below in their original order of appearance) provide a useful framework for an assessment of candidate technologies:

- **Providing low-cost electricity service,** from a life cycle perspective, costs are usually expressed as the Levelised Unit Electricity Cost (LUEC)
- **Environmental Considerations,** including emissions, water effluents, solid waste and land use,
- **Socio-economics**, involving the impacts on the provincial economy including employment, provincial GDP, and balance of trade.
- **Safety,** in that all options must meet safety requirements and standards,
- **Flexibility**, to respond to uncertainties in future load growth, fuel prices, etc. It is under this consideration that a diversity of fuel supplies provides security to Ontario's electricity system,
- **Resource Preference,** dealing with the source and availability of the primary fuel, and where equipment might be manufactured.
- **Technical Soundness**, addressing the technical maturity of an option and the extent of Ontario's experience with that option, and
- **Reliability,** in that all options must meet standards of reliability.

Comparison of Generating Technologies

The Organization for Economic Co-operation and Development (OECD) has compiled data on the characteristics and costs of different technologies for generating electricity. Data from the European and North American countries are presented in Figure 12, below. The reader is advised to utilize the broad range of LUEC information with caution since it addresses a wide range of assumptions and site conditions. For example, the range of LUEC's for Combined Cycle Gas Turbine is based on fuel prices of US$3.70/GJ to US$5.72/GJ. However, the spot price[19] of natural gas on August 22, 2005 is US$9.178/GJ.

The merits of these technologies, in the context of Ontario's baseload gap and the criteria developed above, are discussed below.

Wind or Biomass

AECL's analysis assumes the addition of more than 1,300 MW of wind generation to Ontario's generating resources. There are a number of reasons[20] that wind generation is unsuitable to fill much more than this:

- Reduced feasibility of remaining wind development sites,
- The absence of dispatchability for wind generation,
- A need for replacement generation (at least 70% of installed wind) when the wind is not blowing, and
- Challenges in maintaining grid stability and reliability.

---

[18] Ontario Hydro publication "*Providing the Balance of Power*", 1989. Page 14-5.
[19] NYMEX commodity quote for August 22, 2005 at www.nymex.com of US$9.683/MMBTU = US$9.178/GJ
[20] The German utility E.On provides an interesting perspective on the challenges of large amounts of wind resources in their power system in their publication Wind Report 2004, available on their website at http://www.eon-energie.com/bestellsystem/bf_service_book.php?lcode=englisch.

Figure 12 - Side-by-Side Comparison of Different Electricity Generation Sources per OECD

	Units	Wind+ (onshore)	Biomass	Hydro (Run-of-River)	Combined Cycle Gas Turbine++	Cogen-eration	Clean Coal	New Nuclear
Capital Cost	US$/kW$_{net}$	980 - 1630	1700 - 2180	1540 –4280	360 -1030	610 -3720	940 - 1940	1090 - 2145
O&M Cost	US$/MWh	5-36	10-13	2-21	1-8	1-34	4-15	7-11
Fuel Cost	US$/MWh	-	13-53	-	28-45	0-39**	9-35	4-8
Levelised Unit Electricity Cost (LUEC)	US$/MWh	46-144	50-101	64-146	41-63	32-144	37-64	32-53
Net Efficiency	%	-	38-45	-	40 – 60	35-50*	35-51	31-37
Economic Life of Plant	years	20-40	40	30-60	20-40	15-40	40	40
Typical Application		Baseload	Baseload	Baseload, Intermediate, Peaking	Baseload, Intermediate, Peaking	Base-load	Baseload	Baseload / Intermediate
Dispatchable?		No	Limited	Yes	Yes	No	Yes	Yes

Sources:
OECD Projected Cost of Generating Electricity 2005 update, (OECD Countries: Europe & North America), July 1, 2003 basedate, 10% real discount rate
* Electricity only ** net of heat credit
+ Does not include investment in backup capacity required when wind is not blowing
++ Based on fuel costs of US$3.70/GJ to US$5.72/GJ. Current natural gas prices in North America are US$9.178/GJ (see footnote 17)

Similarly, concerns about dispatchability and suitable sites make biomass an unsuitable candidate for more than a minor contribution to the 5,700 MW gap in Ontario's future baseload supply.

Hydroelectric

Where there are abundant hydro resources, hydroelectric generation can make an excellent candidate to meet all types of demand. However, the gap analysis in this paper assumes the development of 1,400 MW of new hydroelectric sites in the province, together with the 1,380 MW Conawapa site in Manitoba. Hydroelectric development beyond this aggressive target will be challenged by the availability of suitable sites and the costly transmission system upgrades associated with their remote location.

Cogeneration

While cogeneration (the use of "waste" heat to support industrial activity) markedly improves the efficiency of gas-fired generation, developers around the world have had difficulty balancing the needs of the electric utility and the "steam host". Few industrial companies that require large quantities of heat have been prepared to make the long-term commitment (i.e., 15 to 20 years) needed to make cogeneration economically feasible. Nevertheless, AECL's analysis assumes that, with government incentives, 1,000 MW of cogeneration will be installed in the next five years. It is highly likely that this level of cogeneration will consume all of the feasible installations.

Clean Coal

While there are many definitions[21] of "clean coal", the one most suitable to Ontario's situation would likely involve Integrated Gasification Combined Cycle (IGCC) with carbon sequestration. The IGCC technology involves converting coal into a gas similar to natural gas and then "scrubbing" the emissions to eliminate sulpher and nitrous compounds. IGCC technology is relatively immature[22] and thus costs and reliability are highly uncertain. Sequestration of carbon emissions is required to make coal-fired generation truly "clean" and involves capturing the CO_2 emissions from the IGCC process and storing them, most likely in permeable rock formations. This sequestration technology is also relatively immature.

Given the state of these "clean coal" technologies and the attendant cost and reliability uncertainties, clean coal is an unlikely candidate for filling Ontario's baseload gap.

---

[21] The figures for "clean coal" published by the OECD in Figure 12 are derived from a mixture of conventional coal with advanced emission "scrubbers" and IGCC technologies. No carbon sequestration costs are represented in the data.

[22] EPCOR, a western Canadian utility with experience in coal-fired generation, expressed doubts of the commercial readiness of IGCC at a Clean Coal conference in April 2005. See page 15 of the presentation at www.epcor.ca/NR/rdonlyres/0A28C40D-A2CA-46FE-B96E-07084548AE23/0/cleancoal05.pdf

Nuclear

Ontario's CANDU nuclear power stations have delivered reliable, inexpensive and clean baseload power for more than 30 years. During this time, Ontario's nuclear stations have enjoyed an unequalled safety record and avoided millions of tons of greenhouse gas emissions. The small amount of spent nuclear fuel generated to date is safely stored on site while more permanent storage is assessed. Canada is following the lead of other jurisdictions around the world in implementing long term, deep geological storage technology[23]. The long-term nature of these implementation plans (90 years) is a testimony to the small volume of waste to be managed.

With respect to energy costs, the LUEC data of Figure 12 illustrate that new nuclear is one of the least cost alternatives for power generation. Also, since most of the costs of nuclear power generation are fixed (by interest rates on capital cost), this cost is known with a high degree of certainty under modern, fixed price contracting.

A new nuclear power project, if implemented with AECL's CANDU technology, also generates an unequalled amount of economic activity for Ontario, an important assessment criterion. The Canadian Energy Research Institute estimates[24] that a new build program of two advanced CANDU reactors will contribute more than $33 billion to Canada's GDP and create over 279,000 person-years of employment. CANDU technology, unlike it's nuclear competitors, features a domestic fuel source and component supply base, further enhancing security of fuel supply and generating local economic benefits long into the future.

With respect to the diversity of supply sources, providing 5,700 MW of new nuclear supply in Ontario by 2025 would translate into a 40% share for nuclear power generation (i.e., from Figure 11, 26% + 14%). This proportion approximates the current and historical share of nuclear power in Ontario over the last few decades, a period under which Ontario has enjoyed a diverse and secure portfolio of fuel sources.

Notwithstanding the cost, economic, and diversity-of-supply benefits provided by new nuclear generation, the time to place a nuclear power plant into service is also a major consideration. AECL estimates that the environmental assessment and concurrent licensing of its CANDU technology could require 3 to 4 years, at which point a decision to build can be made. Taken with an estimated 5-year construction period, placing a new CANDU plant into service could take 9 years. Since Ontario's baseload gap widens dramatically in 2014-2015, it is imperative that decision makers soon initiate an environmental assessment of a new CANDU nuclear plant to provide themselves with the *option* to begin construction in 2009.

The potential to license a reactor within the timeframe of an environmental assessment is highest for AECL's enhanced CANDU 6 design and its next-generation cousin, the ACR-1000. Unlike its "new nuclear" competitors, AECL's technology is well known to Canada's nuclear regulator, the Canadian Nuclear Safety Commission (CNSC). AECL's designs are evolutionary, building upon CANDU 6 technology that is familiar to the

[23] Canada's National Waste Management Organization has issued its draft recommendations, available at www.nwmo.ca.
[24] The Canadian Energy Research Institute, "*Alternative Technologies for New Nuclear Power Plants: Economic Impacts*", draft of report for AECL, June 2005.

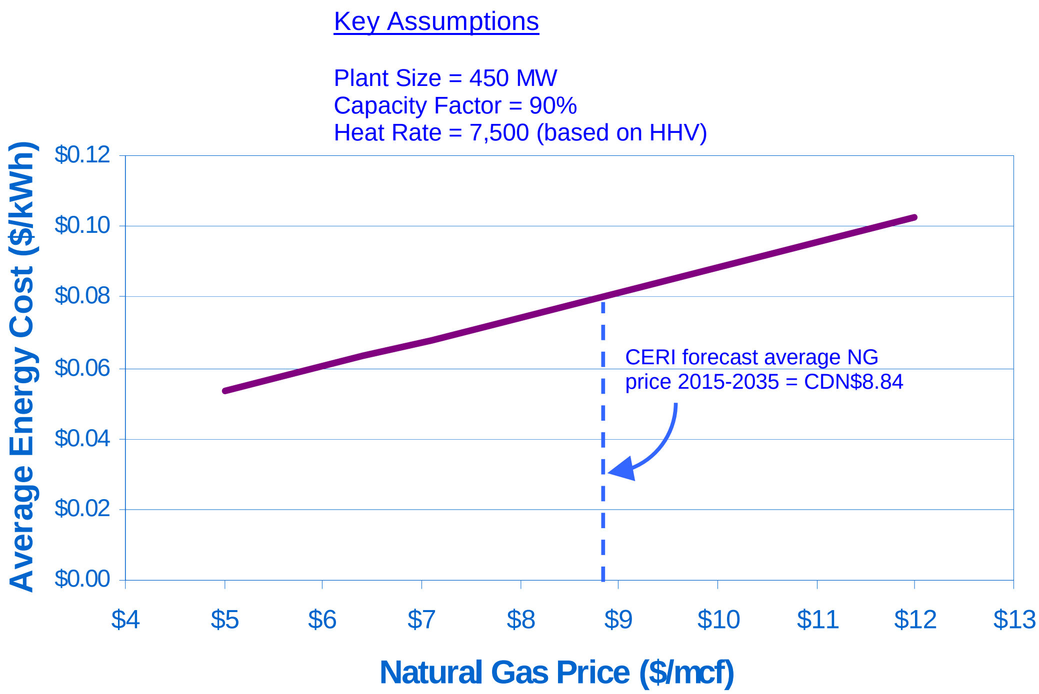
CNSC since they currently regulate the operation of two CANDU 6's (Gentilly-2 and Point Lepreau Generating Stations). In contrast, the licensing process for a foreign reactor design is likely to be protracted and fraught with uncertainty.

Combined Cycle Gas Turbine

Combined Cycle Gas Turbine (CCGT) technology has been utilized in many jurisdictions with varying[25] degrees of success. While CCGT technology is mature and may be implemented quickly, the cost of electricity generated is highly sensitive to the price of natural gas. This relationship[26] between CCGT electricity costs and natural gas prices is presented graphically in Figure 13, below.

The future price of natural gas is the subject of much analysis, since natural gas is in high demand as a feedstock for petrochemical processes and as a heating fuel. The Canadian Energy Research Institute (CERI), after surveying a range of forecasts, estimates[27] that the average price of natural gas (delivered at the Dawn, Ontario hub) over the period 2015 to 2035 (i.e., a twenty-year plant life coming into service at the beginning of the baseload gap) will be CDN$8.84 per 1000 cubic feet in 2003$'s. Figure 13 illustrates that this natural gas forecast corresponds to an electricity price of approximately CDN 8¢ per kWhr or CDN$80 per MWhr in 2003$'s.

Figure 13 – Energy Costs from Baseload CCGT Generation



[25] In the Northeast and Midwest United States, many merchant gas-fired plants are unable to produce power at competitive rates, see "*US Gas Devotees Look for Something Solid*", Financial Times, May 9, 2004 available at www.energybulletin.net/218.html

[26] CCGT algorithms were provided by Acres Management Consulting Limited.

[27] The CERI publication, "*Levelised Unit Electricity Cost Comparison of Alternate Technologies for Baseload Generation in Ontario*" is available from their website at www.ceri.ca. See Appendix A, Section A.2.1, Base Case assumption.

Where the province contracts for gas-fired generation under a commercial arrangement that is indexed to the price of natural gas, Ontario's electricity ratepayers are fully exposed to the volatility of natural gas prices.

Apart from the likely high cost of baseload energy from CCGT generation, the diversity of Ontario's electricity supply is also an important consideration for filling Ontario's baseload gap. Figure 11 illustrates that, during the period from 2015 to 2025, gas-fired generation will comprise approximately 30% of Ontario's supply resources. Implementing additional gas-fired generation to fill the baseload gap would further jeopardize Ontario's goal of a diverse, secure electricity supply.

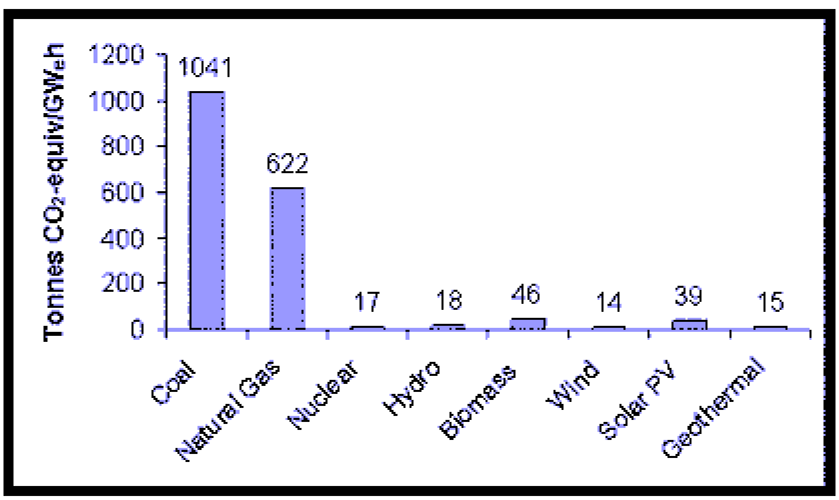
Environmental Impacts of Different Generation Technologies

When considering the environmental impact of generation technologies, AECL advocates a life cycle, "footprint" approach to environmental impacts. Life cycle emission studies consider the emissions of greenhouse gases (and compounds that contribute to acid rain) over the entire life of the plant including emissions:

- During plant construction,
- Through operation and maintenance over the life of the plant (including decommissioning),
- Generated in the creation of construction materials,
- Created in extracting and processing raw fuel materials (e.g., gas, uranium, coal), and,
- Generated by delivering fuel to the plant.

Figure 14 summarizes the results of one such study[28] and contrasts the emissions associated with fossil fuel generation (coal or natural gas) and the low emitting technologies such as nuclear or hydroelectric.

Figure 14 – Lifecycle Emissions of Various Electrical Generation Technologies



Source: University of Wisconsin-Madison, 2002. See footnote 28.

[28] Paul J. Meyer, *Life-cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis*, University of Wisconsin-Madison, August 2002.

Other studies[29, 30, 31] across a broad range of jurisdictions, have confirmed this contrast between the high impact of gas- or coal-fired generation and the low environmental impact of nuclear power generation.

The low environmental impact of nuclear power generation becomes more apparent when a "footprint" approach is utilized to include the impact of generation technologies on land and water resources. Nuclear power boasts one of the lowest[32] environmental footprints of all generating technologies.

Emissions in a Kyoto Context

Canada is a signatory to the Kyoto Protocol of the United Nations Framework Convention on Climate Change, an international treaty under which developed countries seek to reduce their emissions of greenhouse gases. The supply technology chosen for filling Ontario's baseload gap of 5,700 MW could have a material impact on Canada's ability to meet its international obligations under the Kyoto Protocol and its successors. Using the data of Figure 14, the implementation of 5,700 MW with new nuclear generation will avoid more than 815 million tonnes[33] of greenhouse gases over a 30 year time period, compared with gas-fired generation.

The environmental benefits of nuclear generation and other low emissions technology over gas-fired generation may be made more tangible as Canada develops an emissions trading system[34]. Under such a system, projects that avoid greenhouse gas emissions may attract financial rewards while emitting technologies will likely incur a financial penalty. These potential financial penalties for coal- and gas-fired generation have not been incorporated into the unit electricity prices of Figures 12 or 13, above.

Summary and Conclusions

Consistent with the Minister's direction that the OPA consider baseload, intermediate, and peaking demands in its advice on the electricity supply mix, AECL has conducted a 20-year assessment of the gaps in electricity supply and evaluated candidate technologies to fill that gap. The deterministic analysis considered both baseload and peaking load service.

In evaluating potential supply resources, AECL has assumed that large amounts of hydroelectric, wind, and gas-fired generation would be implemented, on a scale not

---

[29] Frans H. Koch, *Hydropower-Internalised Costs and Externalised Benefits*, International Energy Agency (IEA)-Implementing Agreement for Hydropower Technologies and Programmes; Ottawa, Canada, 2000.
[30] W. Krewitt, P. Mayerhofer et al, *ExternE - Externalities of Energy. National Implementation in Germany*; IER, Stuttgart, Germany 1998
[31] Central Research Institute of Electric Power Industry (Japan), *Life-Cycle Analysis of Power Generation Systems*, March 1995.
[32] From "*The Ecology Book*" 2003 pp. 1, available from the Nuclear Energy Institute at http://www.nei.org/documents/Ecology_Book_2003.pdf
[33] Emissions avoided equals (622-17) tonnes CO_2e/GW-hr x 5.7 GW x 90% capacity factor x 8,760 hours/year x 30 years equals 815.6 million tonnes CO_2e.
[34] Environment Canada News Release, *Government of Canada Moves to Create a Market for Emission Reductions in All Sectors of the Economy,* August 11, 2005,

previously seen in Ontario. AECL also assumed a substantial refurbishment program for Ontario's CANDU fleet.

Even with these new sources of supply, the analysis indicates that a gap between Ontario's electricity demand and its supply resources opens in the 2014-2015 timeframe and widens dramatically through 2025. This gap is dominated by a shortfall in baseload resources (~5,700 MW) with some peaking resources (~1,200 MW) required during the annual peak. The baseload gap constitutes 7% of Ontario's supply mix in 2015, growing to 14% in 2025.

An assessment of candidate supply technologies for filling this baseload gap was conducted against criteria of cost, diversity-of-supply, and availability. The benefits of nuclear power over gas-fired generation were evident from this assessment. Also, environmental impact studies of the technologies, from a life cycle basis, further reinforced the role of new nuclear in filling the 5,700 MW shortfall in Ontario's baseload supply.

Although new nuclear power generation will minimize electricity costs and price volatility, restore the diversity of fuel supply, and lower environmental impacts, the assessment acknowledges a 9- to 10-year period to plan, approve and construct a new CANDU plant. Foreign technologies that are unfamiliar to the CNSC are likely to undergo a much longer and more uncertain licensing process. To maintain the *option* of beginning plant construction in 2009, decision-makers are advised of the urgency to initiate an environmental assessment for a new CANDU plant at the earliest opportunity.

Maintaining the option to construct new CANDU nuclear generating plants will ensure that Ontario's citizens and industries enjoy an inexpensive, secure, and environmentally friendly supply of electricity far into the future.