ONTARIO SOCIETY OF PROFESSIONAL ENGINEERS

Wind and the Electrical Grid

Mitigating the Rise in Electricity Rates and Greenhouse Gas Emissions

March 14, 2012

THE VOICE OF ONTARIO'S ENGINEERS

Executive Summary

The Ontario Society of Professional Engineers (OSPE) has undertaken an independent engineering review of wind generation and its impact on Ontario's electrical grid because of growing amounts of hydraulic spill, nuclear shutdowns and periods of negative wholesale electricity prices during severe surplus base load generation periods. This situation is expected to get much worse over the next several years as significant amounts of wind, hydraulic and nuclear generation will be coming into service while expected electrical demand will continue to be stagnant even with the introduction of electric plug-in vehicles.

This document presents the results of the OSPE review. It also makes a number of recommendations that OSPE believes will mitigate the rise in electricity rates and the rise in greenhouse gas emissions due to more frequent shutdowns of nuclear units if no action is taken. Ontario's electrical grid is currently suffering from a lack of effective integration of its generation resources and its electrical demand profile. The electrical grid is a very complex engineered system and requires the application of power engineering expertise to optimize its technical, economic and environmental performance.

OSPE believes the Minister of Energy should implement the following recommendations as soon as practicable:

1. Modify market rules so that all significant generation resources including wind, solar and nuclear generation will be subject to IESO[1] dispatching.
2. Renegotiate existing OPA, OPG and OEFC generation contracts to ensure the capacity and energy charges combined with electricity market design will align with the economic and environmental needs of the public.
3. Authorize OPG to contract with entities outside of Ontario for the sale of long-term dependable (firm) GHG-free electricity.
4. Authorize OPA to adjust the FIT rates and annual maximum capacity additions in each category to an affordable level that will sustain the new green energy sectors.
5. Authorize OPA to develop a program designed to better align demand to periods when Ontario supply is available.
6. Assign OPA the overall responsibility of meeting the public's expectations for electrical grid reliability, cost and environmental performance without the need for Ministerial Directives.

In the longer term, the OPA should undertake detailed studies to:

1. Determine if the dispatching capability of existing nuclear plants can be improved economically.
2. Determine if additional daily and seasonal storage capacity can be added or alternatively purchased from adjoining grids (eg: Quebec) economically.
3. Determine if surplus electrical energy can be used economically for new applications such as hydrogen production.
4. Determine if alternate TOU rate structures or other incentives with smart grid capability can be used economically to encourage demand shifting from peak to off-peak periods.

The complete list of 19 recommendations is included in Section 8 – Recommendations.

[1] The abbreviations used in this document are: IESO – Independent Electricity System Operator, OPA – Ontario Power Authority, OPG – Ontario Power Generation, OEFC – Ontario Electricity Financial Corporation, GHG – Greenhouse gases, TOU – Time of Use

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1. Introduction

The Ontario Society for Professional Engineers (OSPE) was founded in 2000 through the collaborative efforts of Professional Engineers Ontario and the Canadian Society of Professional Engineers (CSPE). OSPE's mandate is to advance the professional and economic interests of its members by advocating with governments, offering member services, and providing opportunities for ongoing professional development.

OSPE's interest in advocating for an affordable and balanced energy policy stems from the fact that some of our members are employed in the energy sector and many of our other members work for industries that are impacted by the cost of electricity. Electrical energy is fundamentally tied to our high standard of living in Ontario and the health of our industrial sector. Consequently OSPE advocates for a reliable, safe, abundant, affordable and environmentally sustainable electricity supply.

The grid has recently been experiencing increasing amounts and frequency of surplus base load generation (SBG). Surplus base load generation means that the minimum must-run base load generation is producing more power than the customer demand. Surplus base load generation results in one or more of the following: hydraulic spill, nuclear unit shutdowns and negative wholesale market prices for electricity when we try to export large surpluses on the spot market. This is a symptom of sub-optimal integration of generating resources with the Ontario electrical demand profile. If the situation is not corrected soon, the additional generation that is coming into service over the next 6 years will put additional upward pressure on electricity rates and will raise greenhouse gas emissions due to nuclear shutdowns.

OSPE recognizes that long term planning for the electrical grid is not an exact science because of the many uncertainties that must be reconciled to produce a planning scenario that hopefully will be close to actual conditions in the future. However, the addition of large amounts of intermittent wind generation into Ontario's grid posses some severe engineering challenges. Ontario's grid is heavily dependent on hydraulic plants that have relatively little daily and seasonal storage and nuclear plants with relatively little maneuvering capability.

The problem of surplus base load generation and negative wholesale electricity prices has been growing for about 3 years. After reviewing the Ministry of Energy's Supply Mix Directive and 2010 Long Term Energy Plan, OSPE felt that an independent engineering review of the wind generation plans might shed some insight into the root causes of these problems and potential solutions.

To determine the extent of the problem, OSPE's Energy Task Force undertook a series of analyses that resulted in the following submissions:

- On March 8, 2011, a report was submitted to the Minister of Energy that identified a number of requirements unique to Ontario's electrical grid that should be included in the specifications for new and refurbished nuclear plants in Ontario (R28).
- On March 9, 2011, a submission was forwarded to the Ontario Energy Board that identified an alternative time-of-use (TOU) rate structure that would more fairly allocate costs for peak power to those customers that create a peak demand. The proposed new rate structure would provide a greater incentive for customers who produce a peak demand to invest in demand leveling technologies. (R29).

- On June 13, 2011, a submission was forwarded to the Ontario Power Authority which outlined a number of concerns that were not adequately addressed in the 2011 Integrated Power System Plan consultation documents (R30).
- On December 13, 2011, a submission was forwarded to the Deputy Minister – FIT Program Review, outlining OSPE's suggestion to help make the program more affordable and sustainable (R43).

OSPE also undertook a review of wind generation in the autumn of 2011 and that resulted in a draft version of this document that was issued for comment to OSPE members and industry stakeholders on December 19, 2011 (R44). The draft document generated considerable comment. This final document has been revised based on those comments. OSPE has eliminated the appendix that was included in the draft version of this document and plans to issue it later in 2012 as an information guide describing how the Ontario electrical grid works.

OSPE's understanding of the government objectives in restructuring the electrical energy supply system include:

- The reduction of air and water pollution and other negative health impacts,
- The reduction of greenhouse gas emissions,
- The reduction of energy intensity (conservation and improved energy efficiency),
- The reduction of peak electrical demand (flatten the demand profile),
- The improvement of sustainability (less dependence on declining resources), and
- The increase of green (clean and sustainable) energy jobs in the Ontario economy.

OSPE supports the government's objectives listed above. However, in pursuing those objectives it is important that the government does not lose sight of the engineering principles that must be followed to ensure the electrical grid continues to be reliable, safe and affordable in addition to being environmentally sustainable. The electrical grid is a very complex engineered system and requires the application of power engineering expertise to optimize its technical, economic and environmental performance.

To facilitate the development of green energy supply in Ontario, the government undertook to remove barriers to the introduction of green energy generation. The government passed the Green Energy and Green Economy Act in 2009 (R45). The *Green Energy Act*, Renewable Energy Offer programs, the Feed-In-Tariff (FIT) Program and Ministerial Directives have established a significant wind and solar industry in Ontario in a relatively short period of time. The government is therefore achieving its goal of increasing the green energy jobs in the Ontario economy.

Unfortunately, the global recession in 2008/09 followed by weak economic growth has eliminated any room to accommodate the new wind, hydraulic and nuclear base load generation that is being added by 2018. To make matters more difficult, the present electricity market rules do not permit wind generation to be dispatched and the new high efficiency, combined cycle gas turbine (CCGT) plants that were recently built are not as flexible as expected. The CCGT plants have higher must run power levels, longer must run periods and lower power ramp rates than expected. This means there is a large amount of surplus base load generation during low demand periods when wind is blowing.

When severe surplus base load generation occurs it is often impossible to export all of the surplus energy at positive electricity prices. The electricity market auction process will drive electricity prices lower until the export takes place or a base load plant is forced to shut down.

The IESO is undertaking actions to permit it to dispatch wind, solar and nuclear by the end of 2013 and to set minimum floor prices on energy bids to ensure the market produces efficient outcomes. Wind dispatching has also become necessary elsewhere in North American where wind is a significant portion of total generation and the storage facilities are limited (e.g.: New York, Texas and California).

A further complication is that when a CANDU nuclear unit is shutdown during one evening's surplus, it cannot return to service for 2 to 3 days. That means natural gas-fired generation will need to replace the missing production for the subsequent 2 or 3 days at about 5 times the fuel cost and about 398 kg of carbon dioxide emissions per MWh of production (R27). Consequently both costs and emissions will go up significantly when surplus base load generation occurs and forces one or more nuclear units to shut down.

In 2011 with only about 1,400 MW of wind generation, about 15 million dollars (R3) were spent exporting surplus power at negative prices because of a lack of both technical and contractual capability to manage surplus base load generation. The frequency of nuclear shutdowns will increase dramatically as an additional 400% of wind generation and two refurbished Bruce A nuclear units are added by 2018. The IESO's preliminary estimate of the impact of forced nuclear shutdowns in 2014 alone will be over 180 M$ in extra natural gas fuel costs to consumers and over 1.6 million tons of carbon dioxide emissions (R40) if wind and solar generation are not dispatched down. In the September 2011 IESO "18 Month Outlook" for the electrical grid (R23), the IESO indicated it continues to be concerned about the state of integration of renewable energy into the grid.

The data presented and used in the analysis for this document has been obtained from publicly available sources such as the Independent Electricity System Operator (IESO), Ontario Power Authority (OPA), the Ontario Ministry of Energy (MOE) and energy industry associations. The specific references we used are listed at the end of this document in Section 10. The IESO data for public use is provided in hourly interval format.

This document does not expand on the findings on the state of the electrical grid and its related governance that was reported by the Ontario Auditor General (R35) and the Commission on the Reform of Ontario's Public Services (R47).

2. Ontario's Electrical Grid and Its Load Profile

Before we get into details about wind generation and its impact on the grid we need to define a few terms and get a basic understanding of how the electrical grid works.

In this document we will use the term "grid" to mean the Ontario electrical generation, transmission, inter-grid connections, distribution, customer connections and related control facilities. The term "power" will be used to represent the instantaneous amount of electricity flowing in the wires and is typically expressed as thousands (kilo) of watts or simply kilowatts (kW). The term "energy" will be used to represent a measure of the ability of electricity to do useful work and the units are typically expressed as thousands of watts multiplied by time in hours or simply as kilowatt hours (kWh). When the quantities are very large we typically will replace thousands or kilo (k) with larger units of million or mega (M), billions or giga (G) and trillions or tera (T). Therefore, the symbols used in this document for power will be kW, MW, GW and TW and for energy will be kWh, MWh, GWh and TWh.

The terms load ramping, load following, load cycling, load control and load maneuvering have slightly different meanings in the industry depending on how and why the load change is occurring. For the purposes of this document we will simply refer to a change of power output as a load maneuver and we will not get into the specific details of each type of load change. The term "dispatch" is used in the context of the IESO sending out commands for generators to move their output to a specified MW level at a specified time or at a specified ramp rate.

Generating station and unit sizes vary according to the technology used. The Sir Adam Beck I and II stations at Niagara Falls have 26 units and can produce a maximum power output of about 2,000 MW but only if there is sufficient water flow. The Darlington nuclear station near Oshawa has 4 units that can produce about 3,500 MW continuously. The Nanticoke coal-fired station near Port Dover has 6 units that can produce about 3,000 MW continuously. The Sithe Goreway gas-fired combined cycle station near Brampton has 4 units that can produce about 900 MW continuously. Large wind turbines are typically 1 to 3 MW each and are often clustered into large wind farms of 50 to 200 MW each in order to reduce the installed capital cost per MW. Their actual output varies with the wind speed so it is considered intermittent power.

If a facility could produce power at its maximum nameplate rating 24 hours a day for 365 days a year it would have an annual capacity factor of 100%. However, maintenance, dispatching, and lack of water or wind can reduce a facility's capacity factor. In the case of hydraulic, wind and solar generation, their capacity factors are relatively low because their energy source is affected by weather.

Ontario has interconnections to neighbouring electrical grids in Manitoba, Minnesota, Michigan, New York and Quebec. The practical limit of our export/import capability to those neighbouring grids is about 4,800 MW (R9)(R22) provided those neighbouring grids are all willing to import or export at the same time. Since this does not always happen, the actual export or import capability is situation dependent and varies day-to-day.

Ontario's grid is administered by the Independent Electricity System Operator (IESO). The IESO operates a wholesale market that determines which generating plants run and at what power level through an auction process. The generators offer prices for their output and the IESO selects sufficient sources to meet the demand at the lowest price. The price where supply and demand are in balance is the market clearing price. That price is paid to all generators that are providing power. The price is set every 5 minutes. A more detailed description of how the electricity market works is available at http://ieso.ca/imoweb/siteShared/wholesale_price.asp?sid=md

Facilities to store electricity in large quantities are very expensive. Ontario has a relatively small amount of storage capacity compared to the size of its generating fleet. As a result the electrical grid is operated in a manner that balances the supply and demand of electricity on a moment-to-moment basis. When customer demand is lower than the minimum output of our base load generators (typically nuclear, hydraulic, wind and some must-run gas-fired generation), the system experiences what is called surplus base load generation or SBG.

Since supply and demand must be balanced at all times, the auction process forces those generators who want to remain on-line and not be dispatched off to bid lower prices into the electricity market. If neighbouring grids do not take the surplus base load generation then the price continues to fall and can go negative as generators compete to stay on-line to avoid the high cost of a shutdown. Eventually the low or negative prices in Ontario attract demand from our neighbouring grids. Even so, our neighbours have a limited ability to absorb our surplus energy. If the surplus base load generation is very large then a generating unit or perhaps several will need to be shut down to avoid creating an unstable supply/demand situation.

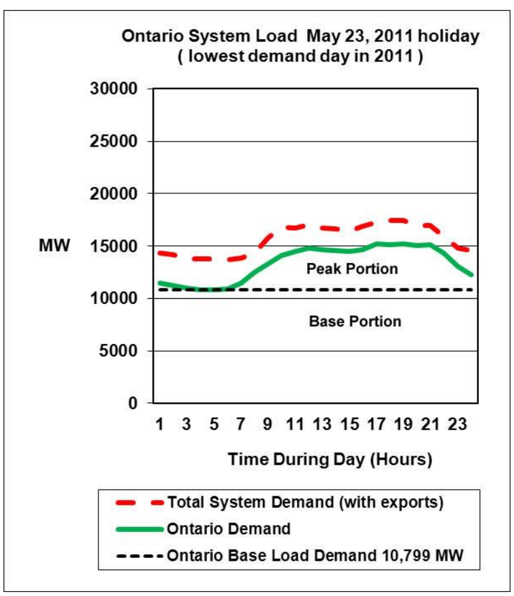
North American utilities all subscribe to the philosophy that consumer demand should not be interrupted unless there is a crisis on the electrical grid. Consequently, most day-to-day control efforts are directed at managing supply to match the demands of consumers at all times.

Another important consideration in grid operation is the current policy in Ontario to allow wind turbines to generate all their output without dispatching restrictions. They have priority access to the grid for the purposes of generating power (R36). This has been done for two reasons. Firstly, if you don't capture the energy when nature provides it, then you lose it. Secondly, wind turbines have a high installed capital cost of typically $2,000 to $2,800 per kW and they have low capacity factors of about 29% average for large wind farms across Ontario in 2010/11 (R3). If you dispatch wind turbines their capacity factor would fall and the cost of electricity on a kWh basis would rise.

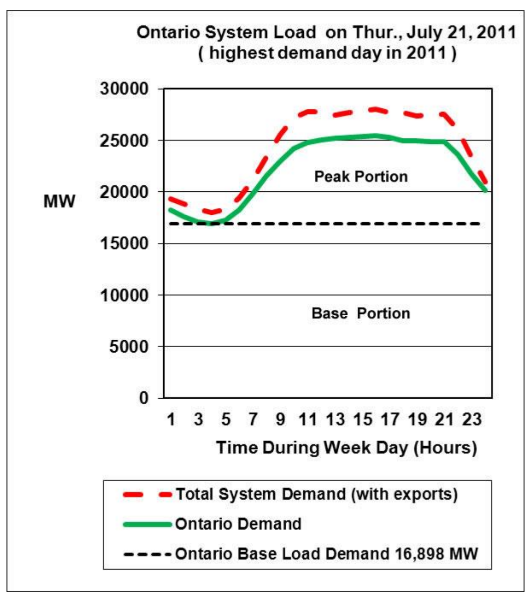
<u>Customer Demand</u>

The Ontario customer demand for electricity varies throughout the year (R10). The lowest demand day in 2011 occurred on the Victoria Day holiday, May 23, 2011. The minimum load that day was 10,799 MW at 5 AM. The highest demand day occurred on a weekday in the summer on July 21, 2011. The highest demand that day was 25,450 MW at 4:00 PM. Figure 1 and Figure 2 below show the demand variation during both days.

<u>Figure 1</u>
<u>Lowest Demand Day in 2011</u>



<u>Figure 2</u>
<u>Highest Demand Day in 2011</u>

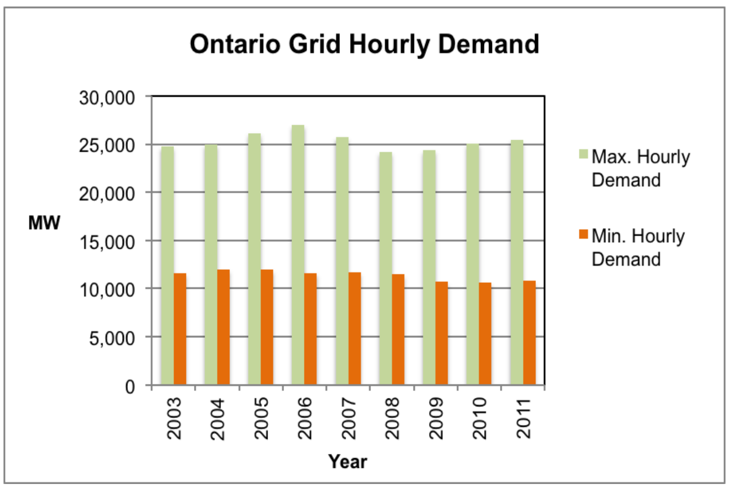


It is important to note that the base load demand (dotted lines in Figure 1 and 2) is much lower in the spring and autumn compared to the summer. Also the peak portion of the summer load (area above the dotted line in Figure 2) is much higher than the peak portion of the spring and autumn load. The winter demand is between the two cases in Figure 1 and 2. Ontario has been a summer peaking grid since 2000 mainly due to the growth in air conditioning.

To optimize overall energy costs, a combination of base load and peak load generating plants are installed on most electrical grids. Seasonal variations in demand can to some extent be managed by careful planning of generating station annual maintenance outages. This means it is economic to install more base load generating plants than the yearly minimum daily base load demand (10,799 MW in 2011). However, if too much base load generation is installed, there will be frequent periods of surplus base load generation. The surplus base load generation can be exported or eliminated by spilling water at the hydraulic units. It can also be eliminated if we dispatch wind generation or if we shut down some of the nuclear units.

Ontario was planning for a small annual growth in energy demand over the past several years. This growth did not materialize. In fact the peak customer demand over the past 5 years has actually dropped by almost 6% or 1,600 MW and the total annual energy demand has dropped by 6% or 9 TWh (R10). The off-peak customer demand has dropped by over 7% or 800 MW. The drop in demand can be attributed to the week economy including the loss of manufacturing jobs, conservation efforts and also embedded generation that has been installed in customer facilities or in distribution system facilities. Embedded generation does not participate in the IESO administered electricity market. The impact of this imbedded generation as seen by the IESO is a lower customer demand. Figure 3 below illustrates the reduced demand since 2006.

Figure 3



This drop in demand has created a divergence between planned generation additions and required generation. It has also undermined the government's plans to significantly increase wind generation in the energy mix. As we will see later in this document, wind turbines produce their maximum output at night. Consequently, wind generation competes directly with nuclear and must-run hydraulic generation for the reduced customer demand.

Unfortunately, no provisions were made to ensure that adequate nuclear maneuvering or additional hydraulic storage or wind dispatching would be available if the demand dropped. As a result we now have periods of severe surplus base load generation.

Available Supply

Ontario's generating resources fall into two categories: base load and peak load generators. Base load generators are best suited to continuous and steady power output. These typically have higher capital cost, lower fuelling cost and limited maneuvering capability. Some examples are run-of-the-river hydraulic and nuclear generating plants. Wind generation is also considered a base load generation resource because a significant amount of its energy is produced at night during the base load period.

Peak load generators are best suited to variable power output. These typically have lower capital costs, higher fuelling costs and good maneuvering capability. Some examples are coal-fired and gas-fired generating plants. Solar generation is considered a peak load generation resource because all of its energy is produced during the peak demand period.

Ontario had 34,882 MW of nameplate capacity, on May 24, 2011(R9). Table 1 below shows a more detailed breakdown by generating type in 2011.

Table 1
Present Ontario Electrical Energy Supply (R9)

Generating Station Type	Installed Capacity (May 24, 2011)		Energy Delivered In 2010	Forecast Capacity At Summer 2011 Peak	
Nuclear	**11,446 MW**	**33%**	**55%**	**11,249 MW**	**38%**
Natural Gas	**9,549 MW**	**27%**	**14%**	**7,914 MW**	**27%**
Hydraulic	**7,947 MW**	**23%**	**20%**	**5,809 MW**	**20%**
Coal	**4,484 MW**	**13%**	**8%**	**4,267 MW**	**14%**
Other Renewables	**1,456 MW**	**4%**	**4%**	**226 MW**	**1%**
- Wind	1,334 MW	4%	2%	189 MW	<1%
- Solar	0 MW	see (*)	0%	0 MW	see (*)
- Bioenergy	122 MW	<1%	1%	37 MW	<1%
TOTAL	**34,882 MW**	**100%**	**100%**	**29,465 MW**	**100%**

(*) Note: The data above excludes generation within customer or distribution utility systems such as combined heat and power (CHP), solar and wind that are not part of the IESO administered market. The total energy consumed in 2010 in the IESO administered grid was 142 TWh.

Base load generating plants in Ontario have not been designed to maneuver well, so their total capacity on any day should ideally be lower than that day's minimum demand. The data in Figure 1 and Figure 2 earlier shows the minimum daily demand varied throughout the year from 10,799 MW to 16,898 MW.

In 2011, 16,898 MW was the maximum base load capacity that was needed during the summer peak. Table 1 shows the grid had an installed base load generating capacity of over 20,000 MW (11,446 MW nuclear, 7,947 MW hydraulic and over 1,334 MW wind generation). However, not all of that capacity is available on any given day. The last column on the right of Table 1 shows the capacity that was expected to be available on the day of summer peak load (just over 17,000

MW of hydraulic, nuclear and wind base load capacity). Surplus energy can be exported to neighbouring grids if they have a need.

The Ontario Long Term Energy Plan (R5) indicates the planned capacity of the electrical grid by 2018 and 2030 will be 38,580 MW and 41,900 MW respectively. However, a significant percentage of that capacity (28% and 27% respectively) will be intermittent renewable generation that cannot be depended on to be available on the annual peak demand day in the summer. The 2018 and 2030 capacities are shown in Table 2 below.

Table 2
Future Ontario Electrical Energy Supply

Energy Source	**Installed Capacity Medium Growth Plan (Dec 31, 2018)**		**Installed Capacity Medium Growth Plan (Dec 31, 2030)**	
Nuclear	**8,507 MW**	**22%**	12,000 MW	29%
Natural Gas	**10,373 MW**	**27%**	10,100 MW	24%
Hydraulic	**9,000 MW**	**23%**	9,000 MW	20%
Coal	**0 MW**	**0%**	0 MW	0%
Other Renewables	**10,700 MW**	**28%**	10,700 MW	27%
- Wind	7,500 MW	(see note 2)	7,500 MW	(see note 2)
- Solar	2,400 MW	(see note 2)	2,400 MW	(see note 2)
- Bioenergy	800 MW	(see note 2)	800 MW	(see note 2)
TOTAL	**38,580 MW**	**100%**	**41,900 MW**	**100%**

Note 1: The data above excludes generation within customer or distribution utility systems such as CHP, solar and wind that are not part of the IESO administered market.
Note 2: The final breakdown of the 10,700 MW of renewables was not specified in the Long Term Energy Plan. The data above has been estimated based on using the same ratio of renewables for the 10,700 MW as that identified in the list of the existing, committed and directed projects in the IPSP Planning and Consultation Overview, Table 4, page 3-14 (R4).
Note 3: The drop in nuclear capacity in 2018 is due to Pickering retirement and refurbishment programs at the other nuclear plants.
Note 4: Actual demand will depend on projected growth. The 2010/2018/2030 energy demand is 142/140/147 TWh for the low growth scenario, 142/148/165 TWh for the medium growth OPA planning scenario and 142/155/198 for the high growth scenario.

As more wind and hydraulic generation are added and more nuclear plants are refurbished or built the potential surplus base load generation will get worse unless there is a significant growth in our Ontario demand or we export the surplus.

System Utilization

Another growing concern is the rising ratio of the annual peak load to the annual minimum load. A flatter customer demand profile across each day (daily) and across the whole year (seasonal) is preferred. As the ratio of peak demand to base demand increases, the system becomes less efficient at utilizing generating plants and the average cost of electricity per unit energy (kWh) rises. Figure 1 and Figure 2 earlier show that Ontario has had some success in flattening the daily load profile from about 11 am to about 9 pm. Unfortunately, the increased use of air conditioning in the summer has resulted in a significant difference between day and night demand and between summer and spring demand. A flatter demand profile also reduces the need for peak load generating plants and transmission and distribution capacity that would operate with a low capacity factor and as a result, high unit energy cost.

This document does not examine solar generation, however, our analysis of wind generation has brought to light another potential problem. The Ontario Long Term Energy Plan projects about 2,400 MW of solar generation on the grid by 2018. According to the OPA website, there were about 8,300 MW of Solar PV applications submitted by November 14, 2011 (R54). There are over 4,000 MW of solar FIT applications in the queue that have not been rejected. Another 1,300 MW have already been awarded contacts. The past rejection rate for applications was less than 50% so if that rejection rate continues we could potentially see close to 3,300 MW or more of solar installations. That is sufficient capacity to create periods of surplus peak load generation (SPG) during low demand sunny days. Surplus peak load generation would occur when the total capacity of operating base load generation including must-run gas-fired generation plus solar generation exceeds the peak demand. Although surplus peak load generation can be exported more easily than surplus base load generation, it is unlikely we will be able to obtain 44 to 80 cents/kWh - the price that Ontario must pay for that solar power.

3. Wind Generation Performance Characteristics and Concerns

Wind generation is easy to construct and distribute geographically and has very low operating costs. Wind generation is considered environmentally friendly but recent opposition from residents close to wind farms regarding health and safety concerns suggests additional study may be required. Wind turbines increase the noise level above background when they are rotating even at low power (R52). There is considerable controversy in Ontario on whether such noise levels, frequency distribution and tonal characteristics are sufficiently disturbing to disrupt nearby residents' lives and cause adverse health effects. The controversy may linger for years if a more direct study is not conducted. Beginning in early 2014, wind generation will be dispatched by the IESO. IESO can dispatch all wind turbines equally or shutdown specific wind farms completely for a period of time. This may provide opportunities to do some controlled studies on the effect of turbine noise in the more populated areas.

Apart from the health and safety concerns of nearby residents, wind generation is intermittent, it has a low capacity factor and it delivers its energy when nature provides it rather than when consumers want it. These weaknesses make wind generation one of the most technically challenging and costly energy sources to integrate into the electrical grid.

Environment Canada data (R12) shows that in Southwestern Ontario, summer is the lowest wind production season and spring, autumn and winter the highest. Also wind blows more strongly at night and less during the morning hours. Figure 4 on the next page shows this data graphically. The purple colour represents the lowest wind speed and the red colour represents the highest wind speeds.

IESO wind generation production data (R3) shown graphically in Figure 5 below, confirms Environment Canada's wind data and shows clearly that wind generation is lowest in the summer and during the morning and is highest in the winter, spring and autumn and at night.

Figure 4
Windsor Wind Speed Map
(near Gosfield Wind Farm, 51 MW)

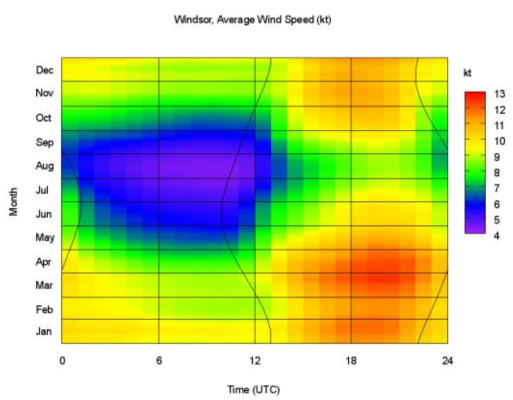
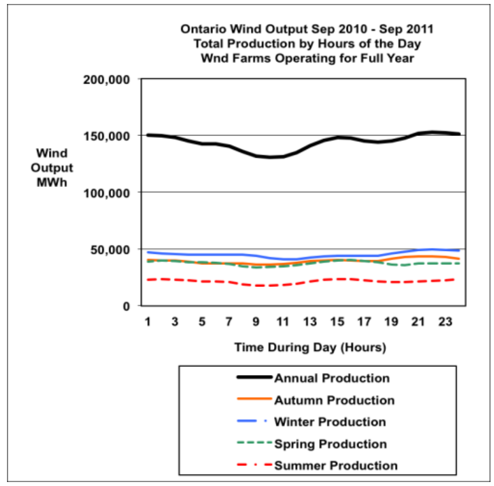


Figure 5
Ontario Cumulative Wind Output
by Hours of the Day



Ontario's grid demand peaks during the day and falls off at night. Also the Ontario grid is now a summer peaking grid and spring and autumn are lower demand seasons. This means that the wind energy production is out of step with the actual daily and seasonal electrical demand profile.

The FIT rate of 13.5 cents/kWh is only for energy delivery if wind turbines are not dispatched. To effectively integrate wind into Ontario's grid you need to either dispatch wind or install significant amounts of seasonal storage. The true cost of wind energy is therefore much higher than the FIT rate. A reasonably accurate estimate can be determined using system simulation studies with real generation, demand and wind production data from IESO's archives.

Figure 5 above shows the average production for the whole year but daily variations can be much more severe. Wind generation can drop 15% of installed capacity per hour in the morning. If 7,500 MW of wind is on-line by 2018, then we can expect a drop of approximately 1,200 MW per hour in wind generation just as the morning ramp-up in demand begins. The morning customer demand ramp-up can reach 1,600 MW per hour in the spring. The IESO operator would then need to find units that in total can ramp up 2,800 MW/h. That is 75% faster than the customer demand ramp.

The production characteristics of wind generation combined with the large planned capacity of wind turbines will place a severe operational challenge on the IESO operators. They have not been given the tools necessary to manage the large and rapid supply/demand imbalance that large amounts of wind generation will impose.

Environment Canada data shows that wind has similar variability across most of southern Ontario where most of the wind turbines are presently located. There is some smoothing of overall generation variability compared to individual wind turbines over minutes and hours but the daily and seasonal variation must be managed by a backup source of energy. Presently, Ontario is using gas-fired generation to provide that backup with a lesser contribution from some hydraulic and nuclear generation that have some limited maneuvering capability. Hydraulic spill is also being used. Unfortunately, spilling water means the energy is wasted. Spilling water is the equivalent to turning off (dispatching) the wind turbines.

Because of wind's variability, the remaining generating stations see a residual demand that is much more variable. Figure 6 below shows the wind generation capacity in 2011 and the planned wind generation capacity in 2019. The grid demand is also shown assuming no overall growth in electrical demand. The difference between the red wind generation and green demand lines is the residual demand that needs to be supplied by other generation. That residual demand in 2019 is plotted in Figure 7. Figure 7 shows that the residual demand available for hydraulic and nuclear plants has dropped from 10,799 MW to 5,137 MW. We can export some but not all of the surplus generation. We will likely have to shutdown several nuclear units on a frequent basis in the future if we don't dispatch wind generation.

Figure 6
Demand and Wind Generation in 2019
Lowest Demand Day

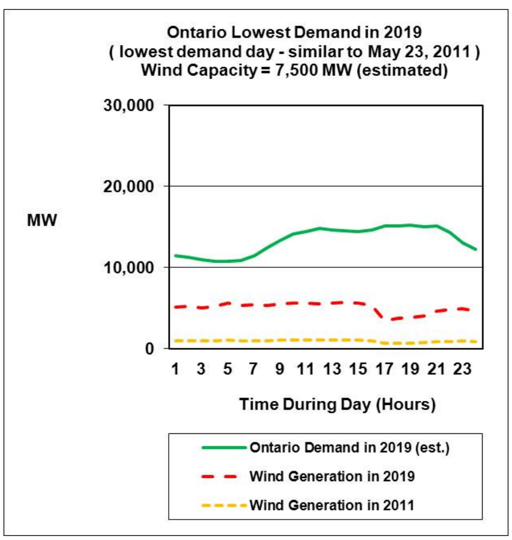
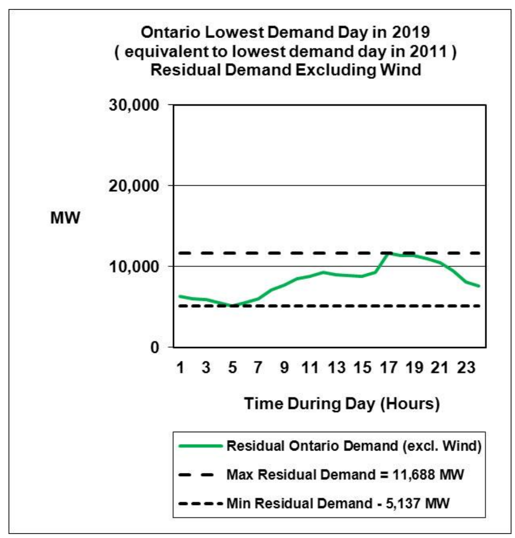


Figure 7
Residual Demand After Wind Gets Priority
on the Lowest Demand Day



The following day the lost nuclear capacity would need to be replaced by gas-fired generation at considerable extra fuel cost and GHG emissions. In addition, the peak portion of the residual load demand will have risen from about 5,900 MW to over 6,500 MW. That extra peak demand will need to be supplied by peak generation resources. Therefore, not requiring wind generation to be dispatched means electricity will be produced with more natural gas generation at higher fuel costs and higher GHG emissions.

This unexpected result occurs because Ontario's electrical grid suffers from supply/demand imbalances created by:

- too little customer demand at night and on weekends in combination with
- too much intermittent wind generation out of step with demand,

- too little nuclear maneuvering, and
- too little daily and seasonal storage capacity

These problems can be solved by a more integrated approach to grid planning. When government economic policy biases supply decisions in one direction (large buildup in intermittent renewables) then compensating action must be taken to provide the IESO operators with sufficient control mechanisms to manage that bias (provisions for better maneuverability at our base load plants, additional storage and/or renewable generation dispatching). The IESO's Feb 24, 2012 18 Month Outlook (R55) states that "Maximum flexibility from all resources is imperative to managing operations effectively."

In 2011 we exported up to 3,500 MW of surplus base load generation. By 2019 with an additional 4,000 MW of base load generation we could reach over 7,000 MW of surplus base load generation if the low electrical demand growth scenario occurs. By 2030 with an additional 8,000 MW of base load generation we could reach over 11,000 MW of surplus base load generation for the low growth scenario and over 7,000 MW of surplus base load generation for the medium growth scenario. These are large surplus base load generation quantities, well beyond our export capability. That suggests a significant frequency and duration of shutdowns for either wind or nuclear generation.

During 2011 the surplus base load generation problems were managed by the IESO with exports, some limited maneuvering capability at hydraulic stations and Bruce B nuclear station and some hydraulic spill. The IESO also shut down a nuclear unit on 3 occasions. There were also 138 hours of negative electricity prices on 56 evenings in 8 of the months between September 15, 2010 and September 14, 2011. Approximately 15 million dollars were paid at negative prices to export that surplus energy. That occurred with only about 1,400 MW of installed wind generation. By the end of 2018 we will have almost 7,500 MW of installed wind generation along with a similar customer demand if economic growth continues to be weak as the government has recently predicted.

The surplus base load generation problem will get worse and more costly as more wind, hydraulic and nuclear base load generation capacity is added over the next 6 years unless we dispatch down our wind turbines or take other measures to reduce surplus base load generation.

It is not OSPE's intention to stop the construction of renewable generation. The government and electricity consumers have invested considerable sums of money to create a new green energy industry. The FIT program can be modified to limit the annual addition of new renewable generation to a maximum rate that can be accommodated by demand growth and ideally at a minimum rate that will sustain the industry that has been created. OSPE provided a submission to the Ministry of Energy for its 2011 FIT Program Review outlining suggestions to help ensure a more affordable and sustainable green energy industry (R43).

The resulting costs from overbuilding of our wind generation capacity, can be mitigated if we find export markets for our surplus power. Exporting power on the spot market is not economically attractive. Also neighbouring utilities are likely to be more interested in purchasing dependable long-term renewable or zero GHG emitting energy. We would have to re-examine our electricity export policies and market rules so that zero GHG emitting electricity could be exported on a dependable (firm) long-term delivery basis in order to maximize its value. OPG is currently the only supplier of large amounts of both renewable and zero GHG emitting energy in Ontario and can reliably enter into such commercial contracts.

4. Potential Solutions to Wind Generation Variability

Wind variability and the more problematic surplus base load generation problem caused by strong winds when customer demand is low can be managed in a number of ways.

Supply side solutions provide grid flexibility so that wind generation can be integrated effectively. The following methods can be used to manage wind variability:

- Improved wind forecasting,
- Improved maneuvering at hydraulic units,
- Improved maneuvering at nuclear units,
- Improved maneuvering at gas-fired units,
- Improved maneuvering at bio-mass units,
- Improved storage capacity,
- Improved import/export capability,
- Dispatching (constraining) wind turbine output.

Demand side solutions provide a more flexible demand that can be adjusted to match the prevailing supply. When wind energy is available customers draw more power and when wind energy is not available customers defer their power consumption until wind energy is available or until off-peak hours. During off-peak hours the peak load plants can be operated for additional hours to accommodate the demand that has been shifted.

These potential solutions are discussed in more detail below.

Improved Wind Forecasting to Manage Wind Variability

The objective of improved wind forecasting is to more efficiently deploy other types of generation to accommodate only the expected variation in wind generation and not the entire nameplate capacity. Wind forecasting can help manage both the expected magnitude and rate of change in wind generation.

The larger number of monitoring stations around the province and improved software tools can allow the forecaster to monitor a weather front and plot its course as it travels across the wind farms. The result is a more accurate forecast that can help grid operators better manage generation resources. Most grids that have a high percentage of wind generation now employ wind forecasting as part of their generation management strategy. Wind forecasting is therefore an important new tool to help manage intermittent wind generation. Improved wind forecasting capability is included in the IESO plans.

It is important to remember that wind forecasting only eliminates unnecessary over reaction to wind variability. Wind forecasting cannot eliminate surplus base load generation caused by customer demand falling below the running capacity of the base load plants. Consequently other solutions are required for that situation.

Improved Maneuvering at Hydraulic Units to Manage Wind Variability

The operating flexibility (storage and spill) provided by existing hydraulic stations is currently being fully utilized. In order to obtain additional maneuvering flexibility we would need to make significant civil engineering modifications to the hydraulic stations. This would be very expensive. Therefore, modifying existing hydraulic stations to get more maneuvering capability may not be economically viable. Detailed studies can confirm this.

Hydraulic storage is discussed in more detail later in this document.

Improved Maneuvering at Nuclear Units to Manage Wind Variability

Nuclear generation is a zero GHG emission source of energy. It would be attractive environmentally to use nuclear generation to back up wind generation rather than gas-fired generation. However, the current CANDU reactors we use in Ontario have not been designed to continuously maneuver their power output. There are reactor physics and other plant technical constraints that limit the frequency, magnitude and speed at which reactor power changes can take place. An alternative is to maneuver the generator output and leave the reactor operating at constant high power levels. The energy imbalance would be directed to a steam bypass system.

The Bruce B and Darlington reactors have a turbine condenser steam dump system that can be used to redirect steam to the condenser and bypass the turbine generator. This steam bypass system allows the units to survive a grid load rejection or blackout by allowing the reactor to continue operating at 60-70% power with the turbine-generator operating at 6% to supply the unit's electrical loads. At this reactor power level the reactor core will continue to burn off neutron absorbing fission products that would otherwise build up and poison (shutdown) the reactor for about 2 days.

These systems were used during the August 2003 blackout to keep 3 units at Bruce B and 1 unit at Darlington operating throughout the blackout. These units re-connected to the grid a few hours after the initial grid collapse. Unfortunately, the turbine condenser steam dump system was design for infrequent use during load rejections and grid blackouts. They are not designed for continuous maneuvering duty. Bruce B staff have modified their turbine condenser steam dump system so it can operate more frequently but it is not rated for continuous duty, 24 hours a day.

The present nuclear plants already discharge the maximum amount of heat into the lake that is permitted by the Ministry of the Environment. If we wanted to reject more steam energy conveniently, we would likely need to reject that steam to the air using air-cooled condensers on the roof. The type of condensers required would resemble those installed at gas-fired plants such as the Sithe Goreway or Halton Hills plants. The air-cooled condensers at a nuclear plant would sit high enough above the roof to avoid costly roof redesign. They would be designed to a higher pressure and temperature because the condensate would be returned to the de-aerator storage tank rather than the turbine condenser storage tank (hot-well). Because of their higher design temperature they would be smaller per MW_t of capacity compared to the gas-fired plants.

Suppose these nuclear plants were fitted with a 30-40% roof mounted air-cooled condenser. The roof mounted air-cooled condensers would not produce any wear and tear on the turbine condensers so they should be able to operate continuously at the same maneuvering rate as the nuclear steam turbines. Nuclear steam turbines have a faster maneuvering rate than the higher temperature coal and gas-fired plant steam turbines. That means we could get 30-40% or about 250-300 MW of continuous maneuvering capability from each unit at Bruce A, Bruce B and Darlington or about 3,000 MW of maneuvering capability if all 12 units were fitted with air-cooled condensers. This could be done without a major licensing effort because the reactor would continue to operate at 100% power level and would not see any change in power during turbine-generator power maneuvers.

If the design was standardized into modules to get manufacturing economies even with its higher design pressure and temperature, the smaller size needed per MW thermal should result in a reasonable cost per MW of maneuvering capacity. The cost and environmental impact should be significantly less than the cost of a new 3,000 MW pumped hydraulic generating station, transmission line and large seasonal storage reservoir.

Another advantage of using nuclear maneuvering to manage wind variability is that we achieve zero GHG emissions from both the wind energy production and its nuclear backup. Unfortunately, we would still consume nuclear fuel because the reactor is still at full power. If the electrical power reduction was expected for an extended period of time (e.g.: a full day of strong winds or a weekend of lower demand) we could reduce nuclear fuel consumption by lowering reactor power. The reactor power reductions would have to be done very slowly to prevent poisoning out the reactor. Power maneuvers would involve considerably more workload for the nuclear operator and additional wear and tear on nuclear systems. Consequently, engineering and safety studies would need to be done to make sure a reactor power maneuver could be done on a regular basis (eg: nightly or weekends).

Since the nuclear plant would not poison out, the plant owner could offer a much higher marginal cost of power into the electricity market auction process. If enough nuclear maneuvering capacity is available this would eliminate the very large negative prices that have occurred in 2011. Nuclear and run-of-the-river plants had to bid very low prices to stay on-line in 2011. In 2010/11 we saw negative wholesale prices as low as negative 139 $/MWh when the normal market price should be around +30 to 40 $/MWh based on the marginal fueling cost of gas-fired plants.

It is important to remember that the Ontario grid experiences some surplus base load generation periods even when there is no wind generation. This has occurred recently because the customer demand has dropped the past few years while 2 units at the Bruce A plant were returned to service. This means we have too many nuclear, run-of-the-river hydraulic and must-run gas-fired units operating during the night in the spring and autumn.

To fully appreciate the implications of this we need to view the grid operation as 3 separate regions. We are assuming that solar PV installations are not approved beyond a capacity level that would create surplus peak load generation (SPG) otherwise we would need to look at a 4th operating region.

- SBG Region A – where there is not enough load for nuclear units irrespective of wind.
- SBG Region B – where there is not enough demand for both nuclear and wind combined.
- Non-SBG Region – where there is sufficient demand for all the nuclear and wind units.

<u>In SBG Region A:</u> A steam bypass system eliminates the need for costly nuclear plant shutdowns. Dispatching wind turbines off does not guarantee a solution to the negative electricity price problem when the grid is operating in SBG Region A. In this regime, wind generation is not setting the price, nuclear generation is. Therefore, it is important that nuclear is able to dispatch down to avoid a large negative electricity price. A robust steam bypass system would enable nuclear generators to offer a more reasonable price into the market and power down without a poison outage. It is important to note that the current IESO proposal to use floor prices to prevent large negative electricity prices will not prevent a nuclear poison outage because dispatching will still take place and force a nuclear plant to shutdown when there is no more wind generation to dispatch down.

In SBG Region B: A steam bypass system would permit a choice of either dispatching wind turbines or dispatching nuclear electrical output down. Dispatching wind turbines is easier. But that means the investment in wind generation is wasted. The other option from a broader provincial viewpoint is to give wind generation priority and force nuclear plants to innovate and provide additional environmental benefits for the province as a whole. If we choose to dispatch nuclear generation instead of wind turbines, then two other environmental opportunities arise:

- Zero GHG steam becomes available at the nuclear plants when their steam bypass systems are operating. This steam can offset gas-fired industrial and residential steam within a district heating steam system. Some nuclear plants in Europe supply steam to their local towns for hot water, space heating and industrial process steam (eg: Hungary's PAKS nuclear plant). The Bruce A station also supplied a large district heating steam system during the 1970s and 1980s before the plant was laid up.

- There would be an incentive for the owners to do the required R&D and safety analysis work to enable reactor power maneuvering in order for the plant to reduce the amount of wasted steam and nuclear fuel used during dispatches.

The end result of dispatching nuclear instead of wind is that you can potentially achieve lower nuclear fuel consumption and lower GHG emissions for the province as a whole for the same electrical energy production.

In the Non-SBG Region: There is no surplus generation. However, if it became a policy goal to further reduce GHG emissions from the electrical grid, you could optimize the combination of additional hydraulic storage and nuclear capacity to provide a zero GHG backup for wind and solar. Nuclear steam bypass would be used to keep the storage capacity needed to a more affordable and environmentally acceptable size.

The cumulative costs and environmental benefits provided by nuclear steam bypass are dependent on the number of operating hours in each of the 3 regions above. These can be studied with reasonable accuracy using system simulation studies using supply, demand and wind generation data from IESO's production data archives and OPA's financial data. Parametric studies can be done to optimize steam bypass capacity and storage capacity.

Steam bypass capability at the nuclear plants provides considerable grid operating flexibility in case planning assumptions do not materialize as expected. It also provides the IESO additional operating advantages during normal and abnormal operating conditions including grid blackout restoration (R28).

You cannot energize a long 500 kV transmission corridor after a blackout with wind turbines. The Bruce transmission lines to the GTA area require about 180 MX of charging power. System restoration must be done with larger hydraulic, gas-fired or nuclear units. Wind and solar generation cannot be added to the restoration process until the system is large enough to withstand the variability of wind and solar generation. Grid restoration studies in the mid 1980s at Ontario Hydro by Power System Operations Division and the Generation Design and Development Division indicated that nuclear units operating on steam bypass could help restore a blacked out grid in about 4 hours. Without nuclear units the process was predicted to take from 24 to 72 hours depending on weather conditions. Following the August 2003 blackout the restoration process took about 24 hours followed by power conservation appeals for another week.

The IESO target for system restoration (R31, R32) after a blackout is 8 hours. That target relies on all major units to be ready to assist with system restoration soon after the load rejection. All large units on the grid can currently meet this requirement except Bruce A. The 8-hour period is a reasonable maximum during the winter. The IESO was not able to achieve this target in August 2003 in part because the grid lost too many operating nuclear units. Only 3 units at Bruce B and 1 unit at Darlington survived the grid collapse and associated load rejection. Brue A units were not operating at that time. The deficiencies at Darlington that resulted in 3 units being lost, instead of the design target of 1 unit loss out of 4, have been corrected.

However, due to design changes at Bruce A (removal of its reactor booster rods) Bruce A would not be able to survive a load rejection from 100% power in any case. It can only survive load rejections from about 60-70% power or lower. The boosters cannot be re-installed for safety reasons. It would be uneconomic to operate the Bruce A reactors at 60-70% power so they will survive a grid blackout. Consequently, the 8 hour restoration target cannot be met unless the Bruce A steam bypass system is upgraded to about 100% steam bypass capacity.

Upgrading the turbine steam condenser to 100% steam dump capacity is not practical because of the regulatory limits on the heat load to the lake. But a 30-40% air-cooled condenser on the roof would restore Bruce A's load rejection capability at full power and provide about 250 MW of continuous power maneuvering capability per unit.

A Bruce A unit is the best candidate for installing an air-cooled condenser on the roof to gain operational experience with nuclear maneuvering using steam bypass before it is added to other nuclear units.

Improved Maneuvering at Gas Fired Units to Manage Wind Variability

Gas fired generation is the current preferred backup to wind generation to manage its variability. Gas fired backup does not work at all in SBG Region A and has limits to what it can do in SBG Region B. Most of our gas-fired capacity is the more efficient CCGT type. These gas-fired plants are not sufficiently flexible to fully manage the full 7,500 MW of wind generation variability on their own. These plants have large must-run loads when they are operating, long must-run periods and slower maneuvering rates than required. Consequently, wind turbine dispatching would be required in both SBG Region A and B if nuclear cannot maneuver its electrical output.

To improve maneuvering rates at CCGT gas-fired plants would require significant process engineering changes. The engineering features needed to improve maneuvering rates are the opposite of what are needed to maintain high thermal efficiency. Also as efficiency drops, GHG emissions rise. Modifying CCGT plants to provide a faster maneuvering rate is not recommended.

The simple cycle gas-fired plants are more maneuverable that CCGT plants but their efficiencies are much lower – typically 35% instead of 55%. Ontario does not have enough simple cycle gas-fired plant capacity to manage a large fleet of wind turbines. Also it would cost too much in fuel consumption and GHG emissions to use these plants for that purpose around-the-clock. Adding additional simple cycle gas-fired plant capacity to manage wind variability is therefore not recommended.

Improved Maneuvering at Biomass Units to Manage Wind Variability

Ontario Power Generation is currently repowering its Atikokan station to use biomass and is making provisions to use biomass at its Thunder Bay station, that is being converted from coal firing to gas firing (R33). These plants already have transmission line connections so that is one expense that will be avoided if biomass is used as fuel at those facilities. Biomass generating plants can maneuver their electrical output. They are also carbon neutral and the environmental impact of their combustion products can be managed by installing the latest post-combustion filtration systems.

Biomass is only considered sustainable if it comes from waste streams and not from biomass that can be used for food production (including soil nutrients) or building materials. Biomass generation is more economical when it is developed close to its fuel source. The maneuvering rates of these plants are very application dependent and as in the case of gas-fired plants the more maneuverable we want to make them the less efficient they become.

Some forms of biomass generation are actually very beneficial to the environment. For example landfill methane gas plants convert methane to carbon dioxide when they produce energy. Methane (natural gas) by weight is about 21 times more potent than carbon dioxide with respect to GHG effects over a 100 year period (R56). Consequently burning landfill gas reduces the GHG impact on the environment by a factor of 7.6 compared to allowing the methane to escape from the landfill site.

To the extent that waste biomass is available in Ontario it can be used to provide a zero GHG backup to wind and solar generation. Modifying these plants to provide a faster maneuvering rate is not recommended.

Improved Storage Capacity to Manage Wind Variability

Storage is an effective option to manage wind generation variability. Its strengths include:

- No GHG emissions and no nuclear fuel consumption,
- It has fast maneuvering rates,
- Daily storage can be distributed close to the wind or solar farm where it can provide a number of other advantages such as:
    - Improved voltage control on the distribution system,
    - Reduced transmission line and transformer ratings, and
    - Improved distribution and transmission capacity factors.

However storage has several disadvantages:

- It is expensive compared to gas-fired or nuclear steam bypass maneuvering. Costs vary from $1,000 to $9,000 per kW (R2)(R46)(R53) depending on technology, geography and energy storage capacity.
- Large seasonal storage capable of managing a large wind fleet requires:
    - A very large hydraulic storage reservoir
    - A large new transmission corridor

There are several commercial storage technologies available. Some storage solutions can deliver small to moderate amounts of power transfer (kW to MW) over a short time frame (seconds to days) such as batteries, fuel cells, flywheels, compressed gas, hot fluids, etc. These are typically best deployed in a distributed manner near their associated wind or solar farm.

Hydraulic storage technologies are capable of large amounts of power transfer (MW to GW) over very long time frames (days to months) such as dam storage or pumped hydraulic storage.

A number of US utilities are now deploying MW scale short-term distributed storage (less than 1 hour) to smooth out the rapid fluctuations that are created by wind and solar energy variability inside their distribution systems. Because storage is expensive, it is deployed sparingly where absolutely necessary for electrical voltage control and to limit the peak power flow in the distribution lines.

Daily storage (a few hours to a few days) can provide considerable benefit to the overall grid because it can eliminate much of the overnight supply/demand imbalances that a strong wind during low demand can create. Daily storage can be provided locally within the distribution system or at the transmission system level in a more central location. For example OPG has a modest pumped storage station at Niagara Falls. There is also daily storage at a number of the existing hydraulic dams.

Seasonal storage (a few months or more) is the most valuable because Ontario's electrical demand has a large seasonal variation that does not coincide with the wind generation seasonal variation. Seasonal storage would allow much higher penetration of wind generation if that energy can be shifted to when it is needed.

Pumped hydraulic storage wastes energy in the conversion to and from the pumped storage reservoir, typically at least 10 to 15% in each conversion if the reservoir pumps and turbines are operated near their maximum operating efficiency point.

Dam storage (holding back water) has no conversion losses but you need enough river flow to effect the power reduction you want. For example a 1,000 MW dam cannot be powered down more than 1,000 MW. For environmental reasons most river flows cannot be stopped completely. Typically only about 60% of Ontario's operating hydraulic capacity is maneuverable. Ontario typically has about 6,000 MW of running hydraulic capacity on most days with another 1,000 MW coming into service by 2018. Consequently dam storage alone will not manage the entire 7,500 MW wind turbine fleet planned for 2018.

OPA is undertaking studies to determine if some hydraulic storage can be added economically such as expanding the Niagara Pumped Storage Station reservoir capacity. For readers who want more information about hydraulic storage, the Ontario Waterpower Association produced a report in 2005 that identifies a number of Ontario sites where hydraulic generation and hydraulic pumped storage can be located (R46). The cost of hydraulic generation facilities was estimated at that time at $2,000 to $4,000 depending on the dam size but not including the transmission lines.

Improved Import/Export Capability to Manage Wind Variability

Ontario recently upgraded the tie lines to Quebec to get additional capacity that can be used to transmit surplus energy for storage in Quebec's James Bay and to obtain energy when we are short. The total transfer capability is about 6,000 MW to the 5 adjoining grids. Only about 4,800 MW is usable simultaneously because of technical constraints. However, all 5 adjoining grids would have to simultaneously import our surplus energy to achieve the 4,800 MW export limit. This rarely happens because our adjoining grids in New York or Michigan also have surplus energy often when we do. From Sep 2010 to Sep 2011 when wholesale electricity prices in Ontario dipped to negative values we never exported more than 3,500 MW and that only occurred once.

To export large amounts of power (MW) and energy (MWh) we would have to change the way we sell our power. Currently it is sold on the spot market which effectively is the incremental fuel cost for that energy unless we have a surplus. During surpluses the price drops and if surplus base load generation is severe, the price can go negative. From Sep 2010 to Sep 2011 the worst case price was negative 139 $/MWh.

From Sept 2010 to Sep 2011 Ontario sold about 278 GWh of energy at negative prices to neighbours and paid about $15 million dollars to do so. That was with only about 1,400 MW of wind generation on-line. When we have 7,500 MW of wind generation in 2018 and if demand growth continues to be weak, we will have a lot more surplus energy. Selling large amounts of power at negative price does not make a lot of economic sense. Table 3 below shows the trend to more costly exports at negative prices.

Table 3
Negative Electricity Price Periods
in the Ontario Wholesale Market

Annual Period **Sep 15 to Sept 14**	**Hours with Negative Prices**	**Days with Negative prices**	**Months with Negative Prices**	**Lowest HOEP $/MWh**	**Exports at Negative Prices in GWh**	**Cost to Export in M$**
2002/03	0	0	0	11.54	0	0
2003/04	0	0	0	5.25	0	0
2004/05	0	0	0	8.6	0	0
2005/06	1	1	1	-3.1	0.8	0.002
2006/07	3	2	1	-1.66	3.8	0.004
2007/08	32	11	6	-14.59	72.4	0.414
2008/09	319	62	9	-52.08	391.0	3.211
2009/10	58	31	5	-128.15	83.7	1.004
2010/11	138	56	8	-138.79	278.2	15.162
Totals	**551**	**163**	**30**		**829.9**	**19.798**

HOEP is the Hourly Ontario Electricity Price (wholesale market)
Conversion of units: 10 $/MWh is equivalent to 1 cent/kWh. So divide $/MWh by 10 to get cents/kWh.

To sell power to neighbouring grids at a more reasonable price closer to retail prices we need to sell that power on a firm, long-term basis and likely in the form of green or zero GHG emission energy so we can take advantage of our neighbours renewable and clean energy standard mandates.

There is only one energy provider in Ontario that controls and can guarantee delivery of large amounts of both green and zero GHG energy all year long. That is OPG. If we change the rules to allow OPG to sell firm long-term power to our neighbouring grids, then we might have a chance to utilize the existing 4,800 MW of transfer capability or even to justify more transmission capacity. What that means is that OPG will not provide energy exclusively to Ontario but also to our neighbours.

If that power can be exported at a higher price than the Ontario wholesale price and that extra revenue is retained by OPG to improve its stations, or by the grid as a whole to reduce the global adjustment, or by OEFC to reduce the stranded debt or by the Ontario government to reduce taxes, then consumers will benefit in the long run.

Because of the large surplus energy we will likely have for an extended period of time (10 to 20 years) it is probably worth the trouble to test the electricity export market and see what green and zero GHG firm long-term power is worth to our neighbouring grids.

One definite environmental benefit is that if the US Ohio valley can offset coal generation with our zero GHG energy then our own air quality will improve because the prevailing winds carry that pollution into Ontario.

Dispatching (Constraining) Wind Turbine Output to Manage Wind Variability

Wind generation can easily be dispatched down. Adjusting the rotor pitch angle will reduce the amount of wind energy delivered to the grid. However, wind generation cannot be dispatched up beyond the maximum power available in the wind at any moment in time. This means that dispatching wind generation down is not a complete solution to manage wind variability. For example if you dispatch wind down from 1000 MW to 500 MW but shortly thereafter the wind power drops off to 200 MW then you still need to find 300 MW to make up the shortfall. A dependable backup supply is therefore required because wind energy may fall off below the required dispatch value.

When we dispatch wind down we don't want to just set the rotor angle to a new fixed value. We prefer to set the MW output to a fixed dispatch value and have the rotor pitch angle varied by the control system to keep the MW fixed. In this way wind speed variations do not affect the wind turbine MW output to the grid.

For those wind turbines that are dispatched, their contribution to the surplus base load generation problem can be eliminated. There are of course economic and environmental consequences. The IESO still needs to honour existing contracts and compensate wind generators not to produce. New contacts will need to be structured with dispatching in mind. This can be done either by separating the capacity and energy charge or by anticipating the capacity factor reduction caused by dispatching and adjusting the energy price to reflect the reduced operating time. Also, the environmental benefits from our investments in wind generation do not materialize if wind generation is turned off too frequently.

It is necessary to dispatch wind turbines as soon as practicable to manage our surplus base load generation. It will take many years to implement other engineering solutions such as improved storage or improved nuclear maneuvering. If we don't dispatch wind turbines then the IESO will be forced to shut down nuclear units and retail electricity rates and GHG emissions will rise more than planned as more wind turbines are added to the grid.

Shifting the Demand to Manage Wind Variability

Theoretically, a mismatch between supply and demand can be eliminated if we shift the demand to a period when the supply is available. This can be done in two ways. We can provide incentives to get customers to shift their peak demand into the night hours or weekends. The other method is to provide the IESO with the means to lower *and* raise customer demand any time it is necessary.

Shifting customer peak demand into the off-peak hours will usually involve some capital equipment such as smart controllers and process equipment. Unfortunately the current difference between peak and off-peak electricity rates do not provide a sufficient economic incentive to make the capital investment. The ratio of peak to off-peak rates needs to be much higher to provide that incentive.

Consumers on the TOU rate plan pay the peak rate for any power used during the peak period even if that consumer does not use any more power during the day than at night. Effectively the present TOU rate plan penalizes customers who have a grid friendly flat demand profile. OSPE submitted a proposal to the OEB in 2011 to modify the TOU rate methodology to eliminate this penalty. Figure 8 below and Figure 9 on the next page show the present and modified TOU rate methodology respectively. The modified TOU methodology would charge customers a base rate for all their base energy use and peak rates for only their incremental peak energy above their base. This allows the peak rates to be higher so as to better incent customers to shift their loads to the off-peak period.

Figure 8

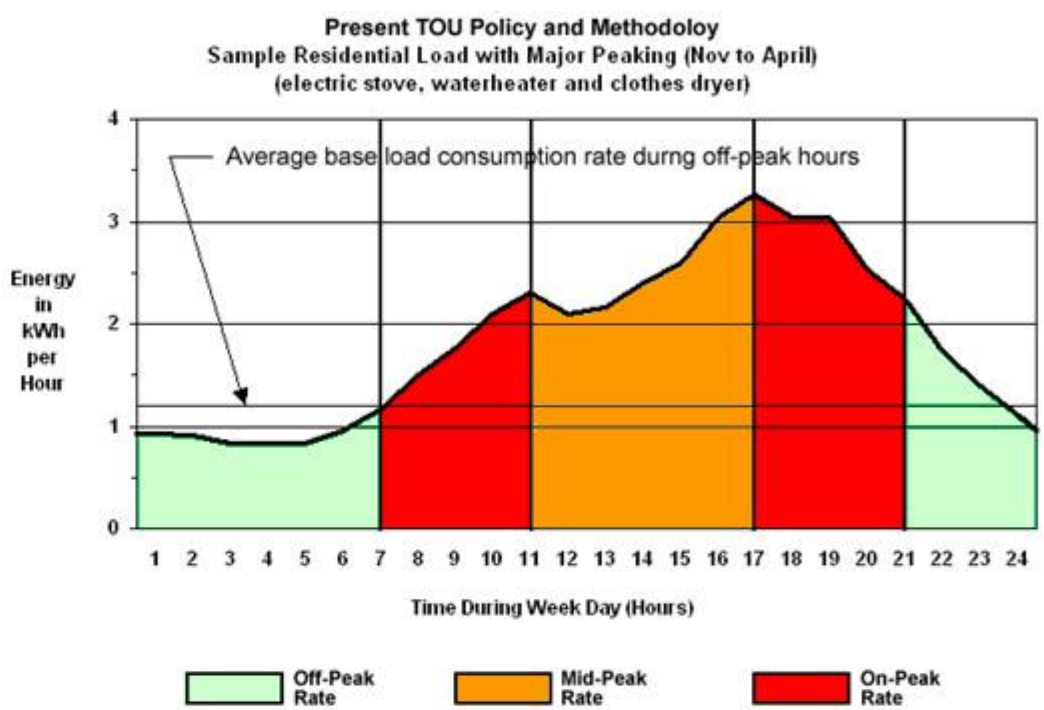
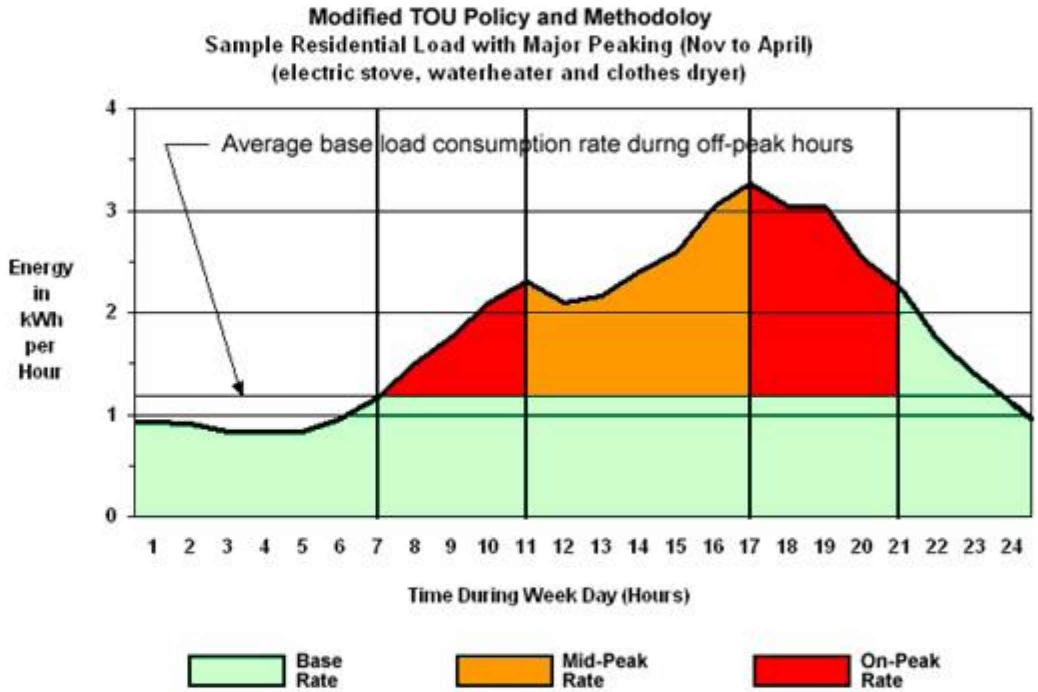


Figure 9



Providing the IESO with the means to adjust customer demand up or down would require us to find customers with the right types of loads that can be managed by the IESO. In order to effectively manage wind generation variability the customer loads must be sufficiently flexible that they can use or store the energy when the wind is blowing. Those loads need to have some form of storage built in or the ability to displace other fuels such as natural gas.

Some utilities in the US have been experimenting with using existing demand reduction schemes in new ways that result in an increase demand when the grid operator wants to drive demand higher. For example if electric water heaters are on a demand management scheme, the grid operator can remotely turn off or reduce their temperature setting during periods when wind generation is low and then turn them on or raise their temperature setting when wind generation is high. This effectively creates additional demand when required even though the demand management scheme was originally designed for a different purpose - to reduce total grid demand when supply is insufficient to meet peak demand.

Water heaters are an ideal storage medium because they operate 12 months of the year 24 hours a day so the scheme is always available. The problem is that in Ontario, there are a limited number of electrical water heaters. Many of these heaters were converted to gas firing over the past couple of decades due to electrical conservation programs and rising electricity prices.

Air conditioning, heat pumps and geothermal storage systems for space heating and cooling could also be used in the winter and summer but they are not effective at shifting the demand during the spring and autumn.

To make IESO controlled demand effective at counteracting wind related surplus base load generation, more willing customers are needed than the minimum required dispatching amount. The reason is that some customers may not be able to provide a demand on some days because their storage is full or their production is shutdown. A smarter information and control interface is also required between the IESO and the customer facilities. Smart grid products will come to market in the next few years that will make demand flexibility easier to implement. Also, to attract sufficient interest and pay for the capital investment needed for this type of demand flexibility, it may be necessary to offer customers price incentives. If the modified TOU methodology described above is not used it may be necessary to create a new class of customers with special metering functionality. Consequently IESO controlled demand is not a simple or quick solution to the large amounts of wind variability we need to manage.

Analyzing various load shifting and storage schemes is not the main purpose of this document so we will not go into details for each application. Below is a list of a few industrial and commercial applications that would help flatten the load profile either by shifting peak load to the off-peak periods or by adding new load to the off-peak periods. The result would be the same, namely, to flatten the load profile and increase demand at night when much of the wind energy is produced and to improve overall grid utilization by lowering the ratio of peak load to base load.

A few typical applications include:

- Creating ice at night for space air conditioning and refrigeration,
- Filling thermal storage for space heating at night,
- Pumping industrial domestic water into storage towers at night,
- Charging electric plug-in vehicle batteries at night,
- Producing industrial commodities such as hydrogen gas at night.

We should make a few comments about two of items above – electric plug-in vehicles and hydrogen production.

Electric Plug-in Vehicles: Judging by some of the popular stories in the press, electric plug in vehicles are going to solve all our electrical grid storage problems. This is simply not possible in the near term. There are two reasons. Firstly, electric plug-in vehicle production is not expected to reach significant production volumes in the USA until 2025 (R42). The most optimistic estimate is 25% of new car production by 2025. It takes about 10 to 15 years to replace the existing fleet of vehicles so electric vehicles will take many years to reach double digit percentage of vehicles on the road. Nearly half of the energy in a plug-in electric vehicle will be needed for passenger compartment space heating and cooling in Ontario’s summer and winter climate. That will reduce the driving range by about half. Consequently, the adoption rate is likely to be lower than the maximum rate mentioned above unless there is a large increase in oil prices or a major breakthrough in battery technology.

Secondly, there is not much energy required to charge an electric car. Most of these cars will have a 20 to 50 kWh storage battery. Lets say 30 kWh on average for discussion purposes. If 500,000 cars or about 8% of Ontario’s passenger car fleet (R48) were electric plug-in vehicles we could completely charge every vehicle every night with about 18 GWh of electricity per day assuming a 20% charging efficiency loss. Between 10 PM and 6 AM we have 8 hours of charging time so we would need 2,250 MW of generating capacity at night to charge these vehicles. We typically have 4,000 MW of off-peak capacity available at night in the spring and autumn and 8,000 MW in the summer. So yes, electric vehicles will help flatten our demand profile, if they are charged at night, but they won’t be a complete solution and not for many years.

If electric vehicles are not charged at night they could make the grid peak load worse or they could create electrical problems on your local residential street. A 230 Volt, 7 kW fast charging station (4 hour charging time) consumes about double the power of a typical high efficiency air conditioner. Therefore some time-based charging controls may be needed to prevent local transformer overloads or a worsening grid peak load.

Hydrogen Production: Articles about the “hydrogen economy” has received some attention recently as GHG emissions have become a greater concern. Hydrogen that is produced when wind energy is available can be used to power an internal combustion engine or fuel cell when wind is not available. This concept is being evaluated (R49). A small amount of hydrogen by volume can also be injected into the natural gas supply with suitable safeguards.

Another concept is to produce hydrogen as a byproduct of other industrial processes at night. Unfortunately due to the capital cost of many industrial processes, there is a strong economic incentive to keep them running continuously at high capacity factor. To operate these facilities at lower capacity factor during the off-peak hours will likely require a substantial incentive.

The barrier to adopting hydrogen as a major fuel in our economy is the current low cost of natural gas. A considerable amount of R&D and time will be needed before hydrogen gas becomes a major component of our energy mix.

5 Life Cycle Costing

Most utilities now are using life cycle costing (LCC) as the basis for deciding what technology will be used to increase generation capacity. LCC has different names in different places. Examples include levelized unit energy cost (LUEC) and levelized cost of electricity (LCOE) in the international literature. We will use the term LCOE in this document. LCOE includes the impact of capacity factor, capital cost, financing costs, fuel costs, operating costs and maintenance costs into the total anticipated costs of the facility recovered via an average cost per unit of energy produced. LCOE is expressed as cents/kWh in North America. LCOE can also include future costs such as carbon taxes, decommissioning costs or long term waste disposal costs.

While LCOE is fairly well understood and established, it is affected significantly by the underlying assumptions used in the calculation. For example, the expected capacity factor of the facility has a significant impact on the LCOE for all facilities. For fuel burning facilities the assumptions for future fuel costs have a significant impact on LCOE. For higher capital cost plants with long construction schedules such as nuclear and hydraulic plants, the financing discount factor will significantly affect the LCOE. Also projected future costs are important for strategic decisions about new energy sources. For example, renewable generation costs especially solar PV are dropping faster than expected, so what may seem expensive today may be economic tomorrow. Consequently, care must be taken when comparing LCOE numbers to ensure the underlying assumptions are clearly understood and accepted.

Comparisons of LCOE data for several technologies from three recognized sources are provided in Table 4 below. In Ontario, the data varies from about 5 cents/kWh for conservation and nuclear refurbishment up to about 80 cents/kWh for solar PV roof top units. Because LCOE data is capacity factor dependent, the three columns in Table 4 below should not be considered directly comparable.

Table 4
New Plant Levelized Cost of Generating Electricity

Type of Plant	IEA/NEA (R2) cents/kWh	US DOE/EIA (R26) cents/kWh	OPA (R4) cents/kWh
Conservation Programs	n/a	n/a	5 to 7
Large Hydraulic	7 to 23	6 to 12	8 to 28
Small Hydraulic	5 to 11	n/a	12 to 13
New Nuclear	6 to 8	11 to 12	n/a
Nuclear Refurbishment	n/a	n/a	5 to 9
Simple Cycle Gas	8 to 11	9 to 12	14 to 54
Combined Cycle Gas	7 to 10	6 to 8	7 to 20
Combined Heat & Power	8 to 27	n/a	11 to 49
Onshore Wind Farms	5 to 14	8 to 12	13 to 14
Solar PV	21 to 63	16 to 32	44 to 80
Bioenergy	5 to 13	10 to 13	10 to 20
Coal to Gas Conversions	n/a	n/a	17 to 47

Notes: (1) The US and CAN dollars are assumed to be at par in the data above. IEA/NEA costs for developed countries have been used and reflect the costs for a 2015 in-service date and a discount rate of 5%. US DOE/EIA data is in 2009US$'s for a 2016 in-service date and a real discount rate of 7.4%. The OPA costs are current costs in 2011. LCOE data is capacity factor dependent so caution should be exercised when comparing data.

(2) If carbon taxes or cap and trade are introduced, then each $30 penalty per ton of carbon dioxide emissions raises the cost of electricity from natural gas-fired plants by about 1 cent/kWh.

We should note that conservation efforts that lower the peak demand (for example high efficiency commercial lighting) are very valuable to the grid. However, conservation efforts that lower the off-peak demand (for example shutting off lights in office buildings at night) is not helpful to the grid because it makes the surplus base load generation problem worse. OSPE is not advocating wasting electricity. We are just pointing out the complexity of the electrical grid and the unintended consequences of some of our decisions. That is why careful engineering, economic and environmental analysis is required before introducing new technology or initiating a major change in direction.

Significant amounts of surplus base load generation will lower the capacity factors of the plants that are dispatched and will create upward pressure on electricity rates.

Figure 10 and 11 on the next page demonstrate how LCOE changes with capacity factor changes due to dispatching for solar, wind and nuclear generation with steam bypass. Figure 10 also shows that if dispatching occurs, the LCOE for wind and solar generation rises very rapidly to extremely high values because these sources have low capacity factors to begin with.

Figure 10
Comparison of Solar, Wind and Nuclear (R2)

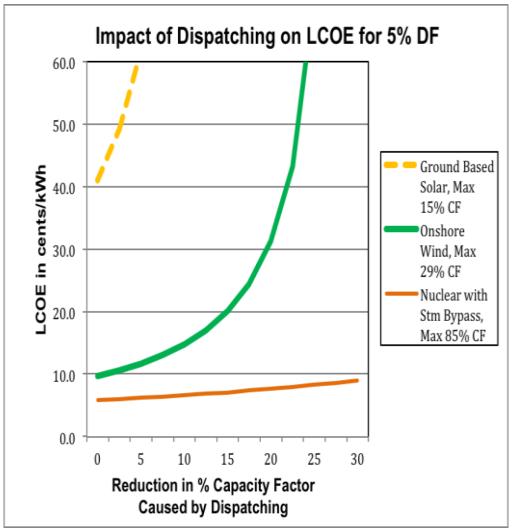
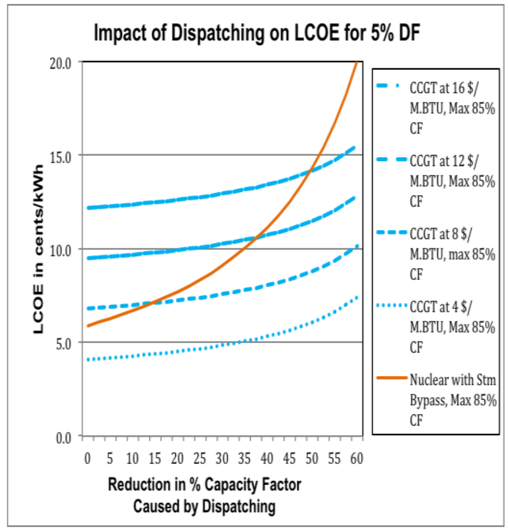


Figure 11
Comparison of Base Load Gas and Nuclear (R2)



Even if wind and solar generation are a small fraction of capacity, these very large LCOE values will impact electricity rates significantly. For illustration purposes, lets say energy demand rises 1% and we want to increase wind capacity by 1% of total grid energy demand to meet that demand increase. Let us also assume that the current average energy price is 7 cents/kWh (close to the average Ontario price in 2011). At an LCOE of 10 cents/kWh for wind energy that is fully utilized at its 29% capacity factor, the rates would rise to 7.03 cents/kWh or about 0.4% for a rise of 1% in wind capacity.
If we need to dispatch wind frequently because it does not produce the energy at the time it is needed the rates would be affected more severely. At an LCOE of 20 cents/kWh (ie: if we use only 50% of the wind energy), the rates would rise to about 7.13 cents/kWh or about 2% for a 1% rise in wind capacity. The more we dispatch wind the greater the impact on rates. At an LCOE of 60 cents/kWh (i.e.: if we use only about 15% of the wind energy) rates would rise to about 7.52 cents/kWh or about 7% for a 1% addition in wind capacity.

Gas fired plants have relatively low capital cots and high fuel costs. These plants do not consume fuel for the foregone portion of production that is dispatched down. Consequently their LCOE curves are less steep than for nuclear plants that have very low fueling costs but relatively high capital costs. This can make gas-fired generation more economic than nuclear generation at low capacity factors. This can be seen on the right side of Figure 11 on the previous page. This is why we use nuclear plants for base load demand and gas-fired plants for peak load demand.

The case of back up service for wind generation is an interesting special situation. Lets look at the Ontario grid in 2018 with 8,500 MW of nuclear generation operating at 85% capacity factor and 7,500 MW wind generation operating at 29% capacity factor. If say 50% of that wind generation was surplus and needed nuclear generation to maneuver down to accommodate wind generation, then the reduction in nuclear capacity factor to allow wind turbines to run would be about (7500*0.5)/8500*29% = 13%. This means that accommodating 50% of surplus wind generation would lower the nuclear generation capacity factor by about 13% from 85% to 72%.

Figure 11 above shows the comparison of LCOE for base load gas and nuclear generation when they are dispatched. For a reduction of 13% in capacity factor nuclear plants are competitive with base load gas-fired plants if fuel costs are above $8 per million BTU. Currently the spot price for natural gas in Canada is below $3 per million BTU ($4 per million BTU delivered to the burner face). In Europe it is about $12 excluding delivery charges and in Japan it is about $16 excluding delivery charges. Long-term contracts for natural gas will be at a higher price. The authors of this document did not have access to the actual prices paid by Ontario plants for their natural gas so this document uses spot prices.

As additional liquefied natural gas transportation capability is developed, the North American natural gas price is expected to rise because gas will be diverted to European and Asian markets. Also if carbon taxes or cap and trade are introduced to limit GHG emissions, nuclear generation will become even more cost effective.

The extent to which the government wants to reduce GHG emissions is a matter of public policy and economics. Decisions on the supply mix related to how much natural gas, renewable or nuclear energy should be installed to achieve GHG emission reductions has significant cost implications for electricity rates in Ontario. There has not been a transparent planning process to determine if the current supply mix is in fact optimal from a cost point of view for both the present and future projections of fuel prices. This is important because electricity prices have a major impact on the ability of our industrial companies to compete in world markets. The projected trends in electricity rates also impact investment decisions on which jurisdiction a company will choose to expand production.

6. Greenhouse Gas Emissions

One of Ontario's objectives to use renewable energy is to reduce greenhouse gas emissions. Coal fired generation emits about 973 g/kWh of carbon dioxide and gas-fired generation emits about 398 g/kWh (R27). Biomass, hydraulic, wind, solar and nuclear generating plants are all zero GHG sources of energy. The overall mix of generation technologies in Ontario resulted in a weighted average of about 134 g/kWh of carbon dioxide emissions for electricity production in 2010 (see Table 5 on the next page).

One way to reduce GHG emissions is to use a zero GHG emitting biomass energy source to back up wind and solar generation. However, the sustainable quantity of biomass in Ontario is limited. Sustainable biomass is the non-usable waste product from various biomass sectors. Therefore only a small portion of the 7,500 MW of wind generation and 2,400 MW of solar generation can be backed up by biomass generation. It would be helpful if the Ontario Ministry of Energy would quantify the recoverable annual amount of renewable biomass and in which locations that biomass would be available.

Another way to reduce GHG emissions is to use nuclear generation to back up wind and solar generation. However, nuclear plants would need a robust steam bypass system to allow the generator to maneuver its electrical output at the speed required by wind generation variability. We are not recommending that reactor power maneuvering be considered at this time. There would be a number of potential technical and licensing issues that would need to be studied and resolved prior to maneuvering the reactor itself on a continuous basis. However, we believe that once steam bypass operations begin, opportunity to sell surplus steam energy and/or reduce wasted nuclear fuel consumption will drive innovation. Industrial steam loads will be found to make use of the surplus steam, as Ontario Hydro did at the Bruce A site in the 1970s and 1980's when some electrical capacity was boxed in at the site due to transmission limitations. We can also expect R&D efforts to find ways to safely maneuver the reactor power to reduce nuclear fuel consumption if all the surplus steam is not required.

Table 5
CO_2 Emissions from Generating Stations

Generating Station Type	CO_2 Emissions (g/kWh) (R27)	Ontario Energy Prod'n in 2010 (R9)	CO_2 Emissions (g/kWh) (R27)	Ontario Energy Prod'n in 2030 (R5)
Nuclear	0	55%	0	53%
Natural Gas	398	14%	398	8%
Hydraulic	0	20%	0	23%
Coal	973	8%	973	0%
Wind	0	2%	0	12%
Solar	0	0%	0	2%
Bio-energy	0	1%	0	2%
Weighted Aver.	**134**	**100%**	**32**	**100%**

Note: The data for natural gas is for an average 45% cycle efficiency. The data for coal is for an average 35% cycle efficiency. Bioenergy is considered neutral with respect to CO_2 emissions.

Nuclear energy is currently the only large scale, zero GHG emitting source of electricity in Ontario that is not limited by geography or weather. Nuclear energy has helped Ontario reduce its GHG emissions safely and competitively for over 4 decades. CANDU reactors have a unique Canadian design with an excellent safety record. They can fuel with Uranium or Thorium. Nuclear energy can provide us decades if not centuries of time to find ways to generate more of our energy needs from affordable renewable sources or perhaps nuclear fusion at some point in the future.

Spent nuclear fuel continues to be a major concern to the public. The Nuclear Waste Management Organization has developed a technical solution for long-term secure storage called Adaptive Phased Management (R51). Public acceptance of that solution will go a long way to removing a major barrier to the wider use of nuclear energy.

For discussion purposes, lets suppose we decided to abandon our nuclear program. We could increase our wind and solar generation capacities. However, in order to avoid building very expensive seasonal storage the proportions of wind and solar relative to gas need to be kept within the gas-fired plants' capacity to load maneuver and provide the required backup. A detailed study would need to be performed to arrive at accurate values. For our purposes lets assume we could manage wind and solar intermittency if the ratio of gas-fired to wind plus solar generating capacity was at least 2:1. Also we will keep the ratio of wind turbines to solar PV at 6:1 because solar energy is much more costly than wind energy.

Table 6 below shows that if we replace nuclear generation with the maximum amount of wind and solar generation backed up by gas-fired plants the carbon dioxide emissions in 2030 would be 512% higher than the current Long Term Energy Plan. If we compare with the 2010 emissions in Table 5 the average weighted carbon dioxide emissions would still be 48% more than in 2010 !

Table 6
CO_2 Emissions from Generating Stations in 2030

	Current Long Term Energy Plan		Nuclear Replaced with Gas, Wind and Solar	
Generating Station Type	**CO_2 Emissions (g/kWh) (R27)**	**Ontario Energy Prod'n in 2030 (R9)**	**CO_2 Emissions (g/kWh) (R27)**	**Ontario Energy Prod'n in 2030 (R9)**
Nuclear	0	53%	0	0%
Natural Gas	398	8%	398	50%
Hydraulic	0	23%	0	23%
Coal	973	0%	973	0%
Wind	0	12%	0	22%
Solar	0	2%	0	4%
Bio-energy	0	2%	0	2%
Weighted Aver.	**32**	**100%**	**198**	**100%**

Note: Totals may not add up to 100% due to numeric round off.

The simplified analysis above suggests that eliminating our nuclear base load generating plants would make GHG emissions from electricity production rise significantly even if we install the maximum amount of wind and solar generation. This occurs because we still need to manage their intermittency with gas-fired generation.

7. Conclusions

General

- The weak economy, successful conservation programs and an aggressive renewable energy program have resulted in severe surplus base load generation periods.
- Due to low electrical demand growth and recent additions to hydraulic and nuclear capacity, Ontario will occasionally have surplus base load generation even if wind generation is dispatched to zero output.
- To protect our investments and jobs in the wind and nuclear generation sectors some creative solutions to manage our surplus generation and mitigate the rise in electricity rates will be needed.
- Ontario's electrical grid is a very large, complex engineered system. It is becoming more complex as the public demands more challenging environmental and economic performance.

- Effective design and operation of the grid requires specialized power engineering knowledge and experience with Ontario's grid and its market design.
- Every energy source has its advantages and disadvantages and each can have a legitimate role to play provided they are properly integrated.
- Wind generation is not properly integrated into the grid resources given the reduced demand for electricity.
- Wind generation can be environmentally benign if deployed in a manner that addresses local residents' health and safety concerns. It can easily be distributed geographically and it has very low operating costs.
- Ontario's existing CANDU reactors have limited maneuvering capability so they are not able to accommodate the variability of wind generation.
- Wind generation has a low capacity factor and its production characteristics do not match well with consumers' electrical demand. This makes it one of the more technically difficult and economically costly energy sources to integrate into Ontario's grid.
- Adding base load generation like wind, hydraulic and nuclear generation when the grid has large amounts of surplus base load generation will drive up electricity rates.
- Electricity rates are being driven to large negative values during periods of severe surplus base load generation because of the market design in combination with the present prohibition on dispatching wind generation and the limited amount of nuclear maneuvering capability.
- The severe surplus base load generation is getting worse.
- We need to manage the severe surplus base load generation before we start to have a significant number of costly nuclear unit shutdowns.
- The IESO is in the process of implementing wind, solar and nuclear dispatching that will eliminate severe surplus base load generation.
- The IESO is in the process of implementing floor prices on energy supply bids so that the market auction will result in acceptable economic and environmental outcomes. Floor process will ensure nuclear shutdowns are minimized but not necessarily eliminated.
- Without a robust steam bypass system, nuclear dispatching will result in nuclear shutdowns.
- Nuclear shutdowns will drive up electricity costs and will raise GHG emissions.
- A sudden halt in construction of wind turbines will likely cause a collapse of this new industrial sector.
- Phasing out nuclear energy by cancelling the Darlington New Build and reactor refurbishment programs will raise GHG emissions significantly because of the need to use gas-fired generation to manage wind and solar energy intermittency and to replace the nuclear capacity.

Root Causes of the Growing Surplus Base Load Generation

- The economic recession in 2008-09 and the slow economic recovery have resulted in a much lower demand that originally planned. Consequently the planned generation additions that are coming into service are making the surplus base load generation problem worse.
- When the *Green Energy Act* was enacted it incorporated policy initiatives used in other jurisdictions that appeared to be working well (ie: adding wind and solar generation <u>without</u> self-contained storage).
- The *Green Energy Act* made wind generation without self-contained storage highly attractive to investors by paying a premium price and making access to the grid easy.

- Hydraulic and nuclear plants provide 75% of Ontario's electrical energy. Existing CANDU nuclear plants have limited maneuvering capability. Hydraulic plants have limited storage.
- Ontario's grid has insufficient daily and seasonal storage capability to manage wind generation's intermittency and seasonality.
- During surplus base load generation periods, wind generation without storage displaces energy from existing zero GHG emitting hydraulic and nuclear generating plants.

Opportunities to Improve Grid Performance

- Adding a 30-40% air-cooled steam bypass system on the roof of the Bruce A units would restore these reactors' full power load rejection and grid blackout recovery capability.
- Improving the existing turbine condenser steam bypass systems or adding an air-cooled steam bypass system on the roof of the existing reactors would eliminate surplus base load generation and forced nuclear unit shutdowns.
- Using nuclear generation to backup the variability of wind generation is uniquely available to Ontario because it will soon have large amounts of both nuclear and wind generation on its grid. Ontario's nuclear generation capacity is sufficient to manage all of the nearly 7,500 MW of intermittent wind generation planned for 2018.
- The benefits of using nuclear units to provide backup for wind generation would be:
    - A near zero GHG emission IESO managed grid,
    - No additional transmission lines would be required,
    - No global warming penalties for our industrial production in the future for electricity that comes from zero GHG emitting energy sources,
    - Industrial process steam would be available near our nuclear plants with a zero GHG footprint,
    - Reduced natural gas demand competition between electricity production and other sectors (e.g.: cooking, space and industrial heating, plastics, chemicals, fertilizers and the transportation sectors),
    - As the economics improve with R&D or changing carbon tax policy, the surplus electrical power could be used directly to produce hydrogen for the industrial or transportation sector, and
    - Once built a nuclear plant has approximately 1/5 to 1/10 the fueling cost of a gas-fired plant so future electrical energy prices will be less sensitive to fuel price increases.

Electrical Grid Planning

- The intermittent nature of wind generation requires that it be explicitly and effectively integrated into the existing grid.
- While social, economic, environmental and political goals can be included as requirements, the actual design and operation of the electrical grid must be based on established power engineering principles so that mandatory technical performance requirements will be met.
- The present grid operating problems related to wind integration demonstrates that additional engineering studies and Ontario specific power engineering expertise are required for implementation planning for wind generation.
- Ontario's electrical grid suffers from:
    - too little customer demand at night and on weekends in combination with,
    - too much intermittent wind generation, or
    - too little nuclear maneuvering, or
    - too little storage capacity.

- The present electricity market price instability during surplus base load generation periods will get worse if wind generation is not effectively integrated.
- The large increase of wind generation capacity (7,500 MW by the end of 2018), while well intentioned, ignores the performance challenges wind generation places on existing base load hydraulic and nuclear generation facilities. The existing facilities have not been designed to cope with the new maneuvering demands imposed by wind generation. The existing base load facilities need to be modified to better integrate with wind generation or substantial seasonal storage capacity needs to be added to the grid or wind generation needs to be dispatched down.
- A reduction in the capacity targets for installed wind generation would help but most of the planned capacity has already been approved.
- Current IESO plans to dispatch wind will help to alleviate the technical performance problems. However, dispatching wind generation frequently, in the absence of other planning and control actions, will drive up the levelized cost of wind generation.
- There is a growing backlog of FIT applications for solar generation. If even half of these applications get approved, we could see surplus peak load generation (SPG) periods in Ontario for the first time during the spring and autumn. Dispatching solar will resolve the SPG problem but it will also drive up the levelized cost of solar and retail electricity rates.

Some Surprises

- Ontario's grid energy supply was already about 75% free of GHG emissions using hydraulic and nuclear plants, before the *Green Energy Act* was enacted.
- As wind production increases, GHG emissions will increase for the base load component of electrical power production in Ontario. This will occur because the gas-fired backup generation required to support wind generation will begin to occupy a larger share of base load generation. Also, if the load demand does not grow, the wind and gas-fired backup generation will force nuclear generation off the grid unless wind generation is dispatched down.
- The shutdown of nuclear generation during severe surplus base load generation periods can result in energy shortfalls the following 2 or 3 days. This will necessitate running higher fuel cost gas-fired plants to make up the shortfall or importing relatively expensive power from neighbouring grids. This will drive up electricity rates and GHG emissions.
- Strong winds during low customer demand periods create severe surplus base load generation conditions.
- Ontario consumers subsidize surplus energy sales at negative electricity prices to consumers in Quebec, New York and Michigan via the global adjustment mechanism.
- The public believes that wind generation is replacing coal-fired generation in Ontario. Because coal is a peak load supply and wind is a base load supply, most of the coal generation is actually being replaced by gas-fired generation that has 50% of the GHG emissions of coal.
- OPG has a different contractual arrangement with OPG for regulated nuclear and hydraulic generation compared to private generators. OPG is not compensated if it bypasses steam at its nuclear plants when it gets dispatched down, but Bruce Power that leases the Bruce B plant from OPG does get paid. Because OPG gets paid more for nuclear power than for hydraulic power it is more economic for OPG to spill hydraulic energy, for example at Niagara Falls, rather than modify its Darlington reactors to be able to reduce their electrical output. Bruce Power, on the other hand, has improved its Bruce B steam bypass system and can offer some limited

maneuvering to the IESO when severe surplus base load generation conditions are present.

- Present OPA and OEFC contracts for electricity production do not incent producers to reduce power output when the grid is in a surplus base load generation condition.
- There does not appear to be any entity other than the Ministry itself that has overall planning ownership of the electrical grid. Ministerial Directives are being used instead of a more rigorous and transparent planning process to establish the supply mix and long-term energy plans.
- Wholesale market prices are significantly lower than the total cost of power production in Ontario. Therefore our exported energy should attract a higher price if it was sold as firm long-term power instead of through the real time (spot) wholesale market.

8. Recommendations

The recommendations have been divided into two groupings, those that can be implemented immediately and those that require more time to carry out detailed studies, analysis and engineering changes to the facilities.

OSPE believes the Minister of Energy should implement the following recommendations as soon as practicable:

1) Modify market rules so that all significant generation resources including wind, solar and nuclear generation will be subject to IESO dispatching.
2) Renegotiate existing OPA, OPG and OEFC generation contracts to ensure the capacity and energy charges combined with electricity market design will align with the economic and environmental needs of the public.
3) Authorize OPG to contract with entities outside of Ontario for the sale of its dependable (firm) GHG-free electricity that is surplus to Ontario's needs.
4) Authorize OPA to adjust the FIT rates and establish annual maximum capacity additions in each category to an affordable level that will sustain the new green energy sectors.
5) Authorize OPA to develop a program designed to better align demand to periods when Ontario supply is available.
6) Assign OPA the overall responsibility of meeting the public's expectations for electrical grid reliability, cost and environmental performance without the need for Ministerial Directives.
7) Establish guidelines for the Ministry of Energy and its related agencies that will ensure appropriate engineering expertise is included during the development of policies, directives and implementation plans of technically complex programs and projects.
8) Maintain the planned nuclear refurbishment program because it promises to deliver the lowest and most stable electrical rates of any energy source with zero GHG emissions.
9) Maintain the planned nuclear new build at Darlington so that GHG emissions can be kept low in the longer term. Include improved reactor maneuvering or a more robust steam bypass system in the technical specifications so that the new reactors do not contribute to surplus base load generation.

In the longer term, the OPA should undertake detailed studies to:

1) Determine if the dispatching capability of existing nuclear plants can be improved economically either through reactor maneuvering or by using a steam bypass system.

2) Determine if additional daily and seasonal storage capacity can be economically added or purchased from adjoining grids (eg: Quebec).
3) Determine if surplus electrical energy can be used economically for new applications such as hydrogen production.
4) Determine if alternate TOU rate structures or other incentives with smart grid capability can be used economically to encourage demand shifting from peak to off-peak periods.
5) Determine whether a common transparent process can be used for OPG, OEFC and OPA contracts for energy supply.
6) Determine the extent of the surplus base load generation problem over the same planning horizon as the Long Term Energy Plan (LTEP) and make those findings public as part of the Integrated Power System Plan (IPSP).
7) Determine the long-term sustainable volume of biomass available (bio-mass from waste) in Ontario that can provide zero GHG backup generation for our intermittent renewables fleet.
8) Determine if it is economically feasible to restore the Bruce A full power load rejection and grid restoration capability and to provide some nuclear dispatching capability to help eliminate surplus base load generation.
9) Determine if it is economically feasible to use nuclear plants to backup wind generation and further reduce GHG emissions.
10) Determine if there is direct linkage between wind turbine noise and public reports of adverse health effects. The dispatching of wind turbines beginning in 2014 may provide an opportunity to shutdown an entire wind farm and conduct a study.

9. Abbreviations

The following abbreviations have been used in this document:

AGC – Automatic Generation Control

ASME – American Society of Mechanical Engineers

CCGT – Combined Cycle Gas Turbine

CHP – Combined Heat and Power

CSPE – Canadian Society of Professional Engineers

DOE – US Department of Energy

EIA – Energy Information Administration, USA

ETF – OSPE’s Energy Task Force

FIT – Feed in Tariff

GHG – Greenhouse Gases

HOEP – Hourly Ontario Energy Price (wholesale market)

IEA – International Energy Agency

IESO – Independent Electricity System Operator

IPSP – Integrated Power System Plan

LCC – Life Cycle Costing

LCOE – Levelized Cost of Electricity

LTEP – Long Term Energy Plan

LNG – Liquefied Natural Gas

LUEC – Levelized Unit Energy Cost

NEA – Nuclear Energy Agency

OEB – Ontario Energy Board

OECD – Organization of Economic Co-operation and Development

OEFC – Ontario Electricity Financial Corporation

OME – Ontario Ministry of Energy

OPA – Ontario Power Authority

OPG – Ontario Power Generation Inc.

OSPE – Ontario Society of Professional Engineers

PV – Photovoltaic

R&D – Research and Development

SBG – Surplus Base-load Generation

SPG – Surplus Peak-load Generation

SMD – Supply Mix Directive

TOU – Time-Of-Use

US – United States of America

10. References

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