132kV oil filled cable failure risk mitigation (feeders 228, 22W and 233)

Case for investment FY23
October 2022

Investment Title	**132kV oil filled cable failure risk mitigation**
<< project # / code >>	NTM-000535
Portfolio	Repex
CFI Date	
Pre RIT-D	☒
Final CFI	☐
Other	☐

Version control and endorsements

Version	Date	Comments
0.6	17 October 2022	Circulated for approval

Author:

Gerry
Hartridge

Digitally signed by Gerry Hartridge
DN: cn=Gerry Hartridge, c=AU, o=Endeavour Energy, ou=Lead Reliability Engineer, email=gerald.hartridge2@endeavourenergy.com.au
Reason: I have reviewed this document
Date: 2022.10.19 14:58:03 +11'00'

Gerry Hartridge

Engineer Asset Investment

Reviewed:

Mark
Alexander

Digitally signed by Mark Alexander
DN: cn=Mark Alexander, c=AU, o=Endeavour Energy, ou=Asset Planning and Performance, email=mark.alexander@endeavourenergy.com.au
Date: 2022.10.19 15:06:39 +11'00'

Mark Alexander

Lead Engineer - Asset Investment

Endorsed by:

David Mate

Asset Performance Manager

Endorsed by:

Digitally signed by Gavin de Hosson
DN: cn=Gavin de Hosson, c=AU, o=Endeavour Energy, ou=Asset Planning & Performance, email=gavin.dehosson@endeavourenergy.com.au
Date: 2022.10.19 15:23:50 +11'00'

Gavin De Hosson

A/Network Planning Manager

Approved by:

Digitally signed by Peter Langdon
DN: cn=Peter Langdon, c=AU, o=Endeavour Energy, ou=Asset Planning and Performance, email=peter.langdon@endeavourenergy.com.au
Date: 2022.11.01 17:06:12 +11'00'

Peter Langdon

Head of Asset Planning and Performance

Contents

1. Executive summary 4

2. Purpose 6

3. Identified needs and/or opportunities 6

3.1 Background 6

3.2 Risks and identified need 9

3.3 Asset age profile 11

3.4 Condition based assessment 11

4. Consequence of nil intervention 12

4.1 Consequences of nil capital intervention 12

4.2 Counterfactual (business as usual) 12

5. Options considered 15

5.1 Risk treatment options 15

5.2 Non-network options 17

5.3 Credible network options 17

5.4 Economic evaluation 17

5.5 Evaluation summary 18

5.6 Economic evaluation assumptions 19

5.7 Scenario assessment 19

6. Preferred option details 20

6.1 Scope and timing 20

6.2 Project scope of works 21

6.3 Project cost details 21

7. Regulatory investment test 22

8. Greater Parramatta 132kV network strategy 22

9. Recommendation 23

10. Attachments 24

11. References 24

1. Executive summary

This case for investment (CFI) recommends investment in the replacement of 132kV oil filled transmission cables on feeders 228, 22W and 233 during the period of FY25 – FY29 to address the reliability, environmental and financial risks associated with these assets failing whilst in service. Additionally, this CFI also proposes to address network capacity constraints due to forecasted load growth.

Given the identified need and estimated cost of the credible network options for addressing the need exceed the $6 million threshold, in accordance with Section 5.17 of the National Electricity Rules, this CFI recommends initiation of the Regulatory Investment Test for Distribution (RIT-D) process to test the feasibility of a non-network option to address the risks posed by the cables.

Endeavour Energy's network has 40.7 kilometres of 132kV oil filled cables installed across six feeders. These cables form part of the 132kV sub-transmission network which provides supply into the Parramatta CBD and surrounding area.

Endeavour Energy's pressurised oil filled cables are categorised into two manufactured types installed in two separate trench/cable routes. Each feeder consists of one cable per phase.

- North trench: 9.9km in length containing two feeders' side-by-side with single core cables for each phase. These cables were manufactured by BICC and were installed in the mid-1960's containing feeders 228, 22W and 233. The capacity rating of each feeder is 111 MVA; and
- South trench: 10.45km in length containing two feeders' side-by-side with single core cables for each phase. These cables were manufactured by Furukawa and were installed in the late 1970's containing feeders 226, 22U and 9J8. The capacity rating of each feeder is 117 MVA.

The three younger Furukawa cables on feeders 226, 22U and 9J8 are in a reasonable condition. Currently, there are no condition-based works proposed for these feeders within the short to medium term whereas the older BICC manufactured cables used on feeders 228, 22W and 233 have condition issues and an increasing probability of failure that warrants intervention in the short-term.

Accordingly, this case for investment focusses only on feeders 228, 22W and 233.

The cable's sheaths are becoming brittle with age and joints are in a degraded condition at multiple points along their routes. The cracking of the sheath and breakdown of the cable joints has resulted in multiple oil leaks. These can lead to a reduction in the insulation resistance in the cable causing an arc flash and damaging electrical fault requiring a lengthy repair procedure. Additionally, if an existing or new oil leak develops into a major oil leak where oil pressure within the cable is unable to be maintained, the cables will need to be deenergised for repair procedures to be undertaken.

The possible consequences of failure include:

- Financial impacts: Restoration works to return a failed 132kV oil filled cable into service have significant costs and require extended outage durations compared to more modern cables. Endeavour Energy do not have the in-house expertise required to perform these works and any restoration works must be contracted to one of a limited number of external companies within Australia who maintain the skillsets and required equipment to undertake this work;

- Reliability impacts: Camellia Transmission Substation, East Parramatta Switching Substation and Granville Zone Substation are supplied via these cables. There is currently network supply redundancy available across the feeders and as such a reliability impact would require concurrent failures to occur. However, reliability risk for feeder 22W and 228 is increasing over time due to a future loss of redundancy from forecasted load growth in the Greater Parramatta. This poses a significant reliability risk should feeder 22W or 228 fail beyond 2027; and

- Environmental impacts: These cables contain free flowing oil inside their lead sheath and a failure either of the sheath or an electrical failure will lead to the leakage of oil into the surrounding area. As these cables are predominantly directly buried in the ground, the oil will pool into the surrounding soil. Given the location of these cable routes, if oil escaped and reaches the water table there is potential for it to pollute the nearby Duck Creek which flows into the Parramatta

River. This poses a potential risk to the environment, wildlife and members of the public in the case of a failure which results in a significant oil leak.

In addition to the condition-based risk assessment, forecast load is indicating a continual growth for feeders 22W and 228. These cable routes are expected to exceed their rated load capacity beyond 2031 and 2034 respectively.

The 132kV oil filled cables within the network serve as sub-transmission lines which provide a secure supply to transmission and zone substations. Generally, there are no practicable non-network solutions for replacing the service they provide. Therefore, network options have been considered to address the identified need. Notwithstanding this, a RIT-D is recommended to be undertaken to explore the feasibility of non-network solutions further.

Network reconfiguration or additional maintenance to extend the life of the cables is not considered to be technically feasible for reducing the risk presented by the cables. Additionally, it is not cost effective to gradually replace sections of these cables due to the interconnection of oil systems along the cable routes. The credible network option for addressing the failure risk of the oil filled cables while maintaining their network function is replacement with a modern equivalent XLPE cables. There are two options for delivering this in a proactive planned manner which are practicably achievable and hence are credible:

1. Like for like replacement with XLPE cables to manage the failure risk; and
2. Replacement of cables with a higher capacity XLPE cables to manage failure risk and provide for the forecast unserved energy due to load growth.

The oil filled cables on feeders 228, 22W and 233 have been identified for proactive intervention at the time when the net present value of the intervention reaches its maximum value. Considering the criticality of these feeders into the future as well as the practicality / lead time issues of delivering this replacement project, the project has been proposed to be completed when the net present value reaches above 99% to ensure the supply to the parramatta region is secure. The maximum net present value (NPV) of the proposed option is $102.9 million. The NPV of the proposed option reaches $102.1 million (99.2% of its maximum value) for intervention during the FY25 – FY29 period.

The benefit to cost ratio (BCR) for the proposed option is 4.

The cost of these works is estimated to be $46.2 million in real FY23 terms. This includes a contingency of 5% applied to the cost of the cable materials and direct charges.

Accordingly, it is recommended that the RIT-D process be commenced to investigate feasibility of non-network solutions to address the risks presented by the oil filled cables proposed for replacement.

2. Purpose

The purpose of this document is to seek endorsement of the case for investment (CFI) for managing the risks posed by the aged 132kV oil filled cables installed between Guildford and Camellia transmission substations.

This case for investment (CFI) recommends commencement of the regulatory investment test – distribution (RIT-D) process for the proposed investment for the replacement of the oil filled cables on 132kV feeders 228, 22W and 233 during the FY25 – FY29 period.

3. Identified needs and/or opportunities

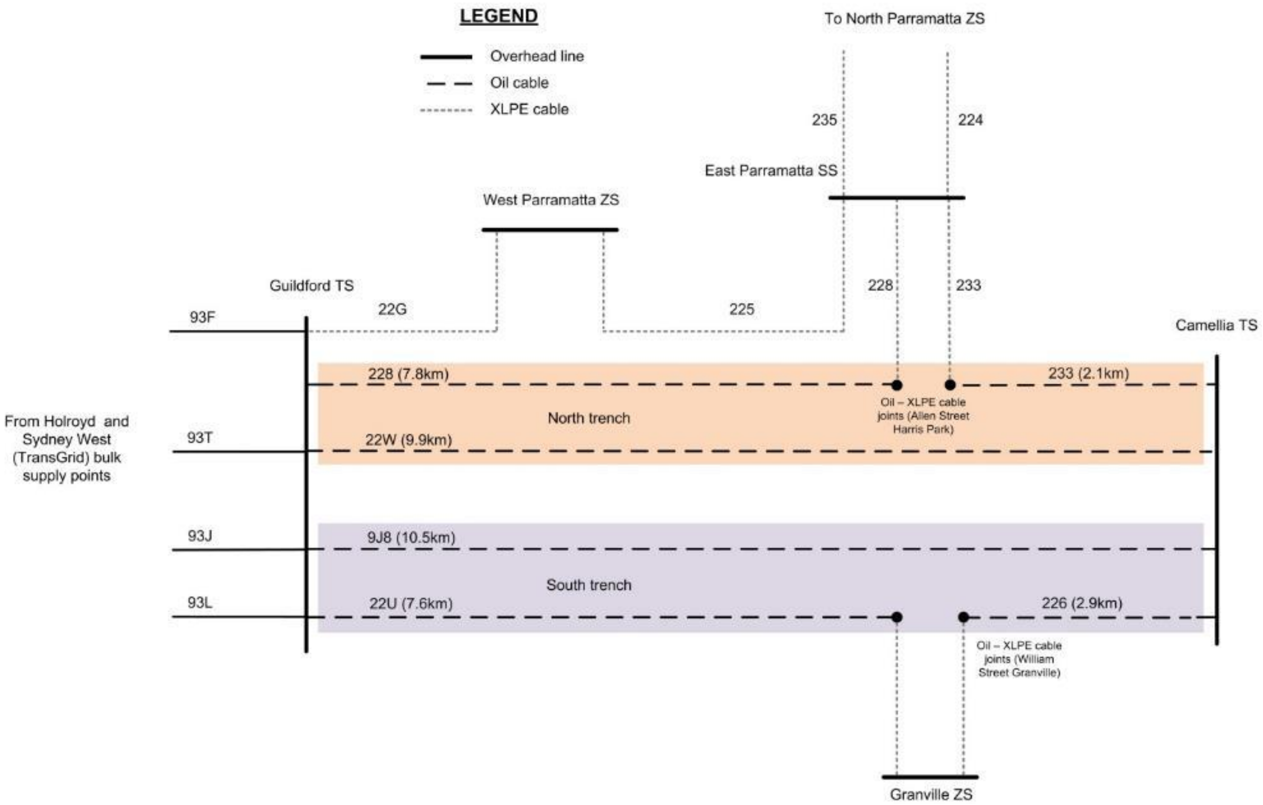
3.1 Background

3.1.1 132kV oil filled cables in the network

Endeavour Energy's network has 40.7 kilometres route length of 132kV oil filled cables installed across six feeders. These cables form part of the 132kV sub-transmission network which supplies the Parramatta CBD and surrounding area. They provide electrical connection between Guildford Transmission Substation, Camellia Transmission Substation, Granville Zone Substation as well as an alternative supply to West Paramatta Zone Substation and East Parramatta Switching Station.

A cable schematic diagram showing the sub-transmission network where these feeders are located is provided in Figure 1 below.

Figure 1 – Guildford to Camellia 132kV cables schematic diagram



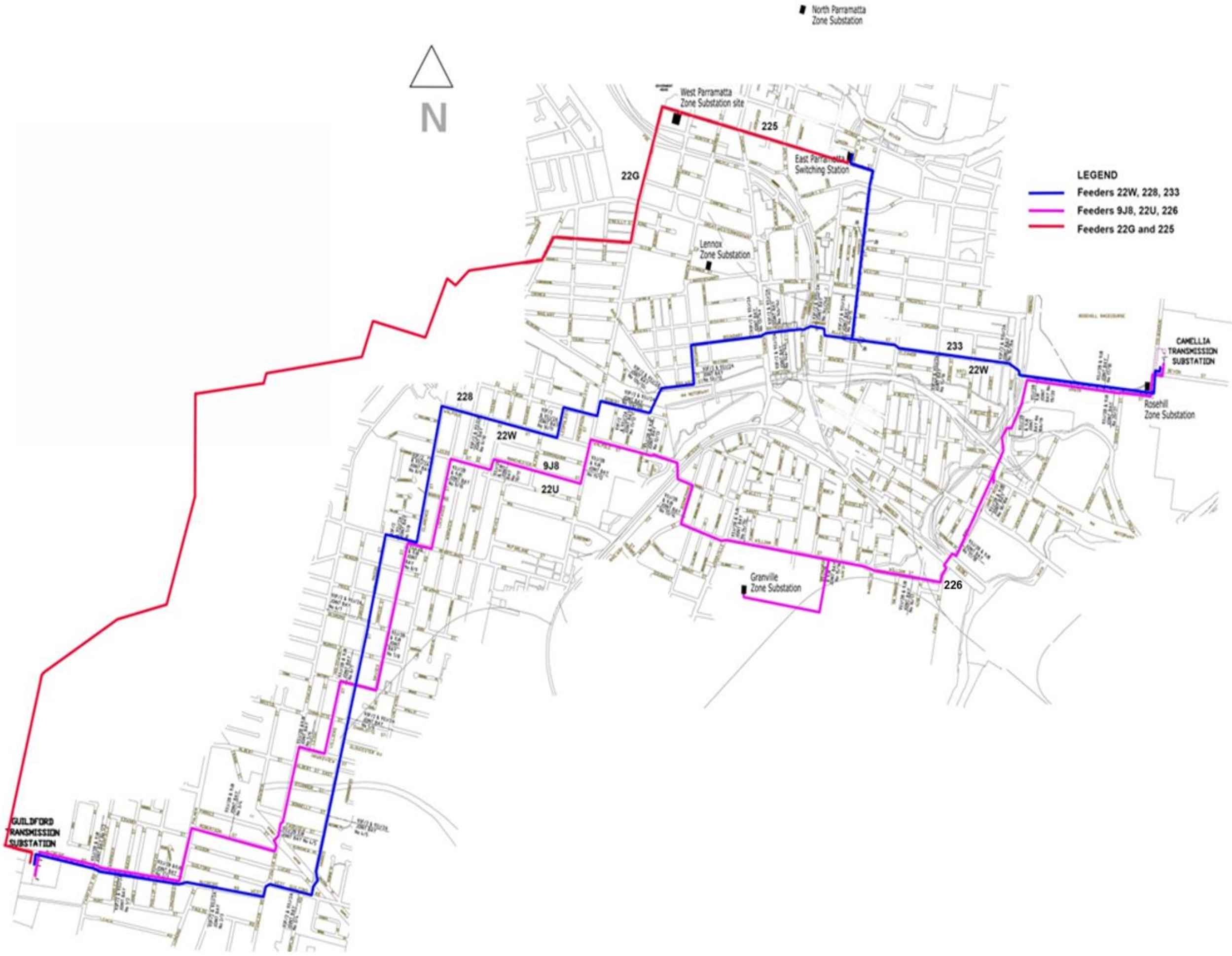
The six oil filled cable feeders are routed along two separate trenches with each trench containing two feeders' side by side. Each feeder is made up of a single cable per phase. Feeders 228, 233 and 22W are in the north trench and were installed in 1965 (57 years of age). Feeders 9J8, 22U and 226 are in the south trench and were installed in 1977 (45 years of age).

A summary of the oil filled cable details is provided in Table 1 and a geographical view of the 132kV network in the Parramatta area is shown in Figure 2.

Table 1 – 132kV oil filled cable feeder details

Feeder No.	From	To	Route length (km)	Rating (MVA)	Manufacturer	Installation date
228	Guildford TS	East Parramatta SS	7.8	111	BICC	1965
233	East Parramatta SS	Camellia TS	2.1	111		
22W	Guildford TS	Camellia TS	9.9	111		
226	Granville ZS	Camellia TS	2.9	117	Furukawa	1977
22U	Guildford TS	Granville ZS	7.5	117		
9J8	Guildford TS	Camellia TS	10.5	117		

Figure 2 – Guildford to Camellia 132kV cables geographical view



3.1.2 Oil filled cable construction

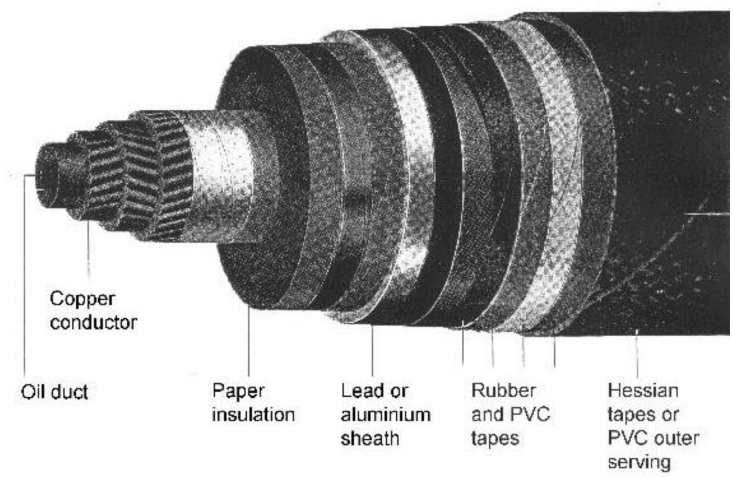
Oil filled cables, (also known as fluid filled cables), require a positive oil pressure to be maintained inside the cable causing any voids within the lapped paper insulation to be suffused with oil. To maintain a positive oil pressure, oil filled cables rely upon an intricate set of supporting auxiliary equipment. This equipment includes buried oil tank reservoirs, feed joints, stop joints, oil pressure alarms and gauges and flushing lines throughout the cable route. Additionally, oil sealing ends, oil tank reservoirs, pressure alarms and gauges are also installed at each termination. The upkeep and maintenance of these supporting systems is critical to the longevity and effective operation of the cables.

Endeavour Energy have two different manufactured types of 132kV oil filled cables installed in the network, BICC and Furukawa.

BICC: feeders 228, 233 and 22W

Oil filled cables on feeders 228, 22W and 233 were manufactured by BICC in Britain and were installed in 1965. These cables are installed in a flat configuration on either side of a single trench (referred to in Figure 1 as the north trench). Their construction includes a stranded copper conductor with oil duct, paper insulation, lead sheath and hessian serving. The feeders comprise three individual phases, with a single cable per phase. A typical cross-section of a cable is shown in Figure 3.

Figure 3 – Typical 132kV oil cable construction



Furukawa: feeders 9J8, 226 and 22U

The other sections of oil filled cables on the network are feeders 9J8, 226 and 22U which were manufactured by Furukawa in Japan and were installed in 1977. These cables are installed in a trefoil configuration on either side of a single trench (referred to in Figure 1 as the south trench). The construction of these cables is similar to the BICC cables including stranded copper conductor with oil duct, paper insulation, a corrugated aluminium sheath in place of a lead sheath and PVC serving in place of hessian tapes.

3.1.3 Cable sheath earthing arrangement

The sheaths of each cable in each feeder are connected to the earth grids of the substations at each end of the cable to provide a continuous earth for fault current to limit earth potential rise hazards during faults on the network. However, because of this arrangement and due to each feeder being comprised of single core cables, load currents will induce circulating currents in the three cable sheaths. To counteract this, the cable sheaths are cross bonded in multiple locations along their lengths. The cross-bonding is carried out in the cable joint boxes and involves each sheath being made electrically connected across to the adjacent phase sheath. This is performed an even number of times along the length of the feeder so that each sheath is electrically coupled to each of the three phases equally and circulating currents are cancelled out.

For this system to work, the sheaths must be effectively insulated from the ground along their entire length and only earthed at mid points between the cross-bond sections and at the substations at each end. Failure of the sheath insulation (the serving) leads to circulating currents in the sheaths which can cause overheating of the cables and more rapid degradation of their paper insulation, as well as arcing (under fault conditions) and corrosion damage to the sheaths.

Protection of the sheathes from high voltages caused by lightning and switching surges is provided by surge arresters installed at each cross-bonding joint.

3.1.4 Modern equivalent cables

The current equivalent of these oil filled cables are cables insulated with solid cross-linked polyethylene (XLPE) and served with high density polyethylene (HPDE). These XLPE cables are single core like the oil cables but don't require any of the oil management infrastructure and are therefore significantly less costly to manufacture, install and operate than the older oil-filled technology. XLPE cables can be jointed to the existing oil filled cables through specialised XLPE to oil joints, however this is not considered practical due to the relocation or installation of new oil filled cable supports systems (oil reservoirs and monitoring equipment) and the failure mode being investigated.

3.2 Risks and identified need

3.2.1 Reported issues with the 132kV oil filled cables

Concerns with the condition of the oil filled cables were initially raised in 2011 after the discovery of a major oil leak on feeder 233. The leak required significant repair works at the time totalling $650,000. The source of the failure was traced to a damaged section of cable sheath. This initial area of failure was located where feeders 233 and 22W pass under both the M4 motorway ramps and James Ruse Drive in Rosehill. At the time of the failure, it was suspected the cause of this damage was due to earth subsidence from a burst water main which occurred four years prior in 2007. During the subsequent investigations, numerous cracks unrelated to the area of the burst water main were visually identified in the sheaths raising concern for the overall condition across other sections of oil filled cables, with the same type of lead sheaths, installed in the network.

In 2017, to better understand the condition of the fleet of 132kV oil filled cables, Endeavour Energy initiated two projects.

- TM302 - *Fluid Cables Auxiliary Equipment:* for the refurbishment of the oil filled cable auxiliary systems to a fully working state. This provided for the ongoing monitoring and alarming of the oil pressure in the cables and the oil levels in the reservoirs. Prior to the completion of this project, visual inspections and testing undertaken had identified that 80% of the cable routes were not adequately monitored due to the poor condition of the original monitoring systems; and

- TM303 - *132kV Cable Fluid Testing*: to collect oil samples from jointing bays across each oil filled cable feeder for dissolved gas analysis examination. TM303 also assessed sheath continuity, serving insulation resistance and sheath surge arrester and link box power cable tests. These tests were conducted in accordance with Endeavour Energy's maintenance instruction MMI 0025 clause 5.2.1 [1]. Note: due to minimal in-house knowledge of 132kV oil filled cables, Endeavour Energy engaged TransGrid's expertise for assistance in the condition assessment and refurbishment of these assets.

The most recent results from the dissolved gas analysis have identified two sections of cable on feeders 228 and 22W with signs of moisture ingress and atmospheric contamination within the oil samples. This is indicative of environmental contaminants passing into the cable system through leaks in the outer cable layers, sheath and/or cable joints.

A further nine oil samples taken from joint locations across feeders 228, 22W, 22U and 9J8 show poor oil health ratings from dissolved gas analysis. The low ratios of carbon dioxide to carbon monoxide in the oil samples on feeders 22U and 9J8 indicate signs of paper degradation while the high hydrogen levels in oil samples on feeders 228 and 22W are indicative of high electrical stresses.

These results are consistent with signs of aged or poor condition cables as per the EPRI Technical Report 1000275 on Guidelines for the Interpretation of Dissolved Gas Analysis (DGA) for Paper-Insulated Underground Transmission Cable Systems [2]. A summary of the cable condition assessment is provided in Appendix C.

In addition, the power cable testing serves as an insulation test to assist in identifying any electrical paths between the cable sheath and ground indicating damage to parts of the outer cable layers. Results are indicating signs of deterioration in the outer cable serving layer with 60% of test sites failing serving insulation resistance thresholds on one or more of the three phases.

Along the routes of feeders 228, 22W, 22U and 9J8, there are twelve known sections of cable out of a total of nineteen sections where oil leaks are present. The exact quantity of leaks within each of these twelve sections is unknown as the feeders are primarily direct buried and there are no practical cost-effective methods for identifying the leak locations. The presence of existing oil leaks indicates that there is an elevated risk of a major oil leak developing which will require interventive restoration works.

Endeavour Energy is currently managing the operation of the six oil filled cable feeders through routine maintenance and regular oil reservoir top-ups. In 2018, an oil pumping register was established to track the quantities of oil required during each top-up. Since the oil pumping register was established, an average quantity of 920 litres of oil has been required annually to maintain acceptable oil levels within the cable systems. A summary of the total quantity of oil required during oil reservoir top-ups by feeder is provided in Table 2 below.

Table 2 – Oil pumping register quantities by feeder FY18-FY21

Type	Feeder	Feeder route length (km)	Total quantity of oil refills required since 2018 (litres)
BICC	228	7.8	2,007
	22W	9.9	693
	233	2.1	None recorded
North trench sub-total		***19.8***	***2,700***
Furukawa	22U	7.5	767
	9J8	10.5	220
	226	2.9	None recorded
South trench sub-total		***20.9***	***987***
Total		**40.7**	**3687**

The condition information available via the dissolved gas results, serving resistance to ground test and the volume of oil leaks indicate these assets are within a wear-out phase typical of network assets approaching a technical end-of-life.

3.2.2 Consequence of cable failure

Failure of a 132kV oil filled cable presents significant financial impacts due to the cost of restoration works required, it may also cause risk to the environment and property near to the cable fault due to leaked oil and may result in loss of supply to customers.

The possible consequences of failure include:

- Financial impacts: Restoration works to return a failed 132kV oil filled cable to service are complex and require specialised services and equipment which are becoming increasingly difficult to source. Any repair works are likely to require many months to complete.

  If the failure involves an oil leak, without an actual 132kV phase fault and subsequent explosion, the failure location is likely to be very difficult and time-consuming to locate, see Section 4.2.1 for additional detail.

  Depending on the level of damage to the cable, the repair works can range from installation of a cable sleeve around the leak location to like for like replacement of a section of cable requiring two additional oil cable joints, providing the parts are available or can be sourced in a practicable timeframe.

  Due to the condition of these cables, disturbance to the cable systems during restoration works has the potential to increase the likelihood of other failures occurring in the same area in the future;

- Reliability impacts: Camellia Transmission Substation, East Parramatta Switching Substation and Granville Zone Substation are supplied via these feeders. There is currently network supply redundancy available across these feeders and as such a reliability impact would require concurrent failures to occur. However, beyond 2027 the rated capacity of redundancy available for feeders 22W and 228 will be exceeded due to forecasted load growth in the Greater Parramatta area. This poses a significant reliability risk should feeders 22W or 228 fail beyond 2027.

- Environmental impacts: These 132kV oil filled cables contain free flowing oil inside the cable and a failure in this type of cable will lead to the leakage of oil into the immediate surrounding area. As these cables are predominantly directly buried in the ground, the oil will flow into the surrounding soil. Given the location of these cable routes, there is potential for escaped oil to move through the soil and pollute the nearby Duck Creek which flows into the Parramatta River. This poses a potential risk to the environment, wildlife and members of the public in the case of a major oil leak;
- No significant regulatory compliance, bushfire or safety consequences are anticipated for failures of these cables.

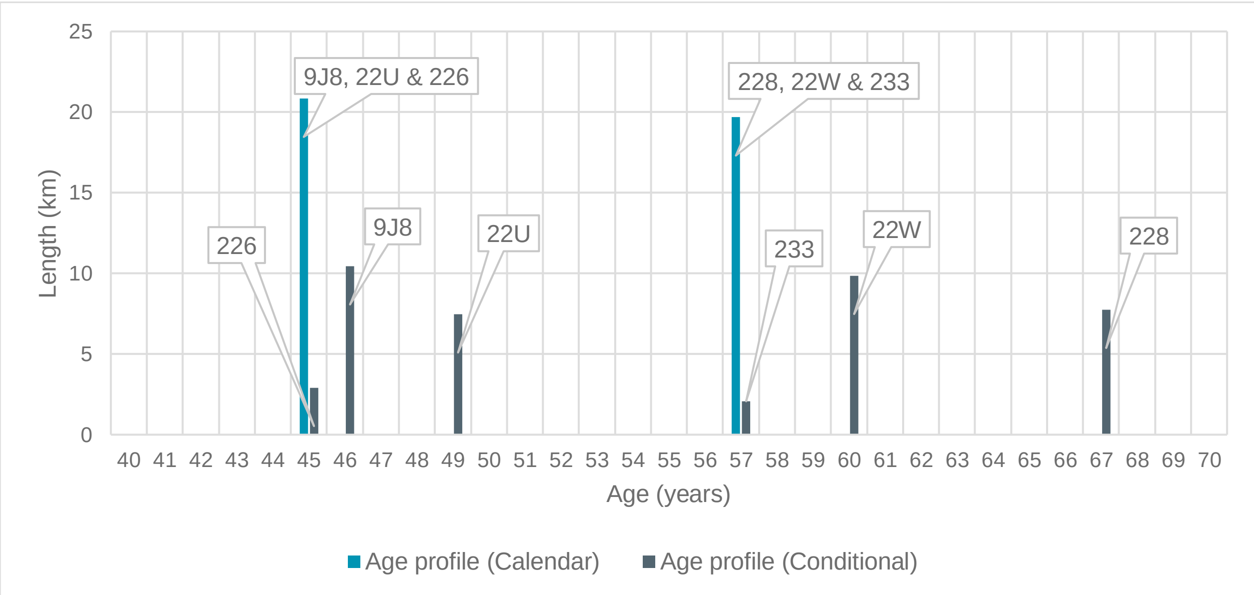
Refer to Appendix B for further detail of the assessed failure consequences.

3.3 Asset age profile

Industry experience for oil filled cables suggest that provided they are installed in a benign environment and appropriately operated and maintained over their lifetime, they will provide effective service for up to 70-80 years. However, the environment in which these cables have been installed is variable with many road, creek and bridge crossings and variations to the quality of the installation along their lengths. Furthermore, the maintenance regime applied to the cables has not been consistent over their service life. The presence of significant oil leaks and the results of the condition assessment indicate that the effective service life for these cables is likely to be lower than the 70 – 80 years noted.

The age profile for the cables is shown in Figure 4. In this profile, the calendar age of each cable has been included as well as an adjusted age to reflect its assessed condition. The adjusted age profile represents the “conditional” age of the cables which better reflects the health of the assets than an age profile based on calendar ages.

Figure 4 – Age profiles of 132kV oil filled cables



Refer to Appendix B for further detail on the calculation of conditional age.

3.4 Condition based assessment

As the condition of these cables degrade over time and their probability of failure increases, their ongoing service costs increase, ultimately leading to a decision to retire the assets to manage the failure risks they present.

Assets are identified for possible proactive intervention at the time when the net present value of the intervention is positive and reaches its maximum value. A preliminary assessment of the value of proactive intervention identified that:

- The older BICC cables on feeders 228, 22W and 233 are in poor condition and show potential to reach a positive and maximum NPV for intervention during the FY23 - FY34 period and should therefore be assessed further; and
- The younger Furukawa cables on feeders 226, 22U and 9J8, which are in better condition, did not reach a maximum NPV for intervention until beyond FY41 and therefore do not warrant further assessment in the short-term.

Accordingly, this CFI focusses only on cables 226, 228 and 233. Cables 226, 22U and 9J8 will be re-assessed in the future as updated conditional information becomes available and load growth in the area continues to develop. Refer to Appendix E for details on the preliminary economic assessment of cables 226, 22U and 9J8 and Section 8 outlining Endeavour Energy's strategy for the 132kV network servicing the Greater Parramatta Area.

4. Consequence of nil intervention

4.1 Consequences of nil capital intervention

The nil intervention case involves not carrying out any capital works. Therefore, cables would be operated until they have failed after which they are retired and not repaired or replaced.

The consequences of this would include:

- The reliability and environmental consequences of failure for each cable as noted in 3.2.2 above; and
- The flow-on risk costs associated with losing key transmission elements from the network.

The failure of multiple key sub-transmission feeders in the transmission network would result over time in widespread and sustained loss of supply to our customers as the network capacity is reduced below the load demand of the supplied transmission and zone substations. 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.

This is not considered to be a tenable solution as the lead time for an alternative solution to be identified would not be acceptable to customers (e.g. years) and would leave the local area without a secure electricity supply. Such an approach would undermine the principles committed to in the Energy Charter to provide customers safe, sustainable and reliable energy [3].

On this basis, the reactive repair and/or replacement of cables 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)

4.2.1 Maintain, repair and restore failed cable

The business as usual (BAU) "counterfactual" scenario includes operating the cables until they fail and repairing the cable to an acceptable working condition post 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 cables, which currently includes:
  - Routine route patrols, oil pressure gauge readings and oil pressure system inspections;
  - Refilling cable oil reservoirs as required;

    - Repair of any minor damage to the cable auxiliary support systems; and
- Reactive repair and restoration of cables after failure.

Currently, "failure" refers to the inability of the cable to perform its required function as a consequence of the condition of the asset:

- Failures disruptive to the supply of electricity;
- Catastrophic failures of equipment or subcomponents;
- Failure of the cable to perform its rated duty.

The failure mode modelled for oil filled cables within this assessment refers to the breakdown of electrical insulation leading to an electrical fault or the development of a major oil leak due to degradation in the cable sheath and/or serving condition.

The typical BAU repair and restoration costs to bring Endeavour Energy's 132kV oil filled cables back into service following a major oil leak are quite significant for each event that this failure mode occurs. This is due to the complex process required in locating the cable's point of failure. Locating the origin of a leak in an oil filled cable directly buried in the ground typically requires performing one of the following two methods:

- Freezing method – The freezing method requires excavation around the cable to apply a "freeze wrap" using liquid nitrogen to freeze the oil inside the cable. Once the freeze has been initiated, the gauges either side of the freeze location are monitored and the side which loses pressure first is deemed to be the side of where the oil leak is present. This process is repeated at different locations until the location of the oil leak is narrowed down to a length short enough (50-100m) to perform an excavation for visual identification of the oil leak.
- PFT tracing method – PFT's are perfluorocarbon tracers which can be added into the cable oil system for the locating of oil leaks. This method requires the insertion of PFT's into the oil cable system which flow through the cable as a liquid under pressure with the oil. Once the PFT's reach the site of the oil leak, they are released from the pressurised oil system and becomes a gas under atmospheric pressure. Vehicles fitted with PFT detection systems then patrol the length of the cable until they detect the escaped PFT gas which has permutated up through the ground. This identifies the approximate site of the leak for excavation to be performed for visual identification of the leak location.

It is worth noting that Endeavour Energy do not have the in-house expertise required to undertake either of the above methods for the location of an oil leak or the subsequent oil filled cable jointing during the cable repair. This poses additional complications to the restoration process leading to increased costs which are dependent on a limited market of available contractors that are capable of these works within Australia. The restoration process also requires extended outages for works to be completed which can exceed six weeks.

The cost of the repair and restoration process is also impacted due to the presence of Dieldrin in the soil sounding the cables. In the 1970's and earlier, Dieldrin was a popular additive to soil to protect assets from termites and rodents. However, by 1980, the use of this chemical was heavily restricted due to its carcinogenic properties. Dieldrin was later banned and deregistered by the Australian Government. This poses additional civil costs for the removal, safe handling and disposal of contaminated back-fill material surrounding these assets during excavations.

In additional to the points above, the availability and lead time associated with obtaining spares is substation, if at all possible. At present the spares held by Endeavour Energy are most probability not suitable or sufficient for repairing a major fault.

4.2.2 BAU risk cost summary

There are two elements to the BAU risk costs which have been considered:

- Condition-based assessment – risk attributed to the failure of a cable and the corresponding costs of consequence; and
- Expected unserved energy – reliability risk due to the current cable load capacity been insufficient to meet future forecasted load demand.

A summary of the condition-based assessment risk presented by the counterfactual case for cables 22W, 228 and 233 is shown in Table 3 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 3 – BAU risk cost summary – Condition-based assessment failure risk

Risk category	PV of residual risk ($M) North trench (Fdrs 22W, 228, 233)	Risk proportion of total (%)
Reliability	60.9	76.2
Financial	16.3	20.3
Environmental	0.3	0.3
Maintenance	2.5	3.1
Subtotal – condition-based failure	**79.9**	**100**

In addition to the condition based BAU risk costs showed above in Table 3, future expected unserved energy risks are also applied to feeders 22W and 228 as increasing load demand requirements from residential and commercial planned developments in the Parramatta CBD are forecast to exceed the rated load capacity of each of these feeders by 2031 and 2034 respectively. Table 4 outlines the additional business-as-usual risk costs for expected unserved energy (EUE) due to forecast network capacity exceedance.

Table 4 – BAU risk cost summary – expected unserved energy due to forecast growth

Feeder	PV of expected unserved energy ($M)	Expected unserved energy (MWh)
22W	54.9	2,723
228	4.3	241
Subtotal - EUE	**59.2**	**2,964**

Refer to Appendix C for additional detail of EUE risk costs.

A combined summary of BAU risk costs including risk incurred due to conditional cable failures and EUE due to load growth is provided in Table 5 below.

Table 5 – BAU risk cost summary – combined total

Risk category	North trench (Fdrs 22W, 228, 233) PV of residual risk ($M)	Risk proportion of total PV (%)
BAU condition-based failure risk	79.9	57.4
Expected unserved energy (Fdrs 22W and 228)	59.2	42.6
Total BAU risk cost	**139.1**	**100**

As noted in Table 5 above, the residual risk presented by the BAU case totals $139.1 million. The residual risk value for each feeder ranges from $2.8 million to $82.4 million and averages $46.4 million across the three feeders.

There is nil significant regulatory compliance, safety and bushfire risks associated with failure of oil filled cables.

5. Options considered

5.1 Risk treatment options

A range of options have been considered to address the risk presented by the oil filled cables being assessed, as an alternative to network investment. These are outlined in the sections below.

5.1.1 Additional maintenance works

Additional maintenance works were undertaken in 2017 under capital program TM302 to refurbish the auxiliary equipment supporting the cable systems.

These works improved the condition of the auxiliary systems and reduced the likelihood of premature failure of the actual cables by restoring their oil pressure and oil reservoir monitoring functions. However, whilst the joint boxes and cross-bonding arrangements can conceivably be refurbished again, there are no practicable solutions for extending the life of the serving and sheath of an oil filled cable and as these cables are directly buried, they are not practically accessible.

On this basis, additional maintenance works are not considered a technically feasible solution for reducing the risk presented by the oil filled cables.

5.1.2 Reconfiguration of the network to allow for load reduction

The existing condition and integrity of the cable sheaths and joints responsible for posing an increased risk of failure are largely independent of the cable load.

Additionally, there are no other network elements which could relieve the subject cables of their load and provision of further elements would be of a similar costs and complexity to replacing the cables.

Therefore, mitigation of the risk presented by oil filled cables due to network reconfiguration is not considered to be an effective risk treatment option in this case.

5.1.3 Gradually replace sections of the cables after failure

This option is similar to the BAU approach except that the failed sections of cable are replaced with XLPE cable rather than a like for like repair with oil filled cable. The adoption of this reactive and gradual replacement approach is not considered practical due to the following reasons:

- Reactively repairing a short section of cable which has functionally failed does not improve the overall condition of the cable as the remainder of the cable condition is unaffected. This approach would not effectively mitigate the risk of future failures which are forecast to increase in the short to medium term;

- It is not cost effective to gradually replace sections of oil filled cables with XLPE cables due to interconnection of the oil hydraulic systems across sections of the cables. The linkage of hydraulic systems between cable sections has significant cost implications including the relocation of oil reservoir tanks and the establishment of new oil stop joints and oil to XLPE cable joints. Additionally, due to the decommissioning costs associated with the removal of the existing cables and contaminated backfill surrounding the cables, the most cost-effective solution for replacement of a 132kV oil filled cable is to install a new cable on a predominantly alternate route to the existing route;
- Given the total route length and location in which the cables are installed, retirement and replacement of the entirety of the cable lengths will require a significant lead time of three to five years for design, environmental assessments and construction to be completed. This poses significant operational difficulties should the works proposed to be delivered in a reactive and unplanned manner.

In addition to the condition-based risk assessment, the demand forecast is indicating continual growth for feeders 22W and 228 and these cables are expected to exceed their rated load capacity beyond 2031 and 2034 respectively. A gradual replacement of short sections of these feeders does not address the risk of expected unserved energy beyond 2031.

Additionally, opportunities current exist to work with other utilities doing construction work along the route (e,g, development of the Sydney Metro trainyards) to obtain new cables routes to reduce construction costs. Delays in replacement of the cables may result in additional costs associated with longer cables routes and the need to work in non-greenfield environments (as currently large areas along the cable route are being cleared for the development of the trainyard).

5.1.4 Summary of risk treatment options

A summary of the risk treatment options is provided in Table 6 below.

Table 6 – 132kV Oil filled cable 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 cables. All refurbishment works are capital works. The supporting auxiliary systems for oil filled cables underwent refurbishment in 2017, however, these works do not improve the condition of the physical cable.	No technically feasible solution
Reduce the load on the asset through network reconfiguration, network automation, demand management or other non-network options	The risk of failure is largely independent of load. Notwithstanding this, forecast load growth in the area will use up all available capacity for offloading the cables by 2031. Furthermore, these sub-transmission cables are integral to the supply of energy to their substations which are required to carry load for the foreseeable future. Further, there are no practicable non-network solutions for replacing the function a cable provides to supply a zone or transmission substation.	No technically feasible solution
Gradually replace sections of oil filled cable after failure	Gradual replacement of minor sections of the oil filled cables after failure does not mitigate the risk posed by the cables and does not address forecast load capacity constraints beyond 2031.	No technically feasible solution

Option	Assessment of effectiveness	Conclusion
Replacement to reduce the consumer's long-term service cost	Replacement options for these cables exist and can be carried out in a proactive and planned manner.	Recommended approach

5.2 Non-network options

The 132kV oil filled cables within the network serve as sub-transmission lines which provide a secure supply route to transmission and zone substations and there does not appear to be any practicable non-network solutions for replacing the service they provide. Due to forecast load growth in the greater Parramatta area, the function provided by the oil filled cables in this area is required for the foreseeable future. Therefore, network options should be considered to address the identified need.

Notwithstanding this, this investment will be subject to the regulatory investment test and the feasibility of non-network solutions to replace or defer the investment will be explored further through that process.

5.3 Credible network options

The credible network option for addressing the failure risk of the oil filled cables while maintaining their network function is replacement with an equivalent XLPE cable. There are two options for delivering this in a proactive planned manner, which are practicably achievable and hence are credible:

1. Like for like replacement with an equivalent XLPE cable to manage failure risk; and
2. Replacement of the cables with higher capacity XLPE cables to manage the failure risk and provide for the expected unserved energy due to the forecast load growth.

Staged replacement of these feeders is not an option, due to the location of the existing feeders (e.g. Parramatta CBD). New cable routes will need to be identified through current construction projects in the area, again making a staged replacement of the oil filled cables impractical.

5.3.1 Option 1 - like for like replacement with equivalent capacity XLPE cables

Under this option, the oil filled cables on feeders 228, 22W and 233 are completely replaced with XLPE cables in a planned proactive manner.

To maintain equivalent feeder capacity a replacement cable size of 630mm^2 has been used in this option.

The total estimated project cost for this option is $35.1 million.

5.3.2 Option 2 - replacement with a higher capacity XLPE cable (augmentation)

This option is the same as Option 1 except that to meet capacity requirements for forecast future load growth, an increased cable capacity has been modelled, with the cable sizes varying between 630mm^2 and 2,000mm^2 across the different sections of the feeders.

The total estimated project cost of this option is $46.2 million.

5.4 Economic evaluation

5.4.1 Option 1 – Like for like replacement with equivalent capacity XLPE cable

This option identifies the replacement of the oil filled cables on feeders 228, 22W and 233 which have an NPV which is positive during the FY25 – FY29 period of interest with an optimal year of intervention in FY34. The presented NPV and PV of residual risk values assume each oil filled cable is replaced during the year in which its NPV reaches its maximum value.

This option presents a residual risk of $64.3 million and provides a benefit of $74.8 million compared to the counterfactual case. The PV of the cost of the option is $23.9 million and the NPV overall is $50.9 million.

The cost of the option in real FY23 terms is $35.1 million. Table 7 below provides a summary of the residual risk presented by this option.

Table 7 – Option 1 residual risk summary

Feeder containing oil filled cables	PV of residual risk ($M)	Risk proportion (%)
228	7.4	11.5
22W	56.6	88.1
233	0.2	0.4
Total	**64.3**	**100**

The high residual risk for this option is due to equivalent capacity cables failing to address the expected unserved energy (from Table 4) and the remaining residual condition-based assessment failure risk (from Table 3) between now and the optimal year of intervention.

5.4.2 Option 2 – Replacement with a higher capacity XLPE cable (augmentation)

This option identifies the replacement of the oil filled cables on feeders 228, 22W and 233 which have an NPV which is positive during the FY25 – FY29 period of interest with an optimal year of intervention in FY30. The presented NPV and PV of residual risk values assumes each oil filled cable is replaced during the year in which its NPV reaches its maximum value.

This option presents a residual risk of $461,000 and provides a benefit of $138.7 million compared to the counterfactual case. The PV of the cost of the option is $35.7 million and the NPV overall is $102.9 million. The cost of the option in real FY23 terms is $46.2 million. Table 8 below provides a summary of the residual risk presented by this option.

Table 8 – Option 2 residual risk summary

Feeder containing oil filled cables	PV of residual risk ($)	Risk proportion (%)
228	19,000	4.2
22W	329,000	71.3
233	113,000	24.5
Total	**461,000**	**100**

Option 2 mitigates the expected unserved energy risk due to forecasted load growth (from Table 4) and results in a lower residual condition-based assessment failure risk (from Table 3) due to an earlier optimal year of intervention.

5.5 Evaluation summary

Table 9 summarises the option outcomes of the cost-benefit assessment for replacement of oil filled cables on feeders 228, 22W and 233 compared to the BAU case.

Table 9 – Option economic evaluation summary

Option	Option type	Residual risk ($M)	PV of benefits ($M)	PV of investment ($M)	NPV ($M)	BCR	Rank	Comments
BAU	Counter-factual	139.1	-	-	-	-	3	BAU
1.	Network	64.3	74.8	23.9	50.9	3.1	2	Technically feasible but lower benefits, BCR and does not

Option	Option type	Residual risk ($M)	PV of benefits ($M)	PV of investment ($M)	NPV ($M)	BCR	Rank	Comments
Like-for-like replacement with XLPE cable								address future network capacity constraints
2. Replacement with higher capacity XLPE cable	Network	0.46	138.7	35.7	102.9	3.9	1	Technically feasible and gives higher BCR - preferred

As shown in Table 9, intervention of oil filled cables on feeders 228, 22W and 233 is economically justified based on a like-for-like replacement with XLPE cables. However, replacement with higher capacity cables to accommodate forecast load growth requirements provides a greater benefit when compared to Option 1's like-for-like replacement. Accordingly, Option 2 for the replacement and augmentation of the capacity of the cables provides a higher NPV overall and is the preferred solution.

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 B 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 10 below.

Table 10 – 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 α 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 α parameter (decreases the mean time to failure for the asset)
Expected unserved energy	30% decrease in the estimated risk and benefit values	Estimated risk values	30% increase in the estimated risk and benefit values

The impact on the preferred option (Option 2)'s NPV is shown in Table 11 below and the resultant NPV by year of intervention curves for each scenarios of the preferred option is shown in Figure 5.

Table 11 – NPV of scenario analysis for the preferred option (Option 2)

Scenario	NPV of preferred option ($M)
Scenario 1 – Low benefits, high costs	42.6
Scenario 2 – Central risks and costs	102.9
Scenario 3 – High benefits, low costs	205.1
Scenario average	116.9

Figure 5 – Option 2, NPV by year of intervention for the range of boundary scenarios

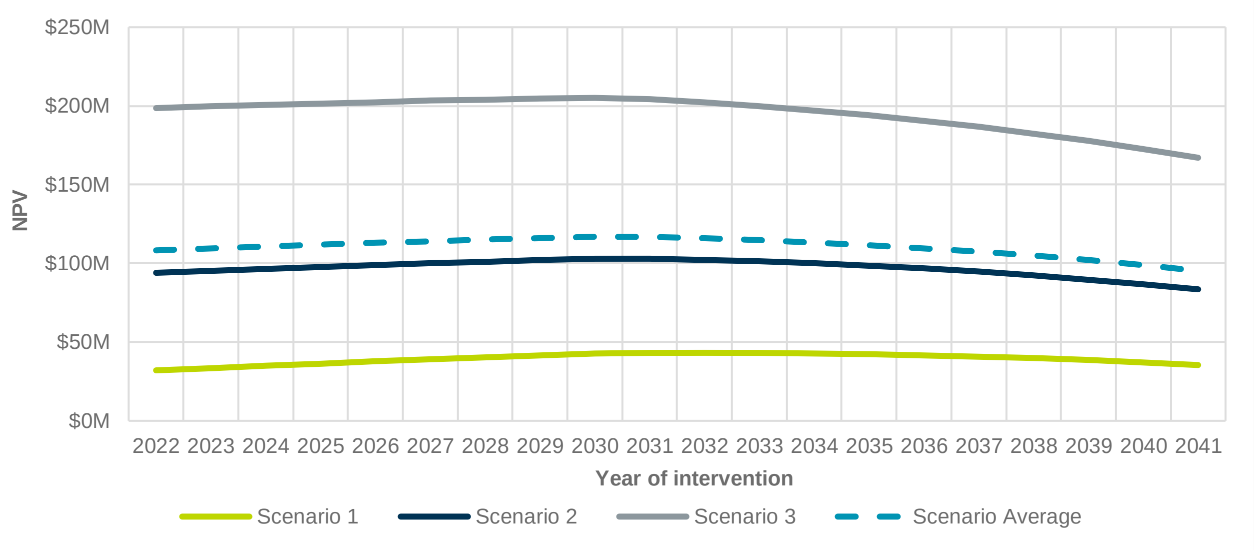


Figure 5 illustrates that the NPV curves by year of intervention for the preferred option maintain a relatively flat shape across the range of tested scenarios indicating minimal benefit of investment deferral. All high-benefit, low-cost cases and low-benefit, high-cost cases have a positive NPV within the FY25 – FY29 period of interest. On this basis it is concluded that the assessment is robust and points to an appropriate level of investment for Option 2.

6. Preferred option details

6.1 Scope and timing

The cost benefit assessment included a review of replacement works whose NPV is positive during the FY25 – FY29 regulatory period. If the NPV of the investment when brought forward to FY29 achieves greater than 99% of its maximum value, it is considered to still be providing the highest value for customers, given the uncertainties surrounding the risk assessment process. The preferred option is Option 2, which includes replacement and augmentation of oil filled cables on feeders 228, 22W and 233. This option reaches greater than 99% of its maximum NPV during the FY25 – FY29 regulatory period.

On this basis, the preferred option has been identified for inclusion in the investment portfolio optimisation process for FY25 – FY29 and should therefore proceed to the RIT-D process.

A contingency of 5% on direct charges and material cost has been included within the cost estimates. The cost of the proposed project is estimated to be $44.4 million and the total estimated cost including the proposed contingency is $46.2 million in real FY23 terms.

Given the size and complexity of the project, it is recommended that an estimated three to five years is allowed for project execution to achieve delivery by the end of FY29 to capture the benefits assessed within this CFI.

6.2 Project scope of works

The proposed scope for retire and replacement of the oil filled cables on feeders 228, 22W and 233 includes:

- Route options analysis and selection of a new route for the replacement feeders which allows the existing feeders to maintain their function during the civil construction works;
- Design and project management;
- A Review of Environmental Factors (REF) to be completed in conjunction with final route selection and detailed design;
- Supply, install and testing of the replacement power cables as detailed in Table 12 below;
- Connect the new feeder cables into the existing feeder bays at each associated substation;
- Supply, install and testing of optical fibre protection and communications links between each of the associated substations;
- Cable impedance measurements and updating of protection scheme settings as required by the change-over from the existing oil filled cables to XLPE cables;
- Decommissioning of the redundant oil filled cables including;
  - Disconnecting the cables from the electrical network;
  - Draining removal and disposal of oil from the cables and auxiliary systems;
  - Removal and disposal of the decommissioned cables from the substation yards if practicable;
  - Capping and shorting the cables and leaving in situ between substations;
  - Decommissioning, removal and disposal of the associated oil pressure systems;
  - Leave the cable pits in situ, back fill and restore;
- Update SAP and GIS and other database as appropriate with details of all new assets commissioned and decommissioned.

Refer to Appendix A for additional details of the design cost estimate and initial proposed route of the new feeders.

6.3 Project cost details

The cost estimate for the proposed replacement works (Option 2) are shown in Table 13. These costs are given in real FY23 terms. Due to the inherent complexities of this project, the initial cost estimates may need to be revised after completion of the final route selection, environmental assessment and detailed design.

The project cost estimates assume installation of single core copper XLPE cables to accommodate the preliminary cable ratings and sizes outlined in Table 12.

Table 12 – Cable rating requirements

Feeder	Section	Estimated design route length (km)	Rating (MVA)	Estimated cable size (mm^2)
233	Camelia to East Parramatta	2.27	160	630
22W	Camelia to ‘Future Lennox’	3.27	127	300 or 630
22W	‘Future Lennox’ to Guildford	6.84	273	2,000
228	East Parramatta to Guildford	7.75	228	2,000

The cable size selection is to be reviewed during detailed design to accommodate any updated forecast load requirements provided by the Network Planning section.

An itemisation of the total project cost estimate is summarised in Table 13 below.

Table 13 – Option 2 itemisation of cost estimate

Item	Total Cost ($)
Design	299,783
Project management	442,634
Labour (construction)	2,047,879
Plant and equipment	401,488
Materials - stores	1,855,242
Cable - non stores	19,608,561
Direct charges/materials	2,364,016
Survey	50,000
Civil works	8,442,784
Restoration	3,109,120
Easement(s)	2,500,000
Provisions	3,275,091
Subtotal	**44,396,693**
Contingency (5% on cost of cables and all direct charges)	1,798,207
Grand total	**46,194,900**

Refer to Appendix A for additional details of the design cost estimate and expected route of the cables.

7. Regulatory investment test

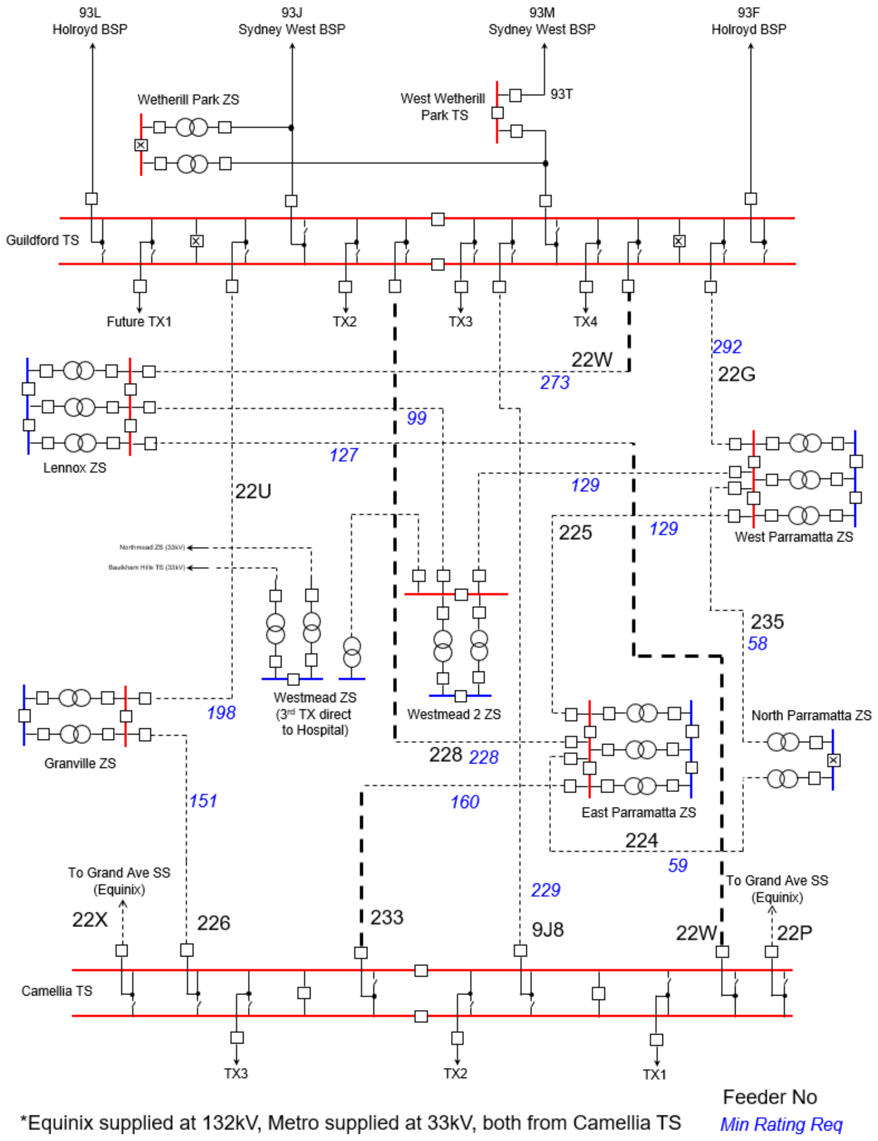
The project costs of the credible options exceed the threshold for application of the Regulatory Investment Test for Distribution (RIT-D) (currently $6.0 million) and therefore the RIT-D is applicable to this project in accordance with clause 5.16.3 of the National Electricity Rules.

The RIT-D process will test for feasibility of non-network options to either address the risks posed by the oil filled cables or to defer the network investment proposed to address those risks.

8. Greater Parramatta 132kV network strategy

The proposed works outlined within this CFI support Endeavour Energy’s current strategy for the future 132kV network servicing the Greater Parramatta area. The highlighted sections of cable in Figure 6 represent the cables proposed for replacement within this CFI. The increased rated capacity in the new XLPE cables proposed within Option 2 support forecasted demand growth due to the future connection of commercial and infrastructure developments in the Greater Parramatta area. The augmentation of feeder 22W also facilitates the future connection of Lennox ZS to the 132kV network to service the Auto Alley precinct of mixed use and business development zonings.

Figure 6 – Greater Parramatta 132kV network future strategy



The remaining 132kV oil filled cables on feeders 9J8, 22U and 226 are also undergoing a separate assessment by the Network Planning team for augmentation to support the Greater Parramatta 132kV strategy.

Due to the limited route options available within the Greater Parramatta area, the augmentation of feeders 9J8, 22U and 226 along with feeders 228, 22W and 233 proposed for replacement within Option 2 of this CFI require a staged delivery plan to maintain existing supplies during construction. This is specifically prevalent along Unwin Street in Rosehill where the existing northern trench for feeders 22W and 233 will need to be remediated for reuse by new feeders for 9J8 and 226 during augmentation of the southern trench cables.

9. Recommendation

It is recommended that the RIT-D process be commenced to test for feasibility of non-network solutions to address the risks presented by the oil filled cables in feeders 228, 22W and 233. Option 2, to replace these feeders with XLPE cables with a higher rated load capacity to service forecast future load growth is the preferred network option to be referenced in the RIT-D process.

10. Attachments

Appendix A – Preferred option design and cost estimate details

Appendix B – Summary of key risk assessment variables and assumptions

Appendix C – Network Planning summary of expected unserved energy assessment

Appendix D – TM302 and TM303 assessment summary

Appendix E – South trench Furukawa feeders (22W, 22U and 9J8) NPV by year of intervention

Appendix F – Images of 132kV oil filled cables

11. References

[1] Endeavour Energy, "MMI 0025 Tests for transmission/sub-transmission underground cables," 2016.

[2] EPRI, "Technical Report 1000275 on Guidelines for the Interpretation of Dissolved Gas Analysis (DGA) for Paper-Insulated Underground Transmission Cable Systems," 2000.

[3] "The Energy Charter," theenergycharter.com.au, January 2019.

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

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

Appendix A – Preferred option design and cost estimate details

The cost estimate details provided by Mains Design are outlined in Figure 7 below. A contingency of 5% has been applied to the cost of cables and direct charges.

Figure 7 – Mains Design cost estimate

MAINS DESIGN

PROJECT ESTIMATE SUMMARY

Project No		**Revision**	A
Project Name	Replacement of Feeders 233, 228 and 22W		
Estimate Description	Replacement of end of life oil filled cables on feeders 233, 228 and 22W		
Estimate Date	25/02/2022	**Estimate Type**	Business Case
Applicable Labour Rates	Std Internal Rates (PPMS)		

Designed & Constructed In-House

Design	$ 299,783		480	Design Man Hours
Project Management	$ 442,634		3929	Project Management Man Hours
Labour (Construction)	$ 2,047,879		25710	Construction Man Hours
Plant & Equipment	$ 401,488		30119	Total Man Hours
Materials - Stores	$ 1,855,242	$	0	*Total Recovered Overheads Included in subtotals to left*
Cable - Non Stores	$ 19,608,561			
Direct Charges/Materials	$ 2,364,016	$	0	*1.5 OT Included in Labour Subtotal*
Survey	$ 50,000	$	0	*2.0 OT Included in Labour Subtotal*
Civil Works	$ 8,442,784			
Restoration	$ 3,109,120			
Easement(s)	$ 2,500,000			
Provisions	$ 3,275,091			
Contingency	$ 1,798,207			
Profit	$ 0	SUB TOTAL	$	46,194,803
		ROUNDED TOTAL	**$**	**46,194,900**

Figure 8 – Expected new north trench cable route (overall)

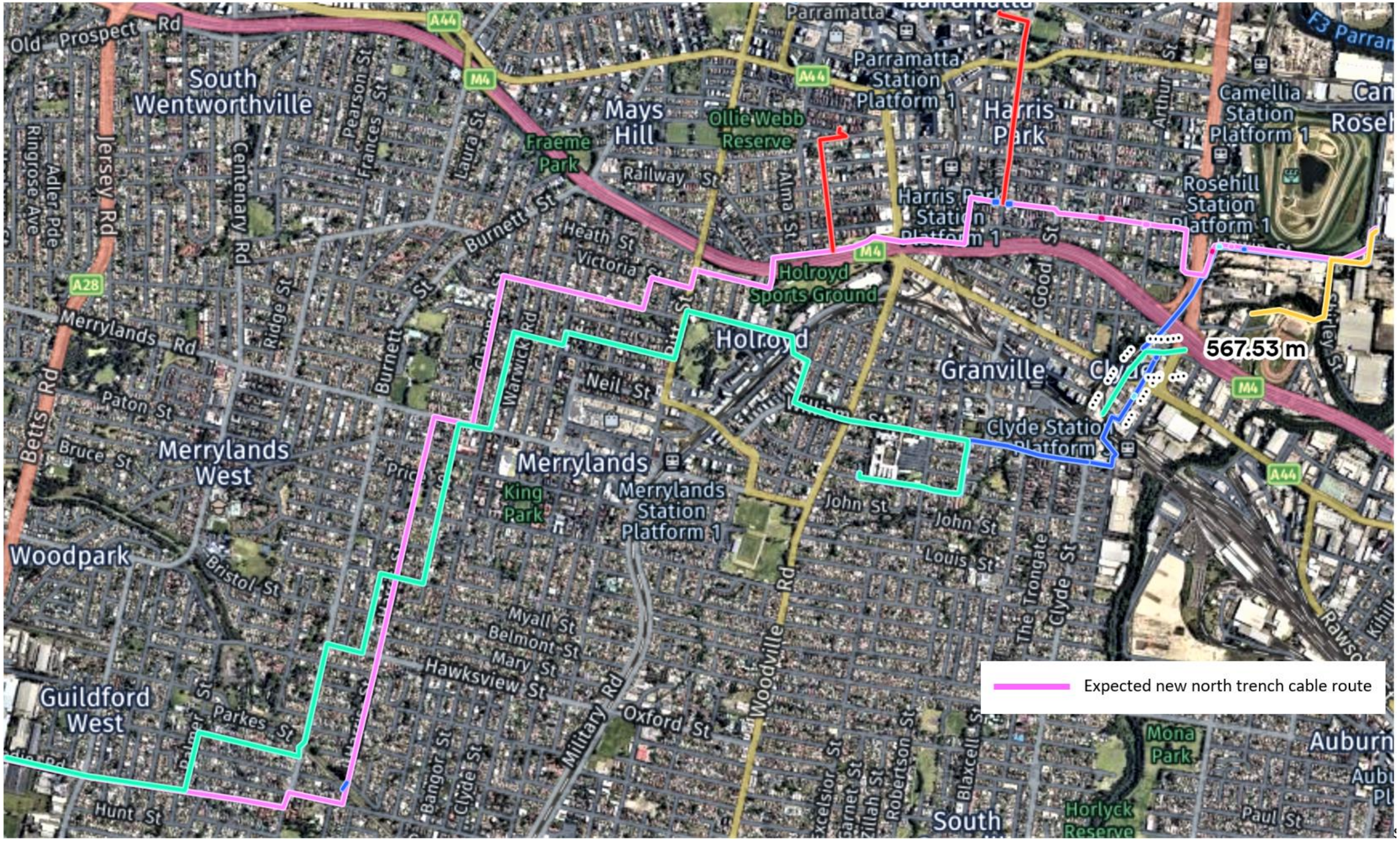
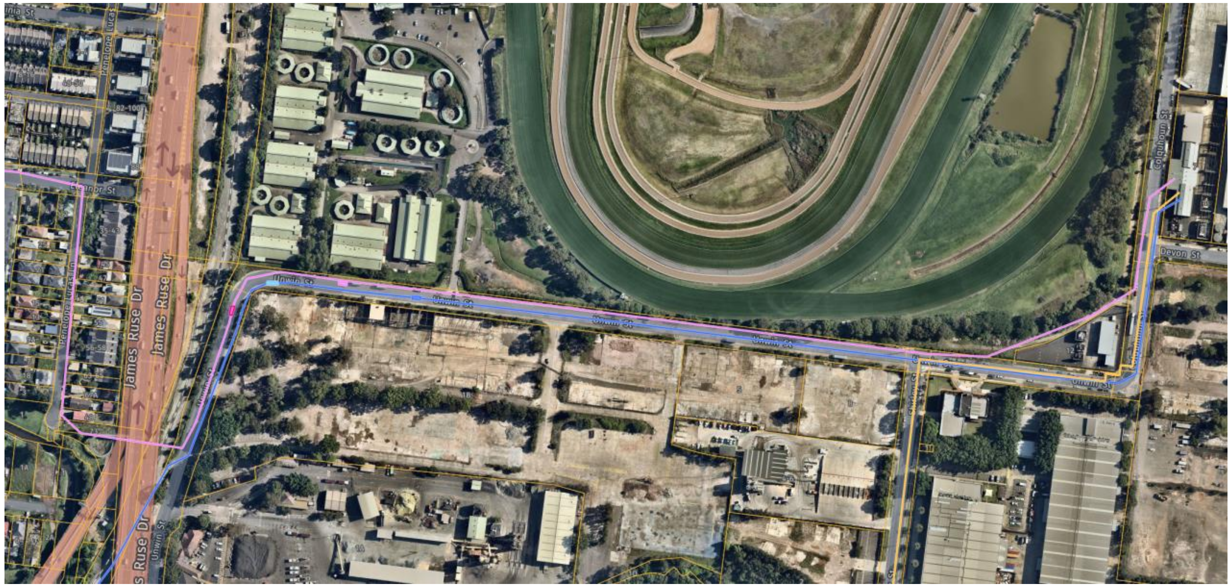


Figure 9 – Expected new north trench cable route (detailed)



From Camellia TS west along Unwin Street

James Ruse Drive under bore, north along Penelope Lucas lane and West along Eleanor Street and Allen Street

South on Wigram Street, under bore west across railway corridor onto Junction Street and continue west along Railway Street

Under bore south across Western Motorway and west along Robert Street picking up the existing cable route

Note: the remainder of the cable route from Robert Street to Guildford TS has been assumed to follow the existing route for the initial cost estimates undertaken by Mains Design within this CFI.

Appendix B – Summary of key risk assessment variables and assumptions

General variables and assumptions

Parameter	Value	Description/justification	Source/assumptions
Population	40.5km	Route length of 132kV oil filled cables in service in Endeavour Energy's (EE) network. Each feeder is comprised of three single core cables giving a total cable length of 121.5km	GIS database and network drawings.
Annual conditional failures	0	Conditional failure is not defined in EE standards. The only recent non-routine inspection and maintenance expenditure recorded has been due to repair of a major oil leak on feeder 233 in 2011 incurring a cost of $650,000.	
Annual functional failures	0.1	A functional failure is considered to be a breakdown of the cable insulation or a major oil leak, causing financial and environmental impacts and potential reliability impacts. A major oil leak requiring major repair works occurred in 2011.	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-FY29 PIP after optimisation
Calculation horizon	55 years	The timeframe over which the cost-benefit analysis is performed. Sensitivity assessment determined the modelling of oil filled cable to be insensitive to the value of calculation horizon.	Repairable V1.0 algorithm
Maintenance costs	$6,852/km	Oil filled cables on feeder 228	Oil pumping summary record from Transmission North. Actual maintenance costs for oil filled cables vary dependent on the quantity of oil leaked annually. General cable inspection maintenance costs of the replacement assets (XLPE cable) are lower, but the difference is not material to the cost-benefit assessment and therefore only maintenance costs pertaining to the upkeep of oil levels within these cables have been considered.
	$2,016/km	Oil filled cables on feeder 22W	
	$546/km	Oil filled cables on feeder 9J8	
	$2,397/km	Oil filled cables on feeder 22U	
	$0/km	Oil filled cables on feeders 233 and 226	
Planned intervention costs – cable replacement	$35,129,400	Like-for-like replacement cost with an equivalent XLPE cable. Cable size is 630mm^2.	Based on Mains Design cost estimates specific to feeders 228, 22W and 233.
	$46,194,900	Augmentation and replacement cost with a an XLPE cable to meet future load growth forecasts. Cable size varies from 630mm^2 to 2000mm^2.	
Failure modes		A single failure mode of the oil filled cable incurring a major oil leak due to deterioration of the sheath/serving is modelled causing potential loss of supply and incurring financial and environmental impacts.	Lesser failure modes such as minor oil leaks result in minimal consequences which are not material to the economic evaluation and have been excluded from the model.
Asset age	Varies for each feeder	Calendar age based on the feeder in-service date compared to the year of assessment (2022)	GIS database and previous TM302 and TM303 projects.

Parameter	Value	Description/justification	Source/assumptions
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. Adjustment based on annual quantities of leaked oil to represent the condition of the cable sheath. Max adjustment +10 years Min Adjustment +0 years Age adjustment = Quantity of oil leaked (L) / Feeder length (km) / 26	Estimates which give a reasonable spread in PoF for cables of similar calendar age but vary in sheath condition based on oil leak rates. The age adjustment was derived to incur a maximum adjustment of +10 years.

Weibull failure probability parameters

Parameter	Value	Description/justification	Source/assumptions
α	6.5	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 sheath damage and correlation with the actual very low annual failure rates being experienced withy the current age profile of the 132kV oil filled cables. The selected shape parameter generates PoF characteristics which represent a very low PoF up until the age of 50 years which then steadily increases to an age of 120 years.
β	90	The "scale" parameter used for calculating probability of failure	Estimated to give a reasonable looking MTTF of around 84 years and correlation with the actual very low annual failure rates being experienced.
ψ	0	The "shift" parameter which gives a failure free period at the start of the asset's life.	The low quantity of 132kV oil filled cables installed on the EE network do not provide sufficient information to derive a shift parameter.

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 the cables.	The land use around each cable 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. All oil filled cable locations reside in urbanised areas and have been assigned a low sensitivity.
Environmental - LoC	100%	Likelihood of the above environmental impact occurring on a cable failure	LoC assumed to be = 1

Reliability risk inputs

Parameter	Value	Description/justification	Source/assumptions
Loss of supply to customers - LoC	1% generally	1% likelihood of loss of load when N-1 supply security is available. Where supply security is lost in future years, PowerFactory modelling provides an estimate of the exceeded capacity. A 30% overload on supporting feeders has been considered acceptable prior to a loss of load been considered.	RisCAT - 1% likelihood the alternate supply path will not be available due to maintenance, or failure. PowerFactory modelling.
Load impacted	Varies based on the substations supplied by the lines the towers support	PowerFactory load flow analysis for feeder loads.	PowerFactory load flow analysis results provided by Network Planning.
Load factor	70%	Load assumed to be lost is 70% of the summer maximum demand value for the supplied substation(s)	Source – studies by Protection Manager.
VCR	Approximately $40,264 per MWhr of unserved energy	Value of customer reliability for an occasional short-term outage.	This value is based on the makeup of customer types supplied by the substations the feeders are supplying and is based on values published by the AER
Duration of interruption	2 hours	2 hours assumed interruption until alternate arrangements are made for supply through switching the network	An average 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 – repair costs of oil filled cable – CoC	$601,650	Value of repair costs incurred to locate and repair a damaged oil filled cable	Estimation based on quotation for cable leak detection works obtained in 2019 inflated to real FY23 dollars
Financial – repair costs of oil filled cable – LoC	100%	Likelihood of the above Financial – repair cost impact occurring on a cable failure	LoC assumed to be = 1

Appendix C – Network Planning summary of expected unserved energy assessment

The EUE risk costs for this assessment were provided by Endeavour Energy's Network Capacity Planning section.

Feeders 22W and 228 are forecast to exceed capacity by 2031 and 2034 respectively and will be overloaded and unable to provide backup in a fault scenario on nearby feeders by 2027. This is due to ongoing residential and commercial developments in the Parramatta CBD, planned developments within the Camellia-Rosehill Precinct as part of the NSW Planning Camellia-Rosehill Place Strategy, as well as other local growth seen in the new Equinix data centre, Sydney Metro West and Westmead Hospital which have contributed to the requirement for increased capacity in the area. This growth is shown below in Table 14 up to 2031. A nominal growth rate of 0.5% per annum is thereafter applied up to 2050.

Table 14 – Additional load contribution in the Greater Parramatta area by 2031

Additional load contribution	Load (MVA)
Westmead Hospital	28
Parramatta CBD	25
Equinix Data Centre	62
Sydney Metro West	55
Camellia-Rosehill Precinct	19
Total	**189**

Endeavour Energy's expected unserved energy (EUE) model returns the EUE in MWh based on future load growth forecasts and current capacity of the assessed assets. The EUE model accounts for asset unavailability due to standardised failure rates and the type of load supplied. The key modelling parameters and assumptions used within the EUE model for feeders 22W and 228 are outlined in Table 15 below.

Table 15 – Expected unserved energy modelling parameters

Modelling parameter	Value
Line class	Underground urban reticulation
Load duration curve	Mixed
Value of customer reliability (VCR)	$40,264/MWh

The assessment of cable overload and fault scenario analysis across the fleet of 132kV oil filled cables is provided in Table 16.

Table 16 – Network Planning 132kV oil filled cable overload (base) and fault contingency scenario analysis

			Loads								
Year	Feeder	Rating	Base / Fault →	22U Guildford - Granville	226 Granville - Camellia	9J8 Guildford - Camellia	22W Guildford - Camellia	228 Guildford - East Parramatta	233 East Parramatta - Camellia	22G Guildford - West Parramatta	225 West Parramatta - East Parramatta
2024	22U Guildford - Granville	117	78	x	39	102	101	90	82	92	74
2024	226 Granville - Camellia	117	41	39	x	66	64	54	46	56	37
2024	9J8 Guildford - Camellia	117	80	106	94	x	106	94	85	97	75
2024	22W Guildford - Camellia	117	76	101	89	103	x	89	81	92	71
2024	228 Guildford - East Parramatta	111	71	85	78	86	85	x	66	109	60
2024	233 East Parramatta - Camellia	111	19	42	32	45	43	33	x	35	30
2025	22U Guildford - Granville	117	80	x	40	104	103	92	82	94	74
2025	226 Granville - Camellia	117	42	41	x	66	65	54	45	57	34
2025	9J8 Guildford - Camellia	117	82	108	96	x	108	96	85	99	76
2025	22W Guildford - Camellia	117	77	103	91	105	x	91	81	94	72
2025	228 Guildford - East Parramatta	111	74	88	81	89	88	x	70	113	61
2025	233 East Parramatta - Camellia	111	17	40	29	43	41	36	x	42	30
2026	22U Guildford - Granville	117	92	x	41	121	119	105	99	107	88
2026	226 Granville - Camellia	117	54	41	x	83	80	67	62	70	50
2026	9J8 Guildford - Camellia	117	96	126	113	x	127	111	105	115	92
2026	22W Guildford - Camellia	117	91	120	107	123	x	105	100	109	87
2026	228 Guildford - East Parramatta	111	80	96	89	98	96	x	68	122	72
2026	233 East Parramatta - Camellia	111	32	61	49	65	62	29	x	28	40
2027	22U Guildford - Granville	117	98	x	41	129	127	113	106	115	94
2027	226 Granville - Camellia	117	60	41	x	91	89	75	69	78	56
2027	9J8 Guildford - Camellia	117	103	136	123	x	137	120	114	124	99
2027	22W Guildford - Camellia	117	98	129	117	132	x	114	108	117	94
2027	228 Guildford - East Parramatta	111	87	104	97	105	104	x	73	132	77
2027	233 East Parramatta - Camellia	111	34	66	54	70	67	31	x	30	44
2028	22U Guildford - Granville	117	105	x	41	139	137	122	114	124	100
2028	226 Granville - Camellia	117	68	41	x	102	99	84	77	87	63
2028	9J8 Guildford - Camellia	117	112	147	134	x	148	130	123	134	106
2028	22W Guildford - Camellia	117	106	140	127	144	x	124	116	127	101
2028	228 Guildford - East Parramatta	111	94	113	106	115	113	x	80	143	82
2028	233 East Parramatta - Camellia	111	36	70	58	75	72	34	x	33	48
2029	22U Guildford - Granville	117	108	x	40	143	141	125	117	128	103
2029	226 Granville - Camellia	117	70	41	x	105	103	87	80	90	66
2029	9J8 Guildford - Camellia	117	115	151	138	x	152	134	126	138	109
2029	22W Guildford - Camellia	117	109	143	132	148	x	127	119	131	104
2029	228 Guildford - East Parramatta	111	97	116	109	118	117	x	84	148	85
2029	233 East Parramatta - Camellia	111	37	72	60	76	73	38	x	37	47
2030	22U Guildford - Granville	117	110	x	40	145	143	127	118	130	105
2030	226 Granville - Camellia	117	72	41	x	107	105	89	81	93	67
2030	9J8 Guildford - Camellia	117	117	154	141	x	155	137	127	141	111
2030	22W Guildford - Camellia	117	111	146	134	150	x	130	121	134	106
2030	228 Guildford - East Parramatta	111	100	119	113	122	120	x	87	153	88
2030	233 East Parramatta - Camellia	111	36	70	59	107	72	41	x	41	45
2031	22U Guildford - Granville	117	122	x	40	161	159	141	133	143	118
2031	226 Granville - Camellia	117	84	41	x	124	121	103	97	107	81
2031	9J8 Guildford - Camellia	117	131	172	159	x	174	153	145	157	127
2031	22W Guildford - Camellia	117	124	163	152	168	x	145	138	149	121
2031	228 Guildford - East Parramatta	111	109	130	124	133	131	x	91	166	100
2031	233 East Parramatta - Camellia	111	46	85	74	91	88	40	x	36	53

Appendix D – TM302 and TM303 assessment summary

A summary of the health of the oil across each section of the oil filled cables is provided in Figure 10 and Figure 11. The analysis results are based on criteria provided in the Electric Power Research Institute (EPRI) – Canada report No. 1000275 (September 2000).

Figure 10 – Health of oil across sections of feeders 228, 22W and 233

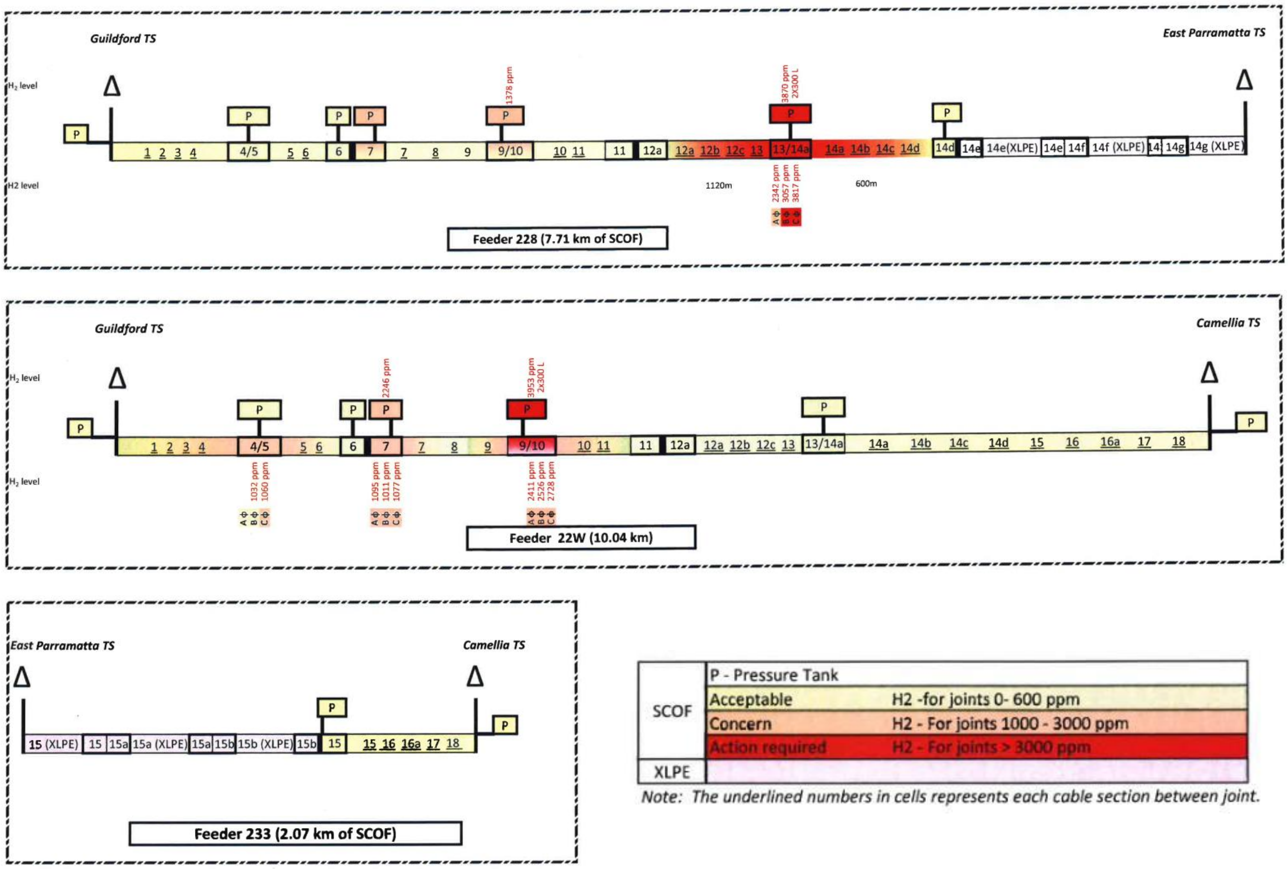
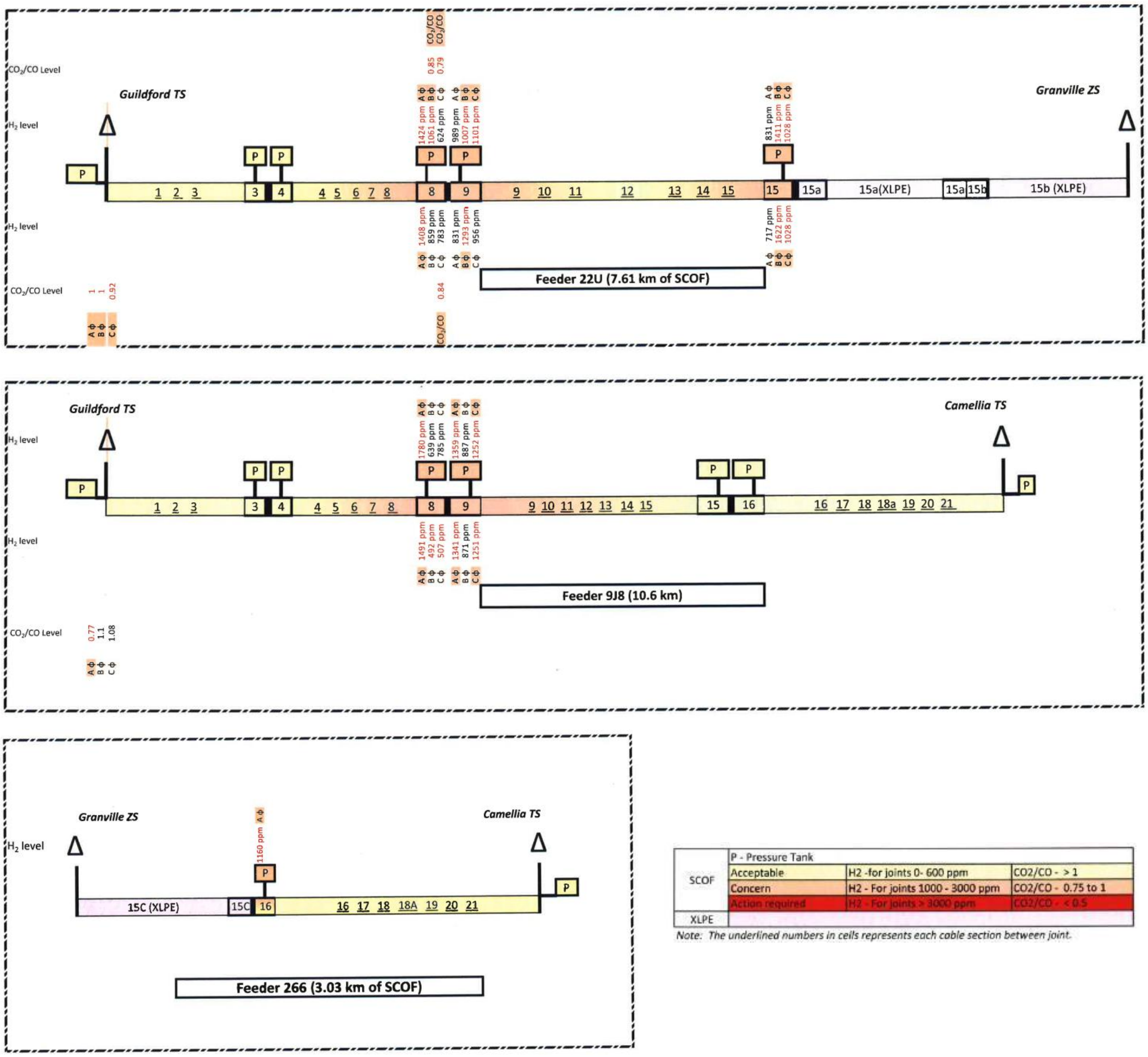


Figure 11 – health of oil across sections of feeders 22U, 9J8 and 226



The full condition assessment reports and dissolved gas analysis oil results are available in TM302 and TM303 program completion documentation stored in the below network directories:

G:\Samp\Program Directors\Major Projects\Projects\02_Completed\TM302 T1529 Fluid Cables Auxiliary Equipment

and

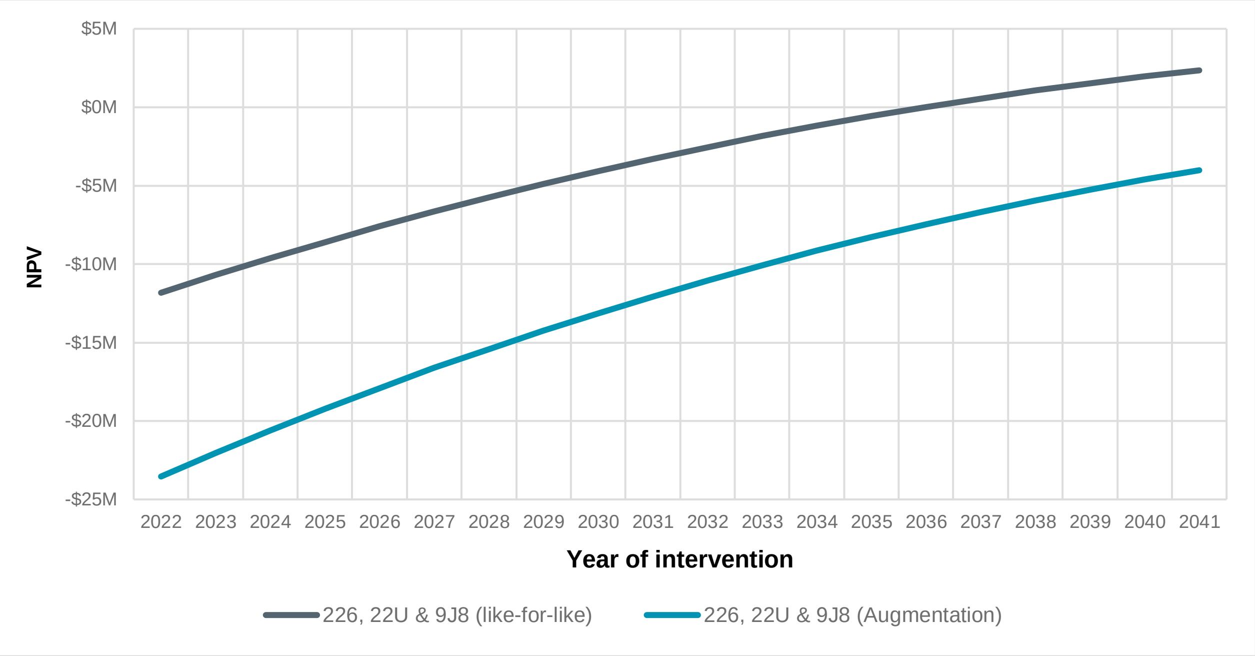
G:\Samp\Program Directors\Major Projects\Projects\02_Completed\TM303 T1530 132kV Cable Fluid Testing

Appendix E – South trench Furukawa feeders (22W, 22U and 9J8) NPV by year of intervention

The latest condition-based results indicate that Furukawa cables are in a satisfactory condition for the near future and will not require intervention in the short to medium term. However, this will be re-assessed in future as updated conditional data is made available.

Assets are identified for proactive intervention at the time when the net present value of the intervention reaches its maximum value. The assessment conducted as part of this CFI into the proactive replacement of Furukawa manufactured cables along the southern trench route yielded no economically feasible interventions within the FY23 – FY29 investment period or the following FY30-FY34 period. Figure 12 below illustrates that the NPV of a condition-based project to replace the Furukawa feeders has not reached its maximum value by FY41.

Figure 12 – South trench Furukawa feeders (22W, 22U and 9J8) NPV by year of intervention



Appendix F – Images of 132kV oil filled cables

Top Left *– Feeder 228 joint bay 4-5 (cable oil in base of joint pit) - 2017*

Top Right *– Feeder 228 at Guildford TS (severely corroded oil reservoir tanks prior to TM302) - 2017*

Middle *– Feeder 233 sheath (existing cracks around sheath and additional cracks forming) - 2011*

Bottom left *– Feeder 9J8 (leaking oil at bridge crossing in Rosehill) - 2013*

Bottom Right *– Feeder 22W & 233 (ground subsidence and debris impacting cables after water mains failure in 2007) - 2007*

Produced by Asset Planning and Performance Branch

W Endeavourenergy.com.au
E consultation@endeavourenergy.com.au
T 133 718

ABN 11 247 365 823

Endeavour Energy