3.3.2 Asset Strategy

Hydro One's strategy for steel structures is to manage the fleet through a combination of planned structure replacements, component refurbishments and tower coating in order to maintain reliability of the system. Structure replacements and component refurbishments are usually part of line refurbishment and are described earlier in this section. This investment category focuses on preserving structures through a tower coating program.

Based on International Organization for Standardization (ISO) the environment is divided into six atmospheric corrosivity categories. In accordance with ISO 12944 and a study completed by EPRI, the province of Ontario is divided into four corrosion zones ranging from C2 to C5. Each of these corrosion zones has a range of corrosion rates which can be used to estimate the service life of HDG steel based on its location. C2 and C3 zones are defined as light corrosion zones and the towers located in these two zones will likely have the original galvanizing protection layer for at least 140 years. This means towers will be protected and maintained in good condition for minimum of 115 years without requiring any coating. Based on Hydro One asset records, there are approximately 39,000 steel structures in these light corrosion zones and 2,200 of them are older than 100 years. However, none of them are older than 115 years and there is no immediate tower coating needs for structures within these zones.

C4 & C5 zones are defined as heavy corrosion zones which have very high corrosion rates for zinc and carbon steel (See Figure 32 below). Based on EPRI study, the towers will lose their protective zinc in 35-65 years after installation. Furthermore they would lose 10% of their metal in the following 30-60 years. At this stage, structures are no longer able to withstand the original design loads and either a major refurbishment or complete tower replacement would be required.

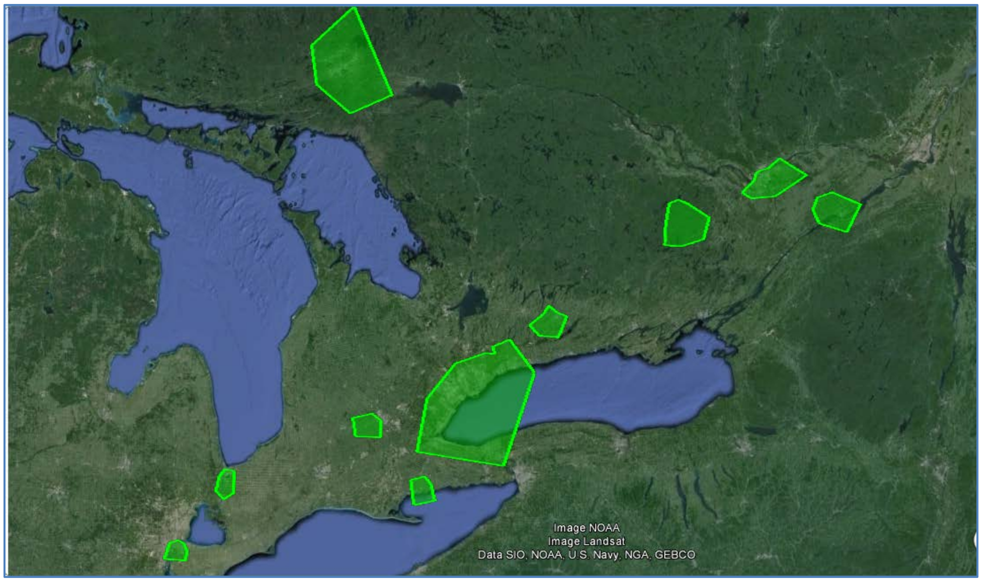


Figure 32: C4 & C5 corrosion regions in Ontario (courtesy of EPRI).

An effective tower coating program can maintain a steel tower structure at its design capacity indefinitely by re-application of the coating approximately every 35 to 65 years.

If towers are not re-coated prior to corrosion and metal loss, the opportunity is lost and the tower will ultimately have to be replaced.

3.3.3 Asset Assessment Details

Demographics

Hydro One has approximately 52,000 steel structures; the demographic of the steel structure population is outlined in Figure 33. There are approximately 13,000 steel structures are located in heavy corrosion zones such as Windsor, Sarnia, Hamilton and GTA. 7,500 of them currently meet tower coating criteria and approximately an additional 4,700 steel structures will meet this tower coating criteria over the next 10 years if the historical coating rate is maintained. The demographic of the steel structures in heavy corrosion zones are outlined in Figure 34.

Hydro One uses an average expected service life ("ESL") of 80 years for steel structures if the structures are not re-coated. Currently 2,100 structures in high corrosion zones are beyond ESL and exceed the coating criteria. These structures will need detailed engineering assessment and potentially require heavy refurbishment or even complete replacement.

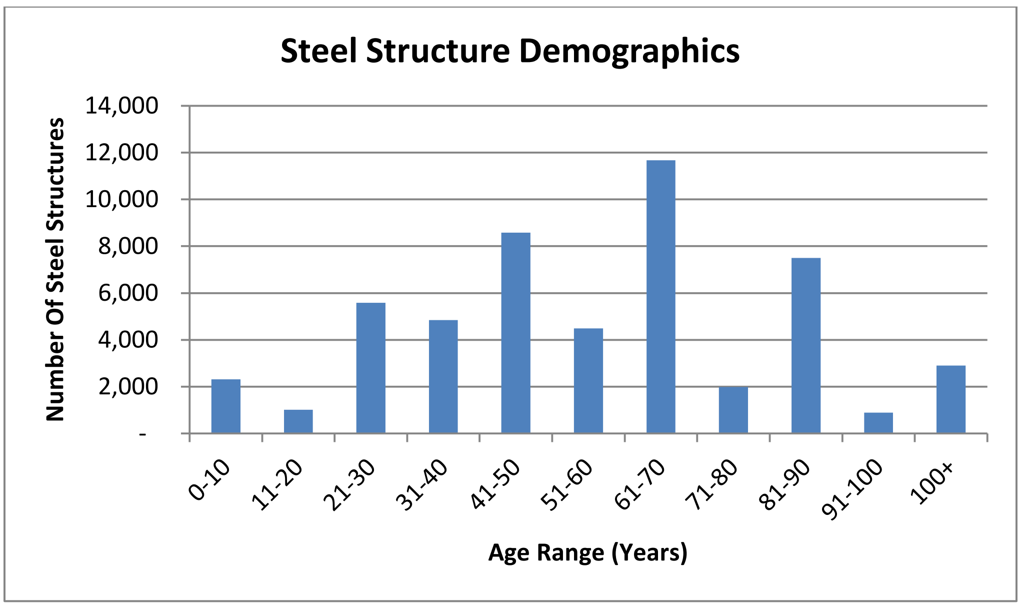


Figure 33: Demographics of Steel Structure Fleet province wide

Witness: Chong Kiat Ng

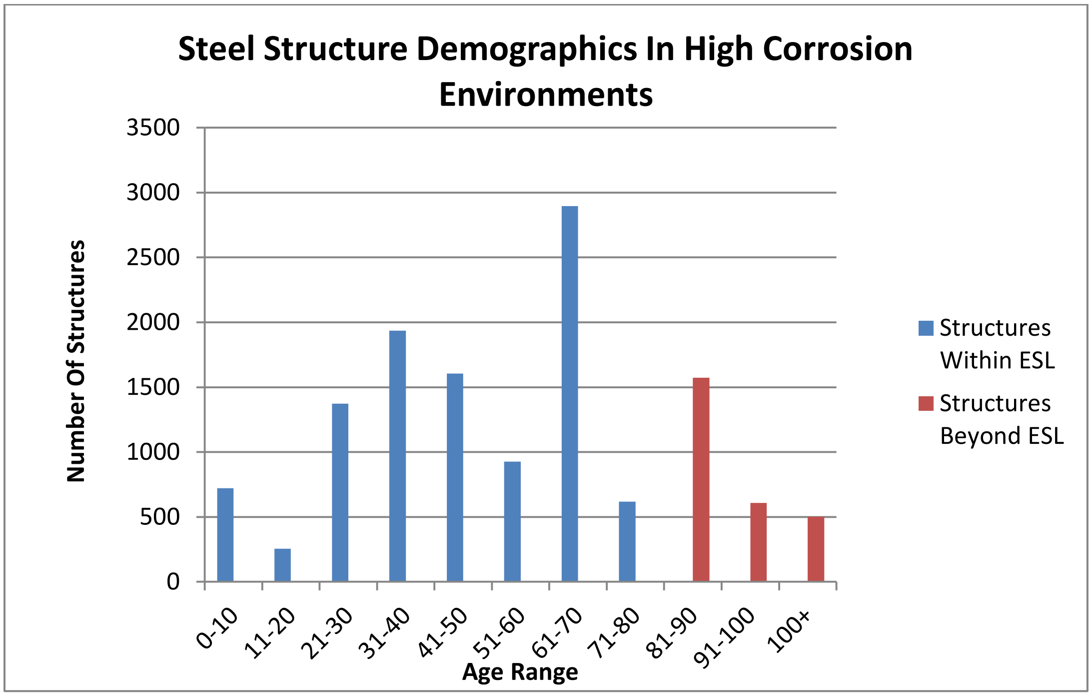


Figure 34: Demographics of Steel Structure Fleet in Heavy Corrosion Zones

Based on the historical data, the average rate for structure renewal is about 200 towers per year. As outlined in Figure 35, at historic tower coating rates, the steel structures requiring coating in high corrosion zones will increase by 34% in 10 years. However, with planned coating plan, all structures requiring coating will be coated in the next 10 years.

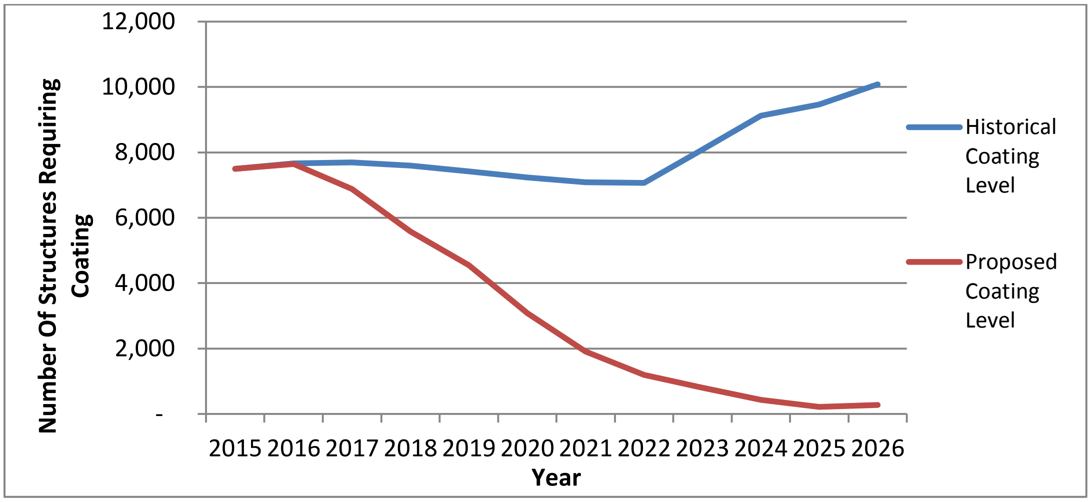


Figure 35: Projection of Steel Structures requiring Coating

<u>Performance</u>

Forced outages for steel structures represent the number of times an outage is caused by steel structure failure such as complete tower collapse, or a broken (or bent) tower member. It excludes forced outages caused by external interferences such as animal contact and weather related incidents.

The number of forced outages due to steel structure failures has shown slight decrease over the past 10 years as outlined in Figure 36. With the current condition of the steel structures and the demographics of the fleet, it is expected that increased capital programs will be required to prevent future increases in forced outages due to steel structure failures.

Witness: Chong Kiat Ng

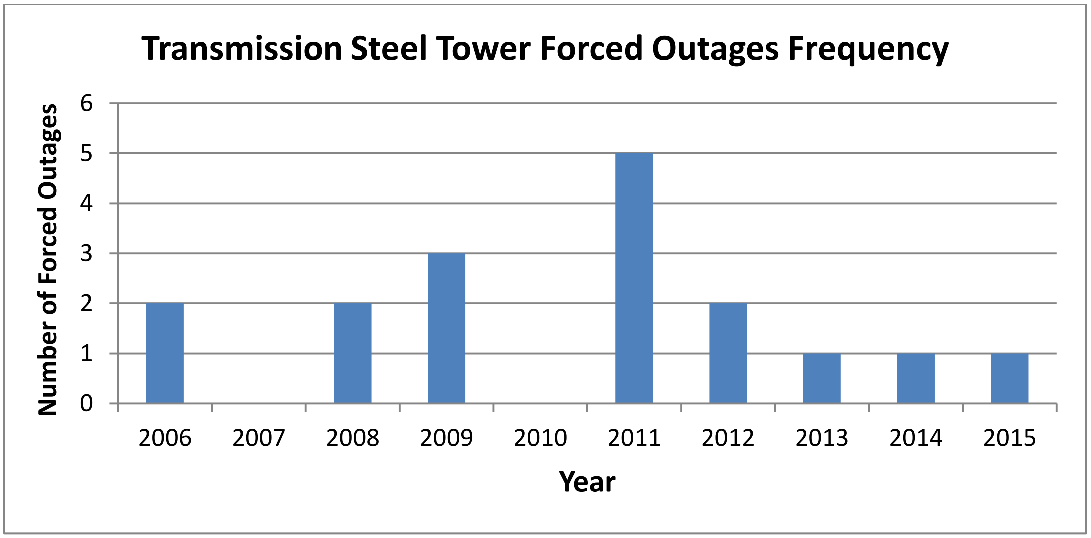


Figure 36: Forced Outages due to Steel Structure Failures

The forced outage duration due to steel structure failures, displayed in Figure 37, demonstrates a stable outage duration trend over the last 10 years, except for the spike in 2011. This type of spike is not unexpected given the very remote locations of some of the circuits with difficult access. This can place considerable strain on the system as it may result in loss of supply to large customers including local distribution companies and generation connections.

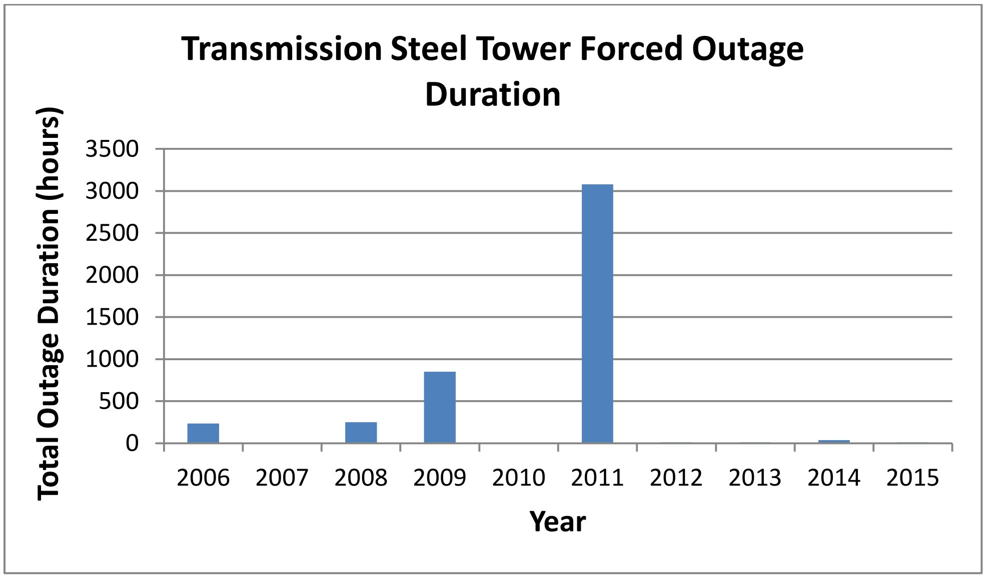


Figure 37: Forced Outage Duration due to Steel Structure Failures

<u>Condition</u>

Transmission steel structure condition assessment is initiated based on demographics, geographic zone and result of study conducted by industry experts over the past several years. The initial assessment results will be verified by the established Hydro One maintenance program which includes inspections, patrols and detail corrosion assessment. Towers are visually inspected in accordance with NACE ("Nation Association of Corrosion Engineers") guidelines on the degree of corrosion. Detailed corrosion assessment includes climbing towers and measuring the remaining thickness of protective coating, loss of metal if any and assessment of bolts and fittings.

Based on the current assessment, 4% of Hydro One's steel structures require major refurbishment or replacement as outlined in Figure 38. 14% of the steel structures require coating and will be addressed in the steel structure coating program. This assessment is continuously reviewed and updated as more structures meet the coating criteria every year.

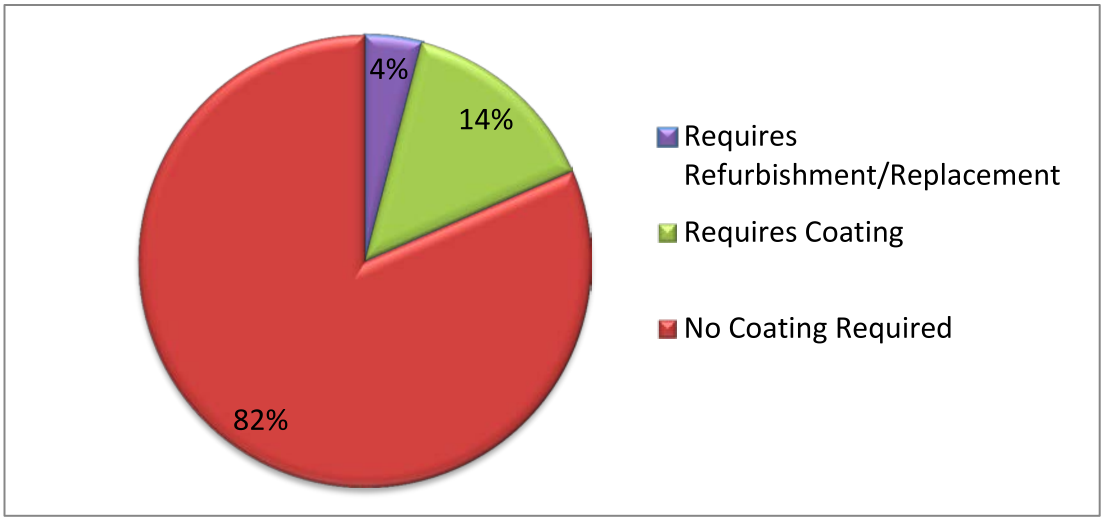


Figure 38: Steel Structure Fleet Condition Assessment

In order to maintain the condition of the fleet, the rate of refurbishment/coating will need to be increased as per Hydro One's investment plan.

Other Influencing Factors

- Innovation - Hydro One is continuing to investigate the use of alternative coating products in order to reduce the cycle time involved in the re-coating process by potentially reducing the amount of steel surface preparation and decreasing the drying time which is coating product dependent. This will reduce outage time, when required, and permit a higher number of towers to be coated each year.
- Work Method – A revised work method has been established that allows for tower coating in live line conditions. This live line work method will minimize the outage constraints and maximize the quantity of towers to be coated.

Witness: Chong Kiat Ng

Table 11: Steel Structure Replacement

Steel Structure Portfolio		Historic			Bridge	Test	
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
# of Renewal	228	235	121	300	462	1250	1600
% of Fleet	0.4	0.5%	0.2%	0.6%	0.9%	2.4%	3.1%

The capital investment in the test years is an increase over historic levels. The strategy to manage the fleet of steel towers is a combination of planned replacements, component refurbishment and tower coating. The number of towers that have been refurbished, coated, or replaced over the past 10 years has been very low. As a result of recent condition inspections and tower coating studies the rapid deterioration of steel structures in highly corrosive areas needs to be addressed with an increase in the fleet renewal rate. Hydro One plans to undertake an aggressive tower coating program to sustain these assets. Tower coating has been identified as the preferred alternative as it has a significant life cycle cost advantage and has less impact to the system as circuit outages required for coating are minimal.

3.4 Transmission Lines Insulators

3.4.1 Asset Overview

Transmission line insulators are an integral component of the transmission system. They mechanically support and electrically insulate the conductor from the structure and must provide sufficient dielectric strength to prevent short circuits to ground. There are approximately 420,000 insulator strings in Hydro One’s overhead transmission network. They are assessed through visual inspection, infrared thermography and in-situ live-line electrical testing. Insulators are categorized into three types; porcelain, glass and polymer as described below and depicted in Figure 40.

Steel Structure Coating

Hydro One's transmission system includes about 50,000 steel structures. Steel structures are manufactured with a zinc-based galvanized coating that protects the underlying steel against corrosion. The coating will generally last from 30 to 60 years, with the more corrosive environments depleting the galvanizing at a quicker rate. Assessment of the steel structure condition is carried out on an annual basis as part of the maintenance program, with a focus on transmission line sections that are greater than 30 years and are located in highly corrosive areas or in locations where known problems exist. The assessments determine the amount of galvanizing that remains on the structure, or in the case where the coating is depleted, the amount of metal loss that has occurred. This program focuses on coating steel tower structures that the assessment has deemed in need of corrosion protection due to loss of galvanized coating.

Additional details for this program are provided in the Investment Summary Document S45 in Exhibit D2, Tab 2, Schedule 3.

Steel Structure Replacements

Once the galvanized coating on a steel structure has been depleted, the bare steel becomes exposed to the environment and begins to corrode at a much faster rate. If the tower is not re-coated and corrosion is allowed to continue, components of the steel structures will begin to lose strength and eventually fall below Hydro One Transmission's design standards. Once a structure is identified as being in poor condition through visual inspection and measurement of the zinc coating, a detailed corrosion assessment is conducted to determine whether it is possible to replace a portion of the steel structure and coat the remaining structure to protect it from corrosion or whether it is more economical to replace the entire structure. This program addresses the replacement of steel structures where the corrosion assessment has deemed the structure to be at end of life.

Additional details for this program are provided in the Investment Summary Document S46 in Exhibit D2, Tab 2, Schedule 3.

Steel Structure Foundation Refurbishments

The foundations of the transmission structures are integral to the strength of the steel structure. One of the earlier vintages of steel structures is the lattice steel structures which are constructed with a grillage (buried steel) foundation. These particular structure foundations are prone to deterioration of the protective zinc coating and/or corrosion at or below the groundline depending on the ground conditions. About 60% of lattice type steel towers on the Hydro One transmission system have grillage footings. The transmission lines foundation refurbishment program is focused on assessing the condition of the foundations and anchors and repairing or replacing foundations and anchors that have been deemed not to satisfy the original installed design requirements. The assessment of foundation uses a pre-specified rating system and the decision to coat, repair or replace depends on the severity of corrosion or metal loss found.

Additional details for this program are provided in the Investment Summary Document S47 in Exhibit D2, Tab 2, Schedule 3.

Shieldwire Replacements

The shieldwire in Hydro One's transmission system is primarily made up of galvanized steel wire that is positioned above the conductors to protect a circuit against lightning related outages and to provide continuity of the grounding system. When the zinc galvanizing has depleted, the underlying steel begins to corrode, resulting in pitting and loss of metal and eventual failure if not replaced in time. Hydro One Transmission maintains an on-going shieldwire testing program where a sample of wire is removed from a line section and tested in a laboratory to determine the condition of the wire and the need for replacement. This program focuses on the replacement of shieldwire that

- The condition of the steel structure fleet, determined through industry standard maintenance practices, is such that 3% present fair or high condition risks that need to be mitigated.
- The number of forced outages for steel structure has shown slight deterioration over the last 10 years; although the duration of forced outages for steel structures has remained stable.

Given the current demographics of the steel structure population, condition trend and the risks associated with steel structure failures, an increase in the fleet renewal is required to maintain current levels of performance and risk.

Asset Strategy

Hydro One Transmission's strategy for steel structures is to manage the aging fleet of steel structures through a combination of planned replacements, component refurbishments and tower coating in order to maintain reliability of the system while minimizing rate impacts.

Effective tower coating can maintain a steel tower structure indefinitely by re-application of the coating approximately every 20 to 25 years depending on the installed environment of the structure. However tower replacement is a requirement once the structure has degraded to a point where recoating cannot stop the corrosion process. Hydro One Transmission strives to recoat before this point is reached; as the life cycle costs of regular coating programs are estimated to be less than half of a replacement strategy.

Asset Assessment Details

Demographics

Hydro One Transmission uses a normal expected service life ("ESL") of between 80 to 100 years for steel structures if the structures are not re-coated. The average age of the steel structure fleet is currently 56 years of age and 21% are currently beyond their ESL; for which 4% of these are beyond 100 years. The demographics of the steel structure population is outlined in Figure 36.

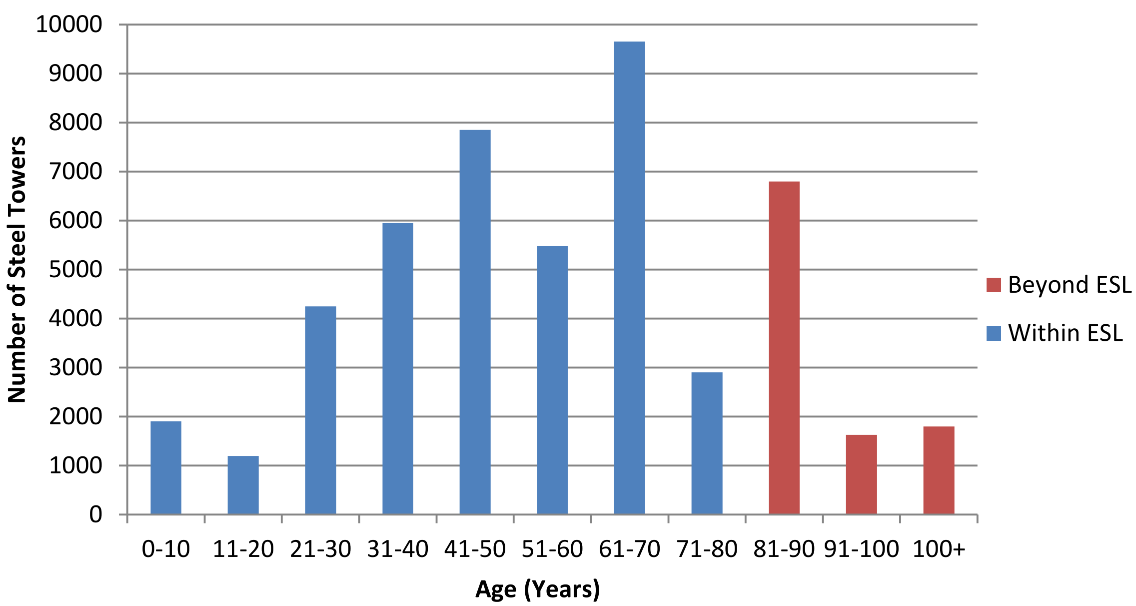


Figure 36: Demographics of Steel Structure Fleet

As can be seen in Figure 37, continuing at the historic fleet renewal rate would result in the percentage of steel structures beyond their expected service life increasing to 24% by 2024. However under the proposed plan, the percentage of steel structures beyond their expected service life will decrease from 21% to 18% over the next 10 years.

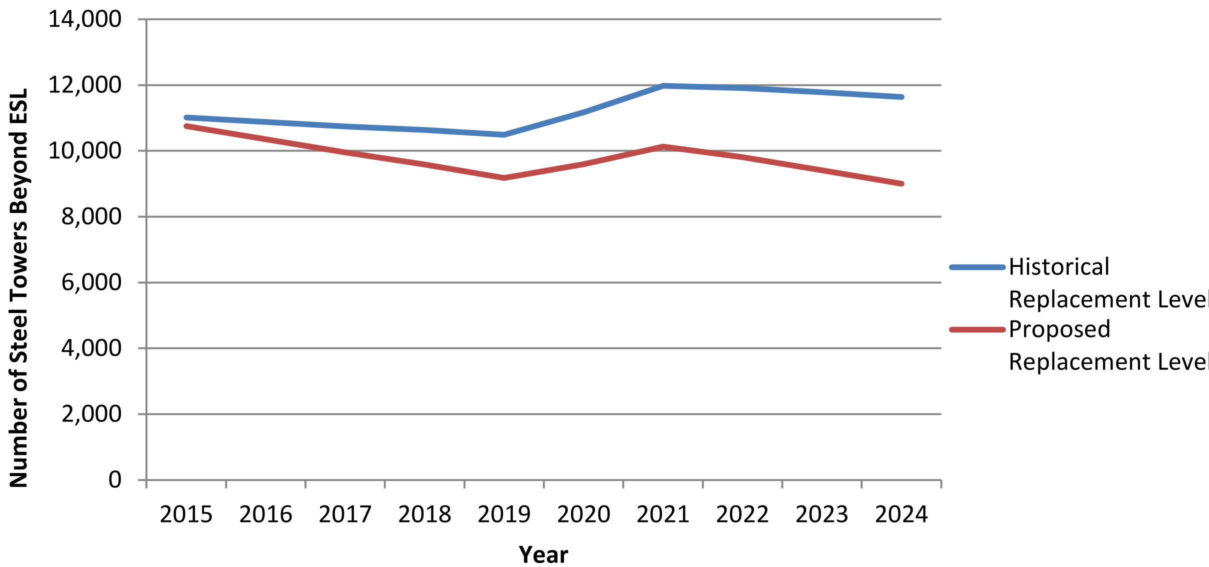


Figure 37: Projection of Steel Structures Beyond Expected Service Life

Performance

Forced outages for steel structures represents the number of times an outage is caused due to a steel structure failure such as failed, broken or bent tower member. It excludes forced outages caused by external interferences (animal contact, weather, etc.). Although single circuit tower outages typically do not result in delivery point interruptions, a multiple circuit tower failure can result in customer outages.

The number of forced outages due to steel structure failures has shown slight increase over the past 10 years, as outlined in Figure 38. With the current condition of the steel structures and the demographics of the fleet, it is expected that an increase in the capital programs will be required to prevent future increases in forced outages due to steel structures.

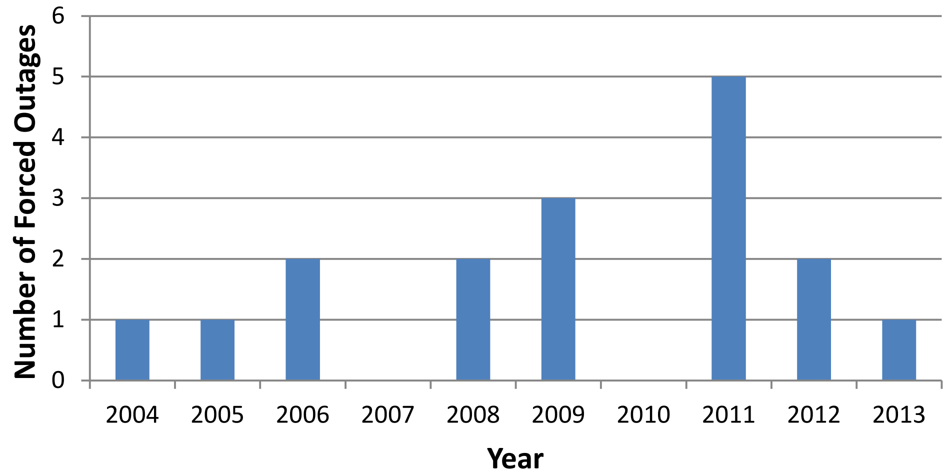


Figure 38: Forced Outages due to Steel Structure Failures

The forced outage duration due to steel structure failures, displayed in Figure 39, demonstrates a stable outage duration trend over the last 10 years, except for the extreme spikes in 2004 and 2005. These type of spikes are not unexpected given the very remote locations of some of the circuits, with difficult access. This can place considerable strain on the system as it may result in loss of supply to large customers including local distribution companies and generation connections.

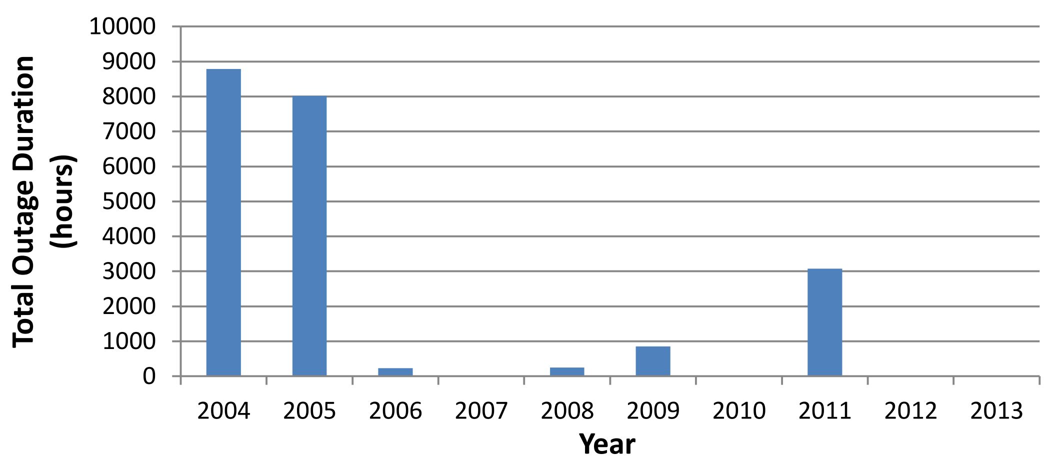


Figure 39: Forced Outage Duration due to Steel Structure Failures

<u>Condition</u>

The condition of the steel structures is determined through inspections, patrols and detailed corrosion assessment. Towers are visually inspected in accordance with NACE ("Nation Association of Corrosion Engineers") guidelines on the degree of corrosion. Detailed corrosion assessment includes climbing towers and measuring the remaining thickness of protective coating, loss of metal if any and assessment of bolts and fittings.

Based on the current assessment of condition, 3% of Hydro One Transmission steel structures have condition in the fair or high risk category, as outlined in Figure 40, and meet the current refurbishment/coating criteria. This assessment is continuously reviewed and adjusted as new conditions are reported or factors are considered. An additional 14% of steel structures need to be assessed in order to determine their condition.

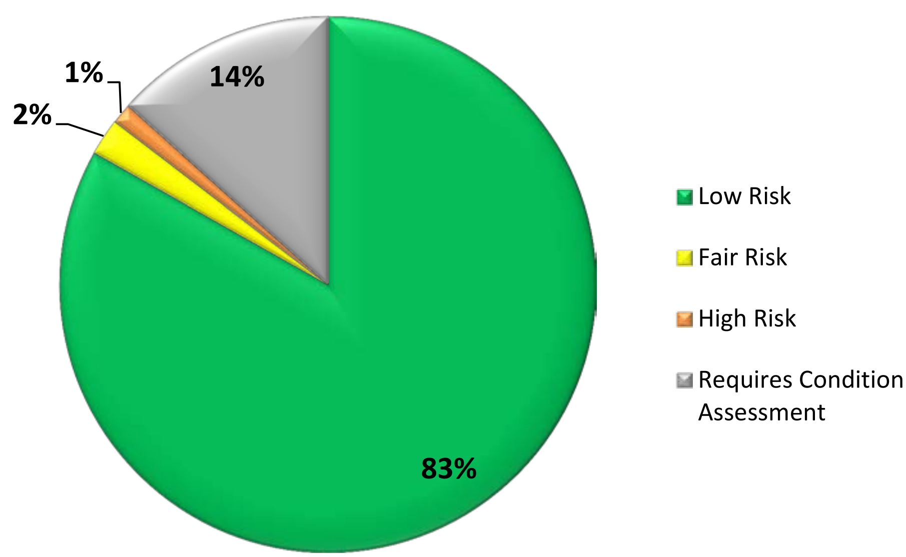


Figure 40: Steel Structure Fleet Condition Assessment

In order to maintain the condition of the fleet, the rate of refurbishment/coating will need to be increased. Towers in fair and high condition will require coating within the next 5 years. Should they exceed this optimum time to coat, the structures will eventually require either partial or full replacement.

Other Influencing Factors

- Innovation - Hydro One Transmission is continuing to investigate using alternative recoating products in order to reduce the amount of steel surface preparation and increase the drying process. This should reduce outage time and therefore permit a higher number of towers to be coated within the limited outage windows. Hydro One Transmission also continues to explore new steel tower coatings that are longer lasting than those that are currently commercially available.

Cost Trends and Impacts

Steel Structure Portfolio	Historic			Bridge	Test	
	2011	2012	2013	2014	2015	2016
# of Refurbishments	0	226	218	350	350	400
# of Replacements	0	0	17	4	4	12
% of Fleet	0%	0.5%	0.5%	0.7%	0.7%	0.8%
Capital ($M)	0.6	8.7	13.3	11.1	10.7	16.0
OM&A ($M)	4.7	4.8	3.1	4.4	4.1	4.2

The capital investment in the test years is an increase over historic levels. The strategy to manage the aging fleet of steel towers is a combination of planned replacements, component refurbishment and tower coating. The number of towers that have been refurbished, coated or replaced over the past 10 years has been very low. The result of recent condition inspections has pointed to rapid deterioration of steel structures in highly corrosive areas, which demonstrates a need to increase the fleet renewal. Hydro One Transmission plans to undertake an aggressive tower coating program to sustain these assets. Tower coating has been identified as the preferred alternative as it has a life cycle cost of roughly half that of tower replacement and is less impactive to the system as circuit outages required for coating are minimal.

OM&A expenditures are relatively stable with assessment activities performed frequently to assess zinc coating thickness and member condition.

4.2.4 Transmission Underground Cables

Asset Overview

Hydro One's transmission system consists of approximately 290 km of underground cables that supply city centres in Toronto, Ottawa and Hamilton with short sections in London, Sarnia, Picton, Windsor and Thunder Bay. Transmission underground cables are typically extensions to, or links between, portions of the overhead transmission system operating at 230 kV and 115 kV. Underground cables are mainly used in urban areas where it is either impossible, or extremely difficult to build overhead transmission lines due to legal, environmental and safety reasons.

Depending on the cable design the three phase conductors may be contained together within a steel pipe or each phase conductor self-contained in its own sheath and installed separately underground. Transmission underground cables are systems, similar to transmission lines, made up of numerous components all of which need to integrate and function properly in order to deliver power with the reliability that is demanded.

There are three different types of high voltage underground cables in use on the transmission system: Low-Pressure Oil-Filled ("LPOF") cables, High-Pressure Oil-Filled Pipe-Type ("HPOF") cables, and Extruded Cross Linked Polyethylene ("XLPE") cables.

UNDERTAKING – TCJ2.3

Undertaking

To provide calculations behind the tower coating evaluations.

Response

Part 1: Net Present Value Calculation

The Net Present Value (NPV) of a tower coating investment for 2 scenarios is presented below. The first scenario assumes an individual tower needs replacement and the second scenario assumes a group of more than 20 towers located in close vicinity needs replacement.

Information and Assumptions

a. Tower replacement age: 75 year-old
b. Average age of eligible towers is 45 year-old
c. Expected new coating life: 35 years
d. Straight line depreciation with ½ year rule in the first year
e. Inflation rate equal to 2%.
f. Study period of 60 years.
g. Start time for the study is 2017.
h. Unit costs for tower coating and replacement as provided below.

Table 1: Tower Coating and Replacement Costs

Single Tower Replacement		**Multiple Towers Replacement**	
115 kV Tower		**115 kV Tower**	
Replacement Cost ($k)	400	Replacement Cost ($k)	250
Coating Cost ($k)	30	Coating Cost ($k)	30
230 kV Tower		**230 kV Tower**	
Replacement Cost ($k)	450	Replacement Cost ($k)	350
Coating Cost ($k)	37	Coating Cost ($k)	37

Notes:

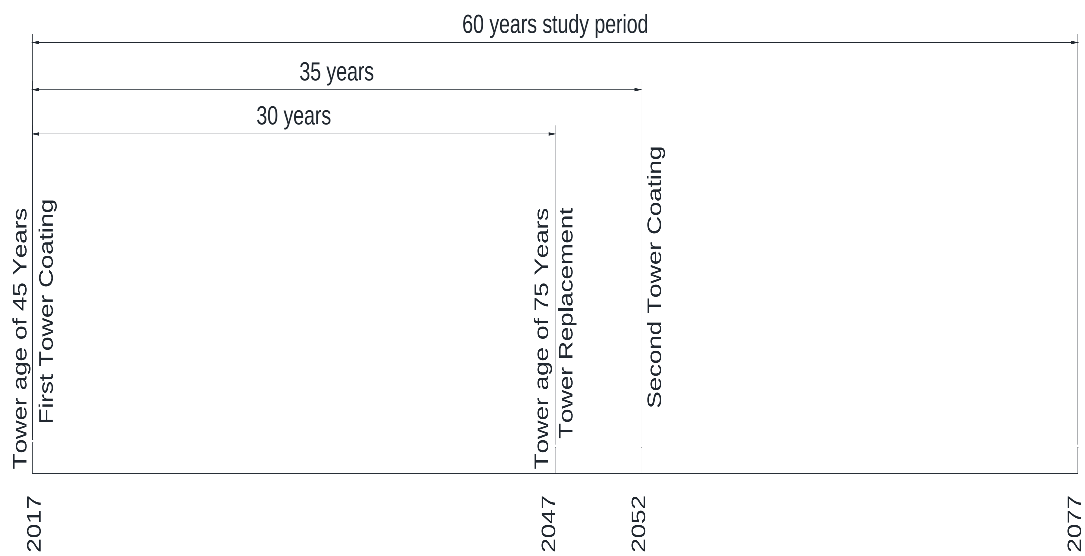
1. Tower replacement costs for replacing only one tower and a group of more than 20 towers in similar areas are presented. The lower unit cost for the latter case is due to economies of scale and savings from access, mobilization and demobilization.

Witness: Chong Kiat Ng

2. Tower coating unit costs remain the same for single or multiple towers coating.

3. The unit cost for tower replacement considers materials, labour and equipment cost. Revenue loss, customer and reliability impact due to a lengthy outage to replace the towers is not considered.

The first application of the tower coating is expected to take place in 2017 (tower at 45 year-old), the second application of coating is 35 years later in 2052 (tower at 80 year-old). Without the application of the coating, the tower will continue to deteriorate starting in 2017 and reaches end of life in 2047(tower at 75 year-old), which will require replacement.



NPV calculation result is summarized in Table 1 below.

Table 2: Summary Results of Calculations

Single Tower Replacement		**Multiple Towers Replacement**	
115 kV Tower		**115 kV Tower**	
PV for Coating Cost ($k)	30	PV for Coating Cost ($k)	30
PV for Replacement ($k)	92	PV for Replacement ($k)	57
Unit Capital Cost Saving ($k)	62	Unit Capital Cost Saving ($k)	27
230 kV Tower		**230 kV Tower**	
PV for Coating Cost ($k)	38	PV for Coating ($k)	38
PV for Replacement ($k)	103	PV for Replacement ($k)	80
Unit Capital Cost Saving ($K)	65	Unit Capital Cost Saving ($)	42

Witness: Chong Kiat Ng

Total capital cost saving resulted from 2017 and 2018 tower coating investment is shown below. Total towers expected to be coated in 2017 and 2018 is 2850. Fifteen percent of coating candidates are 115kV and 85% are 230kV towers.

Table 3: Unit and Total Cost Savings

Single Tower Replacement		**Multiple Towers Replacement**	
115 kV Tower		**115 kV Tower**	
Unit Cost Saving	$62k	Unit Cost Saving	$27k
Total Cost Saving: $62K*2850*0.15	$26.50M	Total Cost Saving: $27K*2850*0.15	$11.54M
230 kV Tower		**230 kV Tower**	
Unit Cost Saving	$65k	Unit Cost Saving	$42k
Total Cost Saving: $65K*2850*0.85	$157.46M	Total Cost Saving: $42K*2850*0.85	$101.75M
Total NPV Capital Cost Saving Resulted from Test Years Tower Coating	**$184.0M**	**Total NPV Capital Cost Saving Resulted from Test Years Tower Coating**	**$113.3M**

Additional Information

There are 2 new developments since 2014 that have significantly improved the NPV analysis of this investment, which is the basis to support increasing investment for tower coating.

A. Engineering Study to Determine Corrosion Zones, Corrosion Rates, Tower Condition Assessment; and End of Life Criteria and Coating Opportunity

i) Corrosion Zones, Corrosion Rates and Tower Condition Assessment:
Hydro One and Electric Power Research Institute (EPRI) conducted an engineering study to define corrosion zones and corrosion rates in the province of Ontario and assess impact of corrosion to Hydro One's transmission tower. The study includes condition assessment of towers located in various corrosion zones. The study concludes that a significant portion of towers located in high corrosive zones are in need of coating to arrest further deterioration and prevent eventual replacements. Refer to Exhibit B1, Tab 2, Schedule 6, Section 3.3 and Exhibit I, Tab 9, Schedule 6, Attachment 2.

ii) Tower End of Life Criteria and Coating Opportunity:
A transmission tower is deemed to have reached end of life when it has lost 10% of steel thickness, rendering it incapable to withstand design load. A new

tower comes with a layer of protective zinc applied over bare steel via hot-dip galvanizing process. This layer varies in thickness. The American Society of Testing and Materials (ASTM) specifies a minimum thickness of 100 microns for tower steel. It is common for fabricator to deliver steels with an average zinc thickness of 150 microns.

The most common steel member thickness for 115 and 230kV towers is 8mm ie, 8000 microns. In high corrosive areas, the average annual zinc corrosion rate is 3.3 microns and bare steel is 27.5 microns.

- Most common steel member thickness = 8mm.
- End of Life Criteria = 10% loss of steel thickness, 800 microns
- Opportunity to coat = in the time interval between when the zinc layer is nearly depleted and before end of life.

New steel members come with 150 microns zinc layer and the annual zinc corrosion rate is 3.3 microns. Hence, it takes 45 years (150/3.3=45) to deplete the zinc layer.

Once zinc layer is depleted, the exposed bare steel will corrode at an annual rate of 27.5 microns. Hence, it takes 29 years (800/27.5=29) to lose 800 microns of thickness.

A tower in high corrosive area will reach end of life in 74 years (45+29)

Therefore, the opportunity to economically extend life of towers located in high corrosive area via coating is around 45 year-old and before 74 year-old. As the towers exceed 75 year-old, various level of refurbishment effort will be required to restore strength before coating can be applied. Eventually, costly tower replacement becomes the only feasible option.

B. Galvatech

Galvatech is a zinc rich coating product manufactured by Rust-Anode. Hydro One became aware of this product in recent years and completed a detailed assessment of its performance. Refer to Exhibit I, Tab 9, Schedule 6, Attachment 3. The unique and desirable performance characteristics of this product are:

i) Does not require extensive surface preparation;
ii) Rapid curing, approximately 2 hours as opposed to 24 hours;

Witness: Chong Kiat Ng

iii) Less dripping, less likely to contaminate other line components such as insulators, which enables live-working technique;

iv) High performance, quality of coating comparable to hot-dip galvanizing process; and

v) Durability, coating is expected to last 30 to 35 years in the high corrosive zones.

These 2 new developments described in (A) and (B) have improved significantly the productivity and efficiency of tower coating investment, which makes it an attractive and prudence asset management undertaking as discussed in Part 1.

<u>Tower Coating Investment Pacing</u>

The Hydro One transmission system consists almost exclusively of overhead transmission lines and owns approximately 52,000 steel structures. Hydro One is planning to coat 1,250 and 1,600 towers in 2017 and 2018 respectively. The total count of 2,850 towers eligible for coating in the test years represents approximately 5.5% of the tower population.

There are approximately 13,000 towers located within high corrosive zones, which is the focal point of the tower coating investment. Currently 7,550 of these 13,000 towers have met coating criteria and are within the window of opportunity for coating. Sixty percent of these 7,550 towers are currently experiencing corrosion and metal loss. As these towers approach 75 years old, the ability to extend their service life by coating diminishes.

Hydro One intends to complete coating these 7,550 towers between 2017 and 2021 to extend the service life of these towers and maximize capital cost savings by minimizing tower replacements. 2017 is intended to be a ramp up year operations with 1,250 towers. Subsequent years from 2018 to 2021 will see an average of 1,600 towers coated per year. The tower coating program will be adjusted after 2021 based on the condition of the remaining towers in high corrosive zones that meet the tower coating criteria and lessons learned from the test years.