132kV steel tower failure risk mitigation

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1. Executive summary

This case for investment (CFI) recommends investment in the refurbishment or replacement of 132kV transmission line steel towers across the network during the period of FY23 – FY29 to address the safety, bushfire, reliability and financial risks associated with this equipment failing whilst in service.

Endeavour Energy has a fleet of 839 steel towers constructed generally in the 1950's through to the 1970's to support 132kV transmission lines supplying transmission and zone substations throughout the network.

The need is that towers which are in a degraded condition with reduced strength in the structural members or foundations can fail causing the tower to collapse during high wind events and cause significant risks for persons, environment and property near to tower and possible loss of supply to customers. The possible consequences of failure include:

- Safety impacts on the public if the tower falls onto a building, onto a roadway or causes the conductors it supports to fall across a roadway;
- Bushfire impacts (including safety impacts and financial loss) due to the energised conductors clashing, causing sparks and initiating a bushfire;
- Reliability impacts due to loss of supply to substations supplied and hence to the customers supplied by the substations. This is only significant for towers which support two circuit, which together provide the sole transmission supply to a substation;
- Environmental impacts (in sensitive areas) caused by the repair/replacement/clean-up operations; and
- Financial impacts, the additional costs associated with clean-up after a failure and the repair/replacement of any adjacent towers which are also pulled over by the failure.

The towers support transmission lines which provide a secure supply to transmission or zone substations and generally there are no practicable non-network solutions for replacing the service they provide. Therefore, network options should be considered to address the identified need.

There are two network options for addressing the failure risk of towers in a proactive planned manner:

1. Refurbish the tower to extend its life by replacing structural members and/or refurbishing the foundations; and
2. Replace the tower, usually with a steel pole structure.

The intervention solution proposed to be generally adopted is to refurbish the towers. This is a small-scale action which manages service level outcomes while deferring the more significant expenditure associated with the alternate longer-term solution of complete tower replacement.

There are 10 towers however, whose structural condition has degraded to a point where refurbishment is not practicable and accordingly it is proposed that these towers be replaced.

Towers are identified for proactive intervention at the time when the net present value of the intervention reaches its maximum value. Where this occurs in the period of FY23 – FY29, the interventions have been included in this program. As a result, it is proposed that 34 towers have superstructure refurbishment and 27 have foundation refurbishment and a further 10 towers be replaced during FY23 – FY29.

The net present value (NPV) of the proposed refurbishment option is unique to each tower and varies from $184,000 to $6.59 million with an average of $2.36 million across the 71 assets proposed for intervention during the period. The total NPV of the proposed program is $167.71 million.

The benefit to cost ratio (BCR) for each tower varies from 3.2 to 67 and averages 23 across the 71 towers.

The total cost of these works is estimated to be $10.52 million in real FY23 terms and it is recommended that the program be approved for consideration in the FY23 Portfolio Investment Plan (PIP) for optimisation.

Refurbishment intervention on a further 158 towers is NPV positive and provides the maximum NPV across the second half of the 10-year investment period (FY30 - FY34) and these are also put forward for optimisation. These 158 investments total a further $16.80 million (in real FY23 terms) giving a total investment for optimisation of $27.32 million.

There are a further 508 towers with an estimated refurbishment cost of $52.16 million that are NPV positive but do not achieve their maximum NPV prior to the conclusion of the investment period (FY34) at the time of completing this economic assessment. These interventions have not been considered within this CFI for optimisation.

This recommendation is made on the basis that the preferred solution represents the highest economic value (economic benefit) compared to other credible network and non-network options.

The project cost of the credible options fall below the threshold for application of the Regulatory Investment Test for Distribution (RIT-D) (currently $6.0 million) and therefore the RIT-D is not applicable to this program.

Whilst, nil tower failures have been experienced to date, the modelling shows there is an increasing likelihood of unexpected tower failure during the FY23 – FY29 period. To accommodate this eventuality, it is proposed that additional funding of $370,000 be made available for reactive tower replacement during the FY23 – FY29 period.

2. Purpose

The purpose of this document is to seek endorsement of the case for investment (CFI) for managing the risks posed by aged 132kV steel towers throughout the network.

This case for investment (CFI) recommends both the proactive intervention for refurbishment of the identified towers during the FY23 – FY29 period and provision of additional capital for the reactive replacement of towers that may fail unexpectedly during the period.

3. Identified needs and/or opportunities

3.1 Background

Endeavour Energy has a fleet of 839 lattice type steel towers which used to support 132kV transmission lines supplying transmission and zone substations throughout the network. The majority of the towers are of double circuit construction and support two electrical circuits or feeders. In rare instances, the circuits may be energised at 66 or 33kV rather than 132kV.

The fleet of towers were constructed generally in the 1950's through to the 1970's, with some new towers built for the establishment of Regentville Bulk Supply Substation in 1997 and the Tallawarra Power Station in 2007. Generally, however, in recent times, 132kV lines have been constructed with concrete or steel poles rather than lattice towers.

The superstructure of the towers above ground consists of galvanised steel members in a lattice structure. The foundations below ground are either mass concrete (called "spread" foundations) or are the "grillage" type which is comprised of steel frame works and plates buried directly in the ground.

The towers are located in two broadly differing environmental conditions – being coastal and non-coastal. Coastal is considered to be within 10km of the coast-line and in this area, the saline atmosphere degrades the zinc coating of the towers and then corrodes the underlying steel significantly more rapidly than in the non-coastal areas.

In the past, programs have been undertaken to recoat the towers in various parts of the network with a range of paint substances to extend the life of the steel superstructure. However, these programs have proven to be uneconomical and/or ineffective and are no longer being considered.

A number of towers in the Wollongong area were coated with paint containing asbestos which is now presenting safety and environmental risks. However, all these towers are currently being replaced with steel pole structures under a separate program.

Furthermore, a number of towers in the Blue Mountains and Western Sydney areas have had their grillage foundations refurbished in recent years.

3.2 Risks and identified need

Towers can fail in two fundamental ways:

- Loss of the galvanising on the above ground structural members leads to corrosion of the underlying steel, particularly in coastal areas, causing loss of strength in key members which collapse and cause the tower to collapse, particularly during high wind events; and
- Corrosion of the foundations below ground, causes loss of strength and the tower to collapse, also during high wind events.

In the coastal areas, a number of towers have lost their galvanising zinc coatings and are now suffering from significant corrosion damage to structural members resulting in an elevated risk of structural failure and collapse.

Likewise, a number of towers in Western Sydney and the Blue Mountains areas have grillage foundations which are exhibiting corrosion damage with an elevated risk of failure and collapse of the tower.

The collapse of a tower can present significant risks for persons, environment and property near to the tower and possible loss of supply to customers. Depending on the location of the tower, the consequences of failure may include:

- Safety impacts on the public if the tower falls onto a building, onto a roadway or causes the conductors it supports to fall across a roadway;
- Bushfire impacts (including safety impacts and financial loss) due to the energised conductors clashing, causing sparks and initiating a bushfire;
- Reliability impacts due to loss of supply to substations supplied and hence to the customers supplied by the substations. This is only significant for towers which support circuits which together provide the sole transmission supply to a substation;
- Environmental impacts (in sensitive areas) caused by the repair/replacement/clean-up operations; and
- Financial impacts, the additional costs associated with clean-up after a failure and the repair/replacement of any adjacent towers which are also pulled over by the failure.

The consequences of failure of many of the towers are significant due to their proximity to housing developments, bushfire risk areas and major roads. As a result, as their condition degrades with age and their probability of failure increases, their ongoing service costs become excessive, leading to a decision to retire the assets to manage the failure risks they present.

There are also other failure modes such as the deformation of the tower structure without collapse and the deformation of crossarms without the conductors falling which have significantly reduced failure consequences.

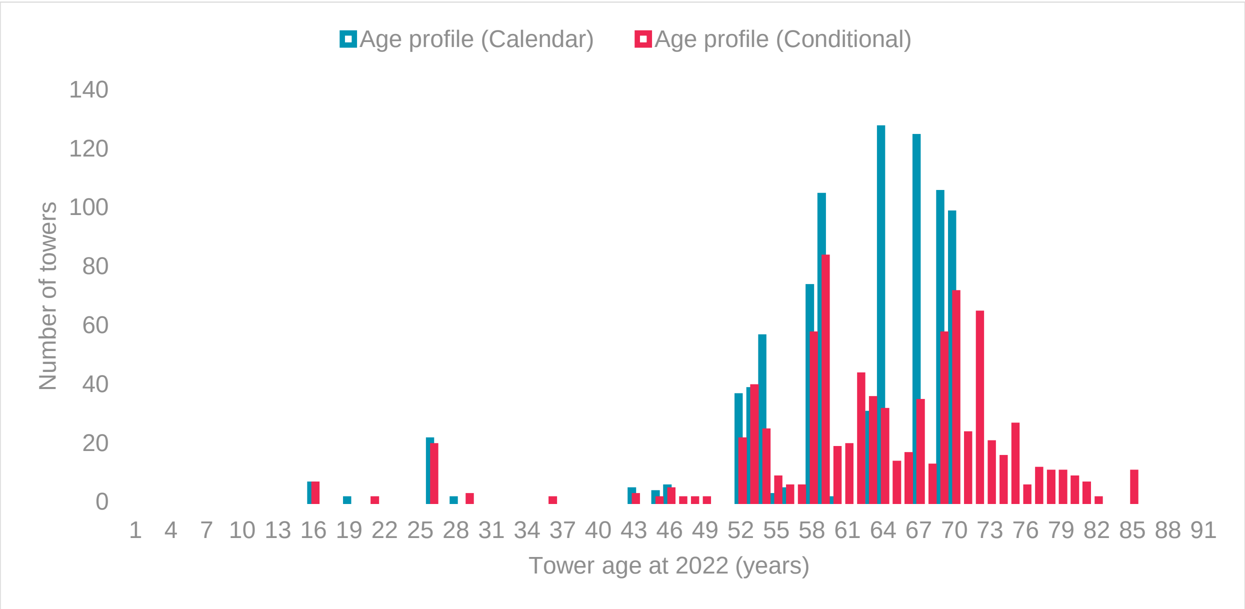
It is also noted that all structures are designed from new to withstand certain environmental (wind) conditions and therefore there is a probability of towers failing if these conditions are exceeded, throughout their lives from new. However, to date, Endeavour Energy has not experienced the failure of any steel towers in our network.

Refer Appendix C for further detail of the assessed failure consequences.

3.3 Asset age profile

The age profile of the fleet of 839 towers is shown in Figure 1 below.

Figure 1 – Age profile of the fleet of towers



In this figure, the calendar age of each tower is shown along with the age adjusted to reflect its condition to give a “conditional” age profile which reflects the health of the assets.

Note that the very young towers are associated with the establishment of TransGrid’s Regentville Bulk Supply Substation in 1997 and Energy Australia’s Tallawarra Power Station in 2007.

4. Consequence of nil intervention

4.1 Consequences of nil capital intervention

The nil intervention case involves not carrying out any capital works. Therefore, towers would be operated until they failed and then retired and not replaced.

The consequences of this would include:

- The consequences of failure for each tower as noted in 3.2 above; and
- The flow-on risk costs associated with losing key transmission elements from the network.

The failure of the transmission network would result over time in widespread and sustained loss of supply to our customers. This would incur very significant costs based on the prevailing value of customer reliability in response to which the market would readjust to provide alternative arrangements of supply to bypass Endeavour Energy’s network.

Clearly this is not a tenable situation as it directly undermines Endeavour Energy’s business model and the principles we have committed to in the Energy Charter [1].

Table 1 below provides a broad estimate of the economic costs of the nil-intervention case.

Table 1 – Nil intervention economic cost summary

Risk category	PV of residual risk ($M)	Comments
Tower failure risk impacts	2,500	The consequences of failure of the fleet of towers (including safety, bushfire, environmental and financial impacts but excluding reliability and reactive capital costs). Refer section 4.2 below for further detail.
Loss of supply to major transmission substations	12,600	The loss of supply to Carlingford, Bellambi TS, Katoomba North and Outer Harbour transmission substations (all of which are supplied by single double circuit tower lines) for a period of six months while other arrangements are made for supply. It is assumed that the loss occurs 20 years into the future. These costs are commensurate with the provision of alternative supplies such as solar farms and grid connected batteries of appropriate capacity to substitute for these substations. Refer Carlingford Transmission Substation Reliability and Safety Mitigation RIT-D screening report [2] for further information.
Total	**15,100**	

On this basis, the reactive replacement of towers which fail will be undertaken, subject to an assessment of the ongoing need for the asset, and the nil intervention case will not be considered further in this CFI.

4.2 Counterfactual (business as usual)

The business as usual (BAU) “counterfactual” scenario includes operating the towers until they fail and then replacement of the tower after failure, providing its service is still required. Nil proactive capital intervention is carried out.

The scope of works under the BAU include:

- Maintenance of the towers, which is currently limited to:

- Routine visual inspection;
- Repair of any minor damage such as bent elements around ground level due to third party impacts and repair of anti-climbing devices; and

- Reactive replacement after failure.

Currently, "failure" refers to a structural failure of either the superstructure or foundations of the tower which results in a functional failure of the asset.

Conditional failures are also possible but currently Endeavour does not have standards which define the criteria for a conditional failure. Apart from isolated replacement of bent members, which appear to have been caused by third party impacts, there have been no failures of towers experienced to date which could be classed as a "conditional failure". Furthermore, nil towers in Endeavour Energy's network have suffered functional failures to date.

A summary of the risk presented by the counterfactual case is shown in and below. All costs are in real FY23 terms and are present values (PV). A discount rate of 3.26% has been used throughout the economic evaluation.

Table 2 – BAU risk cost summary

Risk category	PV of residual risk ($M)	Risk proportion (%)
Safety	2,119	60.4
Reliability	781	22.3
Bushfire	151	4.3
Financial	167	4.8
Environmental	15	0.4
Reactive capital replacement costs	272	7.8
Total	**3,506**	**100**

As noted in Table 2 above, the residual risk presented by the BAU case totals $3,506 million. The residual risk value presented by each tower ranges from $0.072 million to $8.77 million and averages $2.027 million across the fleet of 839 towers.

The higher risk values are considered to be excessive and indicate the need for the higher risk towers to be retired in order to mitigate the risk and that options for intervention should be considered to provide for the continuity of service required of these towers.

5. Options considered

5.1 Risk treatment options

A range of options have been considered to address the risk presented by the towers being assessed as an alternative to network investment. These approaches are summarised in Table 3 below.

Table 3 – Tower risk treatment options

Option	Assessment of effectiveness	Conclusion
Additional maintenance to extend the life of the existing asset	Maintenance procedures unable to extend the life of towers. All refurbishment, coating works etc are capital works. Re-coating towers has proven to not be an economically viable approach	No technically feasible solution in isolation
Reduce the load on the asset through network reconfiguration, network automation, demand	The risk of failure is independent of load. A minor reduction in the consequences of failure could be achieved by transferring load from	No technically feasible solution

Option	Assessment of effectiveness	Conclusion
management or other non-network options	any of the lines but there is little capacity to do this in the surrounding network. The towers are an integral to the supply to their substations which are required to carry load for the foreseeable future. Further, there are no practicable non-network solutions for replacing a line supplying a zone or transmission substation.	
Implementing operational controls such as limiting access, remote switching protocols etc	These controls are in place to limit the safety risks presented by this equipment to workers, but the principal risk that drives the need for intervention is safety to the public and reliability, neither of which can be affected by practicable controls.	Controls only the safety risk elements for workers
A combination of options together or staged to maintain option value and reduce the consumer's long-term service cost	Generally, refurbishment options exist for extending the life of the towers. However, the condition of some towers has degraded to the point where refurbishment is no longer an effective solution and compete replacement needs to be considered.	Recommended approach

5.2 Non-network options

The towers support transmission lines which provide a secure supply to transmission or zone substations and generally there are no practicable non-network solutions for replacing the service they provide.

Therefore, network options should be considered which include intervention to address the identified need.

5.3 Credible network options

There are two network options for addressing the failure risk of towers in a proactive planned manner, which are practicably achievable and hence are credible:

1. Refurbish the tower to extend its life by replacing structural members and/or refurbishing the foundations; and
2. Replace the tower, usually with a steel pole structure.

5.3.1 Tower refurbishment

The refurbishment approach includes the replacement of elements of the tower superstructure as they corrode to a point where the strength of key elements is compromised and/or the refurbishment of the foundations of towers with grillage foundations as they corrode and lose strength.

Both these interventions in affect extend the life of a tower rather than allowing for the retirement of the tower. The extent of this life extension is not known due at this stage due to the limited history of experience with these processes, but a nominal value of 20 years has been assumed. The average estimated cost of refurbishing a tower structure is estimated to be $100,000, which includes replacing a nominal 20 structural elements at $5,000 each. The cost of refurbishing the four grillage foundations of a tower is estimated to be $120,000, based on previous refurbishment works carried out under program TM803 – Steel tower below ground rectification [3].

5.3.2 Tower replacement

Under this option, the intervention includes the complete replacement of the tower (with steel poles) in a planned proactive manner to allow for the retirement of the tower.

A value of $375,000 for replacing the common double circuit suspension towers with a twin steel pole structure and $500,000 for replacing a double circuit tension tower with twin heavy poles or a special steel pole structure have been assumed for this assessment. These values are estimates based on the limited experience of replacing towers within Endeavour Energy's network.

5.3.3 Tower refurbishment compared to replacement

A simple cost benefit assessment indicates that refurbishment provides a similar value to complete replacement when the refurbishment provides an additional 13 years of life extension and provided that only either the superstructure or the foundations but not both require refurbishment for each tower. Refer Appendix B for further details.

In practise, towers in the coastal regions suffer from corrosion of structural members but have concrete “spread” foundations (rather than grillage foundations) and the towers with grillage foundations are not suffering from structural corrosion. As a result, each tower assessed for the value of refurbishment requires either structure or foundation refurbishment but not both and therefore complies with the generalised refurbishment value rule.

Refurbishment of structures is a relatively new process for Endeavour Energy and the strategy may need to be adjusted once experience is gained through designing and carrying out the member replacement works. For instance, it may prove not to be economical to replace tower leg members and on some towers with extensive corrosion to a multitude of key structural members. There are 10 towers where it is known that corrosion of the superstructure has progressed to the point where refurbishment is no longer practicable. For these towers, replacement is the only credible option.

Other towers with similar condition issues, if not already noted, need to be identified during the early stages of the program so that they can be re-assessed for complete replacement.

5.4 Economic evaluation

5.4.1 Comparison of options

In order to compare the two options, an assessment has been made of the value provided by the suite of refurbishment projects and replacement projects whose net present value (NPV) reaches their maximum values during the FY23 – FY29 period.

5.4.2 Option 1 – Tower refurbishment outcomes

This option identifies the refurbishment of the superstructure of 34 towers and the refurbishment of the foundations of 27 towers with an NPV that is positive and reaches its maximum value during the FY23 – FY29 period of interest. This option also includes the complete replacement of 10 towers which are not able to be refurbished due to their deteriorated condition.

This option presents a residual risk of $3,329 million and provides a benefit of $177.6 million compared to the counterfactual case. The PV of the cost of the option is $9.83 million and the NPV overall is $167.7 million. The cost of the option in real FY23 terms is $10.52 million. Table 4 below provides a summary of the residual risk presented by this option. Refer Appendix A for details of the towers identified for intervention during the FY23 – FY29 period under this option.

Table 4 – Option 1 residual risk summary

Risk category	PV of residual risk ($M)	Risk proportion (%)
Safety	2,079	62.5
Reliability	722	21.7
Bushfire	100	3.0
Financial	162	4.9
Environmental	13	0.4
Reactive capital replacement costs	253	7.6
Total	**3,329**	**100**

5.4.3 Option 2 – Tower replacement

This option identifies 125 towers whose NPV of replacement is positive and reaches a maximum value during the FY23 – FY29 period of interest. This option presents a residual risk of $3,044 million and provides a benefit of $461.7 million compared to the counterfactual case. The PV of the cost of the option is $47.0 million and the NPV overall is $414.6 million. The cost of the option in real FY23 terms is $51.9 million.

Table 5 below provides a summary of the residual risk presented by this option. Refer Appendix A for details of the towers identified for intervention during the FY23 – FY29 period under this option.

Table 5 – Option 2 residual risk summary

Risk category	PV of residual risk ($M)	Risk proportion (%)
Safety	1,860	61.1
Reliability	652	21.4
Bushfire	143	4.7
Financial	145	4.8
Environmental	13	0.4
Reactive capital replacement costs	232	7.6
Total	**3,044**	**100**

5.5 Evaluation summary

Table 6 below summarises the outcomes of the cost-benefit assessment the Tower refurbishment and Tower replacement options for Endeavour Energy's fleet of 839 towers compared to the BAU case. The summary shows only the impact of investment in the towers whose NPV of intervention reaches its maximum value in the FY23 - FY29 period.

Table 6 – Option economic evaluation summary

Option	Option type	Volume of inter-ventions	Residual risk ($M)	PV of benefits ($M)	PV of investment ($M)	NPV ($M)	Average BCR	Rank	Comments
BAU	Counter-factual	-	3,506	-	-	-	-	3	BAU
1. Refurbish towers (including 10 tower replacements)	Network	102	3,329	167.7	9.83	167.7	22.7	1	Technically feasible and gives highest BCR - preferred
2. Replace towers	Network	125	3,044	461.7	47.04	414.6	9.8	2	Technically feasible but high cost

As shown in Table 6, tower replacement provides greater benefit than tower refurbishment due to replacement of the towers with a new asset, whereas the refurbishment option only extends the life of the existing aged asset. Accordingly, tower replacement provides a higher NPV overall. However, the costs are also significantly higher than the refurbishment approach.

Due to the lower costs, the refurbishment option provides significantly higher benefit to cost ratio (BCR) metrics than the replacement option, indicating a more capital efficient solution than replacement.

Overall, refurbishment is considered to be a lower cost and lower risk approach than whole tower replacement and will deliver the highest overall value and is therefore the preferred option.

5.6 Economic evaluation assumptions

There are a wide range of assumptions of risk, their likelihoods and consequences which support the cost benefit assessment associated with this project. Refer Appendix C for details of these assumptions.

5.7 Scenario assessment

A scenario assessment has been carried out on the various elements of the risk and cost assumptions used in the economic analysis in order to test the robustness of the evaluation.

Three scenarios have been assessed:

- Scenario 1 – discourages investment with low benefits and high capital costs;
- Scenario 2 - represents the most likely central case based on estimated or established values;
- Scenario 3 - encourages investment with the high benefits with low capital costs.

The values for each of the variables used for each scenario are shown in Table 7 below.

Table 7 – Summary of scenarios investigated

Variable	Scenario 1 – low benefits, high capital costs	Scenario 2 – central values	Scenario 3 – high benefits, low capital costs
Capital cost	10% increase in the estimated network capital costs	Estimated network capital costs	10% decrease in the estimated network capital costs
Value of risk (combination of consequence of the failure risk and the likelihood of the consequence eventuating)	10% decrease in the estimated risk and benefit values	Estimated risk values	10% increase in the estimated risk and benefit values
Weibull distribution end-of-life failure characteristic	10% increase in the Weibull β parameter (increases the mean time to failure for the asset)	Estimated Weibull parameters based on available failure data and calibrated to observed failure rates	10% decrease in the Weibull β parameter (decreases the mean time to failure for the asset)

The impact on the preferred option (Option 1)'s NPV is shown in Table 8 below and the resultant spread of replacement years to give the maximum NPV for each of the 61 towers identified for refurbishment and 10 for replacement under the preferred option is shown in Figure 2. A total of 213 cases (three for each tower) have been assessed and are shown in Figure 2. However, due to space limitations, not all case labels are visible in the legend.

Table 8 – NPV of scenario analysis for the preferred option (Option 1)

Scenario	NPV of preferred option ($M)
Scenario 1 – Low benefits, high costs	51.3
Scenario 2 – Central risks and costs	167.7
Scenario 3 – High benefits, low costs	476.2

Figure 2 – Option 1, maximum NPV replacement years for the range of boundary scenarios

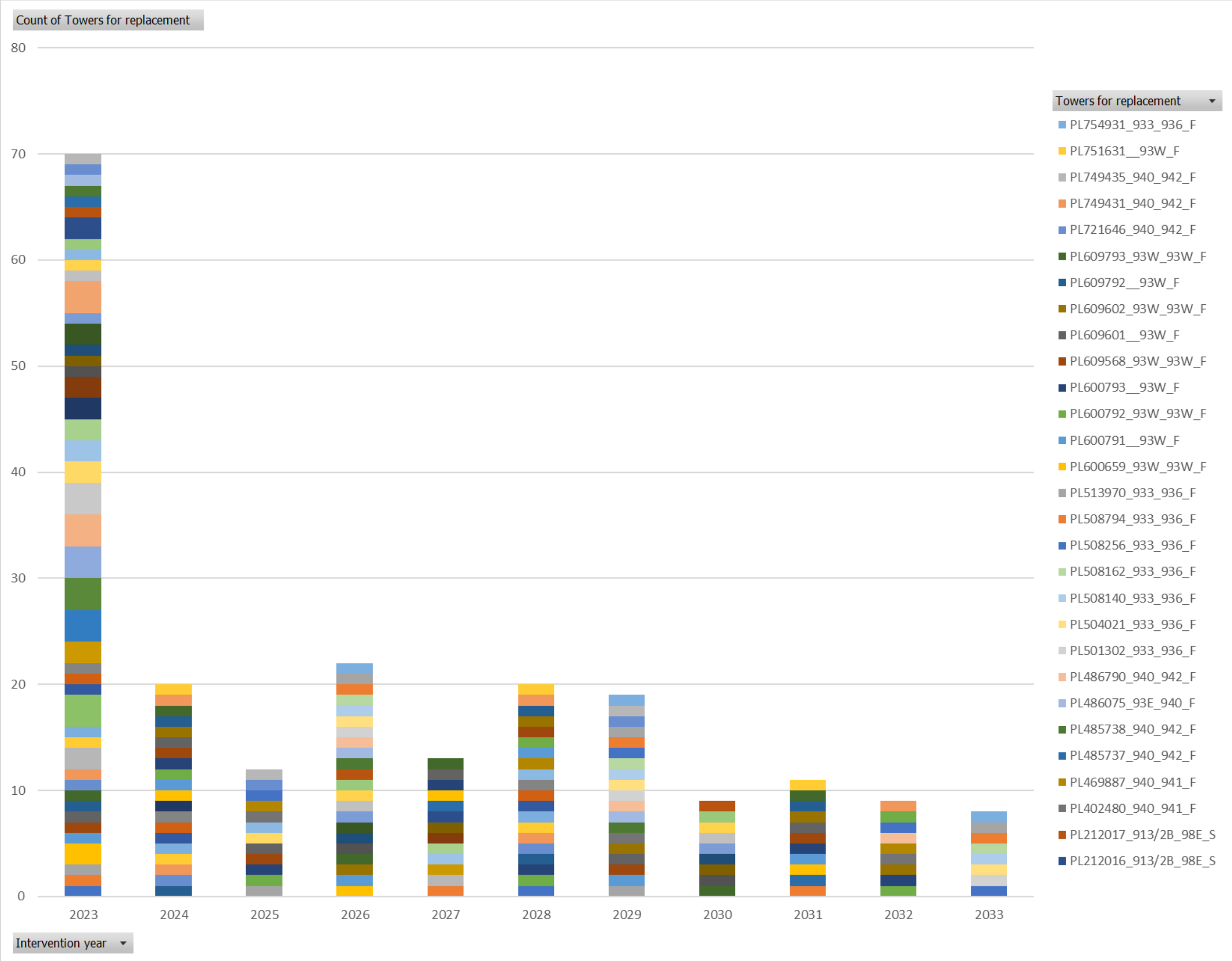


Figure 2 shows that the recommended refurbishments are skewed toward FY23, which is the earliest year that works can now practically be carried out).

All high-benefit, low-cost cases fall in FY23 – FY26, while the low-benefit, high-cost cases are spread across FY23 – FY33.

This assessment shows that there is a reasonable spread of optimum replacement years across the range of boundary scenarios but that the range is skewed towards the start of the period. On this basis it is concluded that the assessment is robust and points to an appropriate level of investment for Option 1.

6. Preferred option details

6.1 FY23 – FY29 scope and timing

The preferred option is Option 1, which includes refurbishment of 34 tower structures and 27 tower foundations to extend the life of the 61 towers and the complete replacement of 10 towers during FY23 – FY29.

The overall cost of the proposed program is estimated to be $10.52 million. A contingency is not proposed to be applied as there are multiple sites in the program and the estimated costs are based on mean values with individual site’s costs evening out to the mean across the program.

6.2 Additional scope and timing

Refurbishment intervention on a further 158 towers is NPV positive and provides the maximum NPV within the forecast period to FY34. These 158 investments total a further $16.80 million (in real FY23 terms) and have been identified as additional scope for inclusion in the investment portfolio optimisation process.

These interventions are considered to still be providing the highest value for customers, given the uncertainties surrounding the risk assessment process.

6.3 Investment summary

6.3.1 Planned proactive works

A summary of the investment proposed to be submitted for portfolio optimisation is shown in Table 9 below.

The foundation refurbishment costs are based on costs previously experienced in carrying out program TM803 – Steel tower below ground rectification [3], escalated to FY23 and therefore are expected to be reasonably accurate.

The costs provided for the structure refurbishment works are broad estimates based on limited replacement of structural elements which have been carried out to date and based on an average of 20 elements being replaced or reinforced on each tower. These costs may need to be updated as the process of carrying out this work is developed and refined over time.

All costs are in real FY23 terms.

Table 9 – Summary of investment for optimisation

NPV criteria	Intervention type	Unit rate ($M)	Quantity of interventions	Total costs ($M)
NPV reaches maximum during FY23 – FY29	Structure refurbishment	0.10	34	3.40
	Foundation refurbishment	0.12	27	3.24
	Tower replacement (Suspension tower)	0.38	9	3.38
	Tower replacement (Tension tower)	0.50	1	0.50
Subtotals			**71**	**10.52**
NPV reaches maximum during FY30 – FY34 Inclusion for optimisation	Structure refurbishment	0.10	108	10.80
	Foundation refurbishment	0.12	50	6.00
Subtotals			**158**	**16.80**
Totals			**229**	**27.32**

6.3.2 Reactive investment

Whilst nil tower failures have been experienced to date, the modelling shows there is an increasing likelihood of unexpected tower failures. Figure 3 below shows the forecast trend of reactive investment likely to be required for the replacement of towers that reach a state of conditional failure (found to be in a poor condition indicative of imminent failure) and/or fail functionally (no longer capable of performing their required function) in the period of FY23 – FY29.

This assessment assumes that the proactive refurbishment and/or replacement of towers as recommended by this CFI is carried out and considers only the probability of failure of other towers, not scheduled for refurbishment. A reactive replacement cost, which takes account of the likelihood of damage to adjacent towers but excludes the economic costs of a tower failure, has been averaged across the fleet of towers under consideration to give an annual forecast of reactive funding requirements. Table 10 below, summarises the proposed reactive funding forecast.

Figure 3 – Reactive replacement costs

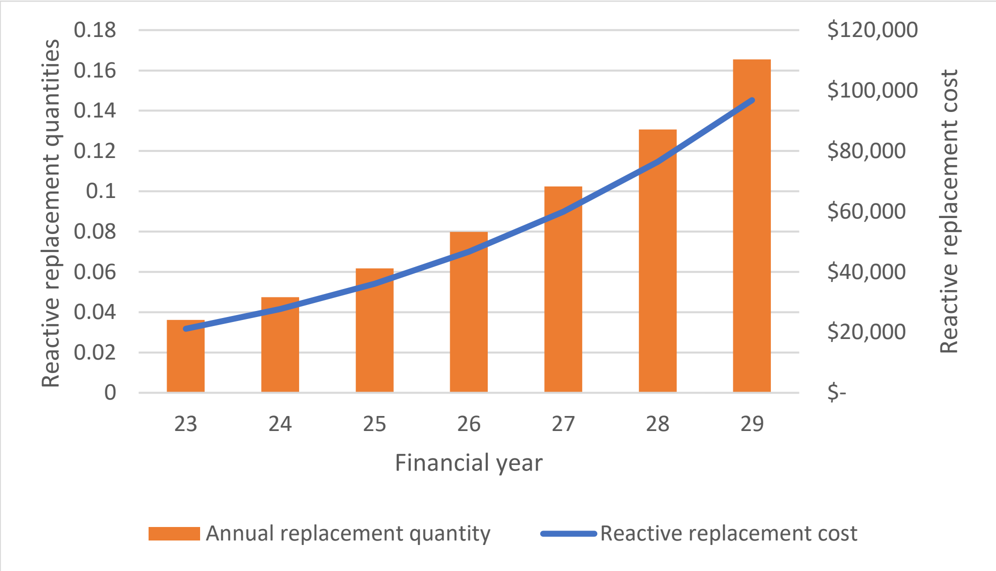


Table 10 – Reactive tower replacement forecast

Regulatory control period	Forecast quantity of failures	Forecast reactive investment ($M)
FY23 – FY24	0.1	0.05
FY25 - FY29	0.5	0.32
Totals	**0.6**	**0.37**

6.4 Project scope of works

6.4.1 Tower structure refurbishment

The proposed scope for structure refurbishment includes:

- Review each structure for level of corrosion of the members;
- Document the corroded members using common methodology/nomenclature for all towers;
- Design replacement members and the methodology for making the replacements/reinforcements. The refurbishment works should aim to provide a nominal 20 years further life of the structure. Alternatively, the works may be staged over a number of years as members progressively corrode.

  Towers where the corrosion of members has advanced to the point where the replacement of members is unlikely to present an effective solution or where corrosion of leg members indicates that refurbishment will be significantly more costly that allowed in this CFI, should be flagged for review for a complete replacement approach;
- Manufacture replacement members;
- Install replacement members;
- Dispose of any redundant members;
- Record the replacements works including:
  - Tower name, plant number and equipment number;
  - Replaced member using standard nomenclature;
  - Date of the works; and

  - Provide photographs before and after the works;
- Document the works undertaken, including the process of review and the ongoing works program if applicable to ensure that the strategy continues to be implemented over time;
- Update the asset information including the works undertaken in SAP.

6.4.2 Tower foundation refurbishment

The proposed scope for foundation refurbishment includes:

- Review each structure for level of corrosion of the foundations by revealing the top 500mm of each of the four foundations;
- Document the observed condition of each foundation;
- Excavate and carry out refurbishment of each foundation which exhibits corrosion damage. Refer to GHD report [4] and instructions and drawing 21-21228-S009, rev C for detail of the refurbishment process and options;
- Record detail of the refurbishment works including:
  - Tower name, plant number and equipment number;
  - Found condition of the foundations
  - Scope of works carried out;
  - Date of the works; and
  - Provide photographs before and after works;
- Update the asset information including the works undertaken in SAP;

7. Regulatory investment test

The project cost of the credible option(s) for each site falls below the threshold for application of the Regulatory Investment Test for Distribution (RIT-D) (currently $6.0 million) and therefore the RIT-D is not applicable to this project.

8. Recommendation

It is recommended that Option 1, for the proactive refurbishment and/or replacement of towers where the intervention provides a maximum NPV in the period of FY23 – FY34, be included in the PIP FY23 and to proceed to the investment portfolio optimisation stage.

It is further proposed that an allowance for an additional $0.37 million be made within the FY23 - FY29 period for the reactive replacement of towers that fail unexpectedly.

9. Attachments

Appendix A – Details of recommended scope for optimisation

Appendix B - Refurbishment and replacement cost benefit test

Appendix C – Risk assessment variables

Appendix D – Images of typical towers

10. References

[1] “The Energy Charter,” theenergycharter.com.au, January 2019.

[2] Endeavour Energy, “Carlingford Transmission Substation reliability and safety risk mitigation, Notice on screening for non-network options,” Endeavour Energy, November 2021.

[3] Endeavour Energy, “TM803 - Steel tower below ground rectification BC FY18 - Y19, rev 1,” 2018.

[4] GHD, “Report for steel transmission tower, foundation condition investigation, December 2007,” GHD Pty Ltd, December 2007.

[5] Endeavour Energy, “Summer Demand Forecast 2022 - 2031,” Network Demand Forecasting Section, 2021.

[6] Australian Energy Regulator, “D19-2978 - AER - Industry practice application note - Asset Replacement Planning,” AER, 25 January 2019.

Appendix A – Details of recommended scope for optimisation

Scope with maximum NPV in FY23 – FY29

Plant No.	Equipment No.	Name	Asset Type	In-Service Date	Refurbishment type	Budget cost ($)	Year of maximum NPV	NPV at maximum	BCR at maximum
PL211982	580113	PL211982_7028_98E_S	TWR_Coastal_Spread_SUS_REP	1954	Tower replacement	$ 375,000	2023	$ 5,940,963	17
PL211826	579214	PL211826__980_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2023	$ 1,398,106	15
PL211998	580128	PL211998_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2023	$ 1,190,856	13
PL212004	580133	PL212004_7028_98E_S	TWR_Coastal_Spread_SUS_REP	1954	Tower replacement	$ 375,000	2023	$ 3,848,613	11
PL211995	580126	PL211995_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2023	$ 1,017,780	11
PL212016	580143	PL212016_913/2B_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2023	$ 800,094	9
PL211979	885980	PL211979_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2023	$ 720,864	8
PL211993	580125	PL211993_7028_98E_S	TWR_Coastal_Spread_TEN_REP	1954	Tower replacement	$ 500,000	2023	$ 3,204,836	7
PL211996	580127	PL211996_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2023	$ 603,185	7
PL211988	580121	PL211988_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2023	$ 583,123	7
PL211991	934111	PL211991_7028_98E_S	TWR_Coastal_Spread_SUS_REP	1954	Tower replacement	$ 375,000	2023	$ 1,908,045	6
PL211992	885981	PL211992_7028_98E_S	TWR_Coastal_Spread_SUS_REP	1954	Tower replacement	$ 375,000	2023	$ 1,581,050	5
PL211990	580123	PL211990_7028_98E_S	TWR_Coastal_Spread_SUS_REP	1954	Tower replacement	$ 375,000	2023	$ 1,553,513	5
PL211989	580122	PL211989_7028_98E_S	TWR_Coastal_Spread_SUS_REP	1954	Tower replacement	$ 375,000	2023	$ 1,464,958	5
PL211997	885982	PL211997_7028_98E_S	TWR_Coastal_Spread_SUS_REP	1954	Tower replacement	$ 375,000	2023	$ 1,217,772	4
PL211994	934112	PL211994_7028_98E_S	TWR_Coastal_Spread_SUS_REP	1954	Tower replacement	$ 375,000	2023	$ 1,133,577	4
PL212002	885983	PL212002_7028_98E_S	TWR_Coastal_Spread_SUS_REP	1954	Tower replacement	$ 375,000	2023	$ 833,364	3
PL211978	580110	PL211978_7028_98E_S	TWR_Coastal_Spread_TEN	1954	Structure refurbishment	$ 100,000	2024	$ 4,433,025	47
PL211981	580112	PL211981_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2024	$ 3,944,785	42
PL211980	580111	PL211980_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2024	$ 1,467,843	16
PL211985	580119	PL211985_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2024	$ 1,107,583	12
PL211975	580107	PL211975__7028_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2024	$ 966,684	11
PL211977	580109	PL211977__7028_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2024	$ 789,004	9
PL211987	580120	PL211987_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2024	$ 409,488	5
PL211986	895035	PL211986_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2024	$ 409,488	5
PL211813	579154	PL211813_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2025	$ 4,070,580	44
PL211835	579250	PL211835_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2025	$ 2,999,900	33
PL211836	885964	PL211836_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2025	$ 2,999,900	33
PL721646	794672	PL721646_940_942_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2025	$ 3,030,211	28
PL749435	870156	PL749435_940_942_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2025	$ 1,674,911	16
PL212011	580139	PL212011_913/2B_98E_S	TWR_Coastal_Spread_TEN	1954	Structure refurbishment	$ 100,000	2025	$ 1,023,109	12
PL212001	580131	PL212001_7028_98E_S	TWR_Coastal_Spread_TEN	1954	Structure refurbishment	$ 100,000	2026	$ 5,970,750	67
PL211827	579215	PL211827_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2026	$ 2,641,142	30
PL212005	580134	PL212005_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2026	$ 2,423,274	28
PL486075	222443	PL486075_93E_940_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2026	$ 2,745,430	26
PL485738	222106	PL485738_940_942_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2026	$ 2,731,917	26
PL211999	580129	PL211999_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2026	$ 1,268,054	15
PL212003	580132	PL212003_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2026	$ 1,141,336	14
PL212006	580135	PL212006_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2026	$ 1,081,393	13
PL212015	580142	PL212015_913/2B_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2026	$ 715,814	9
PL212017	580144	PL212017_913/2B_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2026	$ 715,814	9
PL211976	580108	PL211976_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2026	$ 395,683	5
PL600793	337172	PL600793__93W_F	TWR_Inland_Grillage_TEN	1954	Foundation refurbishment	$ 120,000	2027	$ 6,589,465	63
PL609793	346173	PL609793_93W_93W_F	TWR_Inland_Grillage_TEN	1954	Foundation refurbishment	$ 120,000	2027	$ 6,427,232	62
PL600659	337038	PL600659_93W_93W_F	TWR_Inland_Grillage_TEN	1954	Foundation refurbishment	$ 120,000	2027	$ 4,717,998	46
PL609601	345981	PL609601__93W_F	TWR_Inland_Grillage_TEN	1954	Foundation refurbishment	$ 120,000	2027	$ 4,487,273	44
PL212000	580130	PL212000_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2027	$ 3,043,491	36
PL207140	557539	PL207140_984_988_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2027	$ 624,042	8
PL485737	222105	PL485737_940_942_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2027	$ 289,312	4
PL211831	579246	PL211831_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2028	$ 3,918,109	47
PL600791	337170	PL600791__93W_F	TWR_Inland_Grillage_SUS	1954	Foundation refurbishment	$ 120,000	2028	$ 3,350,958	34
PL751631	872353	PL751631__93W_F	TWR_Inland_Grillage_SUS	1954	Foundation refurbishment	$ 120,000	2028	$ 3,190,482	32
PL609568	345948	PL609568_93W_93W_F	TWR_Inland_Grillage_SUS	1954	Foundation refurbishment	$ 120,000	2028	$ 3,139,243	32
PL609602	345982	PL609602_93W_93W_F	TWR_Inland_Grillage_SUS	1954	Foundation refurbishment	$ 120,000	2028	$ 3,139,243	32
PL211828	579216	PL211828_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2028	$ 2,440,468	30
PL609792	346172	PL609792__93W_F	TWR_Inland_Grillage_TEN	1954	Foundation refurbishment	$ 120,000	2028	$ 2,635,691	27
PL469887	206252	PL469887_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2028	$ 1,230,092	13
PL600792	337171	PL600792_93W_93W_F	TWR_Inland_Grillage_SUS	1954	Foundation refurbishment	$ 120,000	2028	$ 764,728	8
PL749431	870152	PL749431_940_942_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2028	$ 535,431	6
PL206666	556721	PL206666__988_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2028	$ 184,606	3
PL513970	250343	PL513970_933_936_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2029	$ 5,998,624	62
PL508140	244513	PL508140_933_936_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2029	$ 4,397,006	45
PL504021	240396	PL504021_933_936_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2029	$ 4,217,735	44
PL508794	245167	PL508794_933_936_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2029	$ 4,190,507	43
PL754931	934020	PL754931_933_936_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2029	$ 4,190,460	43
PL501302	237677	PL501302_933_936_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2029	$ 4,182,537	43
PL211838	579256	PL211838_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2029	$ 3,082,489	38
PL402480	73716	PL402480_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2029	$ 2,714,299	28
PL486790	223158	PL486790_940_942_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2029	$ 2,393,624	25
PL508162	244535	PL508162_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2029	$ 808,200	9
PL508256	244629	PL508256_933_936_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2029	$ 673,071	8

Scope with maximum NPV in FY30 - FY34

Plant No.	Equipment No.	Name	Asset Type	In-Service Date	Refurbishment type	Budget cost ($)	Year of maximum NPV	NPV at maximum	BCR at maximum
PL754944	934033	PL754944_220_239_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2030	$ 5,858,090	74
PL504063	240438	PL504063_933_936_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2030	$ 4,109,042	52
PL516436	252809	PL516436_220_239_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2030	$ 4,061,964	52
PL211758	570295	PL211758_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2030	$ 3,229,006	41
PL507091	243465	PL507091_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 3,542,584	38
PL506977	243351	PL506977_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 3,532,599	38
PL505996	242370	PL505996_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 3,532,599	38
PL507102	243476	PL507102_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 3,020,298	33
PL754932	934021	PL754932_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 2,980,367	32
PL501304	237679	PL501304_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 2,966,781	32
PL501303	237678	PL501303_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 2,930,454	32
PL510966	247339	PL510966_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 2,930,451	32
PL749931	870652	PL749931_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 2,930,451	32
PL505995	242369	PL505995_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 2,930,449	32
PL508793	245166	PL508793_933_936_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2030	$ 2,382,988	26
PL732780	836790	PL732780_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 2,328,300	25
PL211946	895033	PL211946_7028_98E_S	TWR_Coastal_Spread_TEN	1954	Structure refurbishment	$ 100,000	2030	$ 1,439,473	19
PL486789	223157	PL486789_940_942_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 1,218,390	14
PL489919	226287	PL489919_940_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2030	$ 962,284	13
PL211974	885979	PL211974_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2030	$ 783,484	11
PL211965	580098	PL211965_984_988_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2030	$ 755,904	10
PL500462	236837	PL500462_93E_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2030	$ 699,050	10
PL500427	236802	PL500427_93E_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2030	$ 698,089	10
PL508161	244534	PL508161_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 759,730	9
PL211839	579257	PL211839__980_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2030	$ 631,381	9
PL207139	557538	PL207139_984_988_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2030	$ 562,909	8
PL500648	237023	PL500648_93E_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2030	$ 555,262	8
PL578667	315043	PL578667_219_932_F	TWR_Inland_Grillage_TEN	1959	Foundation refurbishment	$ 120,000	2030	$ 297,734	4
PL508141	244514	PL508141_933_936_F	TWR_Inland_Grillage_SUS	1956	Foundation refurbishment	$ 120,000	2030	$ 280,537	4
PL749793	870514	PL749793_933_936_F	TWR_Inland_Grillage_TEN	1956	Foundation refurbishment	$ 120,000	2030	$ 167,160	3
PL517214	253587	PL517214_220_239_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2031	$ 6,038,028	79
PL519182	255554	PL519182_220_239_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2031	$ 4,207,858	55
PL517213	253586	PL517213_220_239_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2031	$ 2,843,368	38
PL480515	216884	PL480515_941_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2031	$ 2,683,248	36
PL211834	579249	PL211834_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2031	$ 2,674,055	36
PL500646	237021	PL500646_93E_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2031	$ 2,657,107	35
PL211743	570062	PL211743_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2031	$ 2,564,802	34
PL211819	579159	PL211819_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2031	$ 2,288,977	31
PL211746	570171	PL211746_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2031	$ 2,216,724	30
PL578448	314824	PL578448__93U_S	TWR_Inland_Spread_TEN	1954	Structure refurbishment	$ 100,000	2031	$ 1,580,697	21
PL211931	580049	PL211931_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2031	$ 911,513	13
PL528126	264498	PL528126_220_239_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2031	$ 720,621	10
PL754943	934032	PL754943_220_239_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2031	$ 720,621	10
PL212007	580136	PL212007_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2031	$ 626,575	9
PL211966	580099	PL211966_984_988_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2031	$ 544,362	8
PL500426	236801	PL500426_93E_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2031	$ 301,618	5
PL211949	885977	PL211949_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2031	$ 209,523	4
PL527783	264155	PL527783_220_239_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2032	$ 4,329,198	59
PL503973	240348	PL503973_93E_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2032	$ 3,800,978	52
PL211832	579247	PL211832_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2032	$ 3,558,534	48
PL211824	579212	PL211824_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 3,515,585	48
PL211822	579210	PL211822_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 3,493,890	48
PL211833	579248	PL211833_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2032	$ 3,463,422	47
PL211816	885961	PL211816_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 3,255,113	44
PL610920	347300	PL610920_93W_93W_S	TWR_Inland_Spread_SUS	1954	Structure refurbishment	$ 100,000	2032	$ 3,214,614	44
PL211753	570288	PL211753_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 2,902,598	40
PL211773	570347	PL211773_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 2,883,184	39
PL732280	836270	PL732280_220_239_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2032	$ 2,749,561	38
PL492339	228707	PL492339_93E_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2032	$ 2,695,109	37
PL211776	570349	PL211776_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2032	$ 2,575,959	35
PL211748	570270	PL211748_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2032	$ 2,481,028	34
PL501756	238131	PL501756_93E_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2032	$ 2,327,118	32
PL516930	253303	PL516930_220_239_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2032	$ 2,248,902	31
PL527795	264167	PL527795_220_239_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2032	$ 2,186,690	30
PL211818	579158	PL211818_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 2,165,054	30
PL211817	934104	PL211817_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 2,165,054	30
PL211781	570365	PL211781_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 2,011,720	28
PL489444	225812	PL489444_940_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2032	$ 1,797,010	25
PL754918	934007	PL754918_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 1,905,601	22
PL402836	74072	PL402836_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 1,817,618	21
PL489864	226232	PL489864_940_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2032	$ 1,497,195	21
PL211840	579258	PL211840__980_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 1,324,903	19
PL754920	934009	PL754920_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 1,452,316	17
PL510779	247152	PL510779_219_932_F	TWR_Inland_Grillage_TEN	1959	Foundation refurbishment	$ 120,000	2032	$ 1,373,250	16
PL486163	222531	PL486163_93E_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2032	$ 1,021,545	15
PL509134	245507	PL509134_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 1,218,947	15
PL479612	215981	PL479612_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 1,094,767	13
PL404475	79873	PL404475_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 1,083,928	13
PL471755	208113	PL471755_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 1,065,805	13

Scope with maximum NPV in FY30 - FY34 continued.

Plant No.	Equipment No.	Name	Asset Type	In-Service Date	Refurbishment type	Budget cost ($)	Year of maximum NPV	NPV at maximum	BCR at maximum
PL578669	315045	PL578669_219_932_F	TWR_Inland_Grillage_TEN	1959	Foundation refurbishment	$ 120,000	2032	$ 1,052,196	13
PL489865	226233	PL489865_940_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2032	$ 848,798	12
PL207141	934097	PL207141_984_988_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 788,032	12
PL509133	245506	PL509133_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 917,955	11
PL402969	75310	PL402969_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 914,947	11
PL408039	96656	PL408039_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 871,720	11
PL491994	228362	PL491994_93E_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2032	$ 661,921	10
PL515206	251579	PL515206_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 742,042	9
PL749829	870550	PL749829_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 737,619	9
PL754939	934028	PL754939_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 652,711	8
PL515188	251561	PL515188_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 652,711	8
PL207137	557537	PL207137_984_988_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 530,144	8
PL402902	75243	PL402902_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 635,844	8
PL207138	879917	PL207138_984_988_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2032	$ 526,535	8
PL619992	356376	PL619992__93U_S	TWR_Inland_Spread_SUS	1954	Structure refurbishment	$ 100,000	2032	$ 523,102	8
PL402137	73373	PL402137_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 622,624	8
PL732912	836924	PL732912_219_932_F	TWR_Inland_Grillage_TEN	1959	Foundation refurbishment	$ 120,000	2032	$ 615,196	8
PL515166	251539	PL515166_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 291,710	4
PL515185	251558	PL515185_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2032	$ 291,710	4
PL754950	934039	PL754950_220_239_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2033	$ 4,170,938	58
PL206259	555901	PL206259_988_98C_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2033	$ 4,017,061	56
PL211812	579153	PL211812_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2033	$ 2,848,494	40
PL211823	579211	PL211823_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2033	$ 2,745,971	39
PL211771	570345	PL211771_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2033	$ 2,699,212	38
PL720999	793992	PL720999_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 3,208,271	38
PL404881	80279	PL404881_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 3,136,998	37
PL515207	251580	PL515207_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 2,904,557	34
PL515209	251582	PL515209_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 2,903,643	34
PL470603	206968	PL470603_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 2,771,531	33
PL211837	579251	PL211837_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2033	$ 2,260,995	32
PL211820	885962	PL211820_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2033	$ 2,002,131	29
PL721773	794799	PL721773_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 2,365,326	28
PL211934	580067	PL211934_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2033	$ 1,900,913	27
PL211935	580068	PL211935_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2033	$ 1,900,913	27
PL211939	580074	PL211939_7028_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2033	$ 1,900,913	27
PL492296	228664	PL492296_93E_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2033	$ 1,477,541	21
PL469947	206312	PL469947_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 1,415,326	17
PL480770	217141	PL480770_940_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2033	$ 1,126,679	17
PL578385	314761	PL578385__93U_S	TWR_Inland_Spread_SUS	1954	Structure refurbishment	$ 100,000	2033	$ 1,076,668	16
PL212020	580145	PL212020_913/2B_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2033	$ 668,442	10
PL504023	240398	PL504023__942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2033	$ 652,589	10
PL480750	217121	PL480750_940_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2033	$ 614,677	9
PL212019	885986	PL212019_913/2B_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2033	$ 590,106	9
PL212014	885985	PL212014_913/2B_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2033	$ 563,994	9
PL212018	934110	PL212018_913/2B_98E_S	TWR_Coastal_Spread_SUS	1954	Structure refurbishment	$ 100,000	2033	$ 563,994	9
PL404576	79974	PL404576_940_941_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 617,335	8
PL207136	557536	PL207136_984_988_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2033	$ 512,932	8
PL578676	315052	PL578676_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 544,740	7
PL489866	226234	PL489866_940_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2033	$ 446,502	7
PL212010	580138	PL212010_7028_913/2B_S	TWR_Coastal_Spread_TEN	1954	Structure refurbishment	$ 100,000	2033	$ 417,847	7
PL489244	225612	PL489244_940_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2033	$ 351,122	6
PL515167	251540	PL515167_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 156,612	3
PL732906	836918	PL732906_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 152,017	3
PL509723	246096	PL509723_219_932_F	TWR_Inland_Grillage_SUS	1959	Foundation refurbishment	$ 120,000	2033	$ 152,017	3
PL516899	253272	PL516899_220_239_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2034	$ 5,088,268	73
PL211777	570350	PL211777_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2034	$ 3,879,373	56
PL211742	934095	PL211742_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2034	$ 3,154,842	46
PL211779	570352	PL211779_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2034	$ 2,977,145	43
PL206281	555918	PL206281_988_98C_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2034	$ 2,683,525	39
PL211825	579213	PL211825_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2034	$ 2,683,496	39
PL211766	570342	PL211766_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2034	$ 2,377,229	35
PL211750	570276	PL211750_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2034	$ 2,292,152	34
PL211830	579217	PL211830_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2034	$ 2,236,099	33
PL206260	555902	PL206260_988_98C_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2034	$ 2,216,315	33
PL610844	347224	PL610844__93W_S	TWR_Inland_Spread_TEN	1954	Structure refurbishment	$ 100,000	2034	$ 2,026,765	30
PL211829	885963	PL211829_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2034	$ 1,993,610	29
PL754924	934013	PL754924_940_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2034	$ 1,921,238	28
PL211768	895029	PL211768_980_981_S	TWR_Coastal_Spread_SUS	1953	Structure refurbishment	$ 100,000	2034	$ 1,899,511	28
PL211782	570366	PL211782_980_981_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2034	$ 1,883,438	28
PL489242	225610	PL489242_940_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2034	$ 1,747,853	26
PL480751	217122	PL480751_940_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2034	$ 1,298,217	19
PL489443	225811	PL489443_940_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2034	$ 929,213	14
PL207114	557519	PL207114__988_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2034	$ 865,450	13
PL486162	222530	PL486162_93E_942_S	TWR_Inland_Spread_TEN	1956	Structure refurbishment	$ 100,000	2034	$ 832,312	13
PL481064	217435	PL481064_940_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2034	$ 773,213	12
PL489241	225609	PL489241_940_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2034	$ 546,432	9
PL206664	975438	PL206664__988_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2034	$ 369,031	6
PL500425	236800	PL500425_93E_942_S	TWR_Inland_Spread_SUS	1956	Structure refurbishment	$ 100,000	2034	$ 273,145	5
PL207112	557517	PL207112__988_S	TWR_Coastal_Spread_TEN	1953	Structure refurbishment	$ 100,000	2034	$ 149,775	3

Appendix B – Refurbishment and replacement cost benefit test

Simple deferment calculation (excludes probability of failure)								
Discount rate	3.26%							
			Fin year ->	22	23	24	25	26
			Year count ->	0	1	2	3	4
			Present value					
BAU (replace in 0 years)								
Replace tower in	0	years						
Replace cost	$ 375,000	over 1 years	**$ 375,000**	$ 375,000	$ -	$ -	$ -	$ -
Reliability costs	$ -	pa	$ -	$ -	$ -	$ -	$ -	$ -
Total PV of option			**$ 375,000**					
Option 1 - refurbish structure or foundation								
Replace tower in	13	years						
Replace cost	$ 375,000	over 1 years	**$ 247,123**	$ -	$ -	$ -	$ -	$ -
Refurbishment foundation year	0		$ -					
Refurbishment cost - foundation	$ 120,000		**$ 120,000**	$ 120,000	$ -	$ -	$ -	$ -
Refurbishment structure year	0		$ -					
Refurbishment cost - structure	$ -		$ -	$ -	$ -	$ -	$ -	$ -
reliability costs		pa	$ -	$ -	$ -	$ -	$ -	$ -
Total PV of option			**$ 367,123**					
NPV			**$ 7,877**					

	27	28	29	30	31	32	33	34	35	36
Year count ->	5	6	7	8	9	10	11	12	13	14
BAU Replace cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
BAU Reliability costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Option 1 Replace cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 375,000	$ -
Option 1 Refurbishment cost - foundation	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Option 1 Refurbishment cost - structure	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Option 1 reliability costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

Refurbishment provides a positive benefit over replacement providing the refurbishment defers replacement for at least 13 years and only one refurbishment (structure or foundation, but not both) is required.

Fortuitously, in Endeavour Energy's network, at the time of this assessment and in the foreseeable future, it appears that all towers require only structure or foundation refurbishment but not both, therefore giving refurbishment a higher value proposition than complete replacement.

The above assessment shows the replacement costs associated with a standard suspension structure. Due to their higher costs, tension structures are likely to greater benefits due to refurbishment.

Appendix C – Summary of key risk assessment variables and assumptions

General variables and assumptions

Parameter	Value	Description/justification	Source/assumptions
Population	839	Number of towers in service in Endeavour Energy's (EE) network	Ellipse database. Asset type TW. Verified by onsite inspection by DM Consulting in 2014.
Annual conditional failures	0	Conditional failure is not defined in EE standards. Only non-routine inspection and maintenance expenditure has been due to repair of 3rd party impact damage which averages for $10,000 cost pa across the network	Ellipse defect workorder records
Annual functional failures	0	A functional failure is considered to be a collapse of the tower, causing safety, bushfire, financial and evironmental impacts. Nil functional failures have been experienced in the network to date.	EE outage management system (OMS), Ellipse workorder records and anecdotal information.
Discount rate (WACC)	3.26%	Weighted average cost of capital for EE	Regulated rate. Applied to all risk and investment values used in the cost-benefit assessment.
Base year of investment	FY23	All investments for budgeting purposes are expressed in real FY23 dollars	For inclusion into the FY23 PIP after optimisation
Calculation horizon	100 years	The timeframe over which the cost-benefit analysis is performed	FIGLEAF V6.0 algorithm
Maintenance costs	$500	Actual maintenance costs for towers vary around $500 per tower pa. Maintenance costs of the replacement assets (steel poles) are lower but the difference is not material to the cost-benefit assessment and therefore is not included to simplify the assessment.	Ellipse workorders
Planned intervention costs – tower replacement	$250,000	Single circuit 132kV towers	Based on Mains estimates but adjusted up to reflect the experience from project TM031 - Asbestos tower replacement which is experiencing substantial cost increases over estimated values. Requires verification
	$375,000	Double circuit 132kV suspension structures	
	$500,000	Double circuit 132kV tension structures	
Planned intervention – tower refurbishment	$100,000	Tower structure member replacement. Bases on 20 members per structure at $5,000 each.	Estimate based on experience replacing bent members on line 940/941. Requires verification from actuals once program is enacted.
	$120,000	Refurbishment of all four foundations for towers grillage foundations	Based on actuals from the first stage of TM803 Tower foundation refurbishment program indexed to current values
Reactive intervention	$250,000 - $1,060,000	The costs of replacing a tower after functional failure. Varies depending on the type of tower and whether its failure is likely to pull down adjacent towers.	Replacement costs per tower as per planned intervention costs scaled by the likelihood of pulling down adjacent towers. - Suspension towers can be pulled down by a tower failure either side. - Tension towers cannot be pulled down. Add a % of the neighbouring towers CoF (bushfire, safety, enviro, financial, replacement cost) by these rules in AttributeManager_51 in FME: - Tension tower with neighbour suspension tower = 75% of neighbour's CoF; - Suspension tower with neighbour suspension – 25% neighbour's CoF; - Suspension with neighbour tension – 0%

Parameter	Value	Description/justification	Source/assumptions
Failure modes		A single failure mode of tower collapsing is modelled. Tower fails in the lower K section or elsewhere above ground. Conductors flash-over and may reach the ground causing loss of supply, impacting personal safety possible initiation of bushfire and environmental impacts depending on location of the tower.	Lesser failure modes such as deformation of cross-arm, twisting of the tower body, deformation of structural members without tower collapse result in minimal consequences which are not material to the economic evaluation and have been excluded from the model for clarity.
Asset age	Varies for each tower	Calendar age based on the towers in-service date compared to the year of assessment (2021) Youngest tower age = 14 years Oldest tower age = 68 years	TransGrid data. Original drawings from Content Server. Particularly old towers ages adjusted downwards due to the tower being in too good a condition for the stated age and likely not be the original structure.
Conditional age	Varies	Adjustment to the calendar age to reflect the condition of the asset to allow the Weibull function to more accurately assign PoF. **Foundations – adjustment to life** Aged concrete "spread" foundations: +0 years Grillage in very poor condition: -20 years **Superstructure – adjustment to life** Substantial remaining galvanising +20 years No galvanising and significant loss of steel section in structural elements: -20 years Note: 20 years extension in life provided by refurbishment intervention	Estimates which give a reasonable spread in PoF for towers similar calendar but in very different poor condition. Based on condition of grillage foundations from GHD assessment [4], initial stages of program TM803 [3] and visual inspection of the top of the remaining grillage foundations not yet refurbished. Structure based on DM Richards condition assessment 2014, which provided galvanising remaining life and extent of rust on structural elements, and 2019 desktop aerial image survey during the pre-summer bushfire LIDAR surveys which identified extent of rust on structural elements. Additional drone imagery obtained for towers without routine aerial imagery.

Weibull failure probability parameters

Parameter	Value	Description/justification	Source/assumptions
α (Alpha)	Existing and refurbished towers: 60 years Replacement structures: 30 years	The "scale" parameter used for calculating probability of failure	Estimated to give a reasonable looking MTTF of around 97 years and correlation with the actual very low annual failure rates being experienced. MTTF for steel pole replacement structures is not known but estimated to be 68 years as an initial point for modelling.
β (Beta)	8.0	The "shape" parameter used for calculating probability of failure function.	The generalised wear-out function shape for a normal distribution is 3.6. However, a higher value has been estimated to give a rapid increase in PoF after onset of corrosion damage and calibration against the actual very low annual failure rates being experienced with the current age profile of the fleet of towers.
γ (Gamma)	Existing towers: 40 years Refurbished towers: -11 years Replacement structures: 40 years	The "shift" parameter which gives a failure-free period at the start of the asset's life.	Large values estimated values applied to reflect the zero functional failures recorded for the fleet of assets to date, then a forecast rapid increase in failures as corrosion of structural members and grillage takes effect. Refurbished towers are represented in the model with the same Weibull function but a reduced shift parameter to reflect the conditional age of the tower after refurbishment. $\text{Shift}_{\text{refurbished}} = 40 – 71 + 20 = -11$ years Where 71 is the average age at refurbishment, refurbishment gives an additional 20 years of conditional life.

Safety risk inputs

Parameter	Value	Description/justification	Source/assumptions
Value of a fatality	$5,100,000	Value of statistical life (VoSL)	EE Copperleaf Value Model – based on Office of Best Practice Regulation published values
Value of a serious injury	$2,249,000	44.1% of VoSL	GNV1119
Tower falls onto a roadway - LoC	5%	Likelihood of causing a fatality if falls onto a road, subject to number of persons exposed	Estimate "Roadway_impact" input variable
	15%	Likelihood of causing a serious injury if falls onto a road, subject to number of persons exposed	Estimate "Roadway_impact" input variable
	Varies by tower	Falls across roadway and number of persons likely to be present	Calculated by spatial analysis in FME. 40m buffer around the tower centreline touches/intersects with road data from *RoadSegmentEndeavourDec2020* shapefile.
Tower drops conductors across a roadway – LoC	5%	Likelihood of causing a fatality if persons present	Estimate "Roadway_impact" input variable
	15%	Likelihood of causing a serious injury	Estimate "Roadway_impact" input variable
	Varies by tower	Falls across roadway and number of persons likely to be present	Calculated by spatial analysis in FME given the location of the tower and its neighbour in the same line, in relation to roads, and the type of road. Find "nearest towers" in the same line. Find conductor segments between the towers. Find where touch/intersect with a road segment from ESRI shapefile *RoadSegmentEndeavourDec2020*. Some line segments in GIS span multiple towers. To compensate for this, all towers greater than 400m from road/conductor intersection were excluded. Number of road users likely to be present for each type of road provided by the roads shapefile.
Conductors cause electric shock – LoC (based on falling onto buildings)	50%	Nominal likelihood of conductors falling onto or near to the ground such that they could cause a shock to persons in the vicinity. Tower failure near ground level.	Estimate "Persons_impact" input variable
	5%	Likelihood of causing a shock hazard resulting in a fatality if persons present	RiskCAT generalised value for exposure "Persons_impact" input variable
	15%	Likelihood of causing a shock hazard resulting in serious injury if persons present	Estimate "Persons_impact" input variable
	1	Number of persons affected if present	Estimate "Persons_impact" input variable
	Varies by tower	Number of persons likely to be present	Calculated by spatial analysis in FME given the location of **buildings** within 40m buffer area around tower. Buildings type and location from ESRI shapefile *BuildingsDec2020*.
Conductors cause physical injury – LoC (based on falling onto buildings)	1%	Likelihood of falling onto a person and causing a fatality	Estimate "Persons_impact" input variable
	9%	Likelihood of falling onto a person and causing a serious injury	Estimate "Persons_impact" input variable
	1	Number of persons affected if present	Estimate "Persons_impact" input variable
	Varies by tower	Number of persons likely to be present	Calculated by spatial analysis in FME given the location of **buildings** within 40m buffer area around tower. Buildings type and location from ESRI shapefile *BuildingsDec2020*.

Bushfire risk inputs

Parameter	Value	Description/justification	Source/assumptions
Bushfire - LoC	50%	Estimated value based on standardised EE value of 20% for "TR Conductor".	20% for "TR Conductor" based on the recorded quantity of fires started to failures observed across the specific set of assets. Value increased to 50% on the basis that a tower collapse will cause multiple conductors to clash and/or contact the ground with a greater likelihood of starting a fire than a single conductor down. Input the Bushfire model.
Bushfire - CoF	Total Bushfire Risk Cost	Likelihood and consequence of bushfire start evaluated by the Bushfire Model based on the Phoenix RapidFire simulation prepared for EE's network by The University of Melbourne in 2020.	Tower spatial information input into the Bushfire FME model. The model assesses the CoC of a bushfire started by each tower. Other inputs to the model: - Vegetation LoC - CoC for Low, High, Very High, Severe, Extreme, Catastrophic fire risk days - LoC adjustment for Bushfire severity days to produce the "All Annual Risk Cost (Total)" value for reading back into the Towers FME workflow

Environmental risk inputs

Parameter	Value	Description/justification	Source/assumptions
Environmental - CoF	High sensitivity - $100,000 Medium sensitivity - $25,000 Low sensitivity - $10,000	CoC assigned based on the land use around each tower.	The land use around each tower evaluated rom the ESRI shapefile *LanduseEndeavourDec2020*. Sensitivity assigned based on landuse: "High" – National Parks, state forests, wetlands etc "Medium" – Cropping, high value agriculture "Low" – All others Values of consequence are estimates based on clean-up and compensation costs.
Environmental - LoC	100%	Likelihood of the above environmental impact occurring on a tower failure	LoC assumed to be = 1

Reliability risk inputs

Parameter	Value	Description/justification	Source/assumptions
Loss of supply to customers - LoC	1% generally 100% for specific cases	1% likelihood of loss of load when N-1 supply security is available 100% likelihood of loss of load for the failure of a double circuit tower which provides the sole supply to a substation	RisCAT - 1% likelihood the alternate supply path will not be available due to maintenance, or failure. 100% is applicable to towers in the following lines: 980/981 – Bellambi TS 985/989 – Outer Harbour TS 940/941 – North Katoomba TS 930/931 – Carlingford TS Source – Network topology/SOPS
Load impacted	Varies based on the substations supplied by the lines the towers support	The summer maximum demand of the substation	Spreadsheets based on 2020 Summer Maximum Demand planning report
Load factor	70%	Load assumed to be lost is 70% of the summer maximum demand value for the supplied substation(s)	Source – studies of network faults by Protection Manager.

Parameter	Value	Description/justification	Source/assumptions
VCR	$34,340/MWh of unserved energy	Value of customer reliability for an occasional short-term outage	Generalised value across the network from Copperleaf Value Model, based on values published by the AER (Note, value published by Network Planning Manager is $35,811)
Duration of interruption	4 hours	4 hours assumed interruption until alternate arrangements are made for supply through switching the network	A generalised value based on a range of outages of transmission assets. Assumes off-loading to reinstate supply through a combination of SCADA and manual switching.

Financial risk inputs

Parameter	Value	Description/justification	Source/assumptions
Financial general - CoC	$100,000	Switching to restore supply/supply security, clean-up, any temporary diversion works, investigation, media management costs	Estimate, based on typical clean-up and investigation costs
Financial general - LoC	100%	Likelihood of general financial risks being realised on failure	Will always be realised to an average extent.
Financial – damage to buildings – CoC	$750,000	Value of damage if tower falls on a building	Nominal value of building repair/replacement - $750,000. Average house construction cost in NSW. Sourced from media published values.
Financial – damage to buildings – LoC	12.5%	Likelihood of a tower collapse near a building falling onto and causing damage to the building	"Buildings_impact" input variable. Estimate – based on 25% likelihood of a tower collapse being in the direction of the adjacent building and 50% likelihood of the collapse in the direction of the building reaching the ground and causing damage to the building Number of buildings likely to be impacted is derived from the ESRI shapefile *BuildingsDec2020*
Financial – damage to vehicles if tower falls onto road OR drops conductors across a road – CoC	$20,000	Value of vehicles impacted if tower falls onto or drops conductors across a road	Nominal value of vehicle repair/replacement - $20,000. Average vehicle value in NSW. Sourced from media published values. (Note - this has increased to $35,000 during 2021/22 due to Covid influences)
Financial – damage to vehicles if tower falls onto road OR drops conductors across a road – LoC	50%	Likelihood of vehicles being impacted by a tower falling onto a road or dropping a conductor across a road	"Roadway_impact" variable. Estimate based on 50% likelihood of a collapse resulting in the tower or conductors reaching the ground. Number of vehicles likely to be impacted is calculated by the type of road information derived from the ESRI shapefile *RoadSegmentEndeavourDec2020*

Nil intervention case risk inputs

Parameter	Value	Description/justification	Source/assumptions
Tower failure – general risk costs	$2,500 million	This is the PV of the BAU case excluding the risks associated with reactive replacement (capital intervention is not carried out) and excluding reliability risk costs (which are estimated separately)	BAU risk costs
Tower failure - reliability risk costs	$12,600 million	The reliability impact of not replacing towers which suffer functional failure is approximated by assessing the reliability risks associated with the permanent loss of a tower in each of the four lines that provide the exclusive supply a transmission substation – Carlingford, Bellambi, North Katoomba, Outer Harbour.	Average substation demand, VCR values calculated for each substation based on values published by the AER. The six-month period without supply from the substations is an estimate of the possible consequences of a nil-intervention scenario where many other permanent failures had occurred in the network and there was no

Parameter	Value	Description/justification	Source/assumptions
		These failures occur in 20 years' time and leave the substations without supply for a six-month period until an alternative supply arrangement is made.	remaining capacity to off-load the substations. Reliance is placed on non-network solutions. 20 years in the future reflects the fact that this situation would take that sort of timeframe to develop. The overall risk costs are commensurate with solar farm/grid battery replacements for the substations which have lost their supply lines.

Appendix D – Images of typical towers

Typical 132kV double circuit tower near the coast.

Calendar age 68 years (in 2022)

Conditional age 80 years (in 2022)

Close up view of structural corrosion

Grillage foundation with minor corrosion damage, after refurbishment.

Located in Western Sydney. Calendar age 53 years (in 2022)

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