Assessment of the Operability of Clean Energy Assets Post Power Purchase Agreement Expiry

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GLOSSARY

Clean energy benefits: the value of the benefits determined to be derived by or accruing to specified consumers as a result of the clean energy initiative, including as a result of clean energy costs

Clean energy costs: the value of the costs allocated to specified consumers as a result of the clean energy initiative, including as a result of past, present and expected costs incurred in respect of,
(a) the amounts to be paid or reflected by the IESO in adjustments made under section 25.33 of the *Electricity Act, 1998* or any provision that is the successor to that provision, which relate to contracts or amounts for,

- (i) renewable energy generation or capacity,
- (ii) conservation and demand management,
- (iii) energy storage,
- (iv) energy efficiency,
- (v) natural gas generation and capacity, excluding contracts relating to amounts payable by the IESO under section 78.2 of the Ontario Energy Board Act, 1998 and excluding such other contracts as may be prescribed,

(b) payments made or expected to be made under section 78.5 of the Ontario Energy Board Act, 1998, and
(c) such other costs or estimated costs as may be prescribed;

Clean energy initiative: the policies of the Government of Ontario related to,
(a) eliminating coal generation and fostering the growth of and investment in clean, modern and reliable energy sources and technologies,
(b) removing barriers to and promoting opportunities for clean and renewable energy sources and technologies,
(c) promoting conservation, demand management and energy efficiency, and
(d) investing in energy infrastructure to ensure a clean, modern and reliable system;

Fair Hydro Act: A statute [or act] of the Legislative Assembly of Ontario designed to align clean energy costs with clean energy benefits.

1. OVERVIEW

Blake, Cassels & Graydon LLP (Blakes) retained Navigant Consulting Ltd. (Navigant), for purposes of informing legal advice from Blakes to the Ontario Ministry of Energy, to determine the feasibility of operating clean energy assets past the original power purchase agreement term and the associated costs. The analysis considered a subset of clean energy assets, namely natural gas, wind, and solar electricity generation facilities under contract with Ontario's Independent Electricity System Operator (IESO).

Two primary questions are addressed in this report.

1) What is the technical feasibility of operating clean energy assets beyond the original twenty-year power purchase agreement term?
2) What are the costs of operating the clean energy assets over their useful life, considering prudent maintenance and repowering expenditures, which would be borne by ratepayers after the twenty-year power purchase agreement term?

Ontario's natural gas-fired electricity generating facilities are expected to operate for 40 years with prudent maintenance and capital expenditure. Ontario's wind and solar electricity generating facilities are expected to operate for 25 years, or 50 years provided they undergo a major repowering (or refurbishment) in and around year 25.

The second question determines the costs, in addition to the payments under the original power purchase agreements that would be borne by Ontario ratepayers if the clean energy assets operated over their entire useful life. These costs cover on-going operations and maintenance, as well as repowering and/or major maintenance as required.

A table of important technology assumptions is provided in Table 1-2.

Table 1-1 Clean Energy Asset Technology Assumptions

Technology	Parameter	Value
Natural Gas	Repowering Cost (2017$/kW)	Plant-Specific
Natural Gas	Year 1 Fixed O&M (2017$/kW-yr)	Plant-Specific
Wind	2040 Repowering Cost (2017$/kW)	$2,300
Wind	Year 1 Fixed O&M (2017$/kW-yr)	$49
Wind	Fixed O&M Escalation	2%
Wind	Initial Capacity Factor	32%
Wind	Repowered Capacity Factor	37%
Wind	Capacity Factor Degradation	1.6%
Solar	2040 Repowering Cost (2017$/kW)	$930
Solar	Year 1 Fixed O&M (2017$/kW-yr)	$27
Solar	Fixed O&M Escalation	2%
Solar	Initial Capacity Factor	16%
Solar	Repowered Capacity Factor	16%

Solar	Capacity Factor Degradation	0.5%

Source: Navigant analysis
Note: Values presented in the table have been rounded to the nearest 10 or 100

2. TECHNICAL FEASIBILITY OF LIFETIME EXTENSION FOR CLEAN ENERGY ASSETS

This section outlines the assumptions and research underlying the expected lifetimes for the clean energy analysis. It is broken into three subsections, exploring (1) standard practice and experience when planning and designing clean energy assets, (2) the state of the Ontario fleet, and (3) leasing, regulatory, and contract issues associated with lifetime extension. Each of these subsections is further divided between natural gas, wind, and solar assets. The expected lifetimes were formulated using a combination of interviews, literature review, and consulting publicly available and Navigant proprietary databases.

Overall, no significant leasing, regulatory, or contract issues were identified which would limit lifetime extension. Navigant ultimately identified a useful life of forty years for the natural gas assets (with partial repowering in some cases), and a useful life of twenty-five years for solar and wind assets (with another twenty-five years possible after full repowering), after investigating the design and component failure rates and replacement costs for these asset classes.

2.1 Planning and Design Experience

2.1.1 Natural Gas

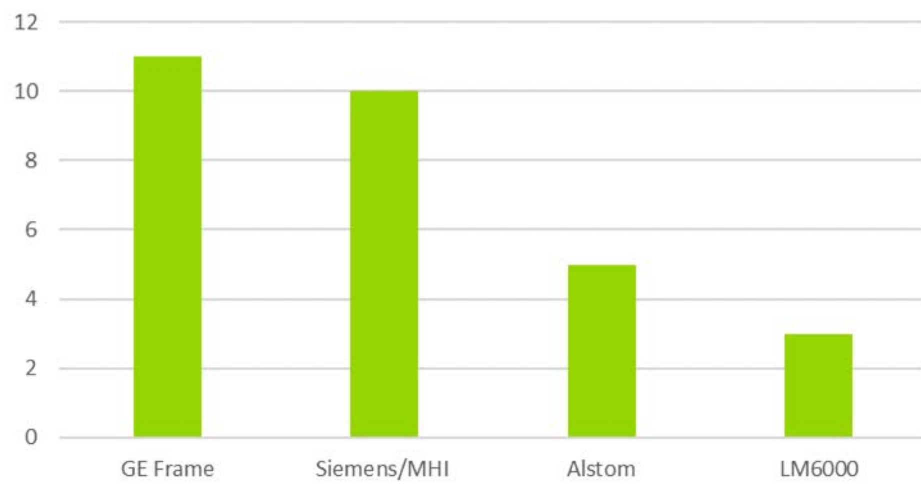
Power stations utilizing natural gas are most frequently developed assuming a twenty-year life of the plant design, which is often dictated by the terms of commercial contracts. The actual plant life, however, can exceed forty years if the operator follows prudent operations and maintenance (O&M) practices and the recommend repair and replacement intervals for combustion turbine hot section components and balance of plant equipment.

Most recently constructed natural gas power stations in Ontario (and throughout North America) utilize combustion turbines as the prime mover, either in simple cycle or combined cycle configuration. In simple cycle configuration, the combustion turbine directly drives a generator, requiring relatively fewer pieces of equipment, which lowers the cost per kilowatt (kW) of capacity. In combined cycle configuration, the exhaust heat from the combustion turbine is recovered in a heat recovery steam generator which produces steam to drive a steam turbine generator. This maximizes efficiency of the energy conversion of natural gas to electricity, but at a higher installed capacity cost than simple cycle configuration. In addition, some plants in Ontario were designed for co-generation, where a percentage of the steam produced in the combined cycle application is delivered and used in non-electric processes.

The three types of units discussed above, simple cycle, combined cycle and co-generation, have different design parameters. The simple cycle units are fast-starting units that are designed for peaking applications to either stabilize the electrical grid with ancillary services, or to provide energy to the grid during times of high demand. Simple cycle units are typically designed for a low number of starts, less than fifty per year and are generally operated by a small operations staff.

There are 29 combustion turbines at the 16 gas-fired power stations in Ontario, of which the units at thirteen were included in the model analysis (the remainder were in service prior to 2005, the analysis start year). Twenty-six of Ontario's combustion turbines are heavy frame type units and three are aero derivative units. The frame turbines include the Frame 7 series manufactured by General Electric (GE), the 501F/G series manufactured by Siemens/Mitsubishi Heavy Industries (MHI), and the GT11 series manufactured by Alstom. The three aero derivative turbines are all versions of the LM6000 turbine manufactured by GE. The distribution of Ontario's gas-fired combustion turbine manufacturers is shown in Figure 2-1 below.

Figure 2-1 Ontario Combustion Turbines by Manufacturer



Source: SNL, ABB Energy Velocity, and Navigant Analysis

The major maintenance and combustion turbine parts purchases are covered under long-term service agreements or contractual service agreements with the original equipment manufacturer. These agreements are very specific and require that the combustion turbines be stopped and maintenance be conducted at the required intervals specified by the manufactures.

Combined cycle units were initially envisioned in the early 1990's as baseload power stations, however over time they changed to mid-merit units that assume load when renewable generation drops off and during periods of high demand. Though slower to start than simple cycle units, combined cycle units can still be brought online quickly to provide larger amounts of energy to the grid than simple cycle units. Given the mid-merit dispatch of these units, combined cycle units are typically designed to start between 150-250 times per year.

Co-generation units are highly efficient and either deliver part of the steam from the heat recovery steam generator to a steam host, or in the case of combined heat and power units, use the steam to generate hot water or cold water for various heating and/or cooling applications. Co-generation units are typically designed for baseload operations (less than 10 starts per year) to serve the steam host, and can meet the steam demand while fluctuating the amount of power generated.

Over the last 15 years the rate of natural gas fired power station development has increased due to lower natural gas prices, environmental regulations (including CO_2 reduction mandates), and the increasing value of flexibility for renewable generation firming. With the growing penetration of renewable energy sources in the Ontario market Navigant has observed that natural gas stations have shifted from principally being dispatched during the day time to cover peak loads to being principally dispatched to firm renewable energy and maintain reliability during periods when wind and solar power plants drop off.

As units reach the end of their power purchase agreements (usually 20 years), they have many lifetime extension options available. As mentioned, combustion turbines can operate for 40 years if proper operations and maintenance practices have been followed. Most combustion turbines have a major inspection that is required on the turbine rotors at either 200,000 factored fired hours/equivalent base hours or 5000 factored starts. The rotor is pulled, disassembled, and inspected to determine if there has been damage to the turbine wheels; when this is complete the rotors are reassembled and can be certified for another 100,000 hours of operations. Given the dispatch regime of units analysed, most the units did not reach this milestone during the first 20 years of operation, and some units did not require it over a forty-year operating life. The heat recovery steam generators can also be operated for more than 20 years with proper repairs and replacement of components in the heat affected zones, the super-heater sections, and high flow rate areas such as the economizer. Steam turbines and generators also have expected lives of at least 40 years if the proper maintenance and inspections are conducted at the recommended intervals.

Given the concurrent expected life of 40 years for combustion turbines, steam turbines, and generators Navigant believes a general expected life of 40 years for natural gas plants is appropriate. Section 2.2.1.1 discusses in more detail current state of Ontario's natural gas fleet to determine if the general expected life is a reasonable assumption.

2.1.2 Wind

Until recently, wind plants were generally built with an expected operational life of 20 years. Today, many wind project developers have increased the expected operational life to 25 or even 30 years. This increase in the expected operational life of wind plants is reflective of reliability improvements in key components such as gearboxes, and that repairs and replacements to components can extend longevity of a wind plant.

The lifetime expectancy of individual components within a wind plant vary widely. The towers are mostly steel and last 50 to 100 years. The foundations and cables have similar lifetimes. The gearboxes generally last 5 to 7 years and therefore are replaced twice on average over a 20 year period. Lastly, blades generally last 10 to 12 years and therefore are replaced once on average over a 20 year period.

Furthermore, the accuracy of wind plant forecasts has improved over time. In the early years of the industry, plants consistently underperformed compared to forecasts of availability, reliability, and cost. More recently, cost and reliability forecasts have become more accurate due to technology advancements in manufacturing and operation of wind turbine components as well as the wealth of industry experience that is now available for forecasting purposes.

Most wind plants have decommissioning plans in place, as required either by lenders or leaseholder agreements. These plans generally call for complete removal of the equipment and reclamation of the land for a suitable use. However, most owners expect that the wind turbines will be either be refurbished (replaced with similar components) or fully repowered (replaced with larger components) at least once prior to the ultimate removal of equipment.

Given that core equipment components are likely to be replaced at least once during the first 20-years of operation of a facility and that typical planning and investment decisions are based on an assumed 25-year operation life, Navigant believes the general expected useful life for a wind facility is 25 years. Section 2.2.1.2 discusses in more detail current state of Ontario's wind resources to determine if the general expected life is a reasonable assumption.

2.1.3 Solar

Solar facilities in Ontario have 20-year power purchase agreements, obtained through either the renewable energy standard offer program (RESOP), feed-in-tariff (FIT) or large renewable procurement (LRP) programs. Twenty-year power purchase agreement terms are typical in the US and other markets, although some can be for less than 20 years.

Several public and private tools have become available to forecast production over the lifetime of a solar asset. Performance of solar facilities relies on key inputs such as system capacity, configuration (fixed tilt vs. single-axis or dual-axis tracker technology) and location. These forecasting models also account for losses due to shading and snow, as well as DC/AC losses. Over time, these models have become more sophisticated and more accurate, resulting in generation experience being consistent with planning assumptions.

As photovoltaic module technology progresses, the technical lifespan of panels has increased from 20 to 25 years, and even 30 years for more advanced models. The lifespan of other components has improved at a slower rate. Ground-mount racking is typically constructed of galvanized steel and aluminium with a 20-year warranty from the manufacturer. Standard warranties for inverters are typically 10 years in duration (an increase from the historical 5 years) with extended options available at extra cost. The technical lifetime for system wiring is typically 12 years. Therefore, inverters and wiring are replaced at least once on average over a 20-year lifetime.

Today, many solar project developers have increased the expected operational life to 25 years for planning and investment decisions. Decommissioning usually doesn't include equipment reuse, as the second set of inverters and wiring would be near end of life and panel technology is advancing quickly enough that it would likely not be reused either.

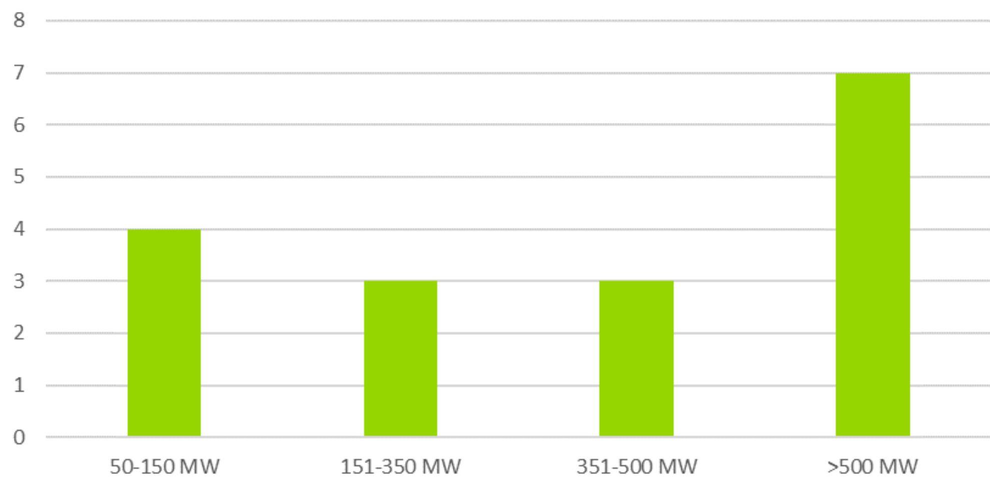
Given that core equipment components, such as inverters and wiring, are likely to be replaced at least once during the first 20-years of operation of a facility, and that the expected lifespan of the panels has increased along with the typical expected operational life for planning and investment decisions to 25-years, Navigant believed the general expected useful life for a solar facility is 25 years. Section 2.2.1.3 discusses in more detail current state of Ontario's solar fleet to determine if the general expected life is a reasonable assumption. State of the Contracted Generator Fleet

2.1.4 Current State of Operating Fleet

2.1.4.1 Natural Gas

A total of 16 natural gas-fired power plants located in Ontario were evaluated with a total installed capacity of 7,291 MW. Of these, 13 plants were considered in this analysis as the remainder of the natural gas fired plants were in service prior to 2005. Most plants were combined cycle but some were also co-generation or simple cycle. The plants had installed capacities ranging from 73 MW to 1,005 MW, with the average installed capacity being 456 MW. The distribution of the natural gas-fired power plants by installed capacity can be seen in Figure 2-2 below.

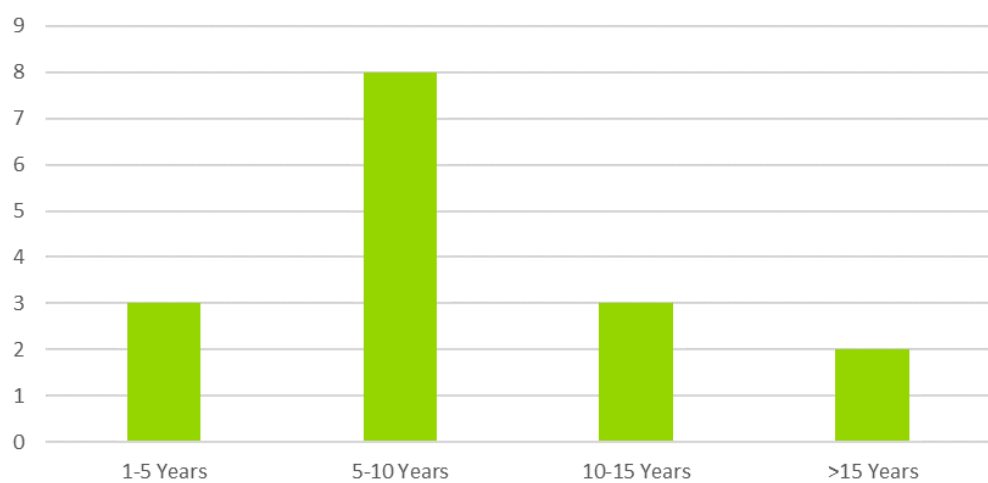
Figure 2-2 Size Distribution of Gas-Fired Generating Stations in Ontario



Source: Navigant Analysis

The average age of the gas-fired plants was nine years, with the oldest being the Cardinal Power Plant which is 23 years old and the newest being the Nappanee Generating Station which is under construction with a milestone commercial operation date of December 2018. Most plants have been in service for under 10 years, as shown in Figure 2-3 below.

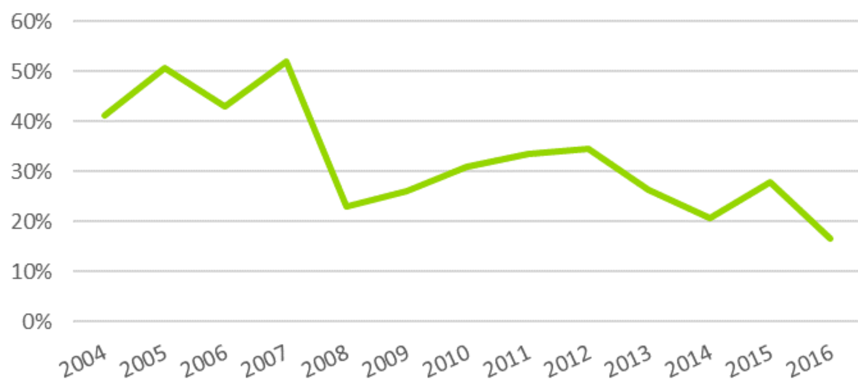
Figure 2-3 Age Distribution of Gas-Fired Generating Stations in Ontario



Source: Navigant Analysis

The net capacity factors for the different type of gas-fired power plants in Ontario have trended downward. Combined cycle units achieved a peak capacity factor in 2007, when there were only two units in commercial operation, of 52%. As more units came online after 2008 the net capacity factor dropped to the mid 20% range and rose through 2012 to 34%. Since 2012, however, the net capacity factor has shown a downward trend as demonstrated in Figure 2-4. Capacity factors have declined in recent years due to renewable builds, the return of some nuclear generating stations to service, low provincial load growth, and reduced power prices in neighbouring jurisdictions. These factors have been partially offset by the retirement of Ontario's coal fleet, but reduced capacity factors in the later years of those stations limited the upside for the natural gas-fired fleet.

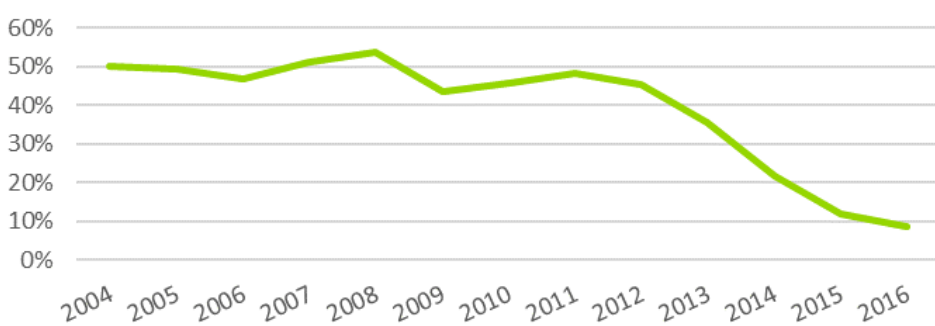
Figure 2-4 CCGT Annual Net Capacity Factor (Ontario)



Source: ABB Energy Velocity

Cogeneration units have also shown a similar trend in capacity factors. From 2004 through 2012, the capacity factor was almost flat at around 50%; however, since 2012, the net capacity factor has shown a steep decline to 9% in 2016 as shown in Figure 2-5 below.

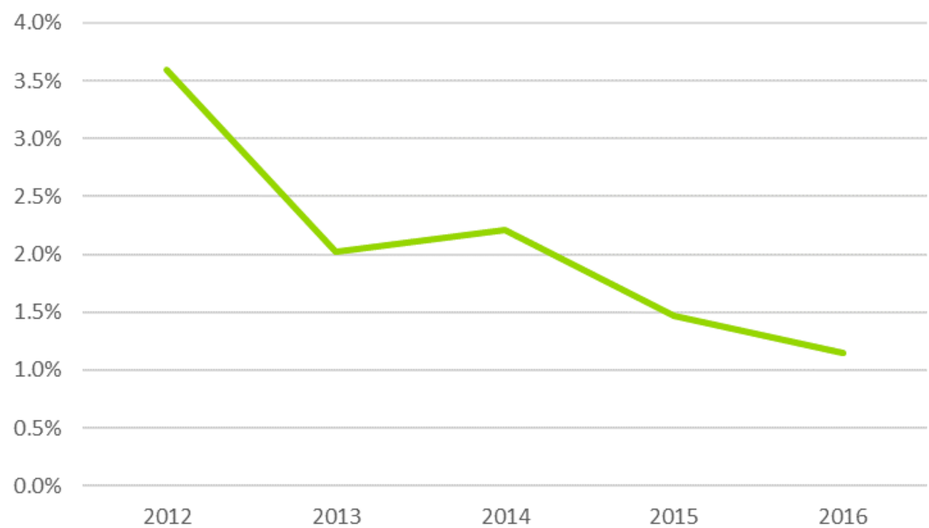
Figure 2-5 Co-Generation Annual Net Capacity Factor (Ontario)



Source: ABB Energy Velocity

The single simple cycle power station, York Energy Centre, which came on line in 2012 has shown a steady downward trend from 4% in 2012 to 1% in 2016 as demonstrated in Figure 2-6.

Figure 2-6 Simple Cycle Net Capacity Factor (Ontario)



Source: ABB Energy Velocity

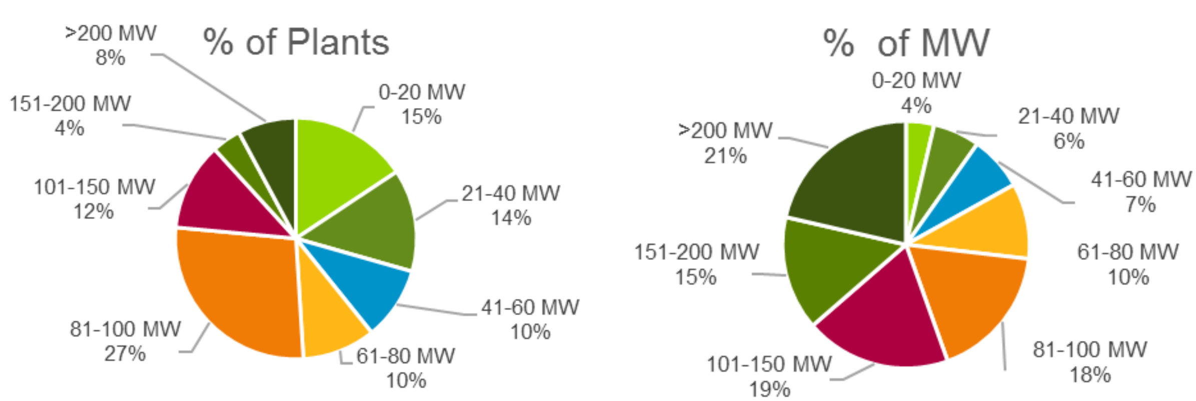
Given the relatively low utilization of the Ontario gas fleet as measured by capacity factor, starts, and hours of operation, Navigant estimates that the plants have a dependable life of 40 years, with a few plants requiring a major rotor replacement, mostly past year 25, over the 40-year life.

2.1.4.2 Wind

The following is a profile of the wind fleet in Ontario as of year-end 2016.

- Number of Plants and MW. There were 656 wind plants in operation in Ontario with a total capacity of 4,751 MW.
- Size Distribution. As shown on the left side of Figure 2-7 below, the most common wind plant size in Ontario is 81-100 MW, with 27% of wind plants, followed by the 21-40 MW segment with 14% of wind plants. On a MW capacity basis, the right side of Figure 2-7 below shows that the >200 MW is the largest segment with 21% of total MW, followed by the 101-150 MW segment with 19% of total MW.

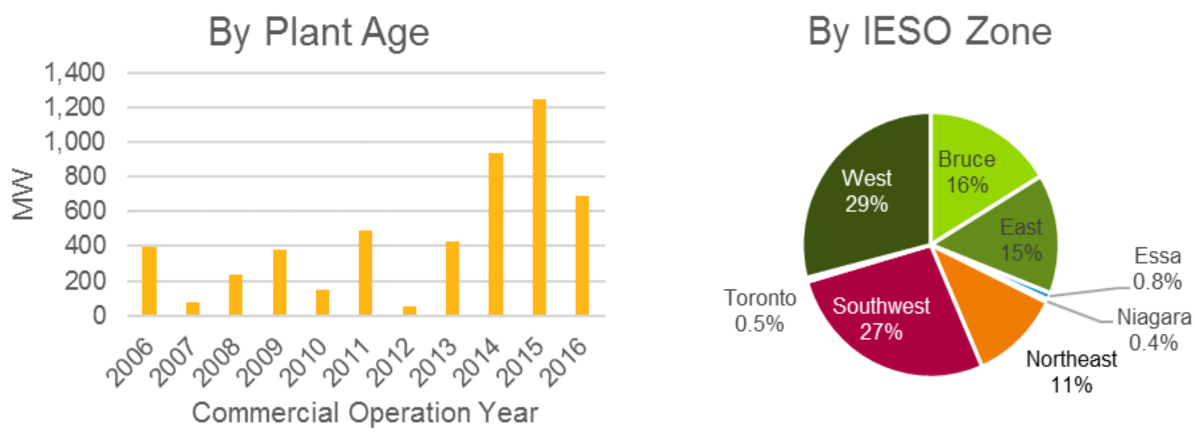
Figure 2-7 Distribution of Wind Plants



Source: Navigant Analysis

- Age Distribution. As shown on the left side of Figure 2-8 below, 2015 saw the highest amount of new wind capacity, when 1,250 MW of capacity was brought online. Fifteen plants with 557 wind turbine generators were started up in Ontario in 2015.
- Location. As shown on the right side of Figure 2-8 below, the West and Southwest zones (as defined by Ontario's Independent Electricity System Operator) had the most wind power capacity, with 29% and 27% of installations, respectively.

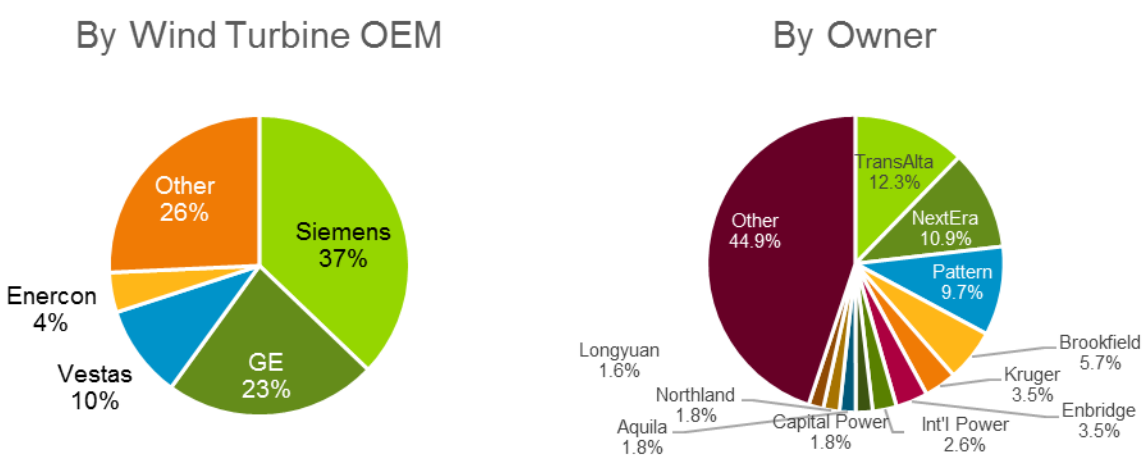
Figure 2-8 Age and Location of Wind Plants (Ontario)



Source: Navigant Analysis

- Wind Turbine OEM Market Share. As shown on the left side of Figure 2-9 below, the winter turbine generator market in Ontario is relatively concentrated, with 74% of the market controlled by the top 4 suppliers: Siemens (37%), GE (23%), Vestas (10%), and Enercon (4%).
- Wind Plant Owner Market Share. As shown on the right side of Figure 2-9 below, the wind plant ownership market in Ontario is relatively dispersed, with only 53% of the market controlled by the top 10 owners. The leading owners are TransAlta Utilities (12%), NextEra Energy (11%), and Pattern Energy (10%).

Figure 2-9 Turbine OEMs and Owners of Wind Plants (Ontario)

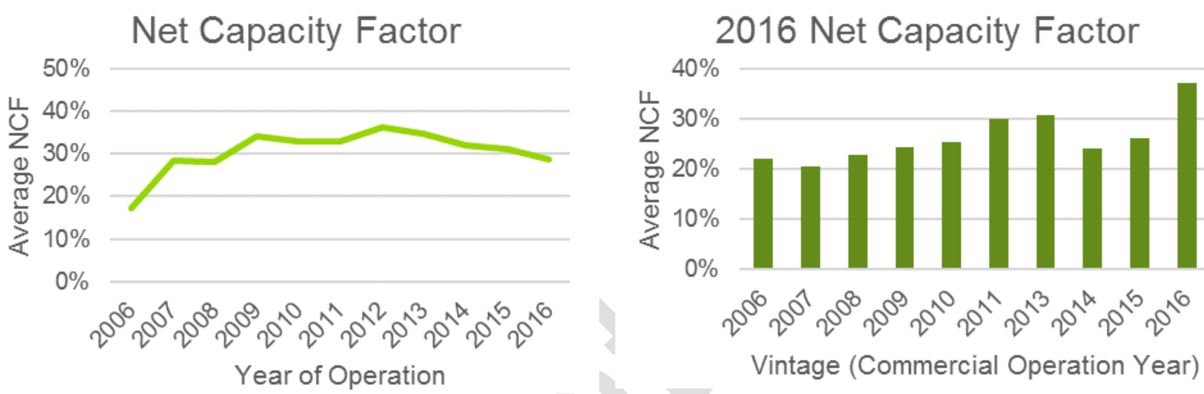


Source: SNL, ABB Energy Velocity, Navigant Analysis

- Net Capacity Factor. As shown on the left side of Figure 2-10 below, the average net capacity factor for wind plants in Ontario was 29% in 2016. This value is slightly lower than the 2012 peak of 36% but considerably higher than the 2006 average of 17%. The slight reduciton since 2012 may be due to lower winds, increased curtailment due to transmission constraints, or the impact of a few smaller plants with lower net capacity factors starting up in 2014.

  The right side of Figure 2-10 below shows average 2016 net capacity factors for wind plants in Ontario by vintage (commercial operation year). The trend is generally upwards, meaning that newer wind plants generally have higher net capacity factors compared to their older counterparts. The average 2016 net capacity factors for plants that started up in 2016 was 37%, considerably higher than any other vintage.

Figure 2-10 Net Capacity Factor of Wind Plants (Ontario)



Source: ABB Energy Velocity

- Plant Condition and Operations and Maintenance Practices. Wind plants in North America typically have winter turbine generator warranties in place for the first two to five years of operation. During the warranty period maintenance is typically performed by the wind turbine generator vendor. When maintenance is performed by an operator other than the original equipment manufacturer, the operator will follow the original equipment manufacturer's maintenance practices as required to maintain the warranty. Most wind plants are therefore usually in excellent condition for the first two to five years of operation regardless of the operator. Two-thirds of the Ontario fleet have been in operation five years or less, so the average Ontario wind plant is generally in very good condition.

Given the age, operating condition, and general maintenance practices at most of Ontario's wind fleet, Navigant estimates that the plants have a dependable life of 25 years.

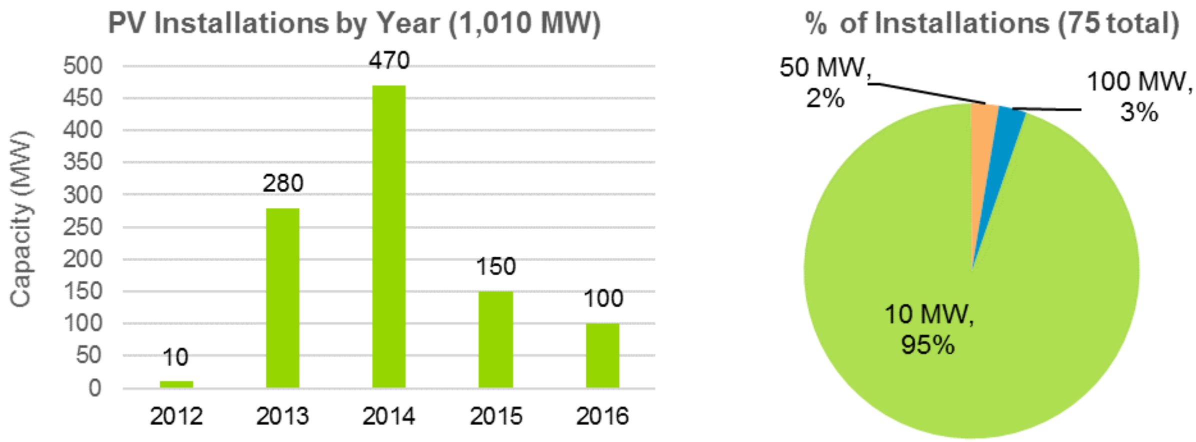
2.1.4.3 Solar

The following is the profile of Ontario's solar fleet as of year-end 2016 (of systems 10 MW or greater):

- Number of Plants and MW. There were a total of 75 solar ground-mounted systems (10 MW or greater) in operation in Ontario with a total capacity of 1,010 MW.
- Age Distribution. The left side of Figure 2-11 below shows the introduction of solar capacity over time starting in 2012. The year 2014 saw the highest capacity and number of installations. The average age of the fleet is 3.3 years.

- Size Distribution. As shown in the right side of Figure 2-11 below, the most common solar system size in Ontario is 10 MW, which was the cap for projects under the Feed-in Tariff program, except for the Samsung projects which are 100 MWs in size, and some of the Large Renewable Procurement projects.

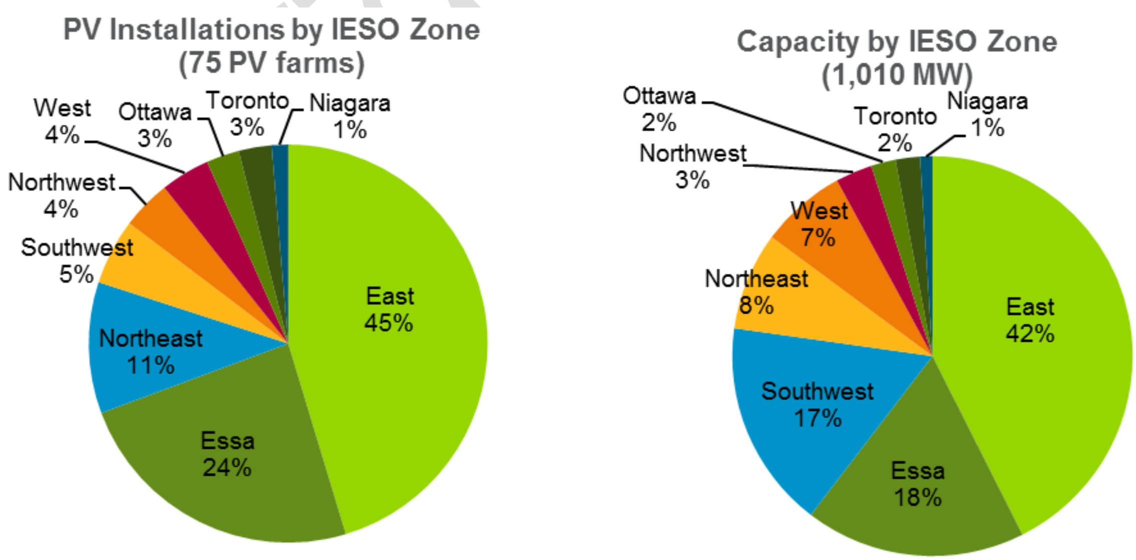
Figure 2-11 Age and Size Distribution of Ontario Solar Systems 10 MW or greater



Source: Navigant Analysis

- Location. The number of installations are presented on the left side of Figure 2-12 below, and the total capacity on the right distributed across the transmission zones (as defined by Ontario's Independent Electricity System Operator). As shown in Figure 2-12 below, 45% of the operating solar systems in Ontario are in the East zone, which hosts 42% of the installed capacity. This large share is driven by available land, available transmission capacity and proximity to the load centres. Only 5% of operating solar systems are in the Southwest zone, but that represents 17% of the installed capacity due to larger system sizes in that region.

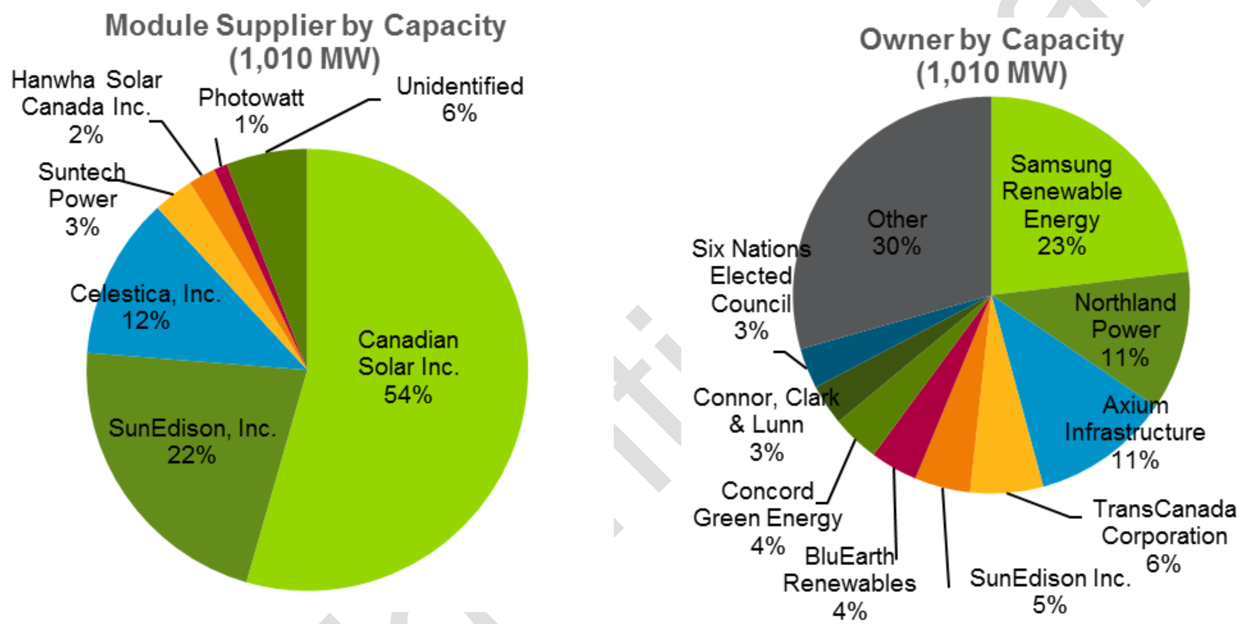
Figure 2-12 Location of Ontario Solar Systems 10 MW or greater



Source: Navigant Analysis

- Photovoltaic Module Supplier Market Share. As shown on the left side of Figure 2-13 below, the module market in Ontario is relatively concentrated, with 54% of the market controlled by the top supplier, Canadian Solar. 22% percent of the market has SunEdison panels (SunEdison filed for bankruptcy protection in the US in April 2016 and the company's Canadian unit filed for bankruptcy in October 2016). Other suppliers include Celestica (which is shutting down their solar manufacturing division in 2017), Suntech Power, Hanwha, and Photowatt.
- Solar System Owner Market Share. The right side of Figure 2-13 below shows the 10 owners with the highest solar operating capacity in Ontario. Samsung owns the largest portion of the operating fleet at 23%. Northland Power and Axium Infrastructure own the second and third largest in terms of capacity respectively.

Figure 2-13 PV Module Supplier OEMs and Owners of Ontario Solar Systems 10 MW or greater



Source: SNL, ABB Energy Velocity, Navigant Analysis

- Net Capacity Factor. The average net capacity factor of the operating solar fleet in Ontario according to data from Ontario's Independent Elctricity System Operator is 16.3% (based on MW-AC). The relatively high capacity factor in the past three years is due to a higher overbuild ratio (on the range of 20% to 40%, the latter in more recent years), driven by the drop in panel prices. The capacity factor for new solar installations can be increased via higher DC-AC oversizing or introduction of axis tracker technology.

Table 2-1 Average Capacity Factor of Ontario's Operating Solar Fleet

Year	Capacity Factor (based on MW-AC)
2014	15.4%
2015	17.4%
2016	16.0%
Average	**16.3%**

Source: IESO

- System Condition. As most operating systems are under five years old, key components have not experienced much degradation, if any at all.
- Operations and Maintenance Practices. Preventative and reactive maintenance for ground-mounted solar systems usually includes panel cleaning, snow removal, lawn mowing and periodic verification of wiring and support integrity. Operations and maintenance costs are only projected to increase with escalation in labour and other material costs. Inverter replacement requires additional costs and is usually offered by the inverter manufacturer. Standard warranties are five to 10 years, with options to purchase extended warranties upfront (e.g., 20-year extended warranty).

Some companies that provide operations and maintenance services for utility-scale solar systems in Ontario include SMA, First Solar, Inc., SunEdison, NextEra Energy Canada ULC, SunPower, Canadian Solar, Inc., Enfinity, Northland Power, Inc., and EDF Renewable Energy, Inc.

Given the age, operating conditions, and standard maintenance practices of most of Ontario's existing solar fleet, Navigant estimates that the solar assets have a dependable life of 25 years.

2.1.5 Component Failure Rates and Operating Life

2.1.5.1 Natural Gas

The generation performance and failure rate data of natural gas-fired plants is not publicly available and is generally held confidential by plant owners. It is reasonable to assume that performance and failure rates for Ontario plants will be like those of plants in Navigant's Generation Knowledge Services (GKS) database. The GKS database contains a broad and growing user and unit mix and currently has over 2,400 generating units representing over 527 GW of capacity, of which over 135 GW consists of simple cycle combustion turbines and combined cycle combustion turbine units.

The following metrics were used in evaluating the Equivalent Availability Factor (EAF) and Equivalent Forced Outage Rate (EFOR), which are reasonable estimates of the performance of Ontario's gas fleet:

$$EAF = \left(\frac{AH - (EUNDH + ESDH)}{PH} \right) \times 100$$

EAF = Equivalent Availability Factor
AH = Available Hours
EUNDH = Equivalent Unit Derated Hours
ESDH = Equivalent Seasonal Derated Hours
PH = Period Hours

$$EFOR = \left(\frac{FOH + EFDH}{SH + FOH + ERSFDH} \right) \times 100$$

EFOR = Equivalent Forced Outage Rate

FOH = Forced Outage Hours
EFDH = Equivalent Forced Derated Hours
SH = Service Hours
FOH = Forced Outage Hours
ERSFDH = Equivalent Reserve Shutdown Forced Derated Hours

Based on the operating data for the Ontario gas-fired fleet, a peer group was developed that would be representative of the Ontario units, which was combined cycle units that were between 150 and 1,000 MW with a net capacity factor of between 10 to 40%. From that database, the median for units were as listed in Table 2-2 below.

Table 2-2 NCF, EAF and EFOR for Ontario Wind Fleet

	NCF	EAF	EFOR
Median	26.16%	83.94%	4.11%

The largest contributor to the EFOR rate was the steam turbine, which caused 11,688 forced outage hours, followed by the combustion turbines with 6,243 hours and the balance of plant (BOP) with 4291 hours. The combustion turbines and BOP contributed to a larger number of events, however (these tended to be of shorter duration than steam turbine events). This is demonstrated in Table 2-3 below.

Table 2-3 Breakdown of EFOR for Ontario Gas Fleet

Component	Total Hours	Percentage	Total Number of Events	Percentage
Boiler	758	3%	74	9%
Steam Generator	11,688	47%	142	17%
Generator	944	4%	53	6%
Balance of Plant	4,291	17%	194	23%
Combustion Turbine	6,243	25%	284	33%
Other	1,179	5%	110	13%

The highest number of steam turbine forced outage hours were due to events on the low-pressure turbine at 5,742 hours and the high-pressure turbine at 1,197 hours. This is due to the time required for system cool down and to remove and reinstall casings. The control system had the largest number of events (49) but only contributed to a few forced outage hours (256), as control system issues are normally very fast to resolve. A summary of the causes of forced outages due to the steam turbine is provided in Table 2-4.

Table 2-4 Breakdown of EFOR for Ontario Steam Turbines

Steam Turbine	Total Hours	Percentage	Total Number of Events	Percentage
High Pressure Turbine	1,197	14%	10	7%
Low Pressure Turbine	5,742	69%	21	15%

Valves	50	1%	24	17%
Lube Oil	8	0%	8	6%
Controls	256	3%	49	35%
Miscellaneous (Steam Turbine)	1,012	12%	29	21%

The combustion turbine outages were driven by issues with the fuel and combustion system (2,634 hours over 120 events), as demonstrated in Table 2-5 below. This was principally due to dry low NOx combustion system issues and component failures.

Table 2-5 Breakdown of EFOR for Ontario Combustion Turbines

Combustion Turbine Component	Total Hours	Percentage	Total Number of Events	Percentage
Inlet Air System and Compressors	1,907	31%	27	11%
Fuel, Ignition and Combustion System	2,634	42%	120	49%
Turbine	426	7%	12	5%
Exhaust System	65	1%	16	7%
Auxiliary	152	2%	1	0%
Miscellaneous (Gas Turbine)	1,019	16%	69	28%

Balance of plant issues contributed to 17% of the total outage hours. The largest number were caused by issues with the electrical system (2,068 hours over 55 events). Issues with the condensate system and feed water systems were also important as shown in Table 2-6 below.

Table 2-6 Breakdown of Balance of Plant EFOR for Ontario Gas Fleet

Balance of Plant	Hours	Percentage	Events	Percentage
Condensing System	418	10%	29	15%
Circulating Water System	43	1%	5	3%
Condensate System	953	22%	18	9%
Feedwater System	554	13%	45	23%
Electrical	2,068	48%	55	28%
Auxiliary System	171	4%	21	11%

Miscellaneous (Balance of Plant)	84	2%	21	11%

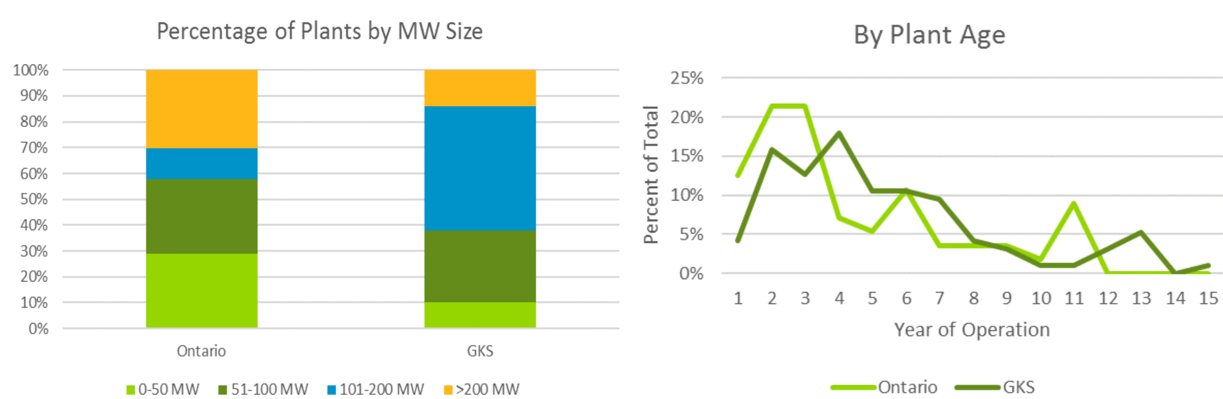
The heat recovery boilers and generators only accounted for a total of 7% of all outage hours with the generator accounting for 944 outage hours and the boiler accounted for 758 hours. The largest driver on the heat recovery boiler was tube leaks, while the generator was driven by a combination of cooling system and exciter issues.

While component failure rates increase with the age and use of natural gas plants, and heat rate degradation will tend to make the plants less completive in energy markets over time, plants following the proper maintenance and replacement regimes as outlined in section 2.1.1 should be able to continue operating over their forty-year expected life with acceptable outage rates.

2.1.5.2 Wind

Wind plant performance and failure rate data is not publicly available and is generally held confidential by plant owners. However, it is reasonable to assume that Ontario wind plants will have performance and failure rates similar to those of wind plants in Navigant's Generation Knowledge Service (GKS) wind database (Ontario has a slightly newer fleet, and fewer mid-size plants than the GKS averages, but they are similar overall). The GKS wind database includes data from approximately 8 GW of capacity from a variety of turbine models, plant sizes, ages, and operations and maintenance contract types. The vast majority, 95%, of the MW capacity in Navigant's GKS database is in North America. Figure 2-14 shows the database distribution by plant size and age, which is similar to the size and age distribution of Ontario's wind fleet.

Figure 2-14 Plant Size and Age Distribution in GKS Wind Database



Source: Navigant GKS Wind Database

The following are median values of selected performance metrics in the GKS wind database, which are reasonable estimates of performance of the Ontario wind fleet:

- Availability. The most common measure of availability used in the wind industry is equipment equivalent availability factor (EEAF). EEAF does not penalize the plant for hours when there is no wind. Median EEAF = 95.6%.

$$EEAF = \frac{[PDTH - (FTH + MTH + PTH)]}{PDTH} \times 100$$

- PDTH = Period Turbine-Hours = (total hours in the period) *(number of turbines)
- FTH = Forced Turbine-Hours = (forced outage hours per turbine) *(number of turbines)
- MTH = Maintenance Turbine-Hours = (maintenance outage hours per turbine) *(number of turbines)
- PTH = Planned Turbine-Hours = (planned outage hours per turbine) *(number of turbines)

- Forced Outage Rate. The most common measure of forced outage rate used in the wind industry is equipment equivalent forced outage rate (EEFOR). Median EEFOR = 2.7%.

$$EEFOR = \frac{FTH}{(CTH + FTH + RUTH)} \times 100$$

  - CTH = Contact Turbine-Hours
  - RUTH = Resource Unavailable Turbine-Hours

- Major Failures. Navigant defines major failures as events which either (a) require a crane to repair or replace a system or (b) require the replacement of a major component within a system, resulting in a cost greater than 5% of the installed cost of the turbine. Table 2-7 below is a summary of average major failure rates in the GKS wind database, both for the most recent benchmark year (2015) and the cumulative rate for the life of the plant. Also, shown in the far-right column of Table 2-7 below are industry average failure rates as reported in a 2013 United States National Renewable Energy Laboratory (NREL) study.[1]
  - 2015 Major Failure Rate = (# of Major Failures in 2015) / (# units)
  - Cumulative Major Failure Rate = (# of Major Failures through 2015) / (# units) / (years since COD)

Table 2-7 Major Failure Rates by System

System	2015 Major Failure Rate	Cumulative Major Failure Rate	Industry Average Failure Rate
Blade	0.2%	0.5%	0.67%
Gearbox	1.1%	1.3%	5.0%
Generator	2.1%	2.1%	3.5%
Main Bearing	0.6%	0.5%	2.0%
Generator Bearing	0.3%	0.4%	n/a
Transformer	0.1%	0.04%	n/a

While component failure rates do increase with age, the plants continue to maintain acceptable operating profiles over the course of their identified useful life (albeit with capacity factor degradation and operations

[1] NREL, Lantz, E., Operations Expenditures: Historical Trends and Continuing Challenges, 2013

and maintenance cost escalation). Beyond the identified useful life, the plants would see accelerated component failures which eventually make continued operation untenable (see section 3.1.1.2).

2.1.5.3 Solar

The operating life of solar systems is usually monitored by the system owner. In the solar industry, the rate at which the system is fully functioning (and available to generate power) expressed as a function of the total time considered, is referred to as the availability rate. For solar, the availability rate is relatively high, approximately 98% to 99%[2], compared to other technologies. This is because components are connected in strings, meaning that should something fail, only a single string or portion of the system will experience an outage, while the rest of the system continues to generate power. It is unlikely for all to fail at once.

- Panels most often experience an outage or failure due to coverage (snow, soiling, or other shading) or a wiring fault. However, the way panels are connected electrically, when one stops generating power, the others continue.
- Inverters for utility-scale systems are usually 1 MW. For a 10 MW system, the typical design is ten (10) 1 MW inverters. This means that if an inverter fails, only one-tenth of the system would power down. Inverters typically last 10-12 years, but it is possible that an outage can occur sooner than that.
- Racking systems are typically tested and rated to handle expected snow and wind loads plus a factor of safety. Therefore, the warranty from the manufacturer covers damage from these occurrences. Should the structural integrity of the racking system be compromised, it is again likely that only the module(s) related to one string would need to be taken offline to repair, not the whole solar system.
- Wiring is required to be protected up to codes and standards to limit the potential for damages.

Overall, it is unlikely that the component failure rates would cause an unacceptable operating profile for the solar fleet over a 25-year operating lifespan.

2.2 Leasing, Regulatory, and Contract Issues

2.2.1 Leasing Structure

When constructing a natural gas-fired power station it is typical for the owner to purchase the land that is used for the site. All the natural gas-fired plant owners that Navigant could interview owned the site land; therefore, no leasing issues were identified that would adversely impact the expected useful life of 40 years.

The terms of land leases for wind plants vary. The minimum length is 20 years, but up to 50 year leases are not unusual. In most cases, there will be an option for the plant owners to extend the lease for an additional 15 years or more. Leases are contracts between the plant owners and landowners, and they are generally written to be more favourable to the plant owners. For example, plant owners can typically construct, erect, use, install, reinstall, replace, relocate, maintain, and remove equipment from time to time, without limitation. No approvals to modify or extend leases are needed by local jurisdictions,

[2] DBRS reported that the independent engineer for the 100 MW (AC) Kingston Solar project assumed inverter availability of 99%.

community, or aboriginal partners, unless they have such approval rights due to having partial ownership in the wind plant. Navigant did not identify any leasing issues that would adversely impact the expected useful life of 25 years for wind assets or any further investments to extend asset life beyond 25 years.

Most solar farms larger than 10 MW are sited on farmland and have a minimum 20-year lease. Some may go as high as 50 years and/or there might be options to extend the lease. Counterparties include private landowners, First Nations, and municipalities. Leases usually have two cost components as follows: (1) a fixed component and (2) a variable component where the variable component is equal to a percentage of revenue generated from the asset (e.g., 3%). No leases require third party approvals such as local jurisdictions, community, or aboriginal partners, unless those parties are partial owners in the project. Navigant did not identify any leasing issues that would adversely impact the expected useful life of 25 years for solar assets or any further investments to extend life beyond 25 years.

2.2.2 Regulatory Issues

No regulatory issues were identified that would adversely impact the expected useful life of natural gas, wind and solar plants of 40 years, 25 years and 25 years respectively.

For partial repowering of wind plants (replacing the drive train and rotor with similar size components), regulatory approvals would generally not be required. The noise profile of the new turbine will generally be less (quieter) than the original turbine and therefore would not need to be remodelled. The rotor diameter will typically be the same as the original in a partial repowering, so a revised permit for increased tip height generally will not be needed. One wind plant owner reported having a permit from the municipality that includes a road allowance for the distribution lines. The city can impose reasonable conditions but cannot generally deny an extension of the permit.

Regulatory approvals would likely be required for full repowering of wind plants (replacing the turbines with larger components). Existing building and operating permits would generally not cover the significant construction work and changes in plant configuration that is associated with full repowering. However, repowering could offer the possibility for expedited permitting because development is occurring at a previously permitted site and these sites have a much longer record of accomplishment of historical environmental data. Existing plants also tend to have increased local familiarity, which might also facilitate the permitting process. On the other hand, if endangered species are found to be in the proximity or other environmental damage has occurred, permitting would likely be more complex and drawn out, or local siting requirements may become more stringent over time.

While some regulatory approvals are required to repower wind assets to extend their life beyond 25 years, Navigant does not believe that they pose insurmountable risks to such investments. Navigant did not identify any regulatory issues that would adversely impact repowering for natural gas and solar plants to extend their useful life beyond 40 years and 25 years respectively.

3. COST OF LIFETIME EXTENSION AND REPOWERING

This section outlines the costs of lifetime extension that would be borne by ratepayers. After considering the various options available, Navigant determined that a full repowering of the wind and solar fleet after 25 years of operation, and partial repowering as needed for the natural gas fleet as the most cost-effective repowering options.

3.1 Repowering and Extension Options

3.1.1 Life Cycle of Plants under Normal Operations and Maintenance

3.1.1.1 Natural Gas

As discussed previously, a combustion turbine power plant can operate for at least 40 years if the owner follows prudent operating practices and recommended outage schedules for the combustion turbine, generator, steam turbine and heat recovery boiler. In general, the operations and maintenance for natural gas-fired plants will increase with the escalation terms within the service contracts for the associated equipment.

Combustion turbine outages are driven by the hot section and combustion components. Manufactures have improved this technology so outages are now not required until either 24,000 factored fired hours or 900 factored starts are reached. When the hot section components are removed, they can be repaired from two to four times depending on the component and the manufacture's recommendations.

Electrical generators and steam turbines are generally linked to scheduled inspection intervals of six years or 48,000 operating hours. Following best practices, owners and operators have managed to extend those intervals to between 10-12 years or 80,000 to 96,000 operating hours.

Heat recovery steam generators with proper maintenance have operated for 15-20 years without major capex being spent. Replacement parts are most commonly needed in the heat-affected zones of the super-heaters or the high flow areas of the economizers.

Maintenance spending increases with the number of starts of a combined cycle power plant. As discussed earlier, units are now designed for 150-250 starts per year. This spending is normally associated with balance of plant equipment and does not materially impact the overall cost of operations.

Depending on the operating profile of the facility, reliable operations after 20 years would most likely require capital expenditures for the heat recovery steam generators, electrical generators, steam turbines and combustion turbines. If no investments are made it would be expected that the units would suffer from forced outages and decreased availability.

Section 3.1.2.1 discusses the repowering costs associated with natural gas plants and evaluates them against their benefits to determine the most cost effective option at the end of life.

3.1.1.2 Wind

As previously discussed, the physical lifetime of a wind plant is generally considered to be 25 years. Historically an assumption of 20 years was used in analyses to match the financial life, but an increasing number of plant owners are using 25 years due to technological advancements that have led to improvements in plant reliability and longevity.

If a wind plant were to continue to be operated beyond the physical lifetime without significant investment, operations and maintenance costs would increase at an accelerated rate and availability would drop at an accelerated rate as wind plants generally have a capacity factor degradation of about 1.6% per year making this option less attractive financially. Ultimately the plant owners will conclude that operating the plant as is has less value than other options such as full repowering, partial repowering, and decommissioning, which are discussed further in Section 3.1.2.2.

3.1.1.3 Solar

As previously discussed, the physical lifetime of a ground-mounted solar photovoltaic system is 25 years. The modules and racking typically come with 10-year product warranty (defects in materials and workmanship) and a 25-year performance warranty. Inverters typically have a 10-year product warranty and last 10-12 years. Wiring typically lasts 10-12 years. Therefore, inverters and wiring would need to be replaced at least once on average over a 25-year lifetime.

If a solar system was to continue to be operated beyond the physical lifetime without significant investment, operations and maintenance costs would remain the same, only increasing with inflation and the price of any material costs involved in maintenance. Replacement of inverters and wiring are separate from general operations and maintenance and would require minimal investment. Inverters do typically fail after year 10 so most installers opt into an extended warranty where available, which is an upfront cost at the time of installation. With the standard warranty the cost of the inverter would just be incurred later, at the time of the replacement.

Photovoltaic modules, and therefore, systems, are projected to degrade by 0.5% each year, which is usually how the capacity factor and system performance is forecasted at the time of installation. The capacity factor of the system can be determined based on the number of years since the components were replaced. If a solar system operated beyond the useful life of 25 years, the capacity factor of year 26 would be that much lower than if a whole new system were installed in its place. Section 3.1.2.3 discusses evaluates the costs and benefits associated with options available at the end of life such as full repowering, partial repowering, and decommissioning.

3.1.2 Cost of Repowering for Lifetime Extension

3.1.2.1 Natural Gas

As discussed above the limiting factor on the combustion turbine would be the turbine rotor that requires a major inspection and potential replacement of turbine wheel at 200,000 factored hours or 5,000 factored starts. The rotor must be removed and sent to a qualified repair shop for disassembly, inspection and repair and/or replacement of the rotor disks. In addition, there would likely be requirements for replacement of super-heater or economizer sections of the heat recovery steam generators.

The costs for the turbine life extension would be in the range of CAD$16M for the inspection and repair/replacement of hot section components. The other work required on the heat recovery steam generators would be in the range of CAD$4M.

The balance of plant equipment would normally be covered during the routine maintenance at the facility. This would include the rebuilding or replacement of pumps, including the boiler feed pumps, and the repair and replacement of motors. It would also include the replacement of any catalysts that are required for emissions control. Steam turbines and electrical generators should be able to operate for the life of the plant with routine inspections and maintenance, assuming there are no incidents with the equipment.

The total repowering costs of a natural gas plant is approximately $20M which is a fraction of the cost of shuttering the plant and building a new one to replace the capacity. According the U.S. Energy Information Administration,[3] the cost of a new natural gas combustion turbine is $1,100/kW meaning that a 100 MW plant would cost $110M. Hence, a partial repowering as needed for gas plants is the most cost efficient option when the asset reaches end of life.

3.1.2.2 Wind

Wind plant owners generally have three options when a plant reaches the end of its useful life.

- *Full repowering*, which is defined as the complete dismantling and replacement of turbine equipment, including the tower and foundation. With full repowering, some of the existing project infrastructure (e.g., roads, buildings, and interconnection equipment) is assumed to be utilized in the new project. There is also the potential to offset repowering costs by recycling or selling the older equipment.
- *Partial repowering*, which is defined as installing a new similar sized drivetrain and rotor on an existing tower. Some peripheral components, such as the power convertors and electronics, may also be replaced. Partial repowering allows existing wind power projects to be updated with equipment that increases energy production, reduces machine loads, increases grid service capabilities, and improves project reliability.
- *Decommissioning*, when the plant is fully disassembled and the land is returned to its original use. The equipment is sold for reuse or scrapped.

Repowering (either full or partial) is a major undertaking that requires substantial capital investment and planning, similar to the development of the original facility. The major benefits of repowering are increased plant availability, the return of operations and maintenance costs to normal levels, and an extended plant lifetime. Performance improvements associated with partial repowering are assumed to be less than under full repowering but greater than the original design of the machine.

Navigant's costs of repowering were developed from a case study of a wind plant with the following characteristics of an average wind plant in the current Ontario fleet:

- 40 Siemens 2.3 MW WTGs, with a total plant capacity of 92 MW;
- Commercial Operation Date and Year 1 of operations in 2015;

Three scenarios were considered:

- decommissioning the plant after 25 years of operation in 2040;
- full repowering after 25 years in 2040, followed by decommissioning after an additional 25 years in 2065.

[3] Capital Cost Estimates for Utility Scale Electricity Generating Plants, Released November 2016 – Table 1. Updated estimates of power plant capital and operating costs https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capcost_assumption.pdf

- partial repowering after 25 years in 2040, followed by decommissioning after an additional 25 years in 2065.

Table 3-1 summarizes the key assumptions of the case study. Capital and operations and maintenance cost assumptions are from a 2013 NREL repowering study,[4] escalated to 2017 USD at 2.5% per year and converted to CAD at a rate of 1.35 CAD = 1 USD. All operations and maintenance costs were converted to fixed operations and maintenance for modelling purposes. Fully repowered plants are assumed to have slightly lower (5%) total installed capital costs because of the ability to reuse or repurpose existing equipment. Partial repowering is estimated to result in an approximately 15% lower capital cost because of reusing existing equipment including towers and foundations. In all scenarios, it is assumed that decommissioning cost (occurring in year 26) equals the resale or scrap value of the components (i.e., net zero cost).

Net capacity factor assumptions are based on projections from NREL's 2016 Annual Technology Baseline report, but are benchmarked to average Ontario fleet values from Ontario's Independent Electricity System Operator. Larger rotors and taller towers, along with other technological advancements, have resulted in significant increases in net capacity factors for utility-scale wind plants over the past 15 years. These advancements are expected to continue for the foreseeable future, albeit at a slower pace. Net capacity factors for this case study is assumed to be 37% for full repowering in 2040, which is a 5% improvement over the initial 32% net capacity factor in 2015, reflecting the technological advancements that are expected during this 25-year period. As defined here, partial repowering was estimated to achieve about 50% of the energy production improvements associated with full repowering.

As can be seen from Table 3-1 below, the fixed and variable operations and maintenance costs are the same in all cases. The capital costs for full repowering are slightly lower than the original plant cost and only 12% higher compared to partial repowering but deliver double the energy production improvements compared to partial repowering, as stated in the study. Hence, a full repowering at the end of the original asset life of 25 years is the most cost effective alternative.

Table 3-1 Wind Repowering Case Study Key Assumptions and Results

	units	Original Plant	Full Repowering	Partial Repowering
Year 1	-	2015	2040	2040
Capital cost	2017 CAD/kW	2,844	2,291	2,049
Fixed O&M in year 1	2017 CAD/kW-year	19.04	19.04	19.04
Variable O&M in year 1	2017 CAD/MWh	9.32	9.32	9.32
O&M increase per year	%/year	2.0%	2.0%	2.0%
NCF in year 1	%	32%	37%	34.5%
NCF decrease per year	%/year	1.6%	1.6%	1.6%

[4] NREL, Wind Power Project Repowering: Financial Feasibility, Decision Drivers, and Supply Chain Effects, December 2013, http://www.nrel.gov/docs/fy14osti/60535.pdf

3.1.2.3 Solar

Similar to wind assets, three scenarios were considered:

- decommissioning the plant after 25 years of operation,
- full repowering after 25 years, followed by decommissioning after an additional 25 years.
- partial repowering after 25 years, followed by decommissioning after an additional 25 years in 2065.

Table 3-2 summarizes the key assumptions related to life extension of solar plants.

Table 3-2 Solar Repowering Case Study Key Assumptions and Results

	units	Original Plant	Full Repowering	Partial Repowering
Year 1	-	2017	2042	
Capital cost	$/W-DC	$1.80	$0.95	
PV Module Cost	$/W-DC	$0.54	$0.24	
Fixed O&M	$/kW-DC	$27	$27	$27
O&M increase per year (Inflation)	%/year	2%	2%	2%
Capacity Factor (based on MW-AC)	%	16.3%	16.3%	16.3%
Capacity Factor decrease per year	%/year	0.5%	0.5%	0.5%

As mentioned in Section 3.1.1.3, to extend the life cycle of a ground-mounted solar photovoltaic system the major pieces of equipment that would need to be replaced are the inverters and the wiring. These two components have a technical lifetime of 10-12 years and so they are replaced at least once in a 25-year lifetime. The expected operating life after replacement of the inverters and wiring would be another 10-12 years.

Attention should also be paid to the lifetime and replacement cost of the solar photovoltaic modules. Panel technology is improving at a much faster rate than other renewable technologies, such as wind, and other key solar components such as racking and inverters. In parallel, module prices have significantly dropped over the past 10 years and are projected to continue to decrease for the next 10 years. If modules are replaced 25 years from now, they may have a much higher efficiency and much lower costs than what exists today. Replacing panels would extend the life of the system an additional 25 years, or perhaps longer based on the technical lifetime of panels at the time. The capacity factor in Table 3-2 is consistent across the full and partial repowering alternatives. While panel efficiency will continue to increase over time, it will not impact capacity factor (it does impact power density). Capacity factor is increased by using tracker technology, but for this analysis, we assume a constant split between fixed tilt and tracker in both 2017 and 2038. By contrast, wind farms have could increase capacity factor by increasing the hub heights to reach better wind regimes.

Due to technological improvements, the capital cost for a full repowering is about half that of the original plant and could potentially have a useful life that is greater than 25 years making it the most cost effective option.

3.2 Leasing, Regulatory, and Other Costs

The owners of natural gas-fired facilities would have to renegotiate new contracts for repair and replacement of combustion turbine parts. This may result in cost savings as there have been third party entrants into the parts supply and repair markets.

Leasing, regulatory, and other development costs are low relative to the total capital expenditures associated with modern wind facilities. These costs are generally assumed to be the same as those required for a greenfield development wind project.

Since the technical lifespan of solar photovoltaic systems, specifically the modules, is expected to exceed a 20-year power purchase agreement, some owners expect the system to run for an additional 5-10 years beyond the PPA and original lease. However, plans to extend the land lease are typically not put in place until closer to the end of the power purchase agreement term, as refinancing the lease early could result in penalties.

At the time of the installation of a solar system, there is usually a budget set aside for decommissioning. If the system were to be decommissioned later than originally intended, there would be no extra costs, and the original budget should cover decommission at year 25 or 30.

In summary, no significant costs for leasing, regulatory or other developmental costs were identified that would adversely impact repowering decisions.

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