



Electricity Generation Optimization in a Period of Surplus Baseload Generation

Carnegie Mellon School of Business

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ONTARIO
POWER
GENERATION

- ⊙ Introduction to Ontario Power Generation and the Ontario power market
- ⊙ Transformation to “Clean and Green”
- ⊙ Coping with Surplus Baseload Generation
- ⊙ Implied CO₂ cost of Renewables in Ontario
- ⊙ Sizing the nuclear fleet for the Ontario System
- ⊙ The value of storage to the Ontario System
- ⊙ Key messages

OPG Corporate Profile

ONTARIO POWER GENERATION

- Owned by the Province of Ontario
- Produces about 60% of Ontario's electricity
- 19,000 MW generating capacity
 - 2 nuclear 6600 MW
 - 65 hydro 7000 MW
 - 5 thermal 5400 MW
- Leases the 6300 MW Bruce Nuclear Plant to Bruce Power
- Over \$32 billion in assets
- Over 10,000 employees
- 2012 revenue – \$4.7 billion
- 2012 net income – \$367 million



- ◉ Safe and reliable production of electricity
- ◉ Deliver value to Ontario as the low-cost generator of choice
- ◉ Provide support for Ontario's Long-Term Energy Plan (LTEP):
 - Shut-down or convert coal-fired generation to biomass or gas by the end of 2014
 - Nuclear power about 50% of Ontario's electricity supply; refurbish Darlington and operate Pickering to its end of life in 2020
 - Manage Hydroelectric, including Niagara Tunnel and Lower Mattagami Projects.
- ◉ Limited role in gas-fired generation.
 - Lennox 2000 MW gas/oil peaking plant
 - Partner in Portlands and Brighton Beach Combined Cycle Gas Turbines (CCGTs)
- ◉ OPG currently is not permitted to participate in wind and solar development.



Niagara Complex: Beck GS and Pumped Storage



Darlington Nuclear GS



April 1, 1999 – split into five entities

ONTARIO **POWER**
GENERATION

The logo for Ontario Power Generation, with 'ONTARIO' in black, 'POWER' in red, and 'GENERATION' in black.

hydro **one**

The logo for Hydro One, with 'hydro' in black and 'one' in red, accompanied by a red stylized 'e' icon.

OEFC
ONTARIO ELECTRICITY FINANCIAL CORPORATION

The logo for the Ontario Electricity Financial Corporation (OEFC), featuring the acronym 'OEFC' in large gold letters on a dark red background, with the full name in smaller white letters below.

ieso

The logo for IESO, featuring a blue globe icon with yellow grid lines to the left of the text 'ieso' in blue.

A Quick History of the Ontario Electricity Market

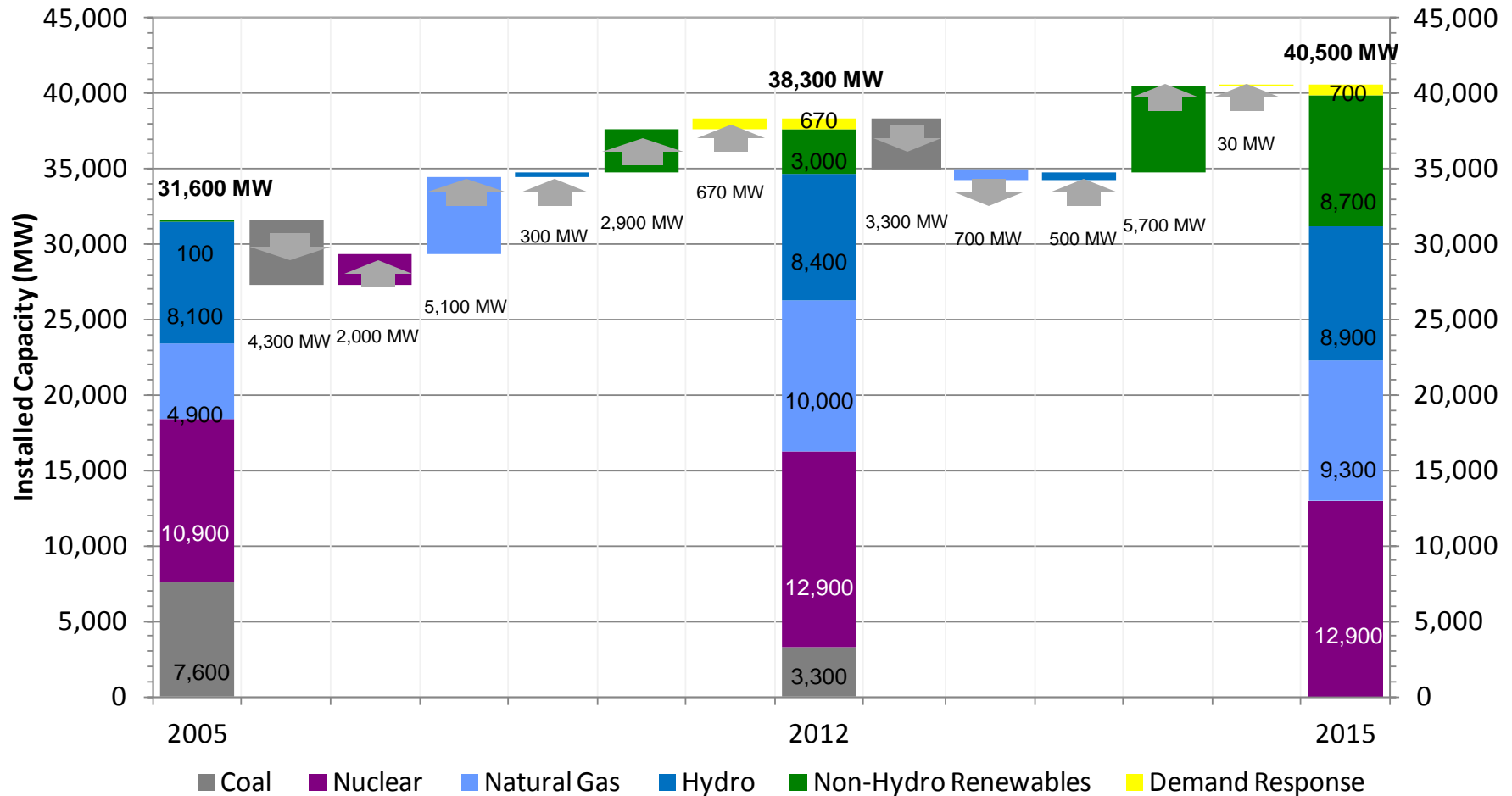
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- ◉ In May 2002, the Ontario electricity market was opened to competition, both wholesale and retail. It was designed as an energy only market. The Hourly Ontario Electricity Price (HOEP) is the average of the 12 five-minute market clearing prices.
- ◉ In the early years of the market, supply was tight and market prices were very high, but consumers were somewhat protected via various rebate mechanisms that limited OPG's earnings.
 - In 2002, in a run-up to provincial elections, the retail market was called off.
- ◉ Subsequently, OPG's nuclear and baseload hydro assets became regulated by the Ontario Energy Board (OEB). OPG's peaking hydro is still exposed to market price (HOEP).
- ◉ In 2003, Ontario government embarked on a path to shut down all coal-fired generation in the province. After several delays, this is now a reality; the use of coal will be almost eliminated by the end of 2013.
- ◉ In 2005, the Ontario Power Authority (OPA) was formed to contract for clean, efficient gas and renewable generation and manage conservation and demand management in the province.
- ◉ In 2010, the Provincial Government issued a Long-term Energy Plan which mandated that OPA contract for 10,700 MW of renewable generation, in addition to the 9000 MW of hydro now on the system or coming into service shortly.
- ◉ Since 2005, and especially after 2008, electricity demand in Ontario has declined rapidly, due to a sluggish economy and conservation and demand management.
- ◉ With 18 nuclear units still in service and the rapid rise of renewable generation, Ontario now finds itself in a surplus situation even with coal retirement.

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Capacity Transformation in Ontario, 2005-15

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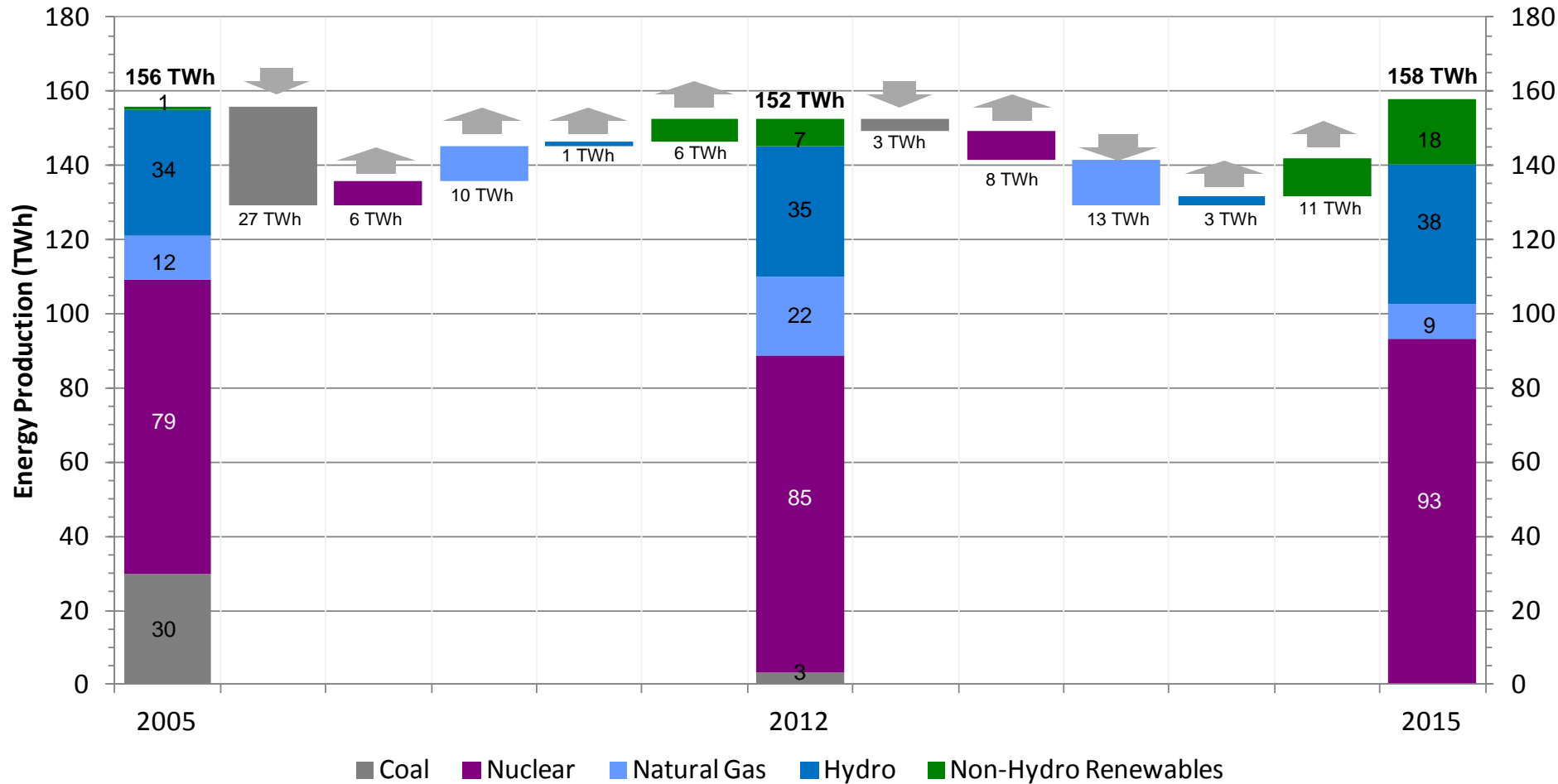


APPrO 2012 – presented by Amir Shalaby – OPA

Source: IESO/OPA. Figures have been rounded.

Energy transformation: coal is replaced by 2014; gas is replaced by non-emitting sources going forward.

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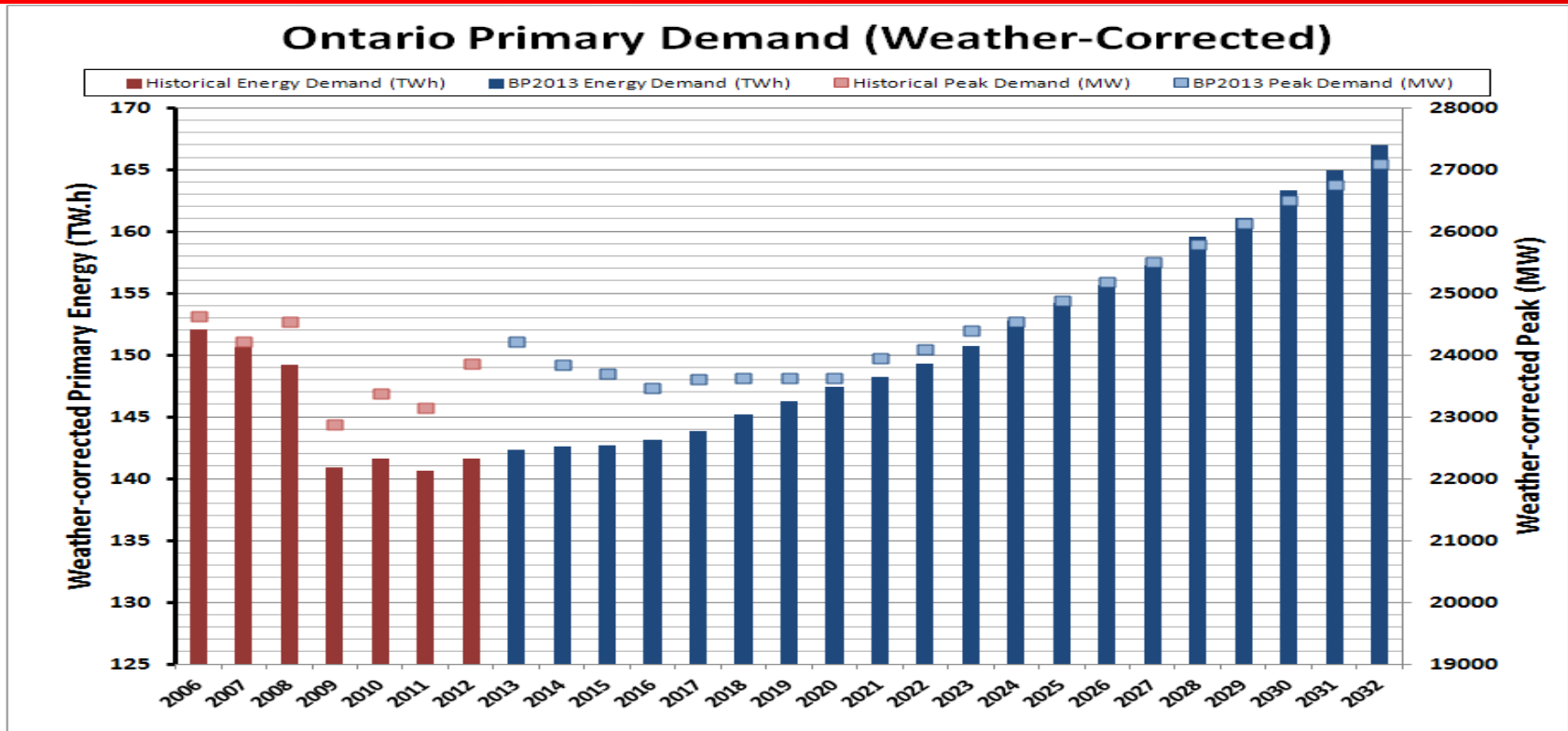


APPrO 2012 – presented by Amir Shalaby – OPA

Source: IESO/OPA. Figures have been rounded.

Primary Demand returns to previous peak around 2025

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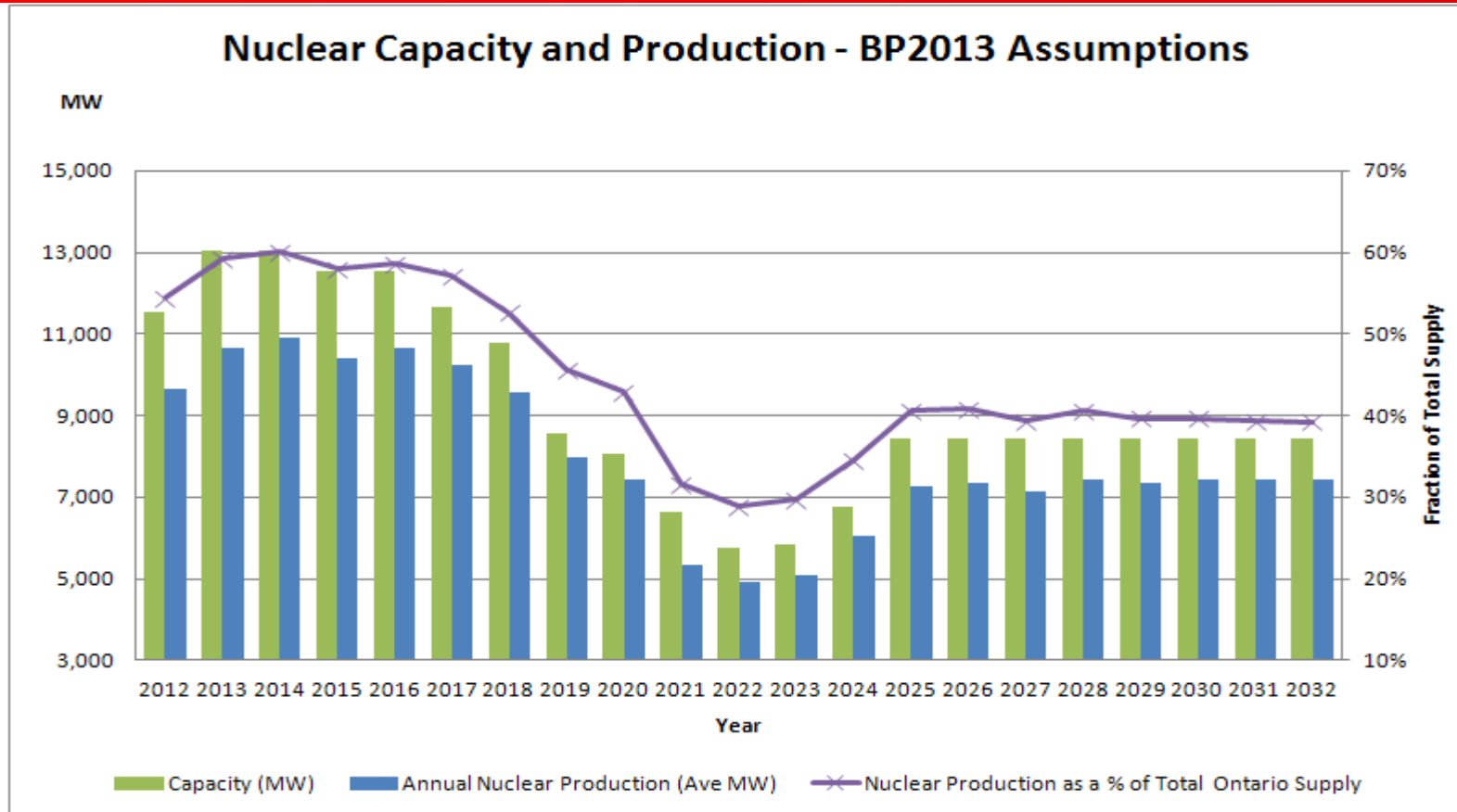


- Collapse of heavy industry resulted in more energy decline than peak. Peak demand sustained by growth in air-conditioning load in residential/commercial buildings.
 - Energy down 8% from 2006 to 2012, peak down 3% in the same period.
- Ontario energy demand remains almost flat through 2015 with annual growth rate less than 0.3% through 2016 then grows 0.5% to 1.0% per year thereafter.
 - Demand depressed as customer cost increasing about 40% over the next 10 years.
 - In OPG forecast, time-of-use rates, real-time pricing, 5 CP program, demand response and conservation programs tend to push peak down proportionately more than energy going forward.
 - OPA shows a decline in annual energy to 2017 and nearly catches up to OPG forecast by 2031; peak higher than OPG after 2016.

- ◉ At the end of 2012, OPG had 7000 MW of installed hydro capacity with an effective capacity at the time of summer peak of 5500 MW.
 - The long-term average annual output of the existing hydro fleet is 34 TWh or about a quarter of Ontario's current demand.
- ◉ OPG's baseload hydroelectric generation on the Great Lakes receives rates that are regulated by the Ontario Energy Board:
 - Beck Complex at Niagara Falls: 2000 MW
 - Saunders GS on the St. Lawrence River near Cornwall: 1000 MW
- ◉ With the exception of a few small newer units, OPG's remaining hydro resources are fully exposed to the market clearing price.
 - Most of these generating units have some storage capability, ranging from a few hours to a few weeks.
 - Ontario's hydro does not have large reservoirs like Quebec, British Columbia and Manitoba that can offer seasonal or multi-year storage.
- ◉ Several new hydro projects will add 500 MW and 2.5 TWh to the grid between 2013 and 2015. There are no further active plans for hydro development at this time.
- ◉ Hydroelectric generation in Ontario pays a water rental fee for all water that is passed through a turbine to produce electricity. This can be considered the 'fuel' cost of hydroelectric generation. The water rental fee varies by the size of the station.

Nuclear Capacity will be need to be refurbished later this decade.....

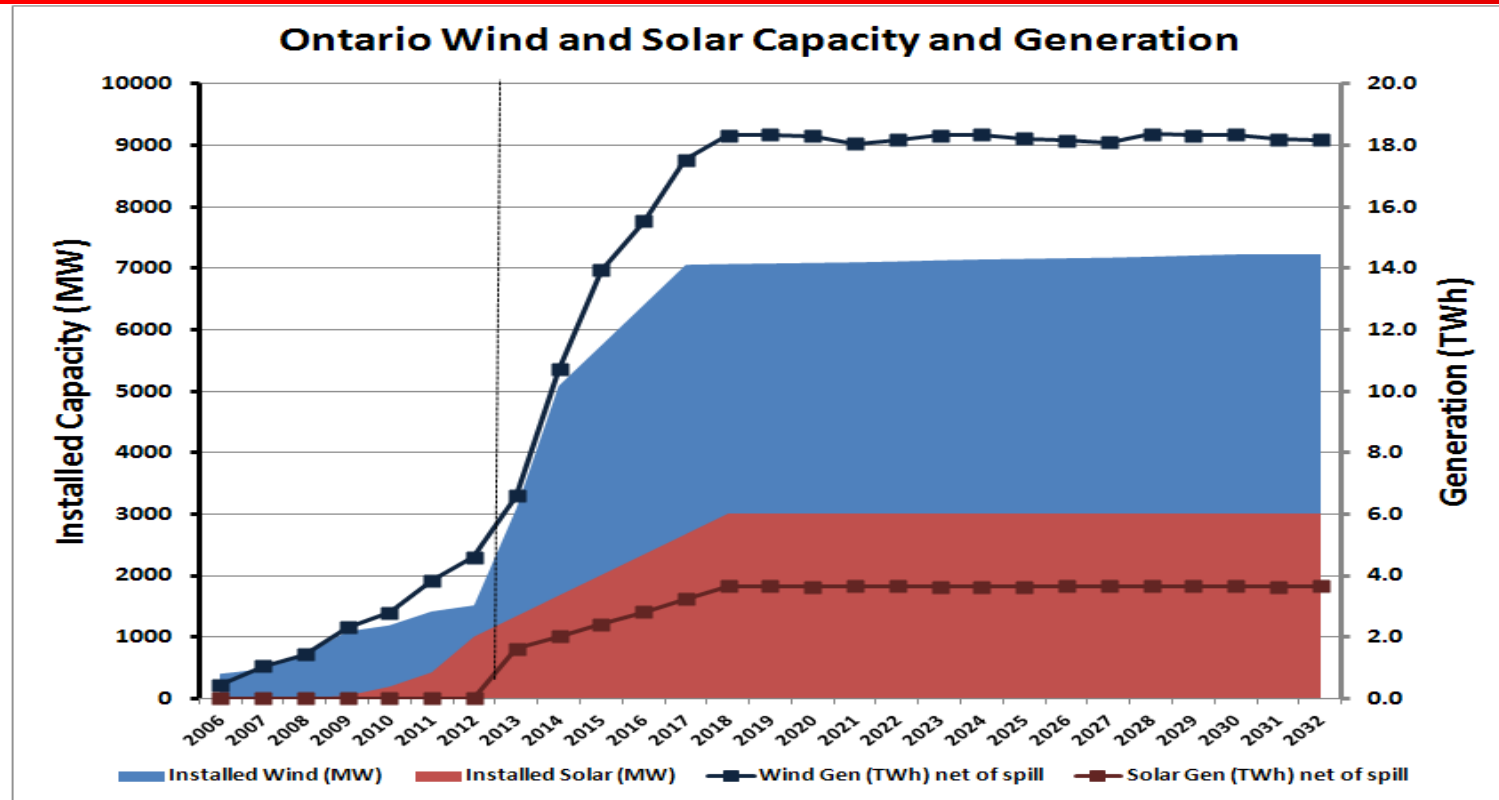
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- 6 Pickering Nuclear Units are expected to be retired by 2020 (3000 MW).
- Two (1500 MW) of the 4 Bruce A units have already been refurbished. OPG's BP2013 assumes that the 4 Bruce B units (3400 MW) will be refurbished starting in 2018.
 - The plans for the Bruce nuclear units are uncertain at this time.
- There is reasonable consensus that the 4 Darlington units (3800MW) will be refurbished between 2016-2024.

Wind + Solar grows to 10,000 MW and 22 TWh by 2018

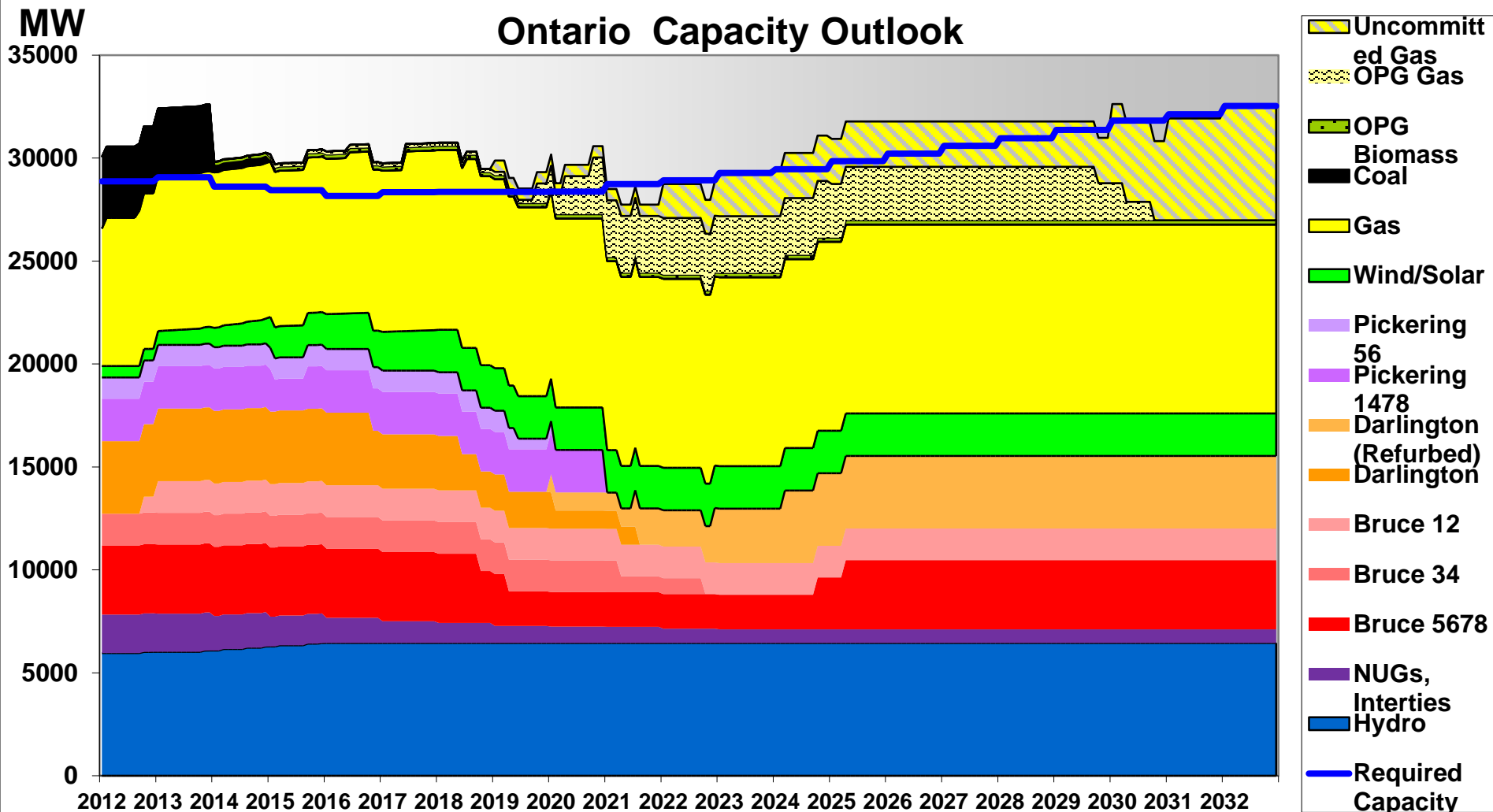
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- ⊙ High proportion of 2018 targets effectively committed.
- ⊙ Effective summer peak capacity contribution from 10,000 installed MWs is about 2,000 MW.
- ⊙ Greatest renewable energy growth step occurs from 2013 to 2014.
- ⊙ FIT Wind modeled as dispatchable, and hence curtailable for SBG, as per MR-381 with 90% offered at -\$10/MWh, 10% offered at -\$25/MWh.

Ontario Effective Capacity Outlook

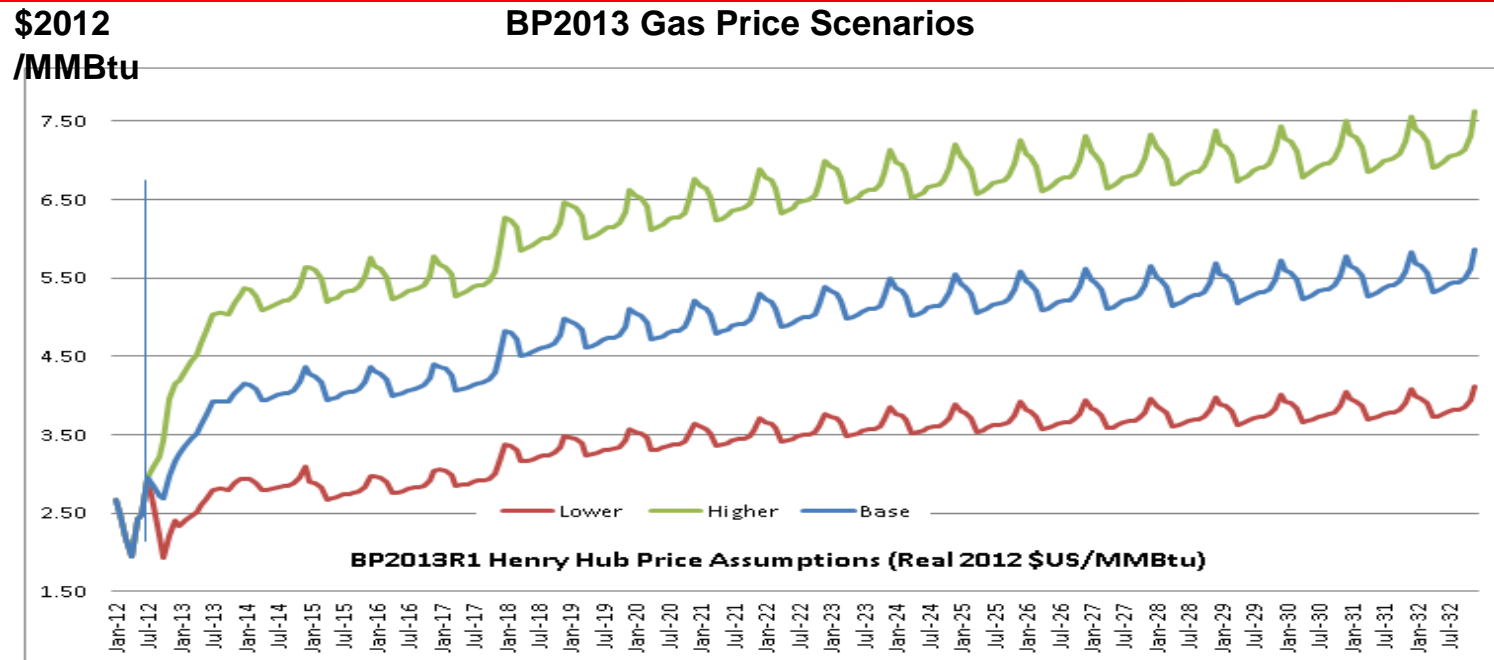
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- The effective capacity at the time of the seasonal weather normal summer peak is shown vs. the required capacity (including a 20% reserve margin). The solid colors indicate installed/committed capacity. The shortfall will have to be made up by converting OPG's coal units to gas and/or building new Combustion Turbines (CT's).

Natural Gas prices expected to recover to over \$4/MMBtu by 2014, about \$5 by 2020 and \$5.50 long-term.

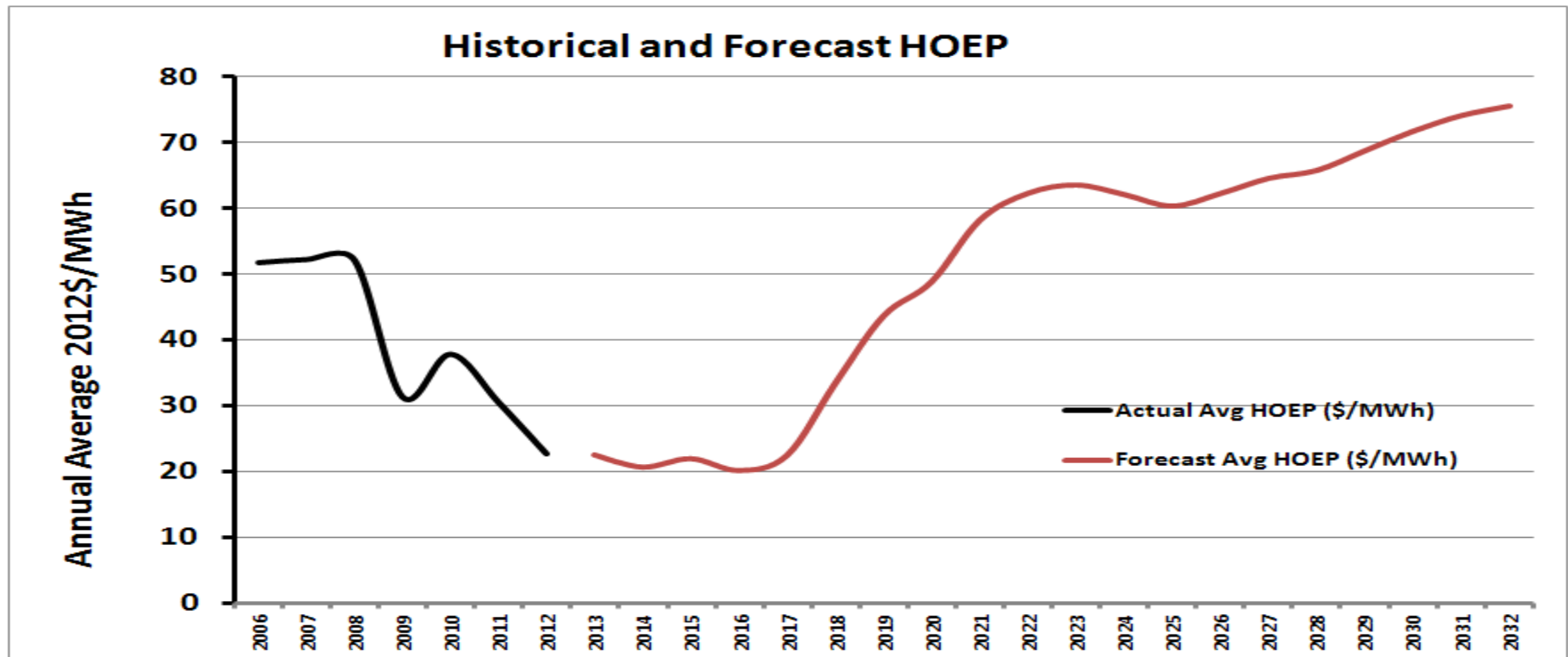
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- Ontario has traditionally had a reliable supply of gas delivered through the TransCanada pipeline from Western Canada. A strong hub has evolved at Dawn near Sarnia with good storage capability for the Ontario market.
- With the development of shale gas in the US Northeast, new transmission is being built to connect these reserves into and through Ontario to enable ongoing stable supplies.
- Increasing interest in exporting Liquefied Natural Gas (LNG) from North America to Asia will slowly push Henry Hub prices towards world levels if shale gas production evolves as generally predicted.
- BP2013 includes carbon adders starting in 2018 at \$15/tonne and increasing at \$3/tonne/year.
 - By 2030, the carbon adder is \$50/tonne, which adds about \$25/MWh to gas-fired generation at a blended CCGT/CT heat rate.

HOEP expected to average less \$20/MWh until nuclear refurbishment starts

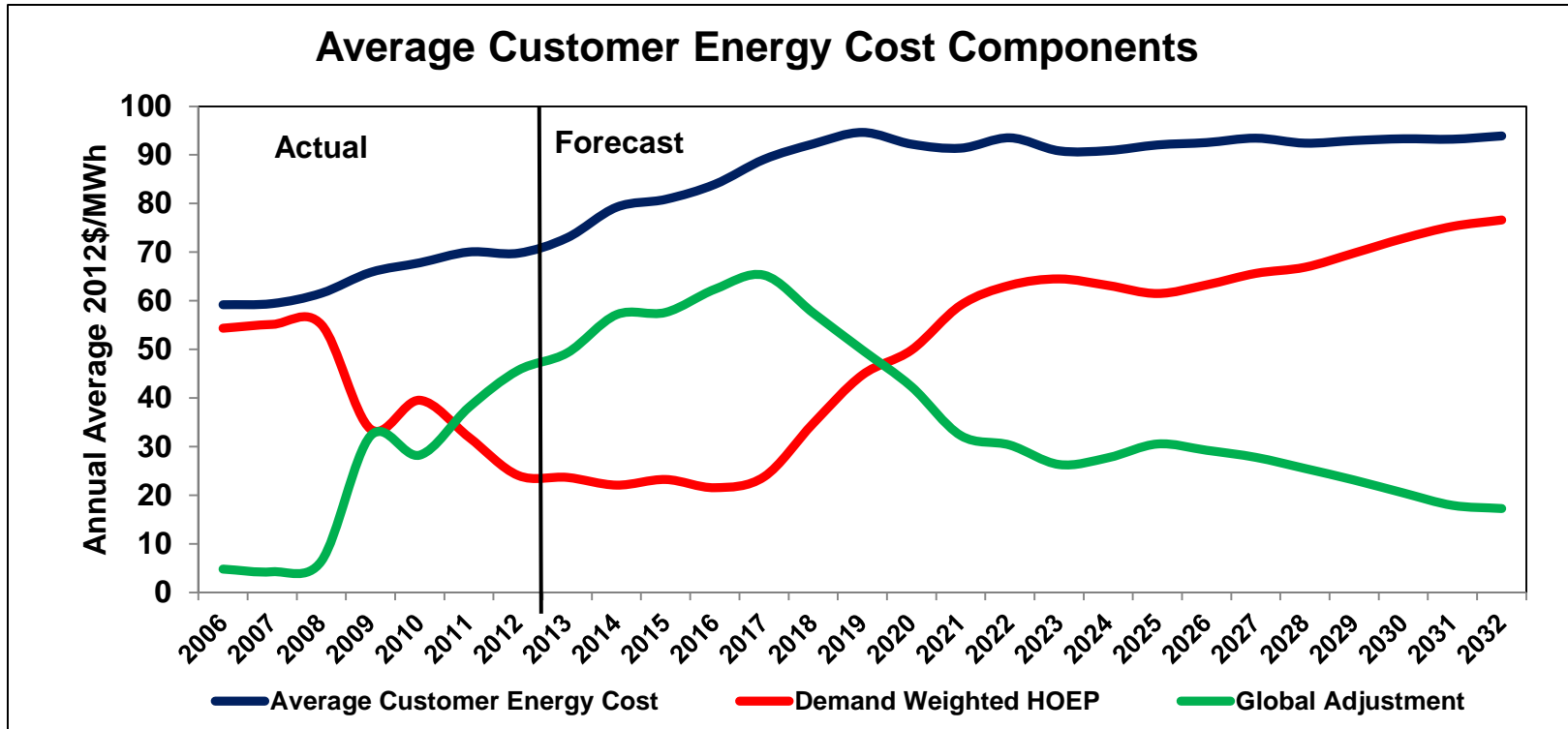
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- Annual Ontario HOEP expected to be in the \$20/MWh range through to 2017 as the impact of increasing natural gas prices is more than offset by increasing volumes of renewable energy.
- Nuclear refurb outages drive Ontario HOEP to levels set by the high heat rate gas units (Lennox, converted coal units).
- After the nuclear refurbishment, increasing gas prices and projected CO2 costs will keep increasing HOEP.

Components of Energy Cost

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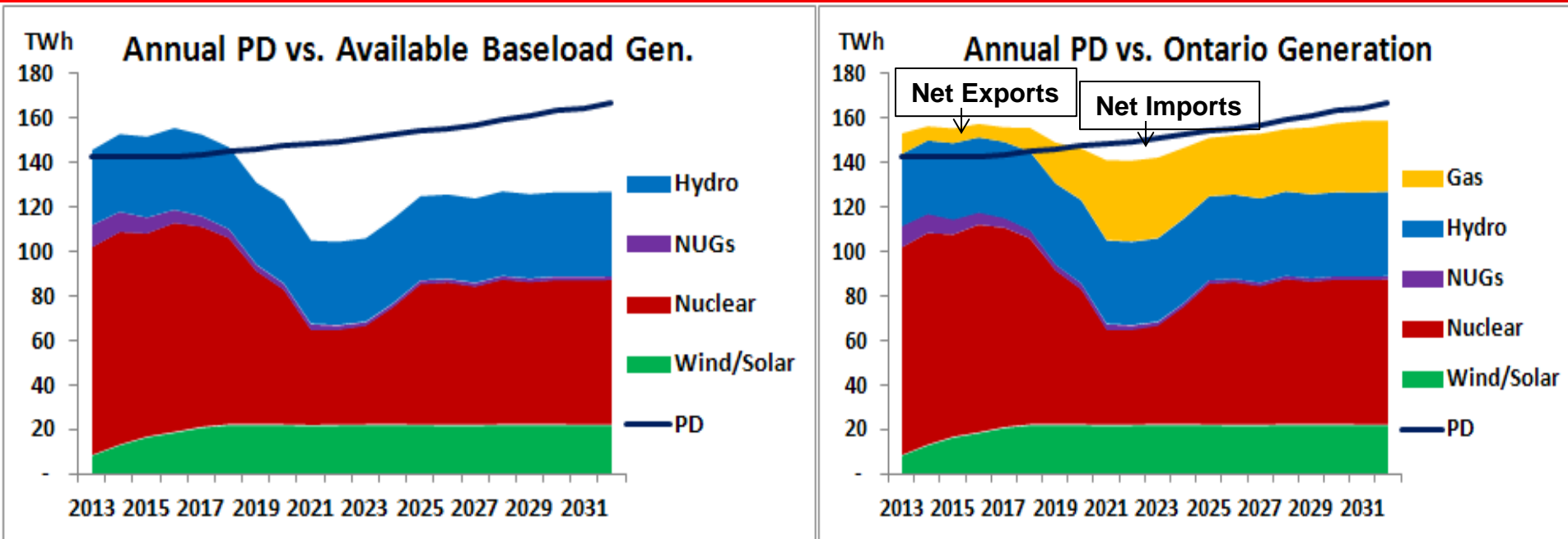


- In Ontario, the Global Adjustment (GA) mechanism is a charge to customers that recovers the difference between the market price and revenues owed to regulated and contracted generators. Conservation and demand management expenditures are also recovered through GA.
 - Currently, GA is allocated to the wholesale cost of power equally across all hours.
- Before nuclear refurbishment starts in Ontario, the GA is much higher than the market price of electricity.
- After the nuclear recovery, and with higher gas prices, the market price rises, the GA diminishes and the average customer cost of energy stabilizes.

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Annual Demand vs. Ontario Generation

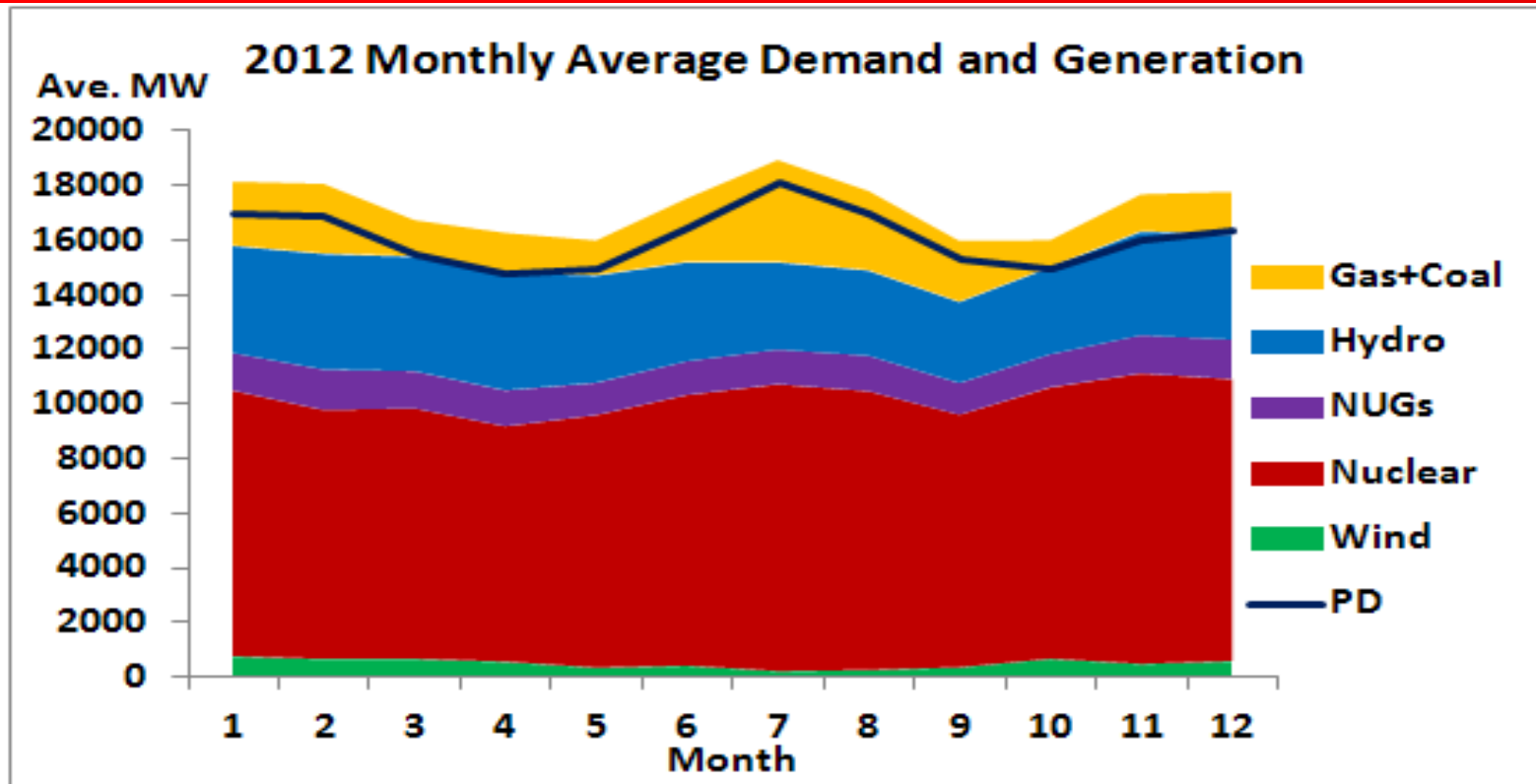
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- ⊙ Baseload generation is defined as:
 - Low marginal cost and no CO2 emitting generation such as nuclear, hydro or wind/solar
 - NUGs who have a contract ensuring that they can run
- ⊙ In the 2013 to 2018 period the sum of this generation is more than the Ontario Primary Demand (PD), therefore some of this generation is surplus to the needs of the Ontario Electricity Consumer.
- ⊙ Gas is dispatched when baseload generation is not available to meet demand.

2012 Monthly Average Demand and Generation Profiles

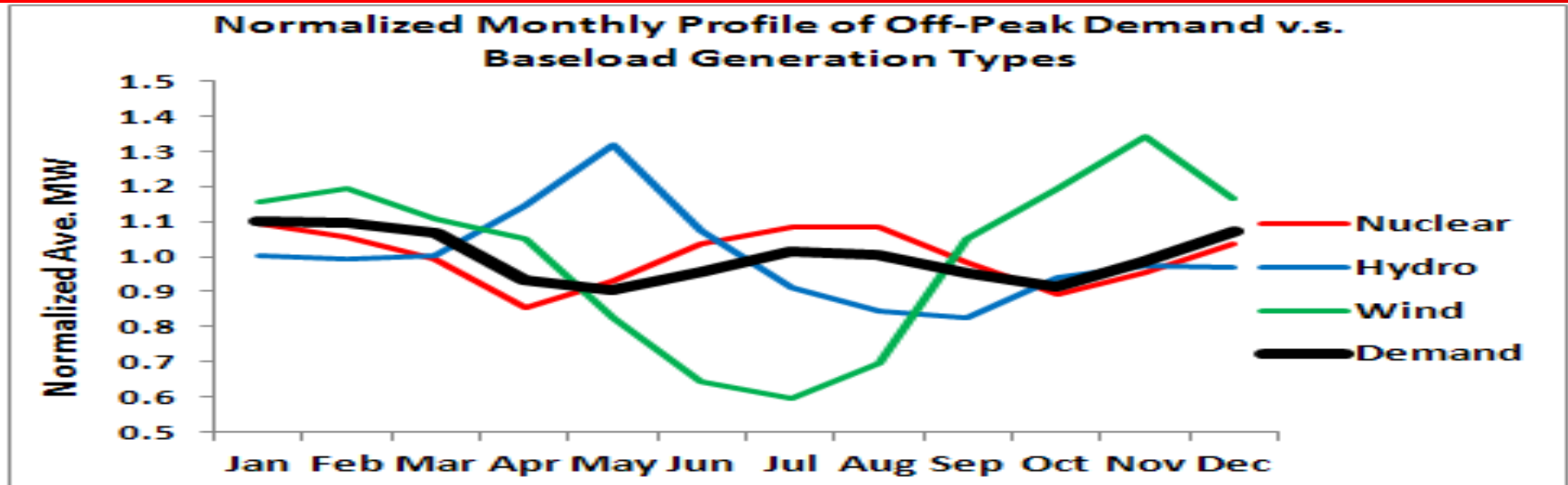
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- The monthly average demand profiles shows that the Ontario system is clearly summer peaking.
- The Ontario system has been net exporting on average every month.
- However, in 2012, it does not yet have more baseload generation on average than demand. That starts in 2013.
- There was a small amount of SBG in 2012, due to the timing mismatch between demand and baseload generation.

Monthly Profiles of Off-peak Renewable Generation

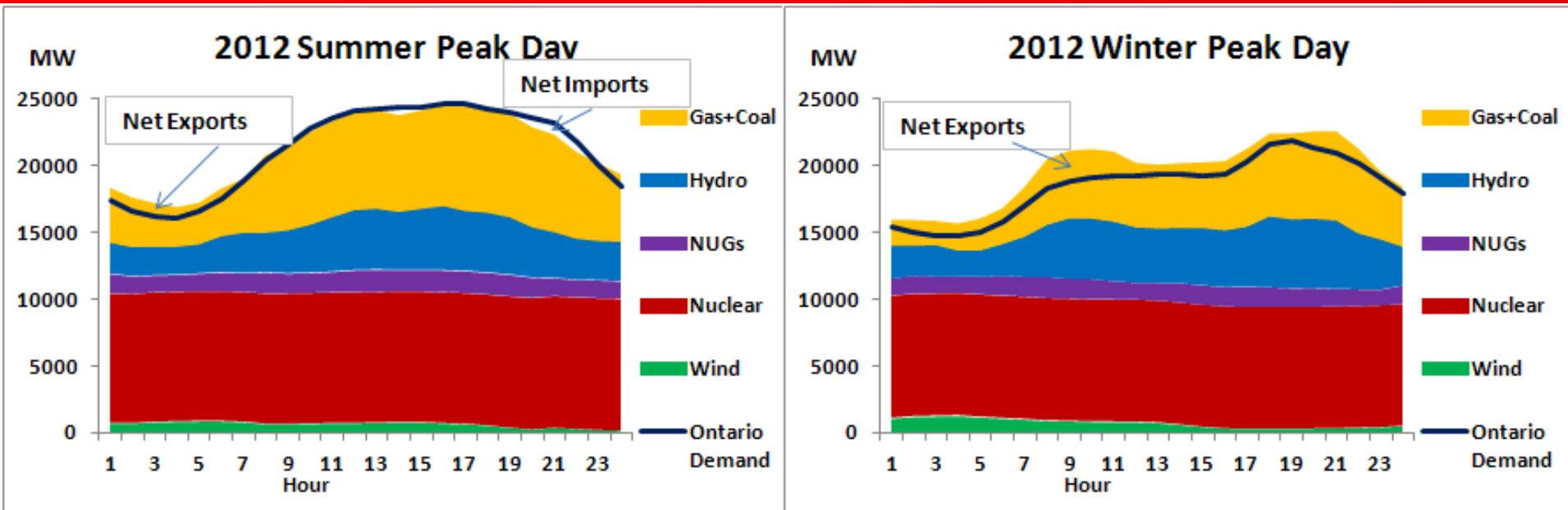
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- Off-Peak energy demand is lowest in the spring and fall. When combined with spring hydro freshet and relatively strong winds in the shoulder seasons, April-June have the greatest surplus energy.
- The nuclear planned outage schedule contributes significantly to reducing spring and fall surplus.
 - Conversely, because nuclear planned outages are not typically scheduled for the summer, the amount of surplus energy in the summer can be higher than the winter.
 - Higher off-peak demand in winter than in summer also contributes.

Summer and Winter Demand Profiles

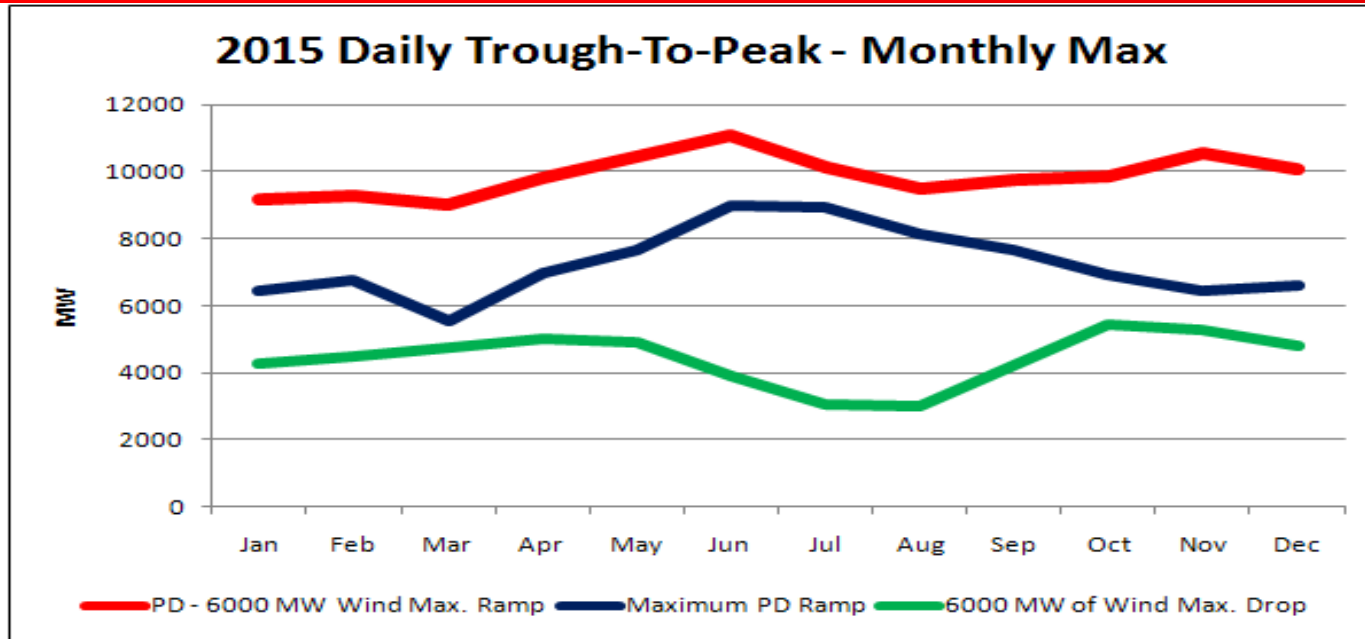
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- In summer, demand in Ontario peaks in the early afternoon, due to air conditioning load.
 - This gives rise to the largest intra-day ramp requirement.
- In winter, there are two peaks, one early in the morning and the other around 6 pm.
 - The daily maximum ramp requirement is less than in the summer, but the daily energy requirement is higher.
- The flexibility of the peaking hydroelectric is used to follow demand net of wind. The remainder of the supply balancing is by gas and coal.
- Because there are some days when night time load has no A/C and the next day may be very hot, Ontario requires about 10,000 MW of ramping capability.

Monthly Pattern in Daily Maximum Ramp Requirement

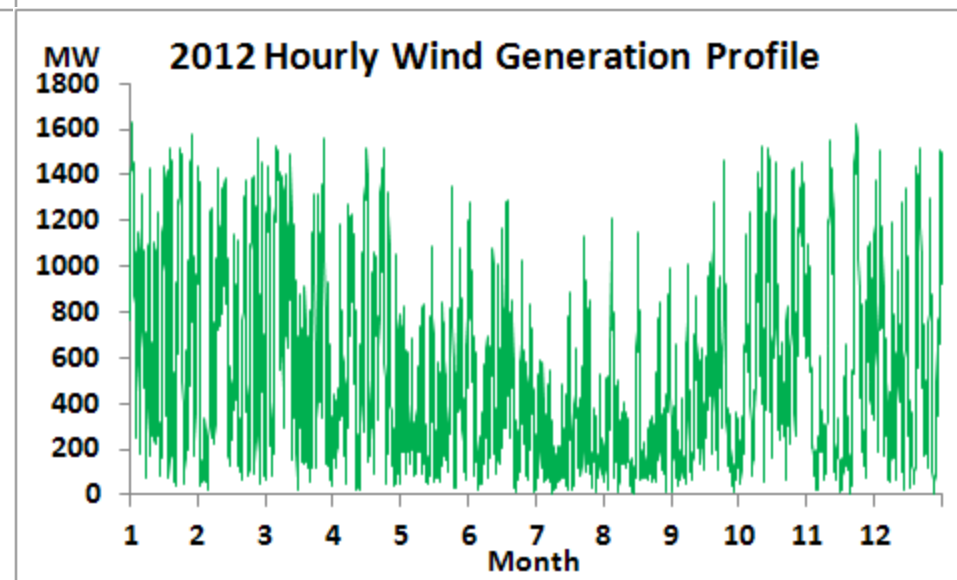
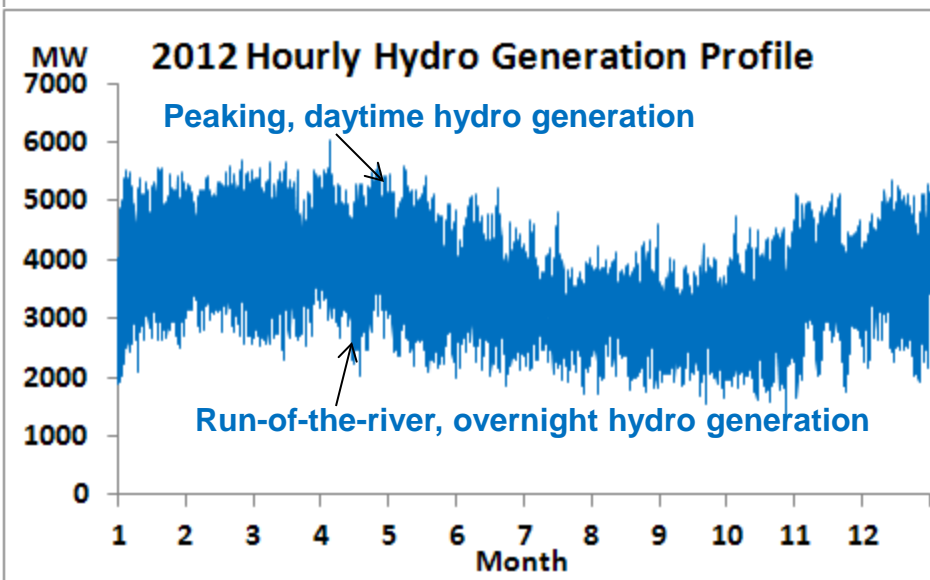
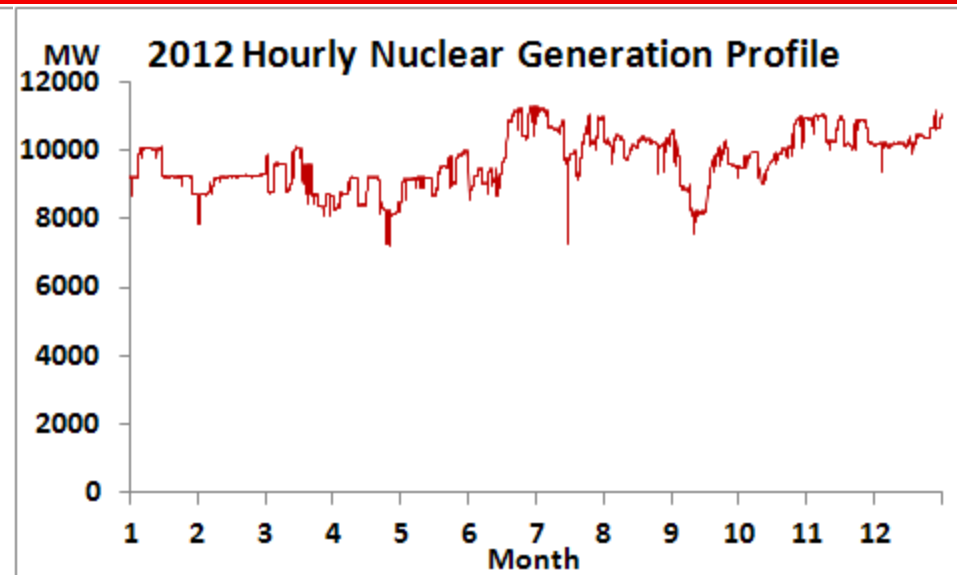
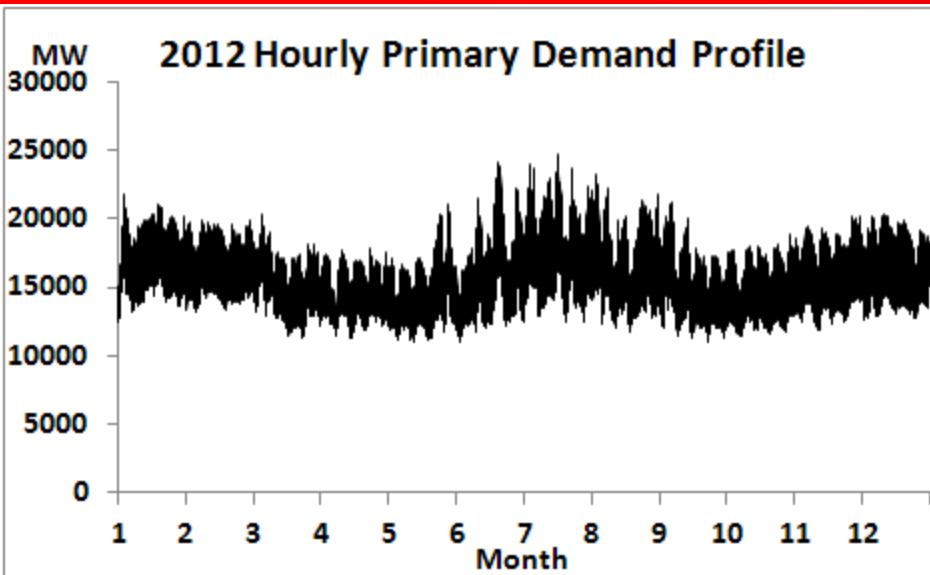
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- ⊙ The maximum daily ramp of the demand profile occurs in early summer, when there is not a lot of air conditioning at night, but it gets really hot during the day.
- ⊙ The worst wind drop on a daily basis occurs in the spring and fall; the least in the summer.
- ⊙ The combined effect of rising demand and decreasing wind generation increases the daily ramp requirement in winter drastically. It also adds moderate additional ramp requirement in the summer.
- ⊙ With the addition of wind capacity, the maximum ramp requirement to be met by hydro and thermal system could occur almost any time of the year. As well, the daily peak requirement on the dispatchable system could occur at any hour of the day.

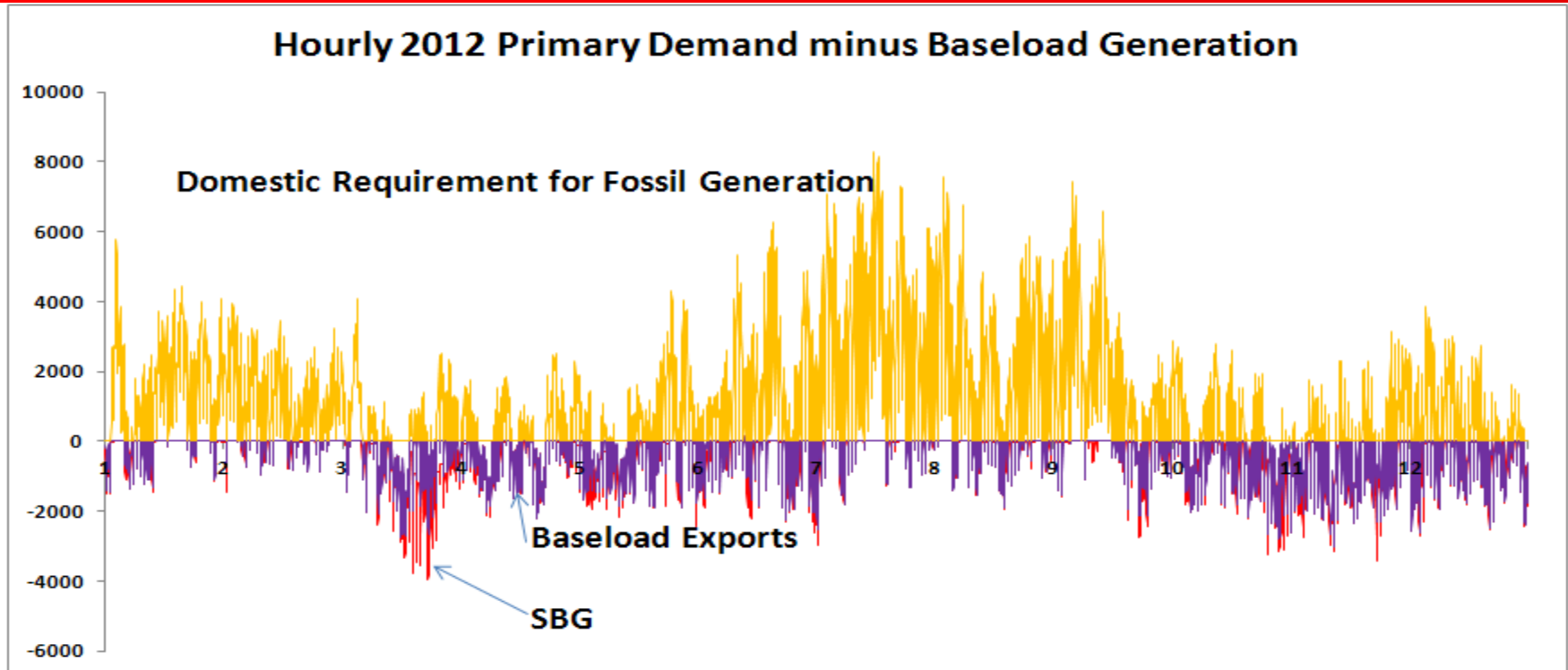
Hourly Profiles of Demand and Baseload Generation

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Actual 2012 Hourly PD-Baseload Generation

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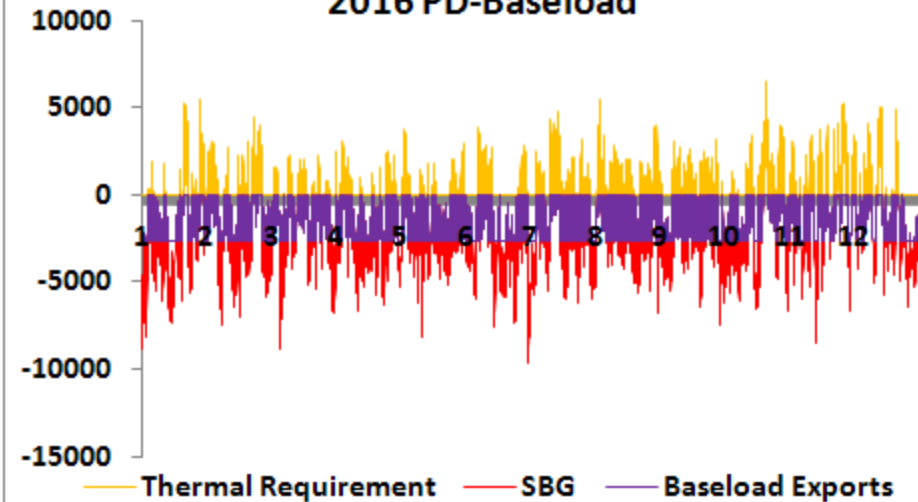


- When the Hourly PD-Baseload Generation (PD-Nuclear-Hydro-Wind-Solar-NUGs) is positive, domestic demand must be met with fossil generation (coal or natural gas) or imports.
- When the Hourly PD-Baseload Generation is negative, this potential surplus energy can be exported (at a loss to Ontario customers) or it becomes SBG (spill).
- In 2012, SBG was a relatively rare occurrence, amounting to less than 0.5 TWh. It was managed by spilling water and occasionally maneuvering nuclear units.

2016-Worst SGB, 2021-No SGB

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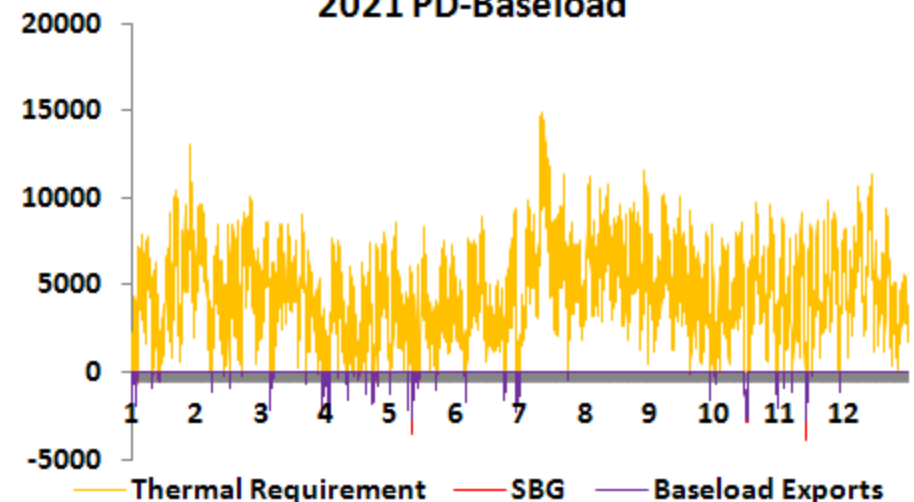
2016 PD-Baseload



- With wind and solar being added rapidly in the next few years with sluggish demand growth net of conservation and demand management, baseload exports and SGB are forecast reach their peak in 2016.
- Prices are expected to clear at baseload/spill prices sometimes all day.

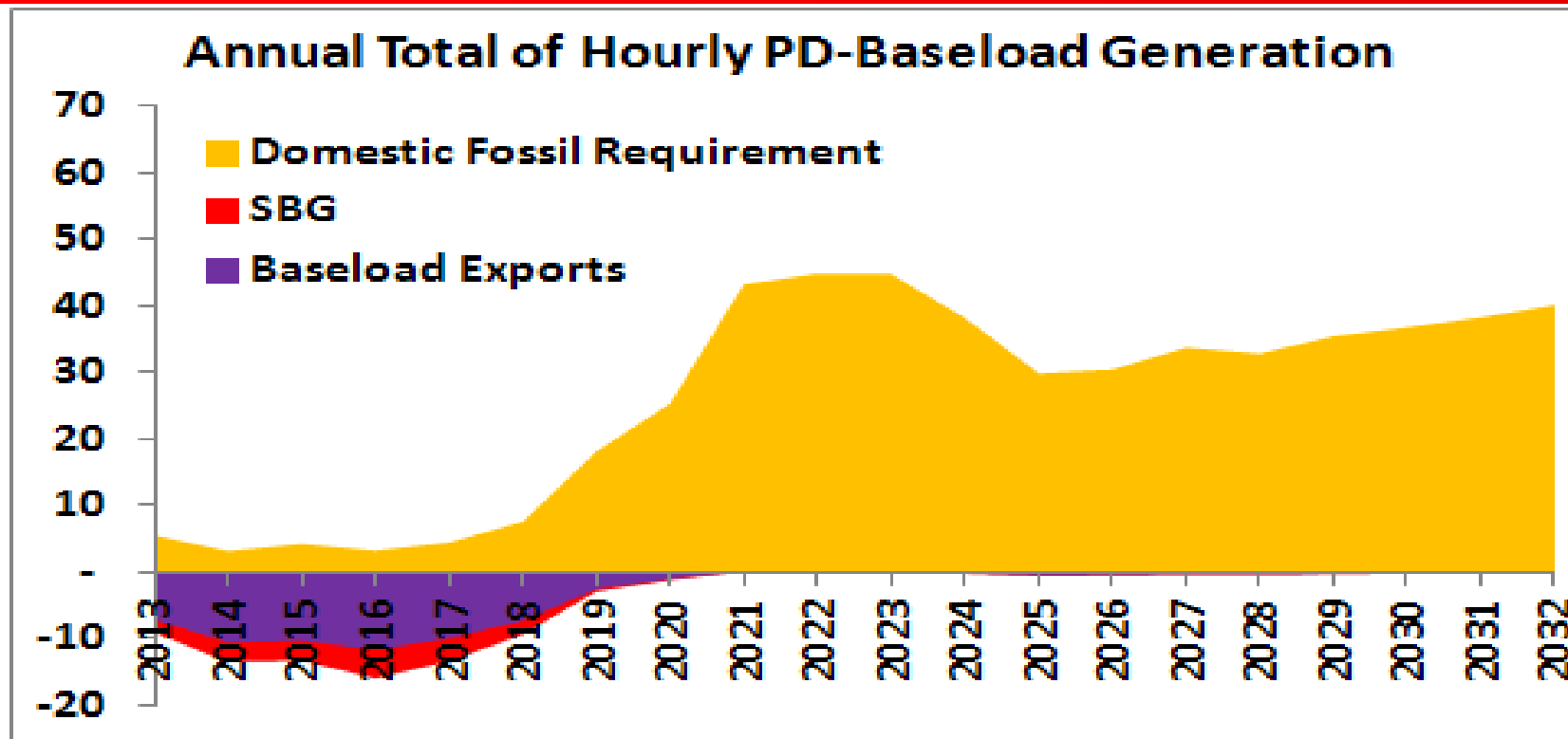
- In 2021, with 6 nuclear units at Pickering retired and some Bruce Power and Darlington Nuclear units under refurbishment, the surplus problem will disappear.
- The market will clear at gas prices, either CT or CCGT.

2021 PD-Baseload



Annual Summary of PD-Baseload Generation

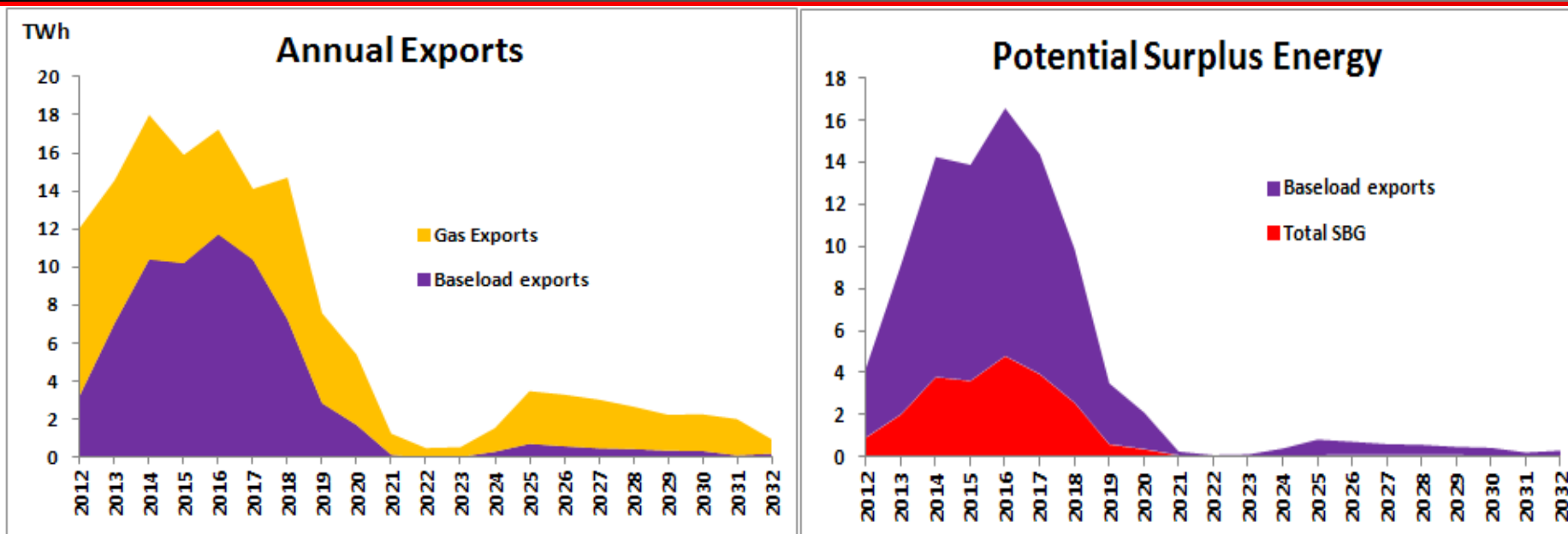
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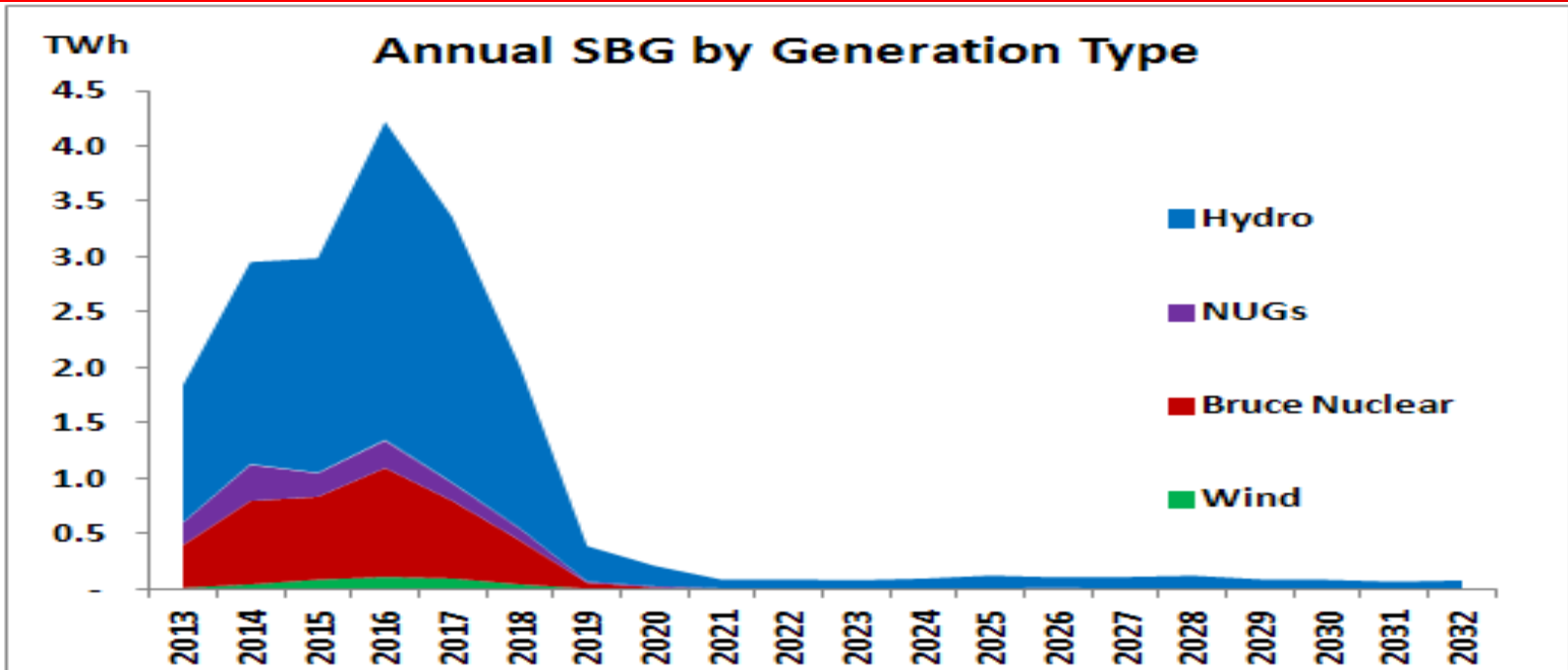
- The current surplus period is forecast to last until nuclear refurbishment starts.
- Due to the timing mismatch between renewable generation and electricity demand, even in the worst surplus years, there is some demand for fossil generation.
- After the refurbished nuclear units return to service, with the presently forecasted level of nuclear capacity, potential surplus energy and SBG will be negligible.
- During the nuclear refurbishment period, the domestic demand for gas/imports will be up to 55 TWh per year.

High net exports will continue until 2018

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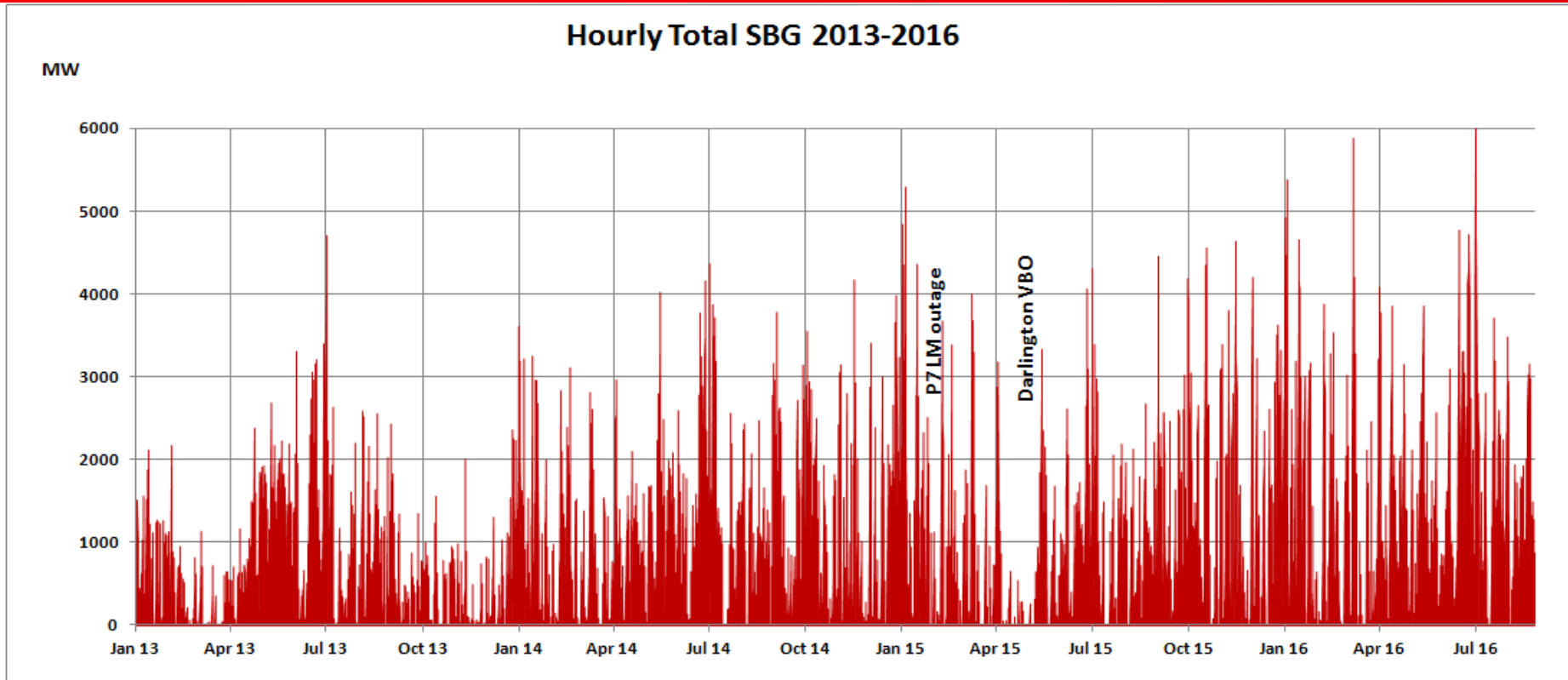
- The province's net exports average about 15TWh per year from 2013 through to 2018.
- Ontario exports gas-fired generation at market prices, but up to 12 TWh per year of excess baseload generation is expected to be sold at well below cost in the export market.
 - When exporting fossil generation, Ontario usually recovers the marginal cost, except if the units were offered at unit commitment prices and are required to stay on for the minimum up-time at their minimum laminations.
- In addition to baseload generation exported at a loss, surplus energy includes SBG in Ontario of about 4 TWh per year. Total potential surplus energy of up to 16 TWh a year is projected from 2013 to 2018.



- BP2013 assumed that a new set of market rules designed to facilitate the integration of Renewable Energy (MR-381) would come into effect.
- Under this regime, hydro generation spills first, followed by 2400 MW Bruce Power units manoeuvring and the residual SBG will be handled by spilling wind.
 - This is achieved by introducing a floor of -\$5/MWh for Bruce manoeuvring and -\$10 to -\$25/MWh for wind.
 - In practice, the IESO says it will use wind dispatchability to micro-manage small changes in SBG and Bruce manoeuvres will be committed in 300 MW blocks.
- Between 2012 and 2015, Ontario's Local Distributing Companies (LDC's) have been allocated \$350 million per year to deliver conservation programs.
- Without renewables, SBG in the pre-nuclear refurbishment period would be reduced by 80%.

Simulated Hourly Total SBG (2013-2016)

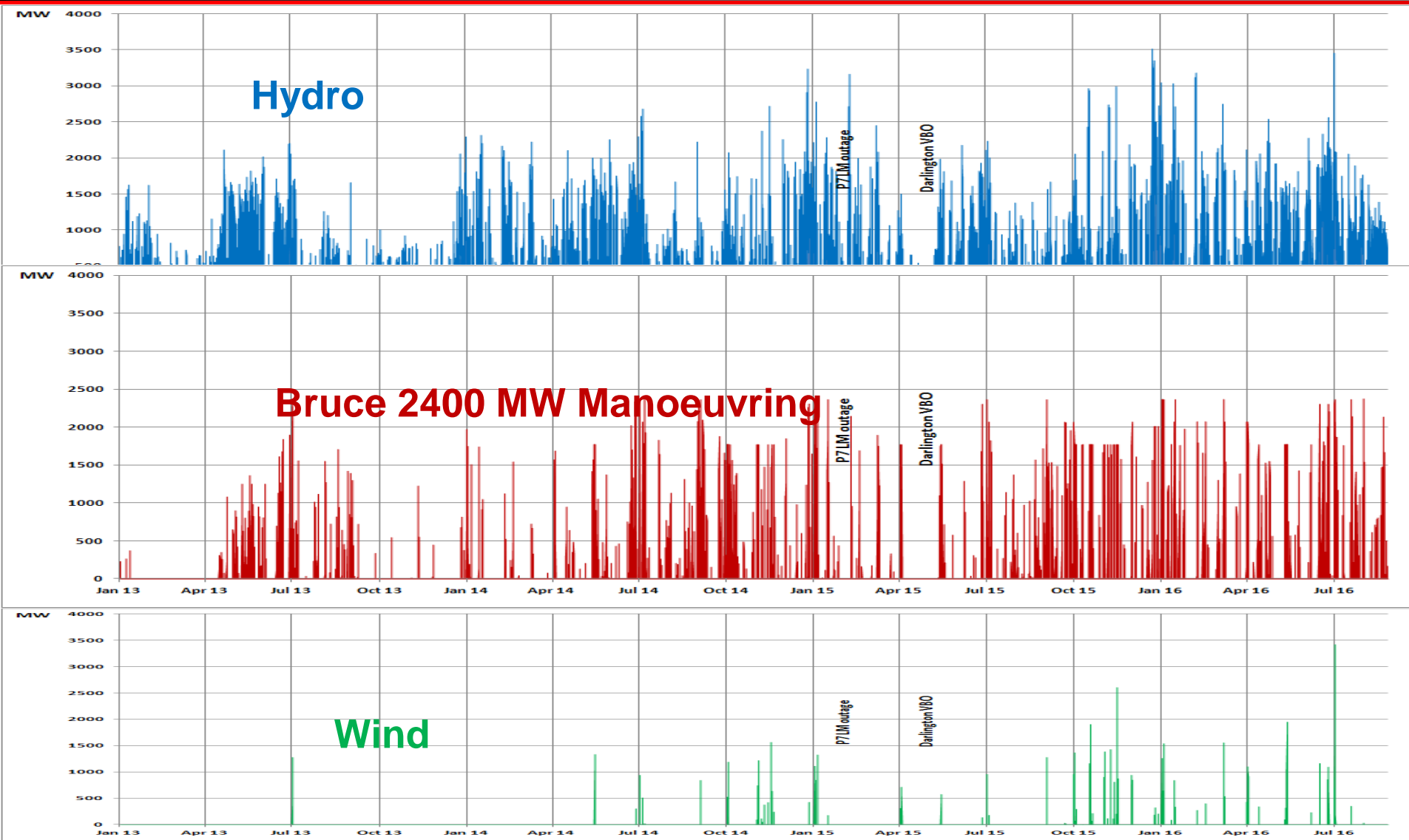
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- In the 2013-2016 period, SBG occurs in 45%(!) of hours, requiring OPG's hydro to be spilled for about 3500 hours/per year.
- Approximately, 8% of hours, or 700 hours/year, will require nuclear manoeuvring after all spillable hydro has been spilled.
- The residual SBG will be handled by wind. Wind will be called on to be dispatched down about 0.8% of the time or about 70 hours per year.

Hourly SBG by Generation Type (2013-2016)

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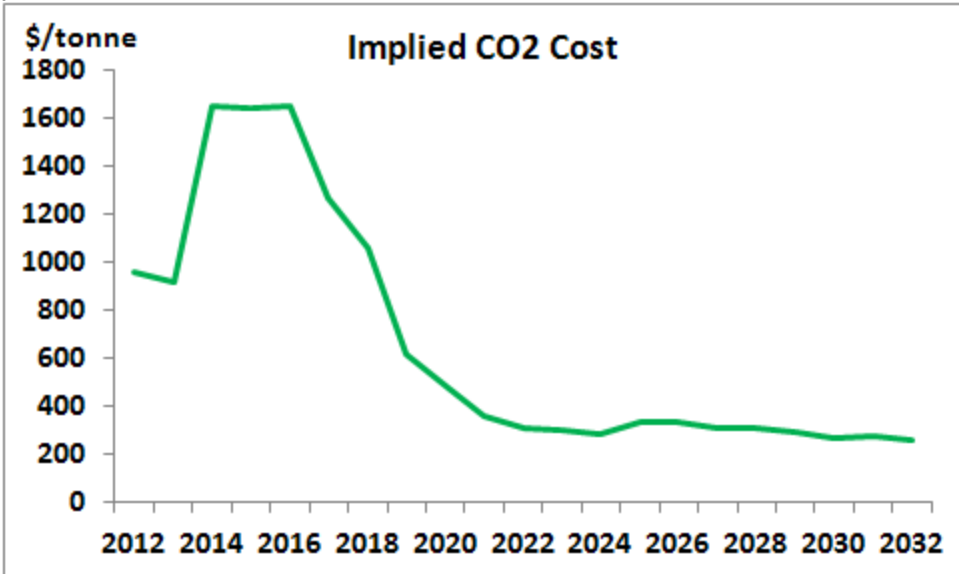
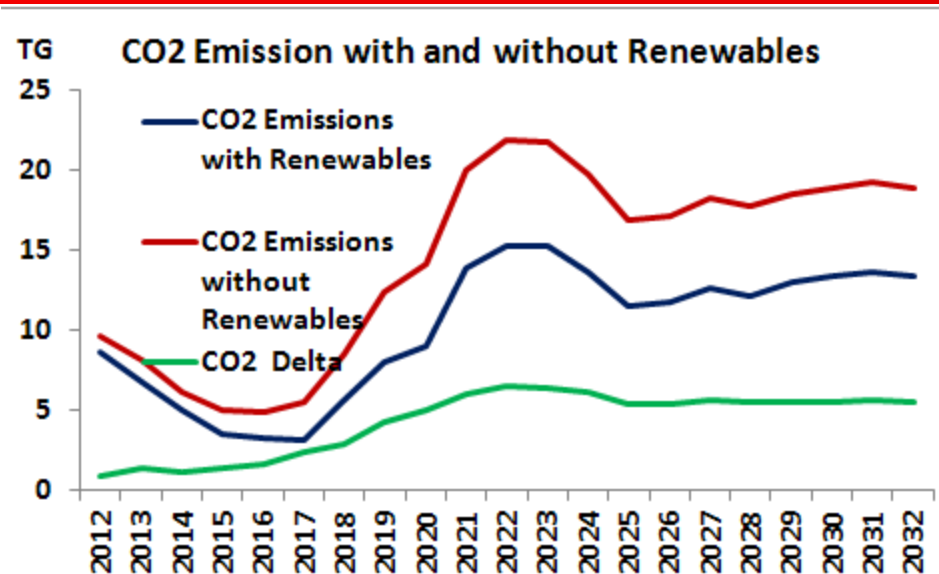
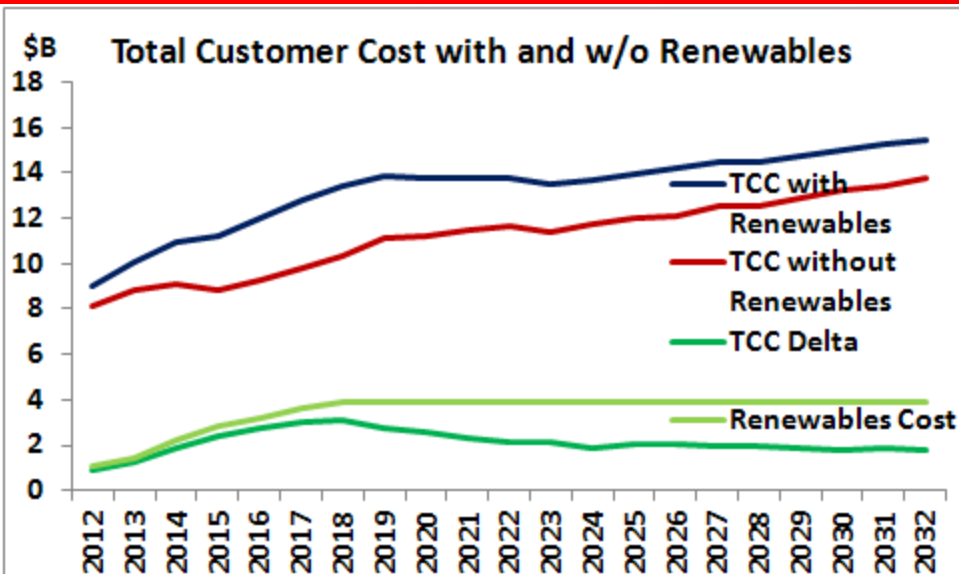
- ◉ OPG's non-regulated hydro resources are offered into the market in a manner which is designed to at least recover their marginal running cost, recognizing the water rental fee.
- ◉ It is in OPG's financial interest not to generate when the cost of production (including water rental fee) exceeds the revenue earned from the market, as any production would be at a loss in net revenue.
 - Much of the time, water can be stored in the forebay to avoid generating
 - However during and following periods of high runoff, storage capability can be limited or exhausted. All water must then be utilized to generate to the extent feasible, or be passed through sluice gates as spill.
 - With some foresight, hydroelectric spill can be initiated earlier in an effort to mitigate negative revenue impacts. These pre-emptive hydroelectric spill tactics are known as 'pre-spill' for short.
- ◉ There are many operational considerations that may limit the ability to spill or pre-spill. However, for most scenarios where excessive surplus generation is expected in many hours over a longer duration of at least 5 days, the economics of pre-emptive hydroelectric spill are usually favourable and, as good utility practice, it is the right thing to do.
- ◉ It is ironic that over the next few years, these spilling tactics may be precipitated to accommodate an excess supply of wind offering with a negative floor price.

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Implied CO₂ Cost with and without Renewables

- a measure of system optimality

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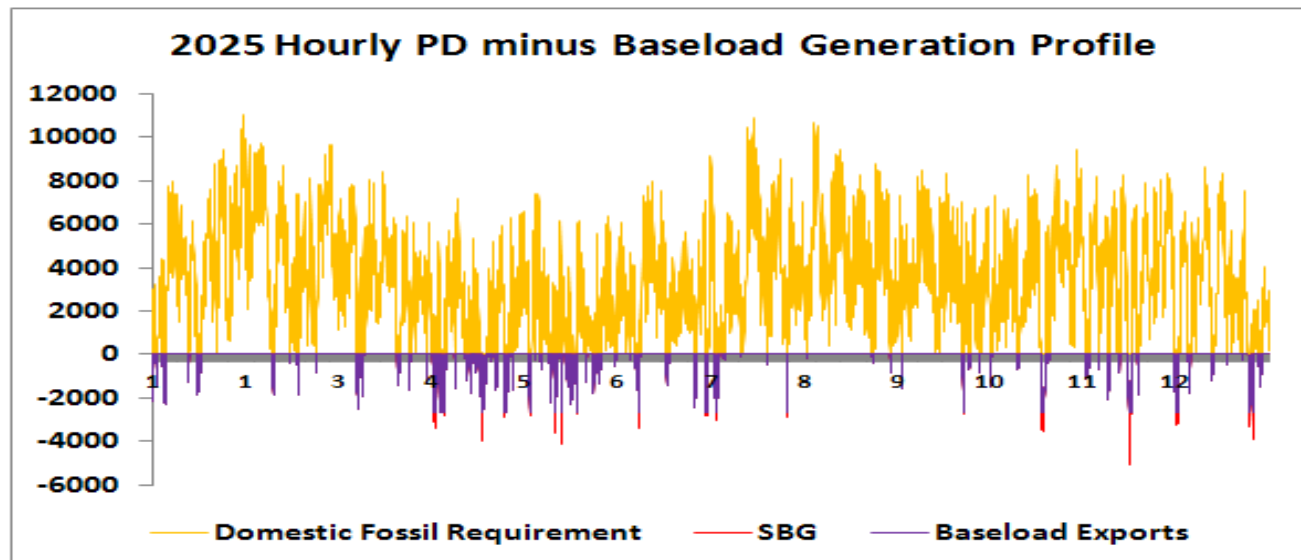
- The cost of renewables rises from \$1B/year now, to \$4B/year by 2018.
- The incremental (delta) Total Customer Cost due to renewables rises from \$1B/year now to \$3B by 2018 and then settles at \$2B after the nuclear recovery.
- The avoided CO₂ emissions rise from 1 TG/year now to 5 TG/year.
- The implied CO₂ cost in Ontario's renewable investment is \$1000/tonne now, but will rise to over \$1600/tonne in the worst SBG years, and then settle at around \$300/tonne.

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How much Nuclear in the mid-2020's?

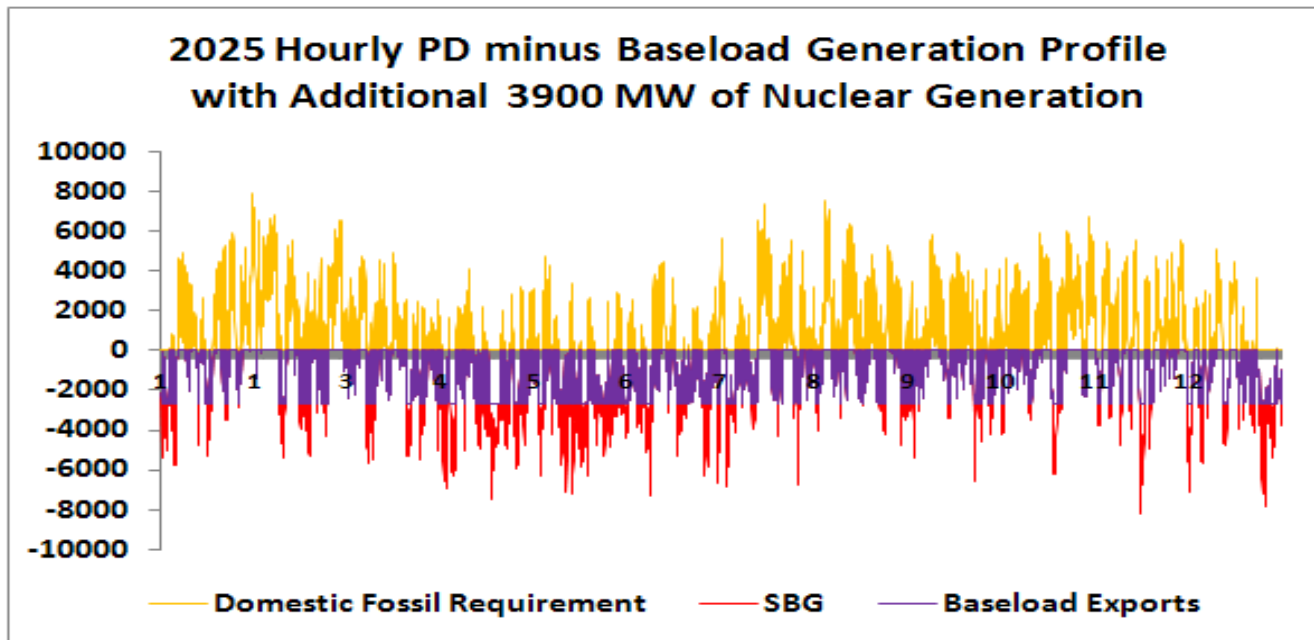
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- Ontario's Long-Term Energy Plan places significant, but not clearly specified, premiums on carbon-free and renewable energy, reduced dependence on imported fuels and less exposure to fuel or carbon price risk going forward. In this context, how much nuclear should be on the Ontario system given installation of the targeted 7000 MW of wind?
- As the plot below shows, with 10 nuclear units in-service in 2025, the Ontario power system has about the right amount of nuclear generation so that the 7000 MW of wind is displacing gas-fired generation or imports, rather than nuclear and hydro, as in the present decade.



How much Nuclear in the mid-2020's?

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- Further additions of nuclear capacity would reintroduce the baseload exports and SBG problem we currently are facing.
 - For instance, if nuclear supply in 2025 increased by refurbishing two more Bruce units (1500 MW) and adding two new nuclear units (2400 MW), it would recreate the 2017 SBG conditions.
- It would take a very high valuation of the cost of carbon emissions (several hundred \$/tonne), or a combination of very high gas prices with a high value attached to carbon, to justify additional nuclear on economic grounds.

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Pumped Storage at Niagara

ONTARIO POWER GENERATION



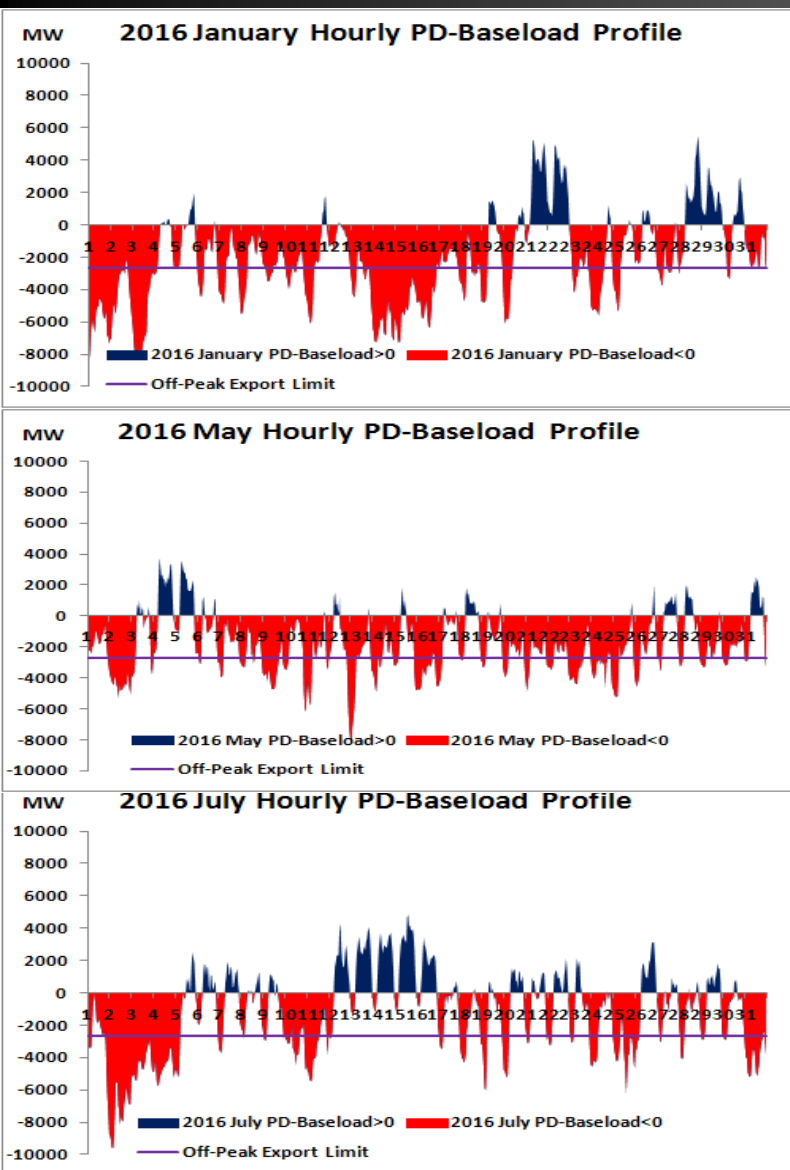
- Ontario has a Pumped Generating Station (PGS) at Beck as part of the Niagara Falls Complex.
 - It consists of 6 units, an average head of 20 m, generating about 100 MW at efficiency.
 - With each cubic metre per second (cms) of water that goes through the PGS in generation mode, we get about 0.18 MW.
- Beck has 24 units with an average head of 90 m, generating about 1800 MW at efficiency.
 - The same cms of water used by the PGS generates 0.80 MW at Beck.
- The Beck-PGS has about 10 hours of storage.
- **While the PGS itself is only about 70% efficient, the combined efficiency of the Beck and PGS is above 90%.**

- ⦿ The Beck PGS can help manage SBG and is the most efficient pumped storage facility in Ontario. It is expected to be able to time-shift about 0.5 TWh of energy per year.
- ⦿ During SBG periods, the PGS can pump away surplus power at night and generate the next day, if there is room in the Beck generators.
- ⦿ Because of the high combined efficiency of the PGS/Beck Complex, it can also pump if the marginal unit at night is CCGT gas, and generate if the marginal unit is CT gas the next day.
- ⦿ Other pumped generating stations of 60-70% efficiency have difficulty playing the CCGT/CT arbitrage, which is also around 70%.

Assessing the Benefits of New Storage

2016: High SBG Conditions Year-Round

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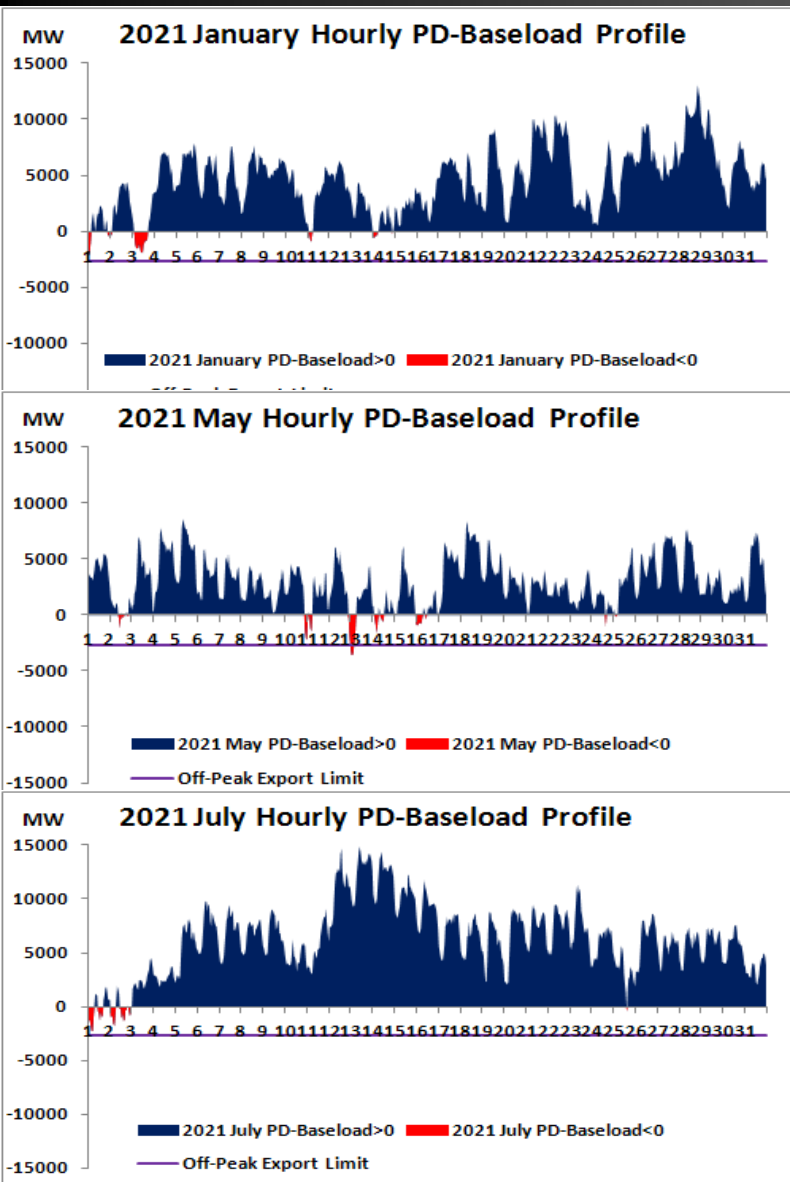


- These plots show expected weather-normal, *hourly* Primary Demand minus Baseload for a typical winter, spring and summer month in 2016.
- Negative values in red indicate that a baseload resource is at the margin.
- Positive values in blue indicate that gas-fired generation is at the margin.
- Ideal conditions for a short-term storage facility would show red periods alternating with blue periods.
- In summer, a reasonable proportion of the days do show conditions conducive to use of storage. In the other seasons, the number of opportunities is limited.

Assessing the Benefits of New Storage

2021: Minimum Nuclear Supply

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- With Pickering reaching End of Life, and 2 units each at Darlington and Bruce B assumed to be off line for refurbishment (BP2013), only about 4000 MW of nuclear is operating in 2021. The picture looks similar from 2018 to 2023.
- The charts indicate that there are very few hours when baseload (red) is at the margin. This implies there is little cheap energy for pumping off-peak available.
- Most hours gas, or imports that displace gas, are at the margin. The expected maximum price differential under these conditions is about 30%. This is about the same as the efficiency loss through storage, leaving little margin to recover fixed costs.
- There were many years in Ontario where coal was on the margin both on and off peak – this is not a new situation.

- ⊙ Introduction to Ontario Power Generation and the Ontario power market
- ⊙ Transformation to “Clean and Green”
- ⊙ Coping with Surplus Baseload Generation
- ⊙ Implied CO₂ cost of Renewables in Ontario
- ⊙ Sizing the nuclear fleet for the Ontario System
- ⊙ The value of storage to the Ontario System
- ⊙ Key messages

- Ontario has chosen a path towards a “clean and green” energy future:
 - Stop the use of coal for generation by the end of 2014.
 - Purchase 10,700 MW of renewable generation via feed-in-tariffs.
 - Refurbish nuclear generation later this decade.
- The consequence is surplus energy in the short-term and a steep increase in the customer cost of energy in the longer-term.
- In the next few years, the combination of high nuclear and wind generation in a system which already had a significant hydro capability results in periods of wasted energy (spilled or exported at a loss). The seasonal timing mismatches between electricity demand, hydro and wind generation exacerbate the problem.
- The management of SBG in Ontario will mean spilling hydroelectric generation (often requiring pre-spill), maneuvering nuclear units and shutting down wind generators. It is the cumulative effect of the FIT contracts and the prevailing economic incentives that are creating this order of SBG management.
- After nuclear refurbishment around 2025, adding additional nuclear generation, given the current level of committed wind, would reintroduce the surplus problem, and raise customer cost, based on the currently expected gas/carbon prices for that period.
- New storage technologies need to become more efficient and lower capital cost to become economic against combustion turbines and to contribute economically to accommodating more nuclear supply.
- The implied CO₂ cost is a useful measure to compare investments in different technologies that replace CO₂ emitting generation.

Thank you & Discussion