# Concept Design and Cost Estimate

## HumeLink Project – Underground

Transgrid

22 August 2022

→ **The Power of Commitment**

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# Executive summary

This report is subject to, and must be read in conjunction with, the limitations set out in Section 1.4 and the assumptions and qualifications contained throughout the Report.

## Background

HumeLink is a proposed transmission network augmentation that reinforces the New South Wales southern shared network to increase transfer capacity between Snowy Mountains and the region's demand centres in the Greater Sydney area. HumeLink is a significant transmission investment, being undertaken at a time in which there is a major energy transition to be accommodated.

Transgrid has investigated overhead transmission network options for HumeLink. Transgrid has enlisted GHD to investigate concept designs for transmission network options which use underground cables.

A desk top study approach has been taken by GHD that draws from an extensive project experience base to provide the design basis information and comparative network topology costings. Stantec consultants have provided extensive global HVDC project experience into the study.

## The report

We have been engaged to undertake a Concept Design to investigate undergrounding options for the HumeLink Transmission line.

Our technical assessment consists of the following sections which are fully articulated in the report:

- Section 2 discusses the route assessment and key constraints to determine the Optimal Route for the HumeLink transmission line.
- Section 3 Considers the 8 Options investigated and their sub options. Compares the sub options and determines the most cost and technically effective preferred options.
- Section 4 provides cost estimates and breakdown including a $/km cable and line cost for each of the 8 preferred options as well as the Gugaa to Wagga Wagga 330kV AC underground line.
- Section 5 provides a high-level schedule for each of the 8 preferred options.
- Section 6 provides a table of non-market benefits for each of the preferred options.
- Appendices provide further detail on the items in Section 2 to Section 5.

## Conclusion

The results of this high-level options concept design study presented in this report are not meant to justify direct or immediate investment. The study is exploratory in nature and with the information available considers the highly challenging nature of the project from a community, environmental and technical perspective.

The actual costs will depend on the type of cable used, method of installation, local environmental conditions and, in particular, the rating required from the circuit, as this will dictate the number of cables installed

A significant benefit of undergrounding cables is the reduction in visual impact. In certain areas, such as protected landscapes, this benefit could be a primary consideration and outweigh disadvantages of undergrounding such as restrictions on land use and the impact on ecological and archaeological sites.

Visual intrusion impacts and threats to sensitive habitats will vary along the route corridor as the landscape and species mix changes. To help reduce some of these impacts undergrounding may be considered in some cases only. However, this can create further difficulties as the transition from overhead lines to underground cables requires termination points. These are often large structures that require sensitive siting. For this reason, numerous adjacent short sections of undergrounding are unlikely to be desirable due to the requirement for large plant/equipment compounds at each termination point.

Buried cables occupy a significant amount of land and, like overhead lines, also require access for maintenance and repair for the duration of their life.

The undergrounding route options presented are outcomes of a limited desk top study that utilises a geospatial constraint analysis tool. Refining this assessment through more detailed site investigations including community, environmental and engineering perspectives would determine the extent of constraints including constructability. If a shorter route with easier terrain and less clearing can be identified through further analysis, the cost of undergrounding is expected to be lower than presented in this report.

The study has explored viable technical options however as a concept study the costing and delivery timing will have a high level of variability. Market testing is required to provide more certainty around these variables.

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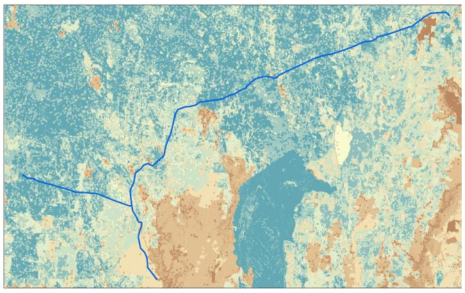
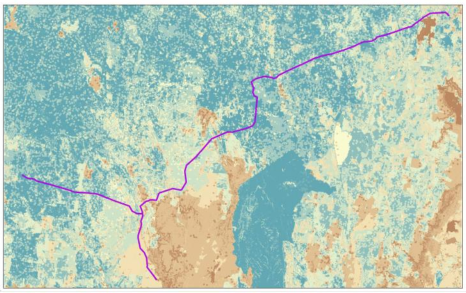
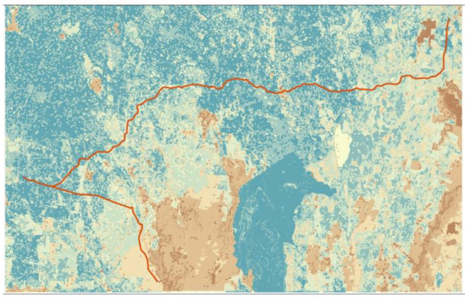
# Route assessment

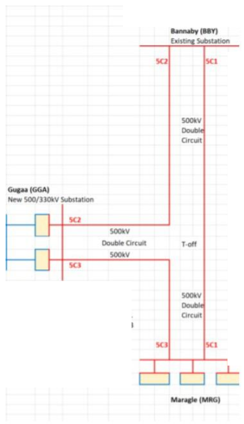
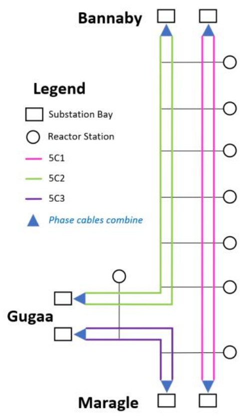
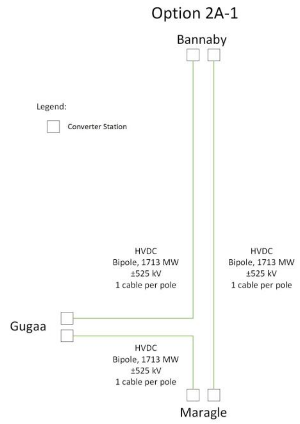
GHD investigated four potential routes to underground the proposed HumeLink project. A multi-criteria analysis (MCA) was undertaken of each route, using GHD's GIS-based MCA methodology known as the 'InDeGO' Method (Infrastructure Development – Geospatial Options) to rate the enviro-social and existing infrastructure constraints for the nominated route options, and quantitatively assess the preferred route subject to the least constraints. The assessment used a suite of existing mapped constraints. InDeGO assigns a total score to each route, with the lowest score representing the route with the least constraints.

A summary of the route assessment is provided below.

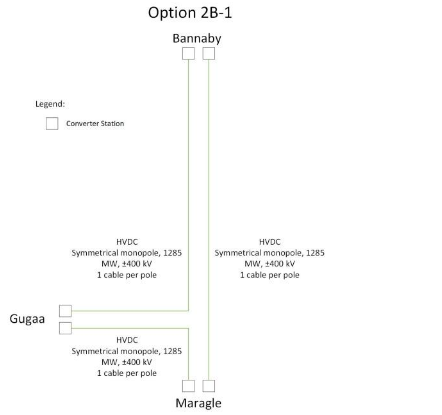
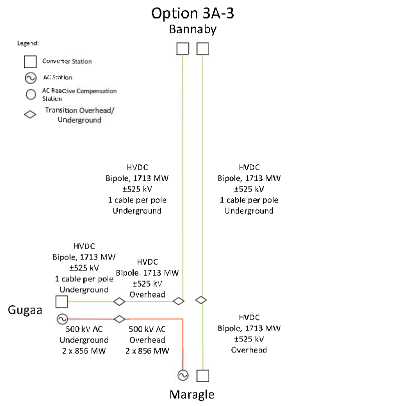
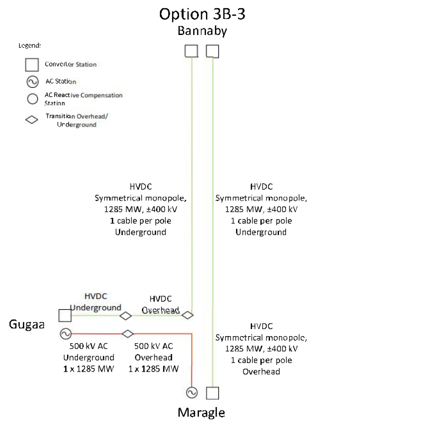
| Route | Tumut North (Route 1) | Blowering Northeast Deviation (Route 2) |
|---|---|---|
| Route Map |  |  |
| Route overview | This route has the least enviro-social constraints of those assessed in InDeGO. | This route is co-located adjacent to existing transmission lines. |
| InDeGO score | 5,204,019 | 5,820,270 |
| Route | Kosciuszko National Park (Route 3) | Hume Highway (Route 4) |
| |  |  |
| Route overview | This route maximises the use of public land by traversing national park and state forest land. | This route traverses alongside the Hume Highway to minimise impacts on private land. |
| InDeGO score | 7,524,744 | 6,256,460 |

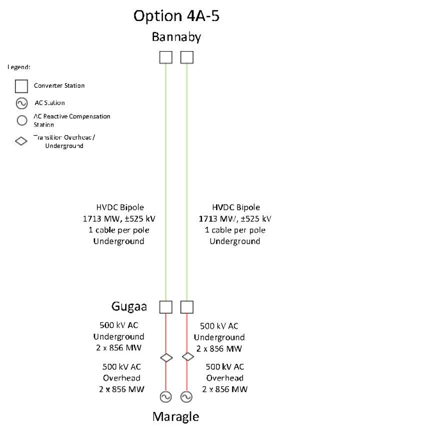
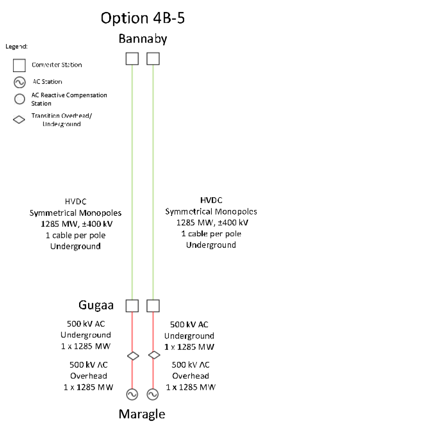
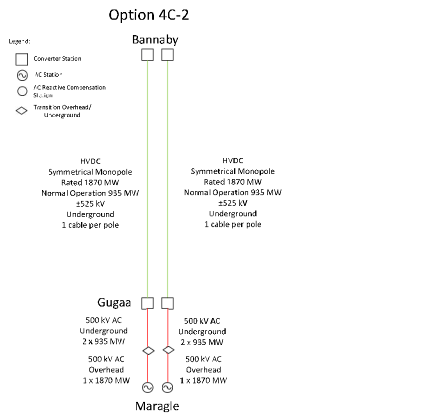
## Options

The concept design study investigated eight transmission line options and their sub-options in order to determine the most efficient and cost-effective option. The eight preferred underground options along with Transgrid's overhead option is summarised in the table below

| Option | OHL option | 1A | 2A-1 |
|---|---|---|---|
| Simple Single Line |  |  |  |
| Explanation | 100% AC overhead<br>Double circuit 500kV towers with 4 x orange conductors per phase (3259MW) | 100% HVAC Underground.<br>Flat configuration, 2 cables per phase per circuit (6 cables per trench (2570 MW) | 100% HVDC Underground<br>3 bipoles (1713 MW, ±525 kV), 1 cable per pole |
| Route | Tumut North Route | Tumut North Route | Tumut North Route (No1) |
| CAPEX | $3.3 Billion (2021) | $17.1 Billion | $11.5 Billion |
| OPEX (11yr avg) | $50.5 Million (2021) | $55.1 Million | $91.9 Million |
| MVA requirements | Yes | Yes | Yes |
| Redundancy | 100% Transmission Capacity after N-1 | 100% Transmission Capacity after N-1 | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal |
| Schedule | 4-5 Years | 11 Years | ≈ 7 Years |

*The 'OHL Option' was not estimated or studied by GHD. Information provided by Transgrid

| Option | 2B-1 | 3A-3 | 3B-3 |
| --- | --- | --- | --- |
| Simple Single Line |  |  |  |
| Explanation | 100% HVDC Underground<br>3 symmetrical monopoles (1285 MW, ±400 kV), 1 cable per pole | HVDC and HVAC Hybrid (Overhead in public land)<br>2 bipoles (1713 MW, ±525 kV), 1 cable per pole. HVAC double circuit to match HVDC redundancy (856MW) | HVDC and HVAC Hybrid (Overhead in public land)<br>2 symetrical monopoles (1285 MW, ±400 kV), 1 cable per pole. HVAC circuit to match HVDC redundancy (1285MW) |
| Route | Tumut North | Blowering Northeast and Kosciuszko Combination | Blowering Northeast and Kosciuszko Combination |
| CAPEX | $9.0 Billion | $9.6 Billion | $7.5 Billion |
| OPEX (10yr avg) | $86.7Million | $129.6 Million | $116.2 Million |
| MVA requirements | Under Certain Circumstances | Yes | No |
| Redundancy | Loss of one element will result in loss of entire symmetrical monopole, but still meets 1285 MW transmission capacity at each terminal | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal | Loss of one element will result in loss of entire symmetrical monopole, but still meets 1285 MW transmission capacity at each terminal |
| Schedule | ≈ 7 Years | ≈ 6 Years | ≈ 6 Years |

| Option | 4A-5 | 4B-5 | 4C-2 |
|---|---|---|---|
| Simple Single Line |  |  |  |
| Explanation | HVDC and HVAC Hybrid<br>2 symetrical monopoles (1713 MW, ±525 kV), 1 cable per pole. HVAC double circuit to match HVDC redundancy (856MW) | HVDC and HVAC Hybrid<br>2 symmetrical DC monopoles (1285 MW, ±400 kV). HVAC circuit to match HVDC redundancy (1285MW) | HVDC and HVAC Hybrid<br>2 symmetrical DC monopoles (1870MW). HVAC underground double circuit (935MW), and overhead circuit (1870) to match HVDC redundancy. |
| Route | Hume Highway | Hume Highway | Hume Highway |
| CAPEX | $11.5 Billion | $9.1 Billion | $10.4 Billion |
| OPEX (10yr avg) | $107.7 Million | $100.8 Million | $105.3 Million |
| MVA requirements | Yes | No | No |
| Redundancy | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal | Loss of one element results in loss of one symmetrical monopole (1285 MW), but still meets 2570 MW transmission capacity at each terminal | Loss of one element results in loss of one symmetrical monopole, but power drop limited to 700 MW |
| Schedule | ≈ 6 Years | ≈ 6 Years | ≈ 6 Years |

*CAPEX, OPEX and Schedule assumptions are detailed in the report
*CAPEX includes direct and indirect costs such as engineering PM costs, terrain factors etc.

## Non-market benefits

**A comparative high-level summary of the non-market benefits of overhead verses underground lines/cables installations is presented in the table below**

| Non-Market Benefits | Underground | Overhead |
|---|---|---|
| **Environmental Impact** | – Less land disruption following construction<br>– Less easement width required for ongoing access for maintenance and repair<br>– Post construction lower ongoing vegetation clearance for underground easements | – Potential less vegetation clearing during construction<br>– Shorter construction time and less overall disturbance and disruption |
| **Productive efficiency of agriculture and communities** | – Possible conditional agriculture activity directly above the buried cable circuits<br>– No risk for aerial spraying activity<br>– No risk of tall machinery or equipment impacts to buried cables | – Potential future land use allowed which includes agriculture and digging (i.e., mining, dams, bores) if minimum clearances to overhead lines maintained<br>– |
| **Electromagnetic fields (EMF) and electromagnetic compatibility (EMC) Impacts** | – Magnetic field reduced quickly with distance from the cable centre line<br>– No electric fields | – Magnetic fields are only 20% of the allowable limit at their maximum |
| **Community benefits (visual amenity, audible noise, etc.)** | – Lower visual impact<br>– No operational noise (Corona)<br>– Negligible impact to public and wildlife activity following construction | – Lower Cost |
| **Bushfire Risk** | – Negligible potential for bushfire ignition<br>– No restricted access for bushfire fighting<br>– Power transmission unlikely to be affected during bushfire<br>– Negligible potential for above ground bushfire to impact and damage undergrounded assets | – Potential for power transmission loss or reduction during bushfires |
| **Impacts on the community and environment** | – Potential to underground sensitive sections<br>– Negligible impact to public and wildlife living in the area following construction and remediation | – Small construction footprint<br>– Low potential for exposure of contaminated soil due to no trenching<br>– Less interruption to community activities during construction<br>– Lower dust and noise generation during construction<br>– Less impact to land use during construction<br>– Lower disturbance to roads and infrastructure during construction<br>– |
| **Operation and maintenance work along the cable route.** | – Less likely to be impacted due to external factors (i.e., falling trees, wildlife, bushfires, vehicles)<br>– Minimal ongoing regular access along cable route required<br>– Overall less maintenance activity required compared to OHL | – Quicker and easier to locate faults along the transmission line<br>– Potential less outage time if fault occurs |
| **Human safety (aerial operations personnel, agricultural machinery operators, line workers at heights and the public)** | – Uninterrupted power transmission during extreme weather conditions<br>– Unlikely for asset damage to occur due to falling trees, passing vehicles etc.<br>– Conditional opportunity to use land for cropping within the easement<br>– No interruption with aerial operations such as crop dusting<br>– Lower interference with radio, television, and other communication signals<br>– Substantially reduced working at heights requirements along cable route | – Permitted digging on agricultural land with approved machinery<br>– Permitted use of land for cropping within easement |
| **Reliability of power supply (i.e., during severe weather conditions)** | – Higher reliability and performance<br>– Uninterrupted power transmission during extreme weather conditions<br>– Negligible chance for power transmission interruptions due to vehicle accidents, falling trees, wildlife etc.<br>– Negligible chance of power transmission interruptions due to lightning strikes and other severe weather conditions | – Normally high due to design criteria |

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# Acronyms and abbreviations

| Abbreviation | Description |
|---|---|
| A | Amps |
| AC | Alternating current |
| AACE | Association for the Advancement of Cost Engineering |
| AHIMS | Areas of very high indigenous significance |
| AUD | Australian Dollar |
| BSAL | Agricultural land |
| CB | Circuit breaker |
| CEEC | Endangered ecological communities |
| CYMCAP | Software |
| DC | Direct current |
| EEC | Endangered ecological communities |
| EHV | Extra high voltage |
| EMF | Electromagnetic fields |
| GHD | GHD Pty Ltd |
| GIS | Geographic Information System |
| HVAC | High Voltage Alternating Current. |
| HVDC | High Voltage Direct Current |
| km | Kilometre |
| kV | Kilovolt |
| LCC | Line Commutated Converters |
| M | Million |
| MCA | Multi-Criteria Analysis |
| MW | Megawatt |
| NSW | New South Wales |
| OH | Overhead |
| P | Active |
| Q | Reactive |
| QLD | Queensland |
| RAMSAR | Wetlands site |
| RFI | Request for Information |
| RFQ | Request for Quote |
| sq.mm Cu | Square millimetre copper |
| TC | Transmission Cable |
| TR | Thermal Resistivity |
| TSB | Thermally Stable Backfill |
| TR | Thermal Resistivity |
| TSB | Thermally Stable Backfill |
| VSC | Voltage Source Converters |
| XLPE | Cross-linked polyethylene cables |

# 1. Introduction

## 1.1 Background

HumeLink is a proposed transmission network augmentation that reinforces the New South Wales southern shared network to increase transfer capacity between Snowy Mountains and the region's demand centres in the Greater Sydney area. HumeLink is a significant transmission investment, being undertaken at a time in which there is a major energy transition to be accommodated. Project completion is due by 2026-27.

Transgrid has investigated transmission network topology options for HumeLink that will provide a wider footprint via Wagga Wagga that would open up both direct and additional capacity for new renewable generation in southern NSW. The current proposed HumeLink network topology comprises overhead 500kV & 330kV double circuit transmission lines connecting four substations: Bannaby, Maragle, Gugaa and Wagga Wagga. This outcome is depicted Figure 1.1 and Figure 1.2 below.

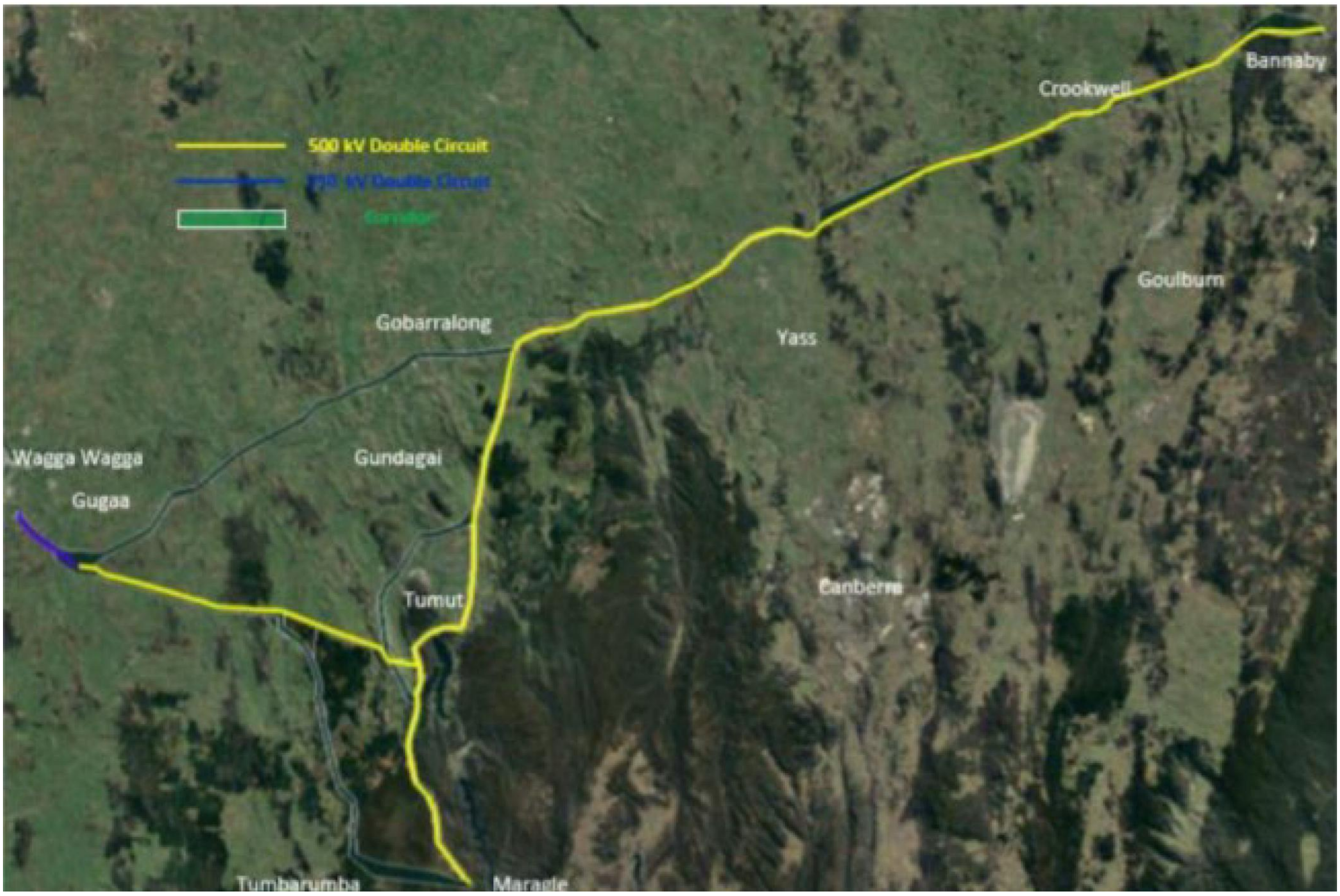



***Figure 1.1 Proposed HumeLink transmission line routes***

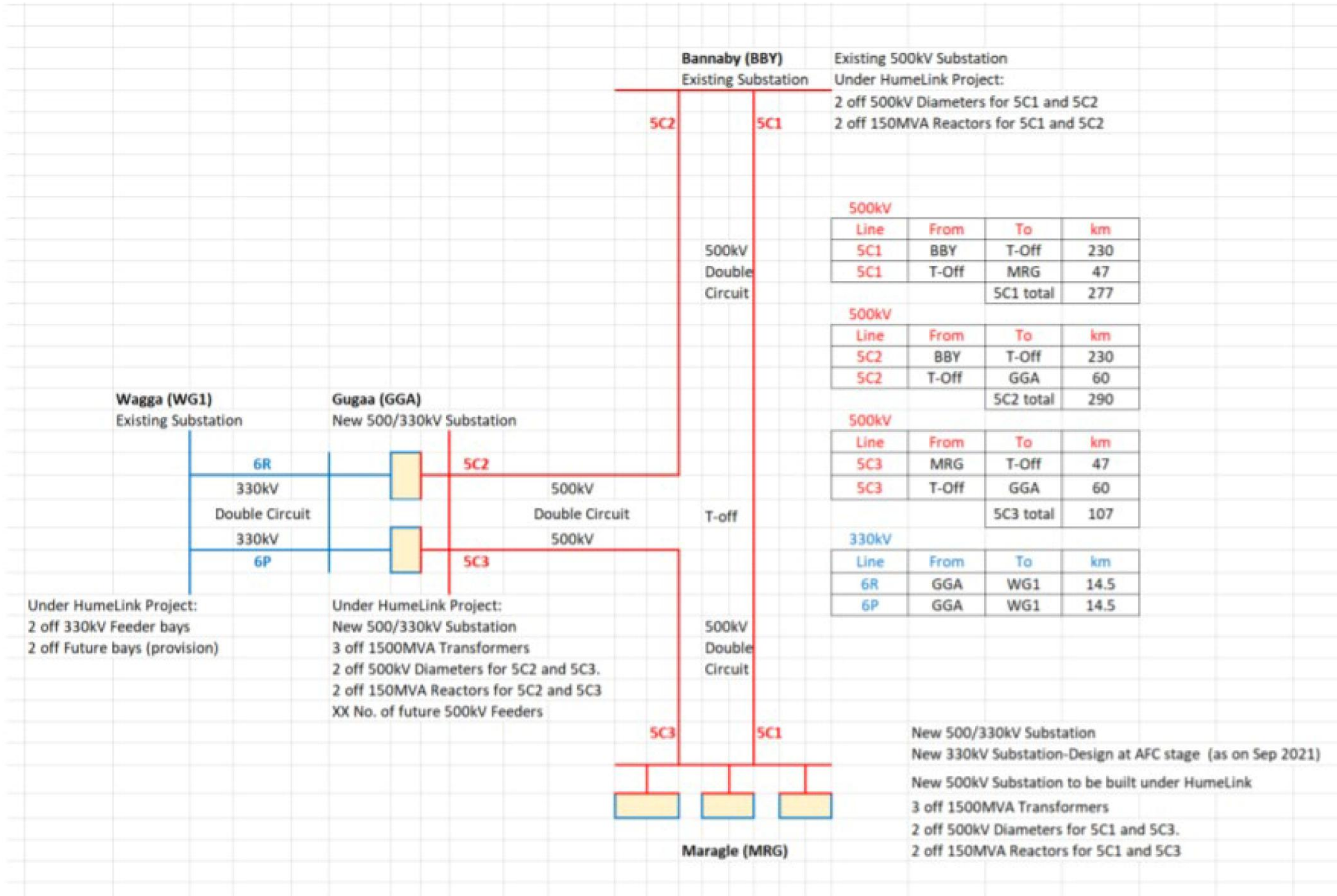



*Figure 1.2 HumeLink network topology*

This document provides a comparison of Transgrid's underground options with the overhead transmission lines option with the objective of investigating all options and sub options listed in Table 1 and Section 3.2 of the RFQ dated 12 Jan 2022. Additional options have also later been included by Transgrid.

## 1.2 Purpose of this report

GHD has been engaged by Transgrid to develop and price the different undergrounding options for the HumeLink project in the view to completing a holistic comparison with the overhead transmission lines topology.

## 1.3 Scope

The scope of work for this engagement has been undertaken in accordance with the Request for Quote (RFQ) (HL-ENGG-RFQ-2) to include the following key tasks:

- Undertake route assessment work using the multi-criteria assessment tool "InDeGO" for the quantitative assessment and evaluation of the environmental, social and existing built environmental constraints.
- Establishment of a project specific geographic information system (GIS) to enable review of the route alignment provided by Transgrid and relevant publicly available data and mapping.
- Provide high-level costing, $/km, and design for a 15km AC 330kV underground portion from Gugaa to Wagga Wagga.
- Provide advice on the advantages and disadvantages if part or parts of the circuit route were made as Overhead. i.e., partly underground in some areas and the rest overhead (OH).
- Consider 7 options and sub-options ( and other agreed options) for the HumeLink circuits, through the implementation of both AC and HVDC underground cables, in order to determine the most cost-effective means of achieving the objectives of the HumeLink project.

For each of the options we shall:

- Prepare a short-list of potential solutions. At a high-level, determine the scope of each potential solution, high level (ballpark) cost estimates and relative pros and cons.
- Undertake a comparative analysis of the potential solutions, including assessment in terms of overall costs, benefits, relative merits, reliability, redundancy etc.
- Based on the comparative analysis, select a preferred solution for further assessment for that Option.

For the preferred solutions for each option, we shall:

- Develop the scope of the preferred solutions to the level or detail necessary to determine a AACE Class 4 cost estimate for the preferred solutions (Class 4 estimate is typically, engineering from 1% to 15% complete, with accuracy ranges of -15% to -30% on the low side, and +20% to +50% on the high side).
- Develop a cost-estimate for each preferred option, at an accuracy of no worse than a AACE Class 4 cost estimate, of sufficient detail and breakdown to allow reasonable comparison between Options.
- Develop a high-level schedule for delivery of each preferred option, based on experience, knowledge of market conditions and, where possible, reference to other similar projects, which cover project development, design, manufacture, factory testing, transportation, construction, installation, testing, and commissioning.
- Develop a comparison table for all preferred options.

Additional Scope that was added throughout the Concept Design process as requested by Transgrid include:

- An 8th option (4C) to be added to the concept design. This design was to be done using the same guidelines as the other options.
- Include HVDC overhead within the options.

## 1.4 Limitations

This report: has been prepared by GHD for Transgrid and may only be used and relied on by Transgrid for the purpose agreed between GHD and Transgrid.

GHD otherwise disclaims responsibility to any person other than Transgrid arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer Section 1.5 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared the preliminary cost estimates set out in Section 4 of this report ('Cost Estimate') using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD.

The Cost Estimate has been prepared for the purpose of high-level comparison only and must not be used for any other purpose.

The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant, or guarantee that the works/project can or will be undertaken at a cost, which is the same or less than the Cost Estimate.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

GHD has prepared this report based on information provided by Transgrid and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

*GHD includes Stantec with regard to the HVDC component for this engagement

## 1.5 Assumptions

Key assumptions made during preparation of this report are described below.

- The route selection of the HVAC overhead transmission lines (OHL)has been undertaken by Transgrid and has been provided to GHD as route options to consider for the UG solution.
- Options cost estimates and Schedule assumptions are provided in Section 4 and 5 of this report

# 2. Route assessment

## 2.1 Overview of the approach

The approach taken to assess potential routes to underground the HumeLink project involved the following key steps:

- Establish a project-specific geographic information system (GIS) web map with a suite of publicly available data and other data provided by Transgrid.
- Develop route options using those previously assessed for the OHL solution as well as more direct route/s along key roads between Gugaa and Bannaby.
- Assess constraints relevant to the routes based on review of the GIS web map.
- Complete a multi-criteria analysis (MCA), using GHD's GIS-based MCA methodology known as the 'InDeGO' Method (Infrastructure Development – Geospatial Options) to rate the enviro-social and existing infrastructure constraints for the nominated route options and quantitatively assess the preferred route subject to the least constraints.
- Identify the optimal underground route or routes based on the MCA (InDeGO score).

Key assumptions relating to the above include:

- Assessment is undertaken from a desktop perspective only; no site survey was completed.
- Constraints are based on available mapping only. No detailed impact assessment was undertaken to identify additional constraints.
- InDeGO analysis assumes a 20-metre-wide impact, which is the standard 10 metre easement required for underground transmission lines plus a 10-metre buffer for construction. This area does not include additional clearing for construction requirements or areas for ancillary facilities such as joint bays so is likely to be an underestimate.
- Permissibility and the likelihood of acquiring approval are not considered in the assessment.

Each of these key steps are described in further detail in the following sections.

## 2.2 Routes assessed

Three routes were derived from the options assessment that was completed for the proposed overhead HumeLink routes and included in this assessment. An additional fourth route was assessed along with two slight variations to route. The key routes were:

- Gugaa to Bannaby via Maragle to Yass via Tumut North (Route 1) - route is co-located adjacent to existing transmission lines, where feasible. This route had the least enviro-social impacts of the four routes assessed for the overhead project (GHD 2022).
- Gugaa to Bannaby via Maragle to Yass via Blowering northeast deviation (Route 2) – amended route between Maragle and Yass via Blowering, which avoids the Tumut region. Maximises the use of public land and co-located adjacent to existing transmission lines, where feasible.
- Gugaa to Bannaby via Wondalga to Maragle to Yass via Kosciuszko National Park (Route 3) - maximises the use of public land by traversing national park and state forest land. This route had the highest enviro-social impact score and highest cost of the four overhead route options assessed (GHD 2022).
- Gugaa to Bannaby via Maragle to Yass via Hume Highway (Route 4) – this route has the same start and end points at Gugaa and Bannaby as the other routes but traverses alongside the Hume Highway for most of the remainder of the route. The route to Maragle is the same as the Tumut North route.

Key distances for the above routes are summarised in Table 2.1 below.

*Table 2.1 Distances for each route*

| Routes (Km) | | Bannaby to Maragle | | | Bannaby to Gugaa | | | Maragle to Gugaa | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | Private | Public | Total | Private | Public | Total | Private | Public |
| Route 1 (Red) | Gugaa to Bannaby via Maragle to Yass via Tumut North | **277** | 233 | 44 | **293** | 275 | 18 | **109** | 77 | 33 |
| Route 2 (Blue) | Gugaa to Bannaby via Maragle to Yass via Blowering northeast deviation | **276** | 214 | 62 | **308** | 270 | 38 | **111** | 78 | 33 |
| Route 3 (Yellow) | Gugaa to Bannaby via Wondalga to Maragle to Yass via Kosciuszko National Park | **265** | 190 | 74 | | | | **111** | 78 | 33 |
| Route 4 (Green) | Gugaa to Bannaby via Hume Highway | | | | **312** | 46 | 266 | **109** | 77 | 33 |

The routes are shown in Figure 2.1.

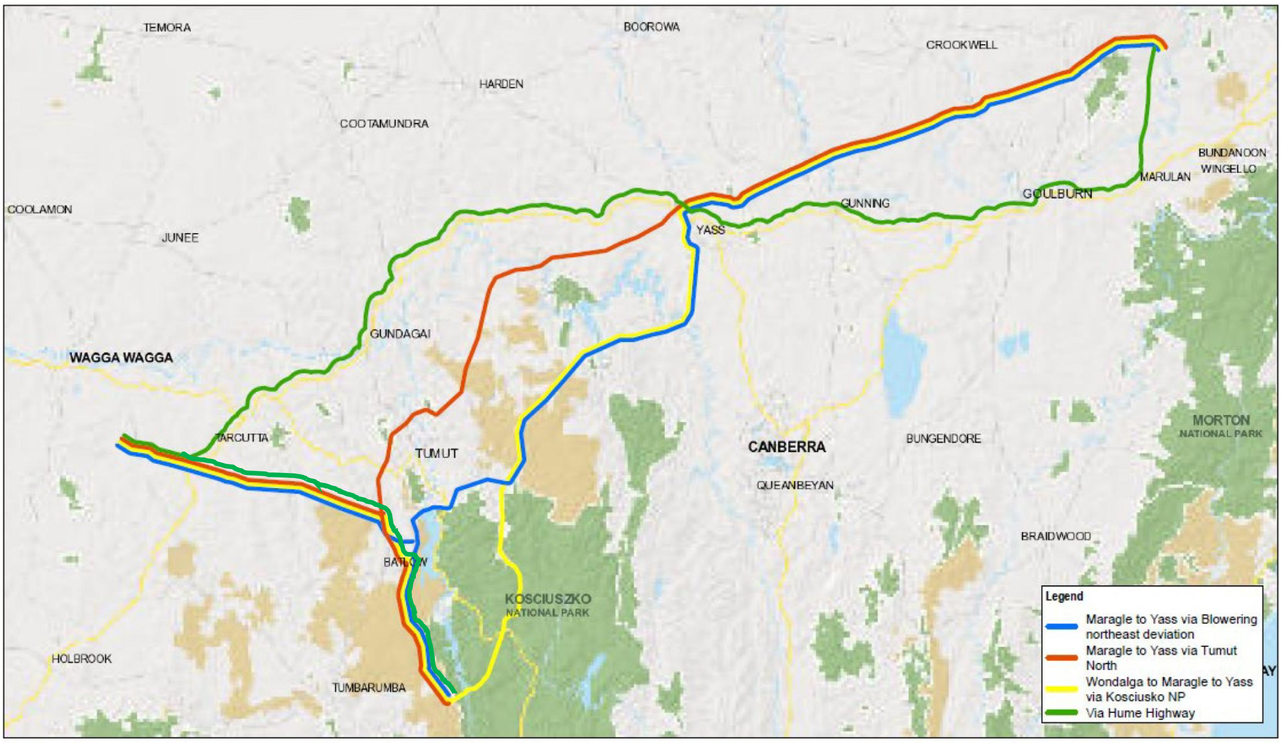



*Figure 2.1 Overview of the route options assessed*

Note: The undergrounding route options presented are outcomes of a limited desk top study that utilises a geospatial constraint analysis tool. To reach a preferred solution refining this assessment through more detailed site investigations including community, environmental and engineering perspectives would determine the extent of constraints including constructability.

## 2.3 Key constraints

Key data layers uploaded to the web map were as follows:

- Defence land
- Licensed airstrips
- Towns and dense residential areas
- Wilderness protection areas
- Water sources for migratory birds protected by international agreements
- Areas of very high indigenous significance
- Network operational risks (two or more transmission lines already present)
- Slope (>50%)
- Areas subject to intensive agricultural / horticultural use
- Existing industry (such as wind farms)
- Significant water crossings (>800m)
- National parks and nature reserves
- Endangered ecological communities
- Wetlands
- Commonwealth land
- Areas subject to Native Title
- Heritage conservation areas
- Residences
- Unlicensed airstrips
- Bushfire and lightning risk areas
- Forested areas

Constraints mapping is provided in Appendix A.

## 2.4 InDeGO analysis

The relevance of mapped constraints to each of the routes was refined based on review of the web map (see Table 2.2). Constraints not relevant to the routes are not considered further in this assessment. Relevant constraints were rated using the scoring listed in Table 2.3. Each constraint that related to the route was assigned a rating with consideration of the likelihood and consequence of impacts due to the constraint.

***Table 2.2 InDeGO constraints***

| Constraint | Total rating |
|---|---|
| Areas of very high indigenous significance (AHIMS sites) | 100 |
| Slope (>50%) | 999 |
| National Park / nature reserve | 100 |
| Endangered ecological communities (CEEC and EEC) | 80 |
| Wetlands (RAMSAR site) | 100 |
| Commonwealth land | 20 |
| Native title | 80 |
| Heritage areas (State and local) | 80 |
| Residences | 60 |
| Unlicenced airstrips | 20 |
| Bushfire risk (bush fire prone land) | 40 |
| Forested areas (State Forest land) | 60 |
| Agricultural land (BSAL land) | 60 |
| Industry (industrial land use zone) | 60 |
| Waterway crossing (> 800m) | 100 |

*Table 2.3 InDeGO score for constraints*

| Rating | Constraint |
|---|---|
| 0 | No constraint |
| 20 | Very low constraint |
| 40 | Low constraint |
| 60 | Medium constraint |
| 80 | High constraint |
| 100 | Very high constraint |
| 999 | NO GO |

Ratings were then entered into the InDeGO software to assess each route and scores calculated. A total score for each route was generated. A higher score is indicative of a higher impact. The overall MCA (InDeGO) scores associated with the potential routes are shown in Figure 2.2 to Figure 2.5.

## 2.5 Optimal route

The total InDeGO scores for each route are tabulated in Table 2.4.

*Table 2.4 MCA comparison of routes assessed – total InDeGO score and % change*

| MCA | Via Tumut North | Via Blowering northeast deviation | Via Kosciusko National Park | Via Hume Highway |
|---|---|---|---|---|
| Total InDeGO score | 5,204,019 | 5,820,270 | 7,524,744 | 6,256,460 |

## 2.6 Additional routes

Two additional routes were created in InDeGO to parallel key roadways to the north and east of the Tumut North option where possible. These routes, and their InDeGO scores, are shown in Figure 2.6 and Figure 2.7. The InDeGO scores for these routes (5,315,329 and 5,281,587) are higher than the Tumut North route but lower than all other options.

A combination of the Kosciusko and Blowering Northeast Deviation routes was also considered during the concept design and cost estimate stages.

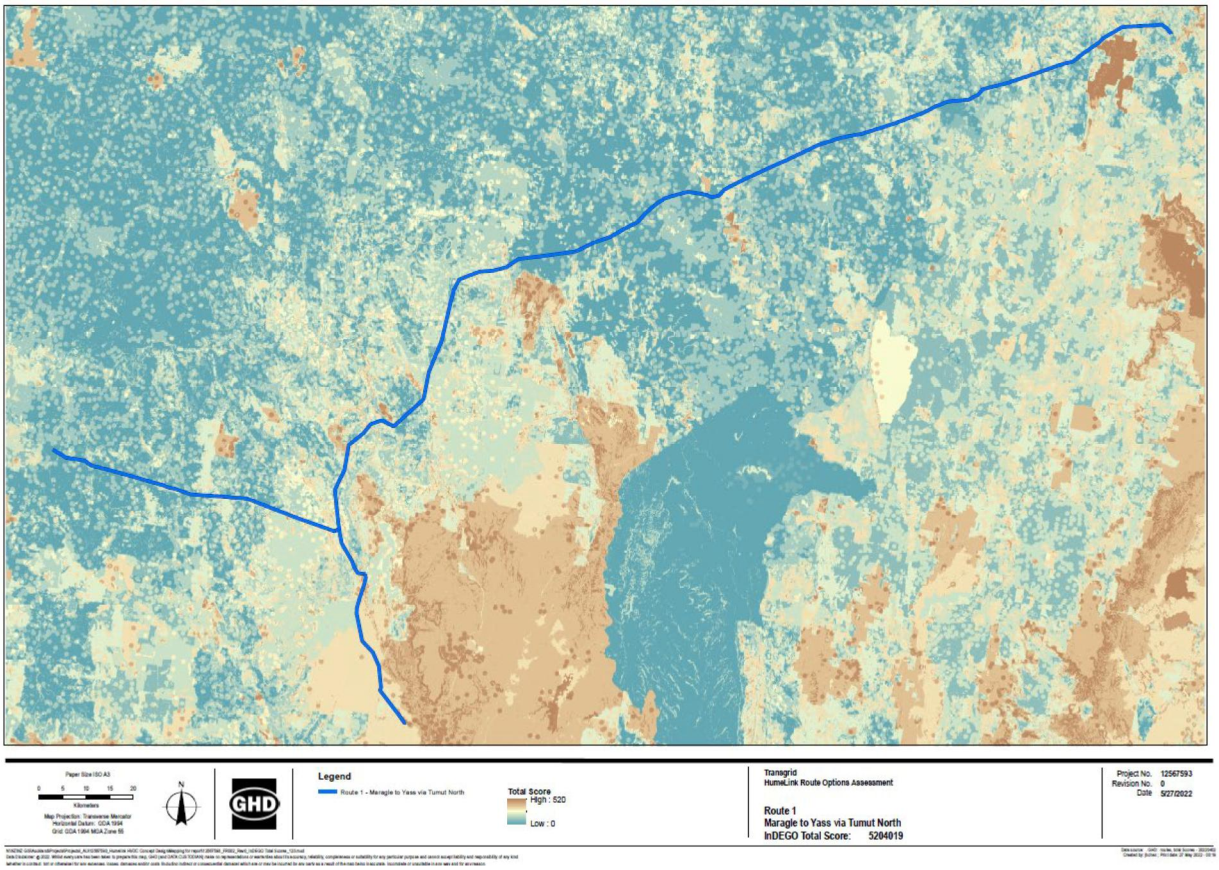



*Figure 2.2* *InDeGO score – Tumut North route*

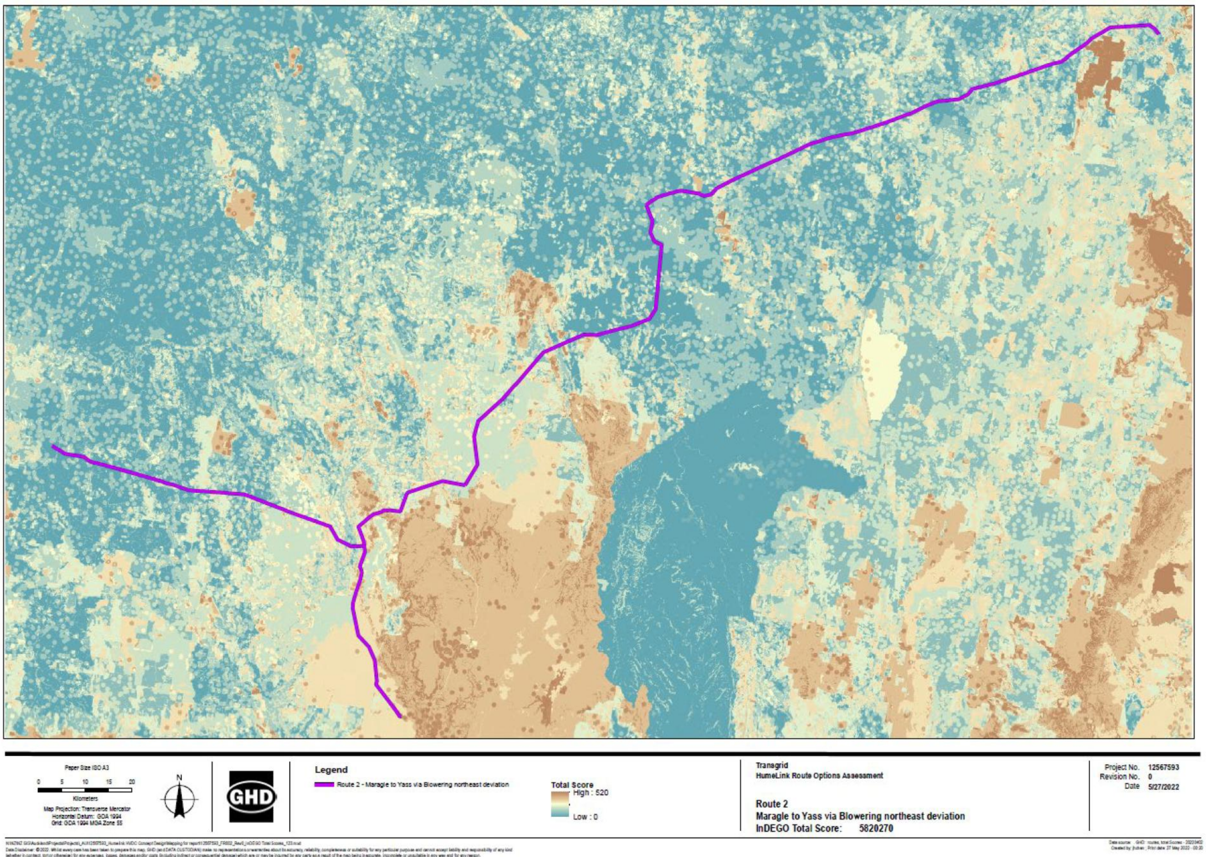



*Figure 2.3 InDeGO score – Blowering deviation route*

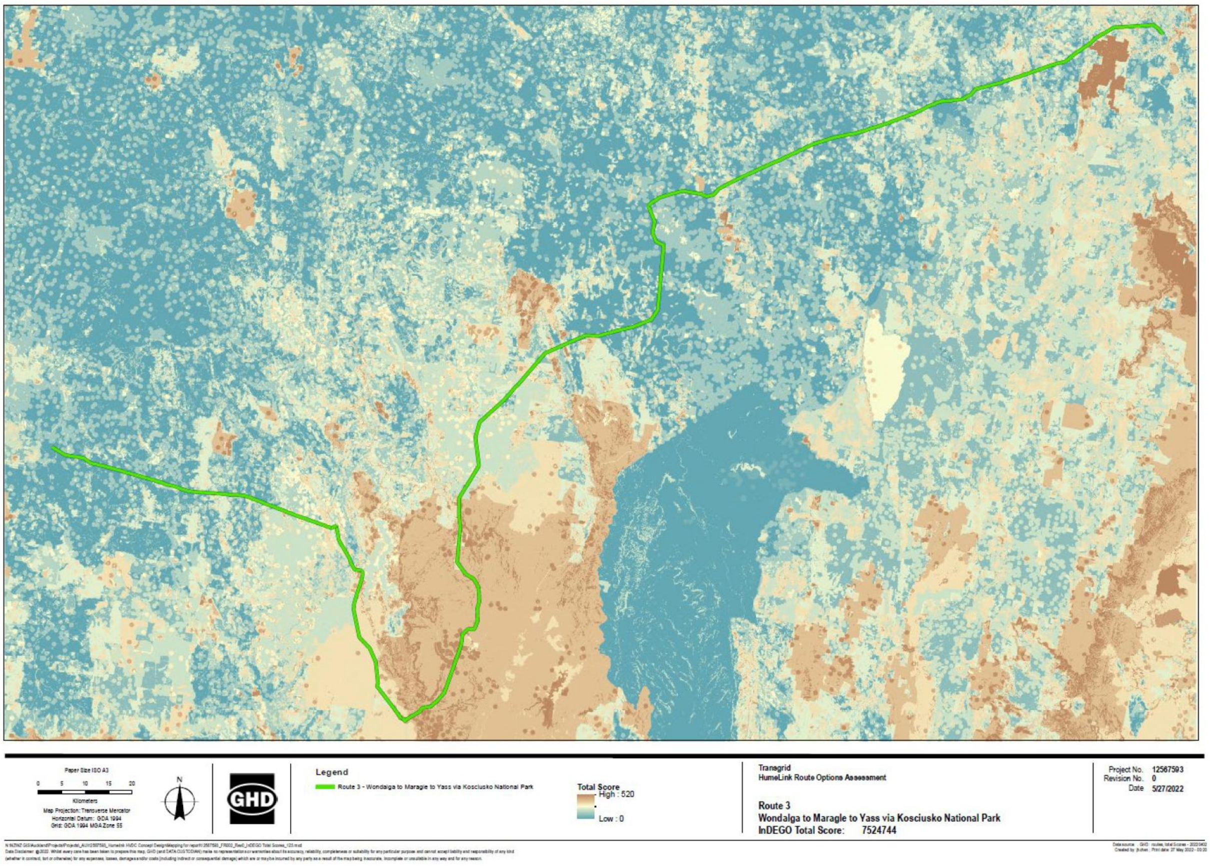



*Figure 2.4 InDeGO score - Kosciusko route*

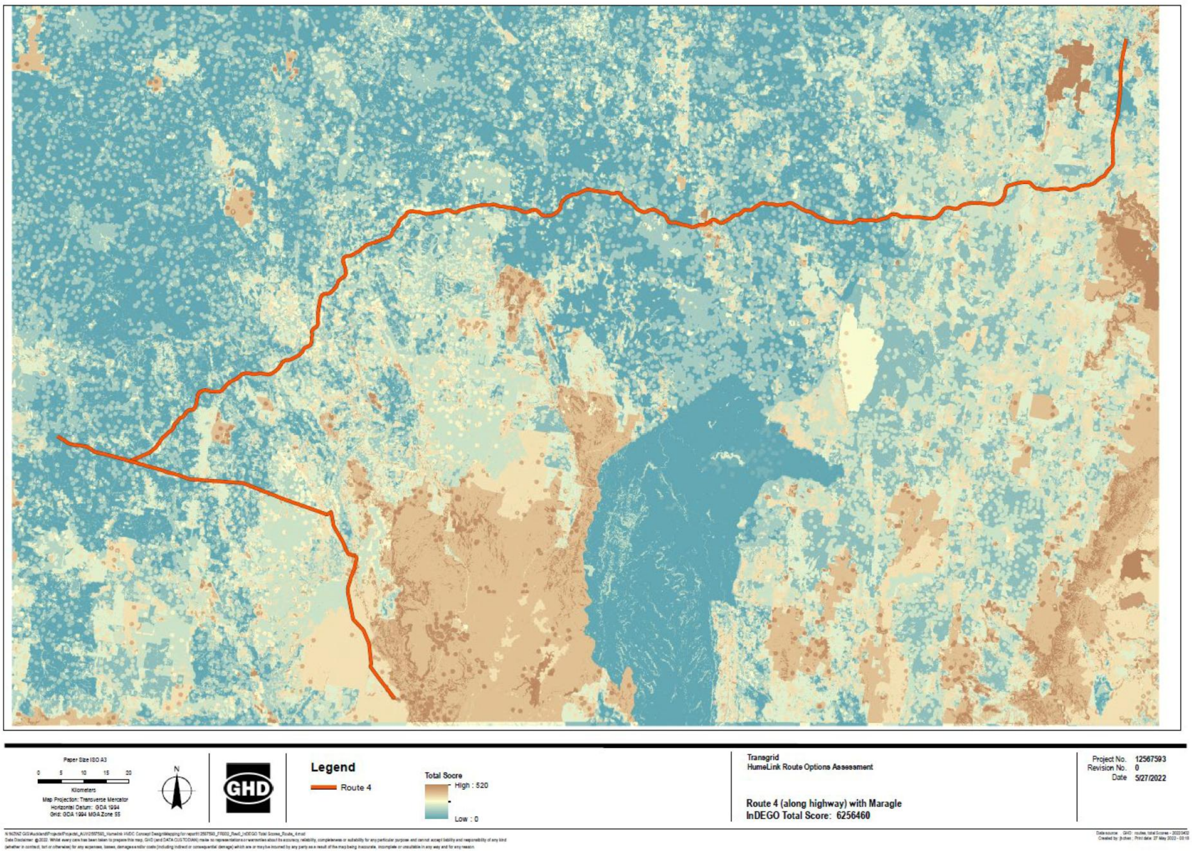



*Figure 2.5* *InDeGO score – Hume Highway route (with Maragle connection)*

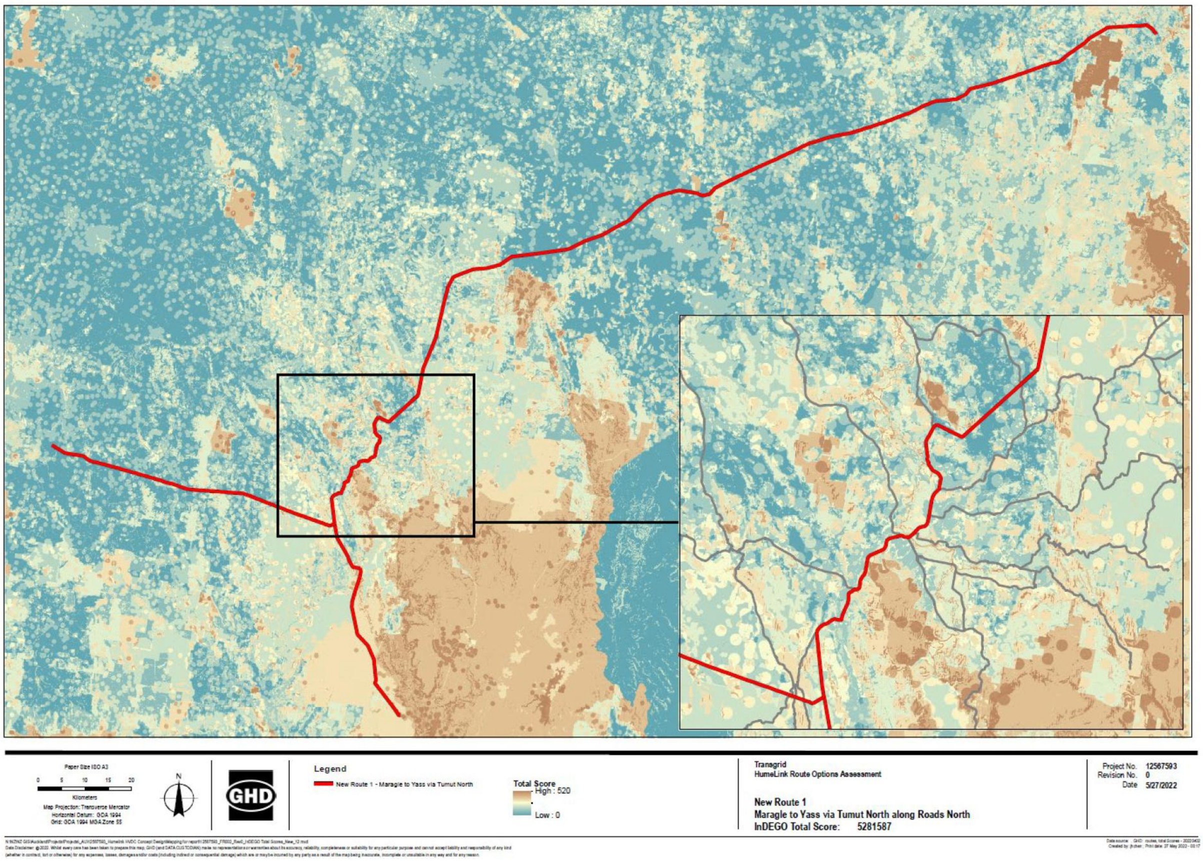



*Figure 2.6* *InDeGO score – additional route 1*

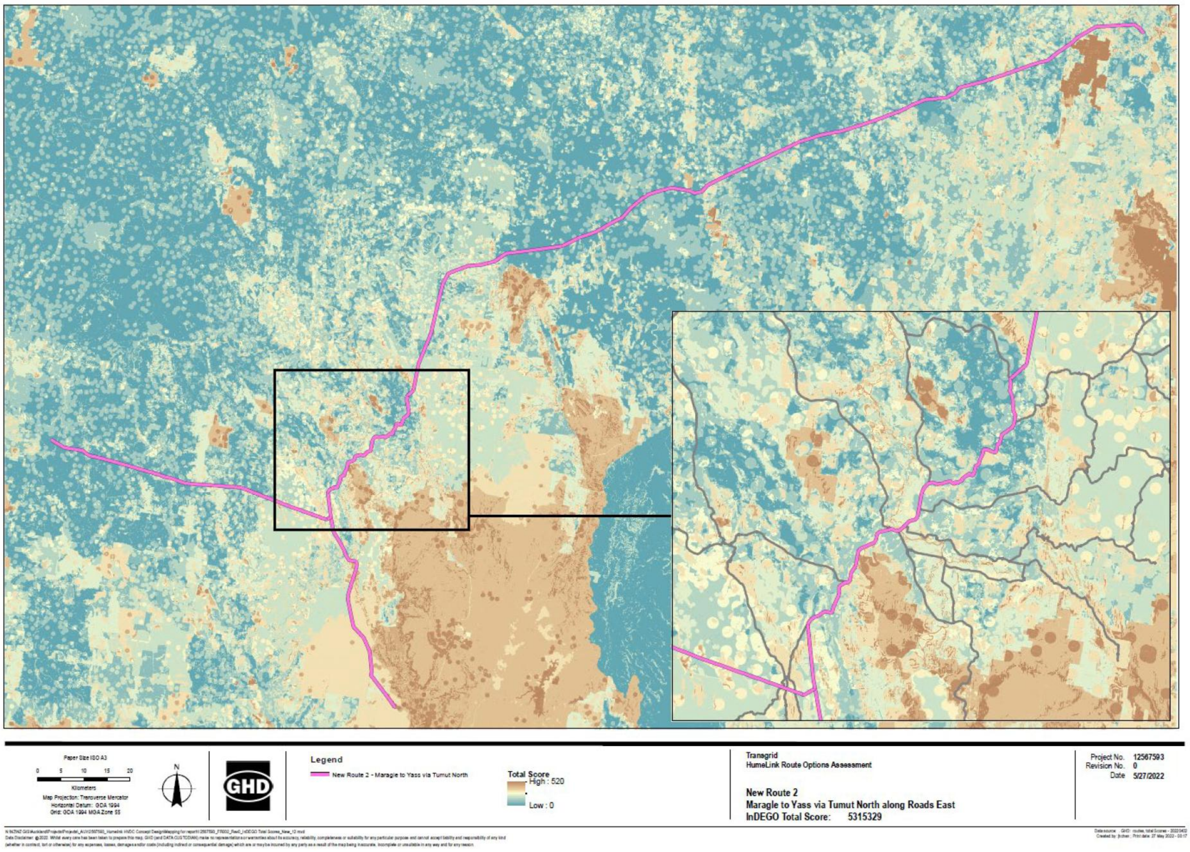



*Figure 2.7* *InDeGO score – additional route 2*

# 3. Concept design

The Costs in section 3 are developed through recent bid pricing and supplier information. They are the sum of Labour, Material and Equipment costs. These costs do not include any indirect costs, Terrain factors/escalations or any additional Direct costs. The Costs in section 3 are presented for comparison of preferred sub-options to non-preferred sub-options. Full cost estimates have only been done for the preferred sub-options and can be found in Section 4. The cost information noted above are presented in section 4 (preferred options only) but not as a total, as seen in the section 3 tables below.

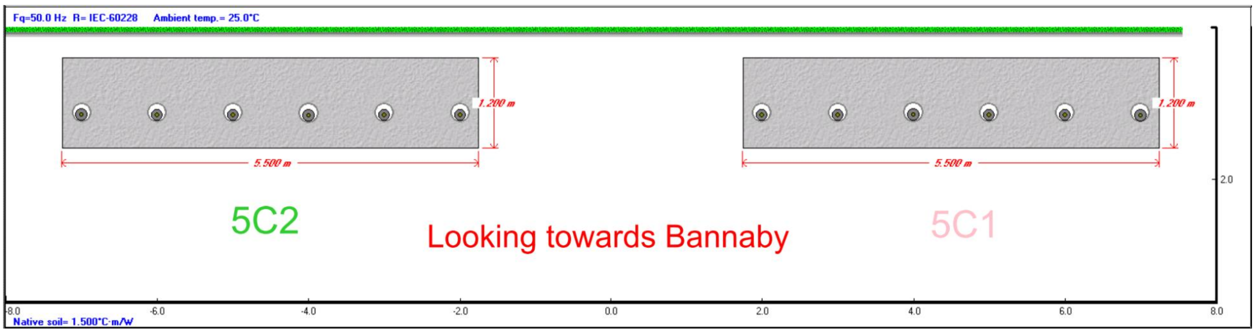
## 3.1 Option 1 – AC underground

### 3.1.1 Comparative analysis of sub-options

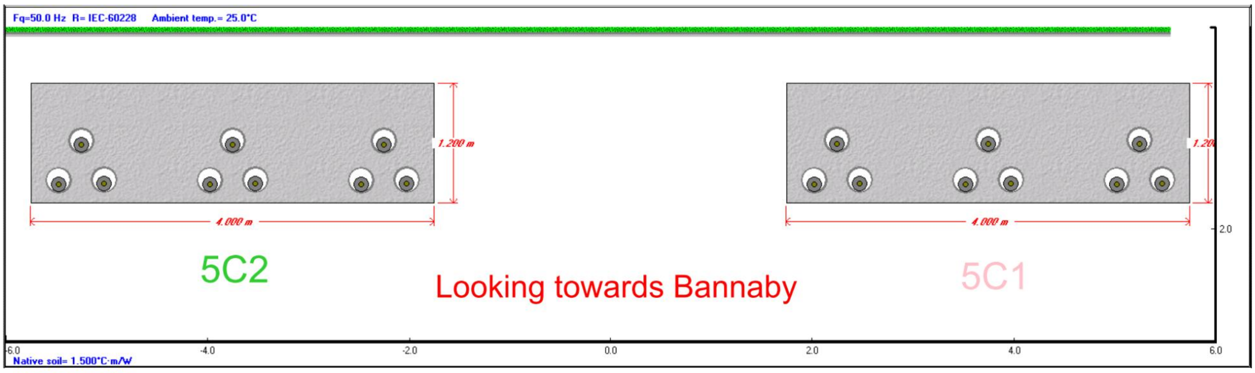
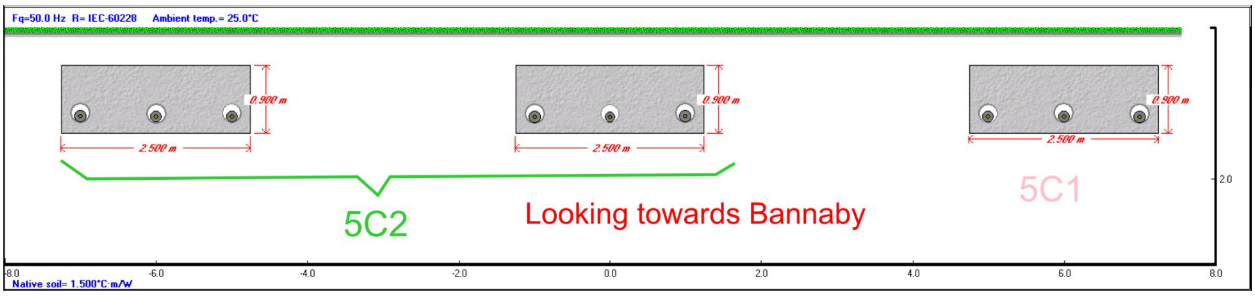
The comparative analysis of the Option 1 sub-options is summarised in Table 3.1. Costs stated are cable transmission cable costs only in AUD.

*Table 3.1 Option 1 comparative analysis*

| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 1A | Cables installed in a flat configuration with 2 cables per phase per circuit to satisfy rating requirement i.e., total of 6 cables per trench.<br>Refer to Appendix B for trench profile | $11.9B | Flat configuratio n provides best thermal rating performance with respect to derating of cables. | Meets the project MVA requirements and a loss of one circuit does not lead to overloading of the second circuit. | Reduced potential for hot spots as the cables are laid in flat formation therefore relatively low risk of cable overload / failure. | This is an N-1 solution | Total Duration (years): 10 |




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Option 1B | Cables installed in a trefoil configuration with 3 cables per phase per circuit to satisfy rating requirement i.e., total of 9 cables per trench.<br>Refer to Appendix B for trench profile | $17.5B | Trefoil configuratio n provides best EMF performance as magnetic fields are inherently balanced. | Reduced number of transpositions i.e., reduced design and installation complexity at joint bays (every ~1 km)<br>Reduced trenching / easement width in comparison to other options | Trefoil formation at high current rating leads to hot spots inside the three cables therefore generally higher risk of cable overload / failure in comparison to 1A. | This is an N-1 solution | N/A |

| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
|  | | | | | | | |
| Option 1C | Modified version of Option 1A with the number of cables halved for circuit 5C1 (or 5C2). Circuit 5C1 can only support 1300 MW or approximately 50% of the rating requirement. | $9.9B | Reduction in the amount of cable required for 5C1. | Simpler to install, operate and protect with a dedicated bay per circuit in comparison to other options. | Reduced hot spots as the cables are laid in flat formation. From a network operation perspective, greater risk of loss of one circuit overloading other circuits in comparison to 1A and 1B. | This is an N-0.5 solution | N/A |
|  | | | | | | | |

### 3.1.2 Preferred solution for option 1

#### Design considerations

The preferred solution for Option 1 is sub-option 1A where the 500 kV circuits are installed with two (2) cables per phase between the three (3) off 500 kV network substations. The cables will be installed in flat formation and spaced apart to account for the potential thermal interactions and de-ratings. Refer to the following figures and Appendix B for design configuration of the preferred solution.

The length of each circuit's cable is limited by manufacturing length and theoretically at 500 kV cable drums could supplied to could accommodate up to 1800 metres of cable. However, in practice the installed section lengths between jointing bays may be lower due to transportation logistics and / or constructability reasons proving to be the actual length-limiting factors.

The design of the jointing bays will include the earthing systems comprising link boxes, cross-bonding, and sheath voltage limiters at intervals as specified by the designers and the suppliers. Condition monitoring and Partial Discharge measuring devices will also be required at several intervals along the cable routes.

The 500 kV cable circuits will require compensation along the length and the recommended method of compensation is by the installation of switchable shunt reactors. Other methods are also possible such as the installation of Static Var Compensators, the application of which would need to be confirmed by system studies. Refer to Appendix B for typical reactor station layouts.

The high-level assessment of the compensation was driven by the rating of the switchgear that will be able to switch the capacitive load resulting from the cable. The inductive reactive compensation requirement was estimated based on a typical 500 kV cable datasheet and sized to compensate approximately 94% of the cable capacitance, such that the 500 kV CB could switch the remaining capacitance. As a result of this assessment several switching stations with shunt reactors have been nominated the first one at 20 km away from the terminal stations and then at every 40 km along the cable length.

The two (2) cables per phase represent a single circuit and are combined at the substation 500 kV bus and connected via tubular bus to a 500 kV switching bay.

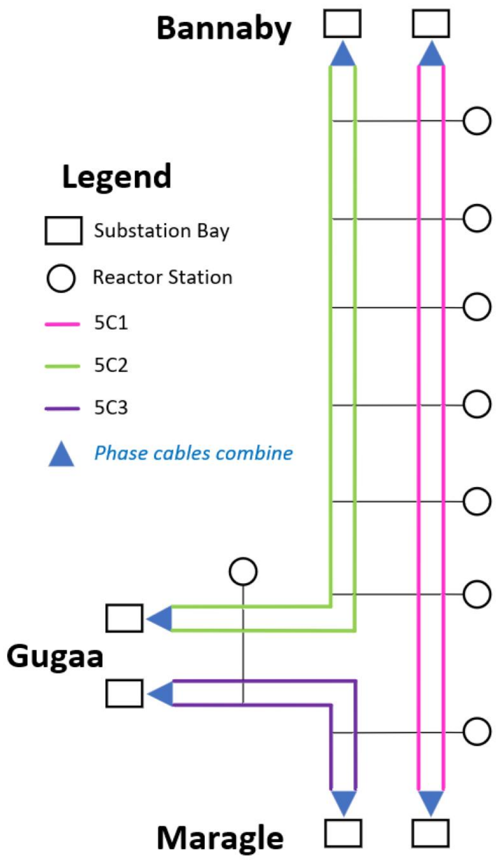



***Figure 3.1 Option 1A 500 kV Network Diagram***

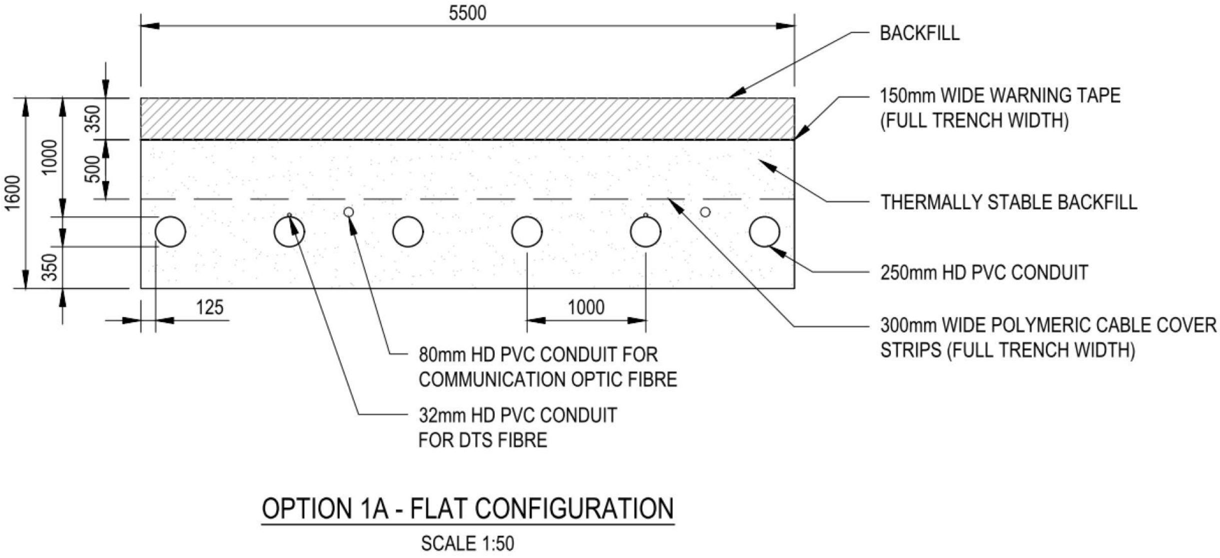



***Figure 3.2 Option 1A Typical Trench Profile per Circuit***

## Installation considerations

The installation of the cables will require environmental, vegetation, and soil assessment along the approved cable easements.

Soil TR testing will be required along the planned cable routes as the testing results are needed to finalise the cable derating calculations and therefore finalise the installation design e.g., extent of TSB, separation distance between cables, etc. The TSB will also be required to be tested to ensure it complies with the design value.

There will be requirements for hardstands areas to allow for the positioning of the cable pulling machinery and the installation of clean rooms for the cable joints. These are highlighted as consideration from an environmental approval's perspective. Alternatives to hardstands can be arranged and clean rooms can be kept simple for easy installation.

EMF, induced voltage, and step and touch voltage assessments will also be required.

Soakage time for initial energisation will be based on the supplier's recommendations and is estimated to be 48 to 72 hours per segment.

Initial cable commissioning tests will require setup of specialised equipment to accommodate testing of the very high capacitance cables. Testing of long AC cables requires compensation for the charging current, which is directly related to the frequency and test voltage required.

Where: $I_c = 2 \times f \times \pi \times C \times V$

- Ic is the charging current in Amperes
- f is the test frequency in Hertz
- C is the cable capacitance in Farads
- V is the test voltage in Volts

To compensate for the very high value of charging current we require large reactive high voltage compensation – "exciter" – coils which are inherently very heavy as they use large amounts of copper and steel. This makes an on-site test very difficult and expensive.

One solution is to lower the AC frequency for the testing. IEC 62067 prescribes a lowest frequency of 20 Hz and this has been used for many years to test high voltage and extra high voltage circuits. More recent developments in testing suggest that we can change the testing to 10 Hz (recently used for testing of AC cable systems). However, testing voltage will still remain high (approximately 380 kV) and there are requirements to provide portable coils of the required inductance and have a source (transformer) of several MVAs. This setup of equipment and the space required on site is considered a complex set up.

## Operation considerations

Once in service the operation of cable will be based on the temperature measurements, network conditions and operational requirements. Planned and unplanned outages will require system studies for N-1 and N-2 contingency levels as tripping of one (1) circuit will lead to significant load changes in the network that can affect system stability.

Energisation under operational conditions will require thorough planning as the cables will have to be switched per segments of (lengths between 20 km and 40 km).

## Maintenance considerations

Cable maintenance is reduced to monitoring of the ratings, temperatures, and partial discharge values during normal operation conditions only. Cable sealing ends may be subjected to pollution and will need to be monitored and tested. The cable sealing ends dielectric properties will have to be tested. The cable sheath will require to be tested. The testing regime will be provided by the cable supplier.

In the event of a cable fault the repairs will be conducted in general by qualified contractors who are approved by the suppliers.

Annual maintenance will be required for the HVAC Reactor Stations. Other auxiliary systems may require more frequent maintenance.

For underground cable systems, it is common to implement a “preventative maintenance program” and a “repair preparedness strategy”.

The purpose of a preventative maintenance program is to prevent cable faults from occurring by performing various monitoring and testing activities. Below is a list of tasks that could be performed for a land-based cable system:

- Monitoring activities along the land cable route, usually by patrol, approximately every 2 weeks.
- Clearing deep-rooted vegetation encroaching on the cable system right of way (ROW).
- Implementing a “call before you dig” program with the municipal government agency.
- Monitoring cable hot spots using distributed temperature sensing (DTS) system.
- Monitoring for third party digging using distributed acoustic sensing (DAS) system.
- Software updates for DTS and DAS systems.
- Checking pollution level on outdoor cable terminations and washing them as necessary.
- Checking the conditions of spare cable and accessories to ensure the shelf life of accessories is valid.

The purpose of the repair preparedness strategy is to minimize the outage time of a cable system should a fault occur. This ensures all documentation, permits, and framework contracts are in place for all aspects associated with repair tasks. Having framework contracts in place help to reduce repair time and prevents the Owner from entering a poor contract by removing the need to negotiate a new contract during an emergency repair situation.

## Design assumptions

The design of the preferred AC underground cable installation is based on requirements defined in the project specification (RFQ) in conjunction with guidance provided by Transgrid throughout the study process and GHD’s experience on high voltage underground cable projects. Additionally, the following were advised by Transgrid through the RFI process.

1. Native soil TR is 1.5 °Cm/W (refer to RFI 8.01 item 1 response).
2. Ground ambient temperature is 25 °C (refer to RFI 8.01 item 2 response).
3. Load profile is continuous flat (Load Factor = 1.0) (refer to RFI 1.01 item 3 response).
4. A minimum clearance of 5 m from the edge of duct bank is required to edge of easement on either side of the installation (refer to RFI 1.01 item 4 response).

TSB TR of 1.0 °Cm/W used in CYMCAP derating calculations is referenced from Transgrid EHV Cable Design and Installation Manual (Revision 3.2).

The CYMCAP cable model is based on datasheet for a typical 500 kV cable (refer to Appendix B).

Cable derating calculations undertaken for the purpose of the underground AC cable installation designs are based on the information above (refer to Appendix B).

Note that with respect to item 1 above, actual soil TR testing data is required to finalise the derating calculations and therefore the installation design. Without actual test data, there is always the inherent risk that modelling based on assumed native soil TR values may not account for localised hot spots in the installation design.

Also note that a separation distance of 4 m has been applied between adjacent circuits for the purpose of easement calculations. 4 m is a typical separation distance between high voltage underground cable circuits at which the effects of mutual heating from adjacent circuit can be ignored. Effect of mutual heating has been tested in CYMCAP for the proposed installation design and has been confirmed to be essentially nil at 4 m separation. In terms of redundancy (N-1), the risk of a cable fault or mechanical damage propagating from one circuit to the adjacent circuit is also considered low when the separation is high. From GHD's experience on past Transgrid, Ausgrid and Endeavour Energy cable projects, 4 m is an acceptable minimum separation between adjacent cable circuits for N-1 to be considered still intact. Please note that 4 m was also verbally advised in one of the early project meetings as an acceptable separation distance between adjacent circuits (Transgrid).

Extent of reactive power support is sized to allow the switchgear to be able to switch a maximum of 400 A of capacitive load.

## Optimal route

Option 1 assessment is based on the Tumut North route (Route 1) and the principal outcomes are applicable to all other options considered.

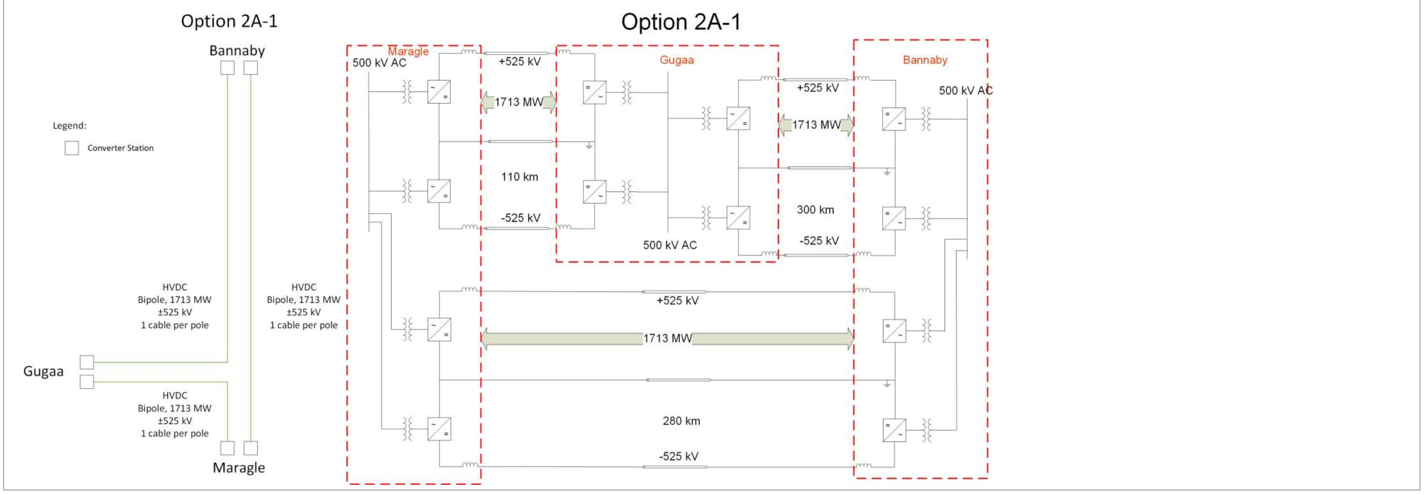
## 3.2 Option 2 – 100% HVDC underground

### 3.2.1 Comparative analysis of sub-options

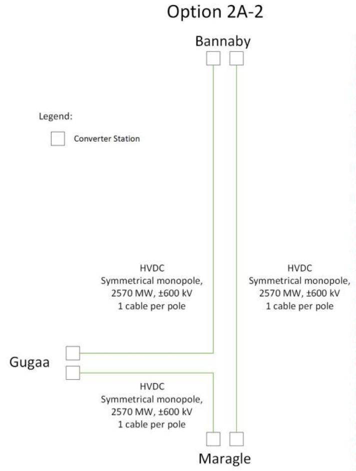
The comparative analysis of the Option 2 sub-options is summarised in Table 3.2.

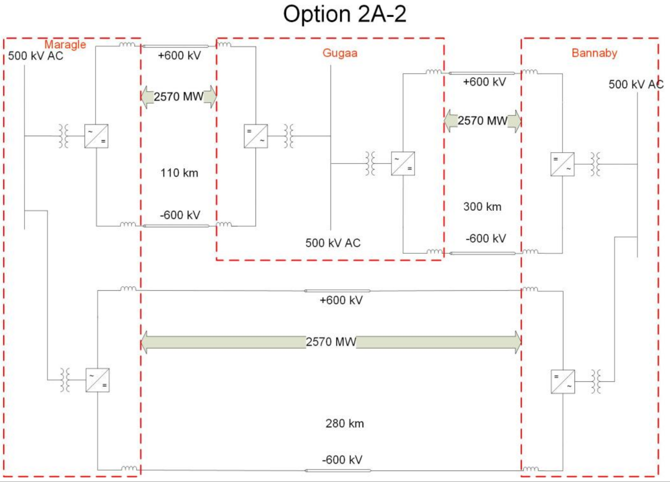
*Table 3.2 Option 2 comparative analysis*

| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 2A-1 | DC underground along all paths consisting of:<br>3 bipoles, each1713 MW, ±525 kV, 1 cable per pole | $5.64 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 6 converter stations, 1 cable per pole, no stations required along the routes or at the T-off | No exposure to severe weather, bushfires, lightning, pollution on insulators | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal | Refer to Section 5.3 |



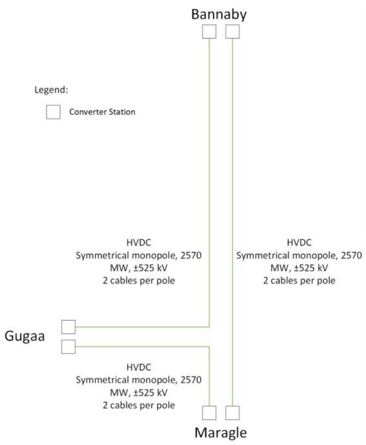
| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 2A-2 | DC underground along all paths consisting of:<br>3 symmetrical monopoles, each 2570 MW, ±600 kV DC; 1 cable per pole | $6.47 B | ±600 kV is not considered feasible to meet the HumeLink project schedule, but would likely be available for 2030 and later in-service dates | 6 converter stations, 1 cable per pole, no stations required along the routes or at the T-off | No exposure to severe weather, bushfires, lightning, pollution on insulators | Loss of one element will result in loss of one entire symmetrical monopole, but still meets 2570 MW transmission capacity at each terminal | |



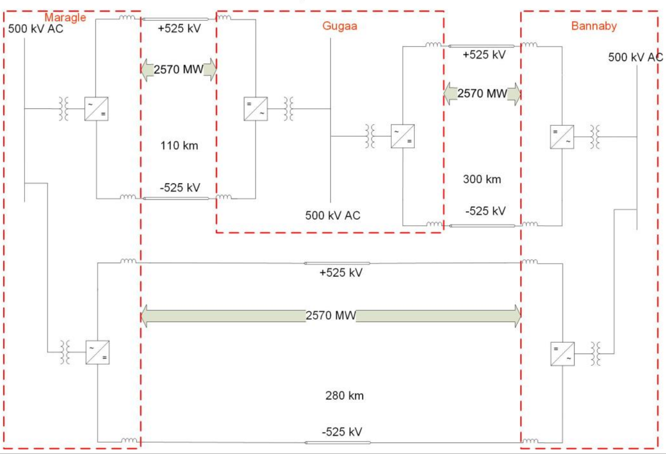



| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 2A-3 | DC underground along all paths consisting of:<br>3 symmetrical monopoles, each 2570 MW, ±525 kV DC; 2 cables per pole | $7.97 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 “Power System Benefits” | 6 converter stations, 2 cables per pole, no stations required along the routes or at the T-off | No exposure to severe weather, bushfires, lightning, pollution on insulators | Loss of one element will result in loss of one entire symmetrical monopole, but still meets 2570 MW transmission capacity at each terminal | |

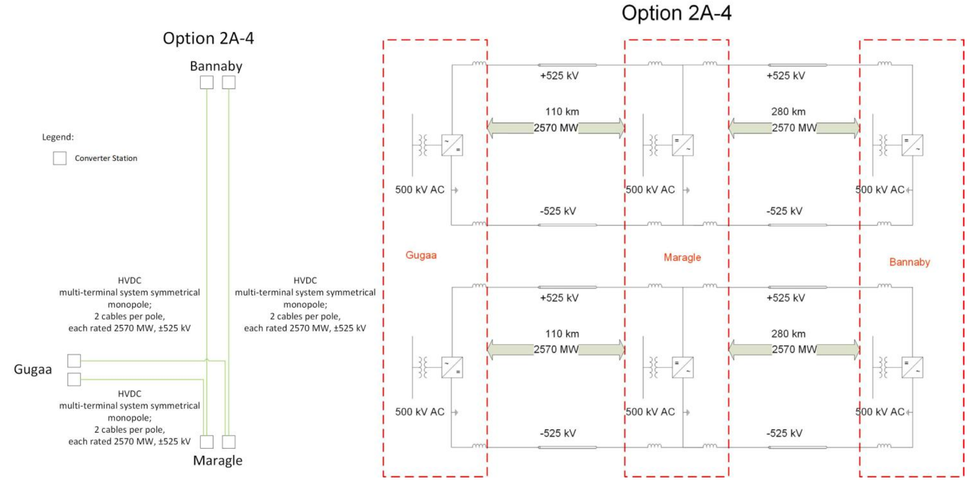
Option 2A-3



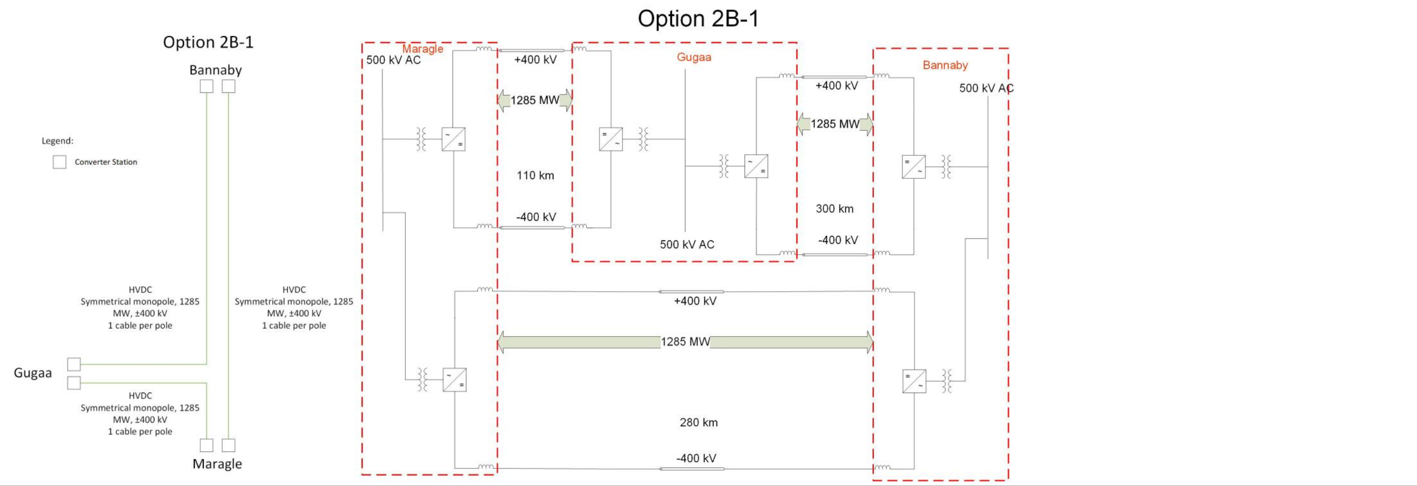

Option 2A-3



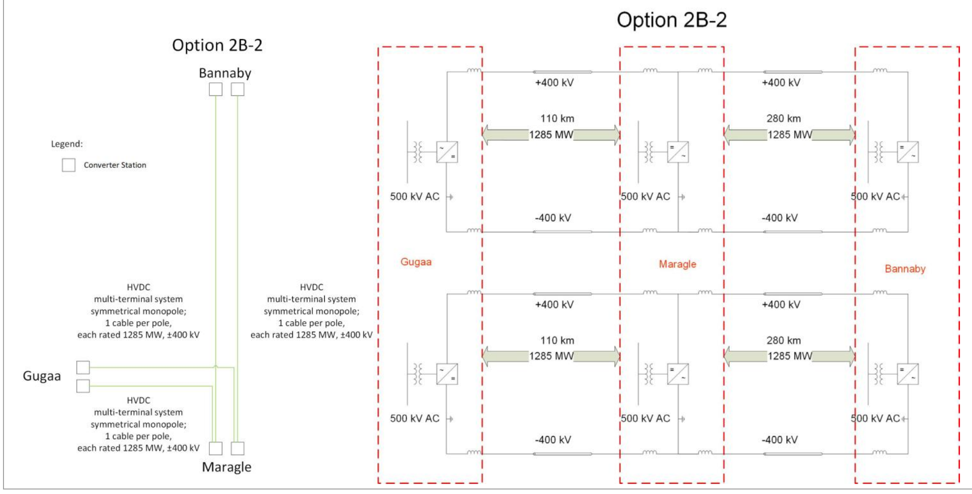
| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 2A-4 | DC underground along all paths consisting of:<br>2 x 3 terminal multi-terminal systems symmetrical monopole, each rated 2570 MW, ±525 kV, 2 cables per pole, | $6.25 B | More complex controls required, but similar HVDC benefits as other HVDC options | 6 converter stations, 2 cables per pole, no stations required along the routes or at the T-off | No exposure to severe weather, bushfires, lightning, pollution on insulators | Loss of one element will result in loss of one entire multi-terminal system | |



| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 2B-1 | DC underground along all paths consisting of:<br>3 symmetrical monopoles each 1285 MW, ±400 kV, 1 cable per pole | $4.40 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 Power System Benefits | 6 converter stations, 1 cable per pole, no stations required along the routes or at the T-off | No exposure to severe weather, bushfires, lightning, pollution on insulators | Loss of one element will result in loss of entire symmetrical monopole, but still meets 1285 MW transmission capacity at each terminal | Refer to Section 5.3 |



| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 2B-2 | DC underground along all paths consisting of:<br>2 x 3 terminal multi-terminal systems symmetrical monopole, each rated 1285 MW, ±400 kV, 1 cable per pole, | $4.93 B | More complex controls required, but similar HVDC benefits as other HVDC options | 6 converter stations, 1 cable per pole, No stations required along the routes or at the T-off | No exposure to severe weather, bushfires, lightning, pollution on insulators | Loss of one element will result in loss of entire symmetrical monopole, but still meets 1285 MW transmission capacity at each terminal | |



### 3.2.2 Preferred solution for option 2

The preferred solutions are as follows:

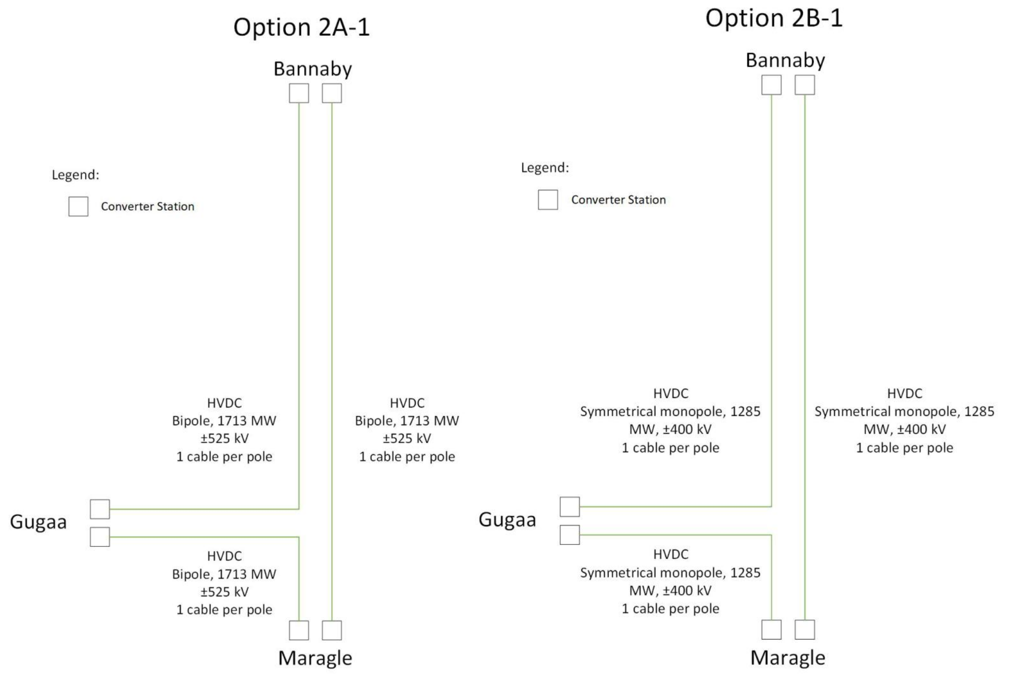



***Figure 3.3 Option 2 preferred solutions***

#### Design considerations

A bipole configuration for the HVDC systems in Option 2A-1 allows for the transmission capacity at each of the three terminals to remain at a minimum of 2570 MW following the loss of a single element on any of the HVDC systems. Having multi-terminal systems rather than the point-to-point systems is more complex from a design perspective and also would require longer lengths of cables. As well, there is limited experience with VSC multi-terminal systems, which introduces some additional project risk. Symmetrical monopole configurations are not feasible for the A option, as 2 cables per pole would be required for a 2570 MW symmetrical monopole, or an increase in voltage to ±600 kV would be necessary. The timeline for projects at ±600 kV is expected to be around 2030, due to the current state of the HVDC cable and converter markets and HVDC cable and converter factory loading, which is much later than the HumeLink expected in-service date. However this does not preclude considering ±600 kV in this project.

A symmetrical monopole configuration is appropriate for the HVDC systems in Option 2B-1, as loss of one element results in at least 50% of the transmission capacity at each of the terminals. As multi-terminal systems are more complex that point to point systems, the preferred option considers only point to point systems, although coordination between the three HVDC control systems will need to be considered during the design stage.

#### Installation considerations

The area required for the converter stations is substantial and will require connections into the AC substations and Gugaa, Maragle, and Bannaby. Ideally, the converter stations should be situated close to the interconnecting AC substations. If the converter stations at each terminal are close to each other, there could be sharing of auxiliary services, such as station power, fire pumphouses, security, etc. This sharing of auxiliary services has been included in the estimate.

The DC cable installation would be similar to the AC cable installation.

#### Operation considerations

Power system studies are required to identify any special controls that would be required for the operation of the HVDC systems. The active and reactive power on the HVDC systems can be controlled to deliver power to any of the terminals as required by the system. The owner will need to identify the performance requirements for the

HVDC systems when preparing the technical specifications for the converters. The owner will need to determine whether or not the HVDC systems will be operated at the HVDC stations or remotely.

### Maintenance considerations

Annual maintenance will be required for the HVDC converters. Other auxiliary systems may require more frequent maintenance. Converter transformers will have maintenance requirements similar to AC transformers. The maintenance program of the HVDC systems will depend largely on the philosophy of the owner (considering spares and redundancy in the HVDC system design) and on the required availability for the system.

For underground cable systems, it is common to implement a “preventative maintenance program” and a “repair preparedness strategy”.

The purpose of a preventative maintenance program is to prevent cable faults from occurring by performing various monitoring and testing activities. Below is a list of tasks that could be performed for a land-based cable system:

- Monitoring activities along the land cable route, usually by patrol, approximately every 2 weeks.
- Clearing deep-rooted vegetation encroaching on the cable system right of way (ROW).
- Implementing a “call before you dig” program with the municipal government agency.
- Monitoring cable hot spots using distributed temperature sensing (DTS) system.
- Monitoring for third party digging using distributed acoustic sensing (DAS) system.
- Software updates for DTS and DAS systems.
- Checking pollution level on outdoor cable terminations and washing them as necessary.
- Checking the conditions of spare cable and accessories to ensure the shelf life of accessories is valid.

The purpose of the repair preparedness strategy is to minimize the outage time of a cable system should a fault occur. This ensures all documentation, permits, and framework contracts are in place for all aspects associated with repair tasks. Having framework contracts in place help to reduce repair time and prevents the Owner from entering a poor contract by removing the need to negotiate a new contract during an emergency repair situation.

### Design assumptions

Conductor size calculations for the HVDC cables are detailed in Appendix C. Appendix D provides conceptual design drawings for the HVDC converter stations and HVDC cable trenches and trenchless installation.

### Optimal route

The optimal route for Option 2 is the Tumut North route (see Figure 2.2).

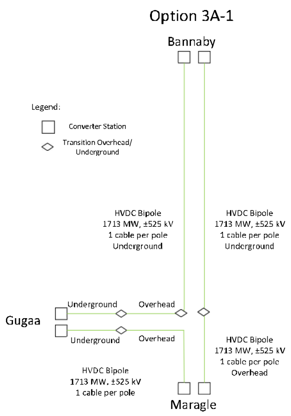
## 3.3 Option 3 – Overhead in public land - HVDC and HVAC Hybrid

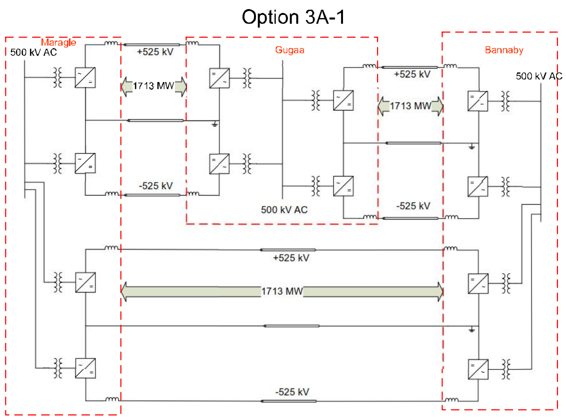
### 3.3.1 Comparative analysis of sub-options

The comparative analysis of the Option 3 sub-options is summarised in Table 3.3. The costs provided in this table are ballpark costs only and do not consider any indirect costs or terrain factors. All sub-options are comparable in cost when considering the accuracy of the estimate.

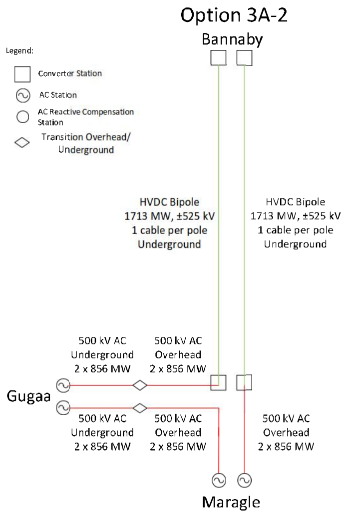
*Table 3.3 Option 3 Comparative Analysis*

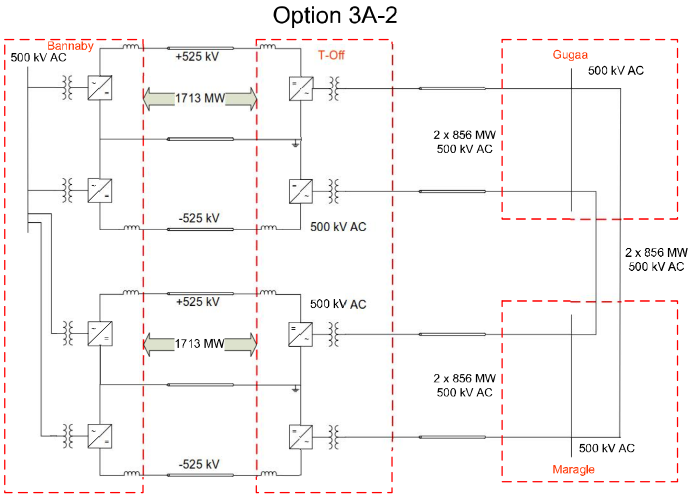
| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 3A-1 | DC from Bannaby to Gugaa and Bannaby to Maragle consisting of 2 bipoles, each 1713 MW, ±525 kV with 1 cable per pole<br>AC underground and overhead from Maragle to Gugaa | $4.67 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 4 converter stations total, 1 cable per pole, 4 transition stations along the route | The overhead portions of the line will be subjected to severe weather events and other factors outlined in Table 6.10 | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal | |



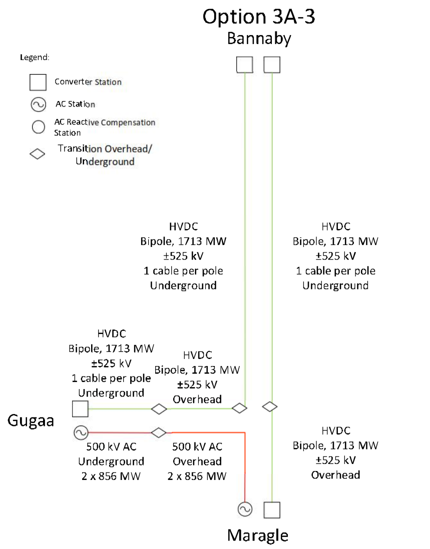



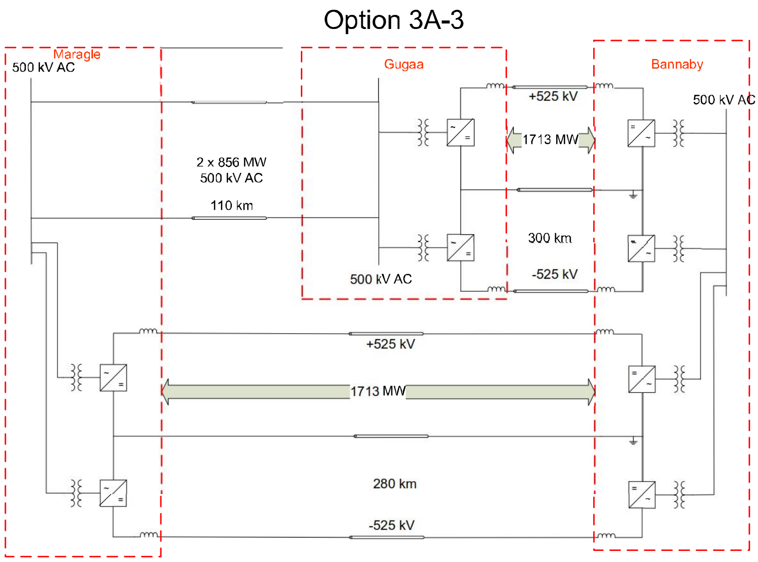
| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 3A-2 | DC from Bannaby to T-off, 2 bipoles, each 1713 MW, ±525 kV, 1 cable per pole.<br>AC underground and overhead from T-off to Maragle and Gugaa<br>AC overhead and underground from Maragle to Gugaa | $4.36 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 4 converter stations total, 1 cable per pole, 2 transition stations along the route | The overhead portions of the line will be subjected to severe weather events and other factors outlined in Table 6.10 | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal | |



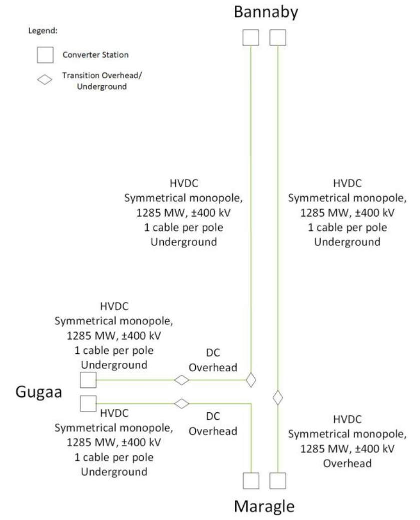
| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 3A-3 | DC from Bannaby to Gugaa and Bannaby to Maragle consisting of:<br>2 bipoles, each 1713 MW, ±525 kV, 1 cable per pole<br>AC underground and overhead from Maragle to Gugaa | $4.27 B | Control of power flows, reactive power support, other HVDC benefits as identified in<br>Table 6.7 "Power System Benefits" | 4 converter stations total, 1 cable per pole, 4 transition stations along the route | The overhead portions of the line will be subjected to severe weather events and other factors outlined in Table 6.10 | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal | Refer to Section 5.4 |



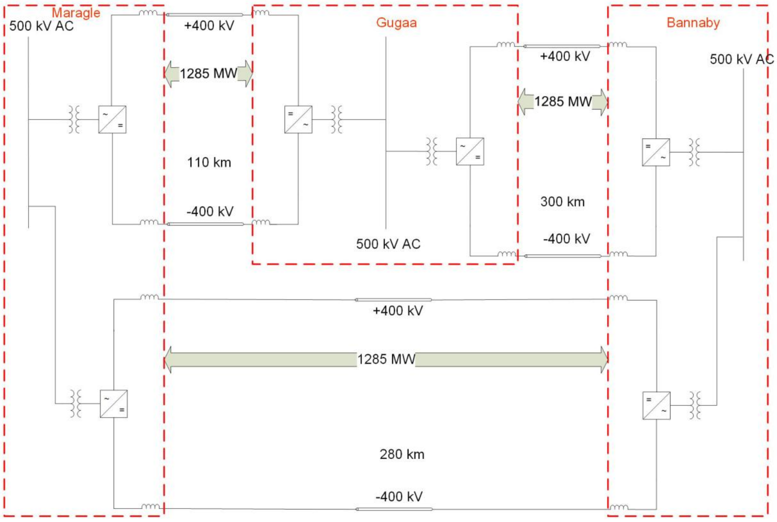



| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 3B-1 | DC underground and overhead sections consisting of:<br>3 symmetrical monopoles, each 1285 MW, ±400 kV, 1 cable per pole | $3.61 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 6 converter stations, 1 cable per pole, 4 transition stations along the route | The overhead portions of the line will be subjected to severe weather events and other factors outlined in Table 6.10 | Loss of one element will result in loss of entire symmetrical monopole, but still meets 1285 MW transmission capacity at each terminal | |

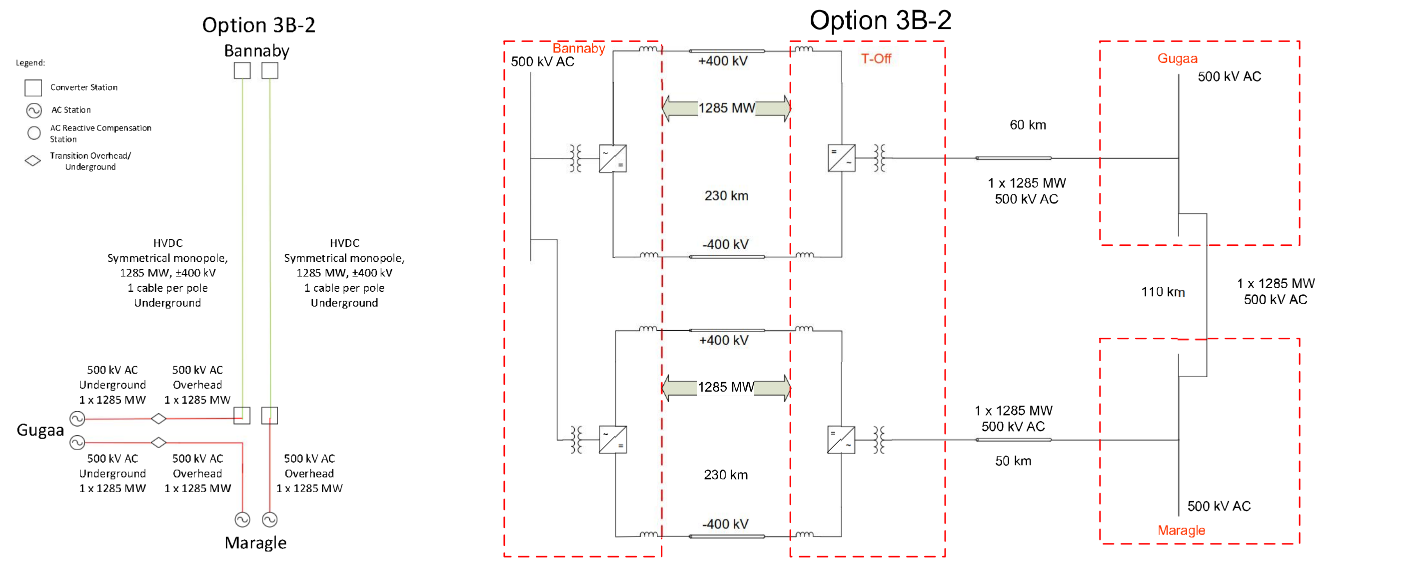
Option 3B-1



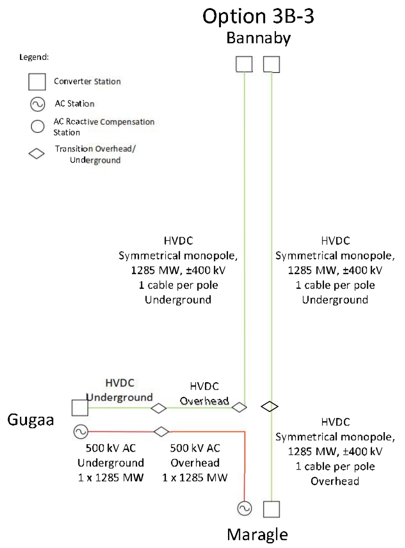

Option 3B-1

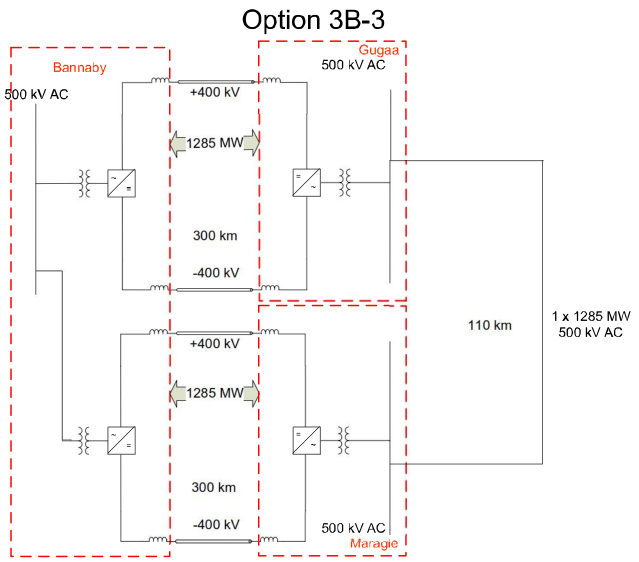


| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 3B-2 | DC underground from Bannaby to T-off consisting of:<br>2 symmetrical monopoles, each 1285 MW, ±400 kV, 1 cable per pole<br>AC overhead and underground from T-off to Maragle and Gugaa<br>AC overhead from Maragle to Gugaa | $3.43 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 4 converter stations total, 2 converter stations at the T-off, 1 cable per pole, 2 transition stations along the route | The overhead portions of the line will be subjected to severe weather events and other factors outlined in Table 6.10 | Loss of one element will result in loss of entire symmetrical monopole, but still meets 1285 MW transmission capacity at each terminal | |



| Option | Description | Costs ($) | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 3B-3 | DC from Bannaby to Gugaa and Bannaby to Maragle consisting of:<br>2 symmetrical monopoles, each 1285 MW, ±400 kV, 1 cable per pole.<br>AC underground and overhead from Maragle to Gugaa | $3.35 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 4 converter stations total (area of each), 1 cable per pole, 4 transition stations along the route | The overhead portions of the line will be subjected to severe weather events and other factors outlined in Table 6.10 | Loss of one element will result in loss of entire symmetrical monopole, but still meets 1285 MW transmission capacity at each terminal | Refer to Section 5.4 |



## 3.3.2 Preferred solution for option 3

The preferred solutions for Options 3A and 3B are as follows:

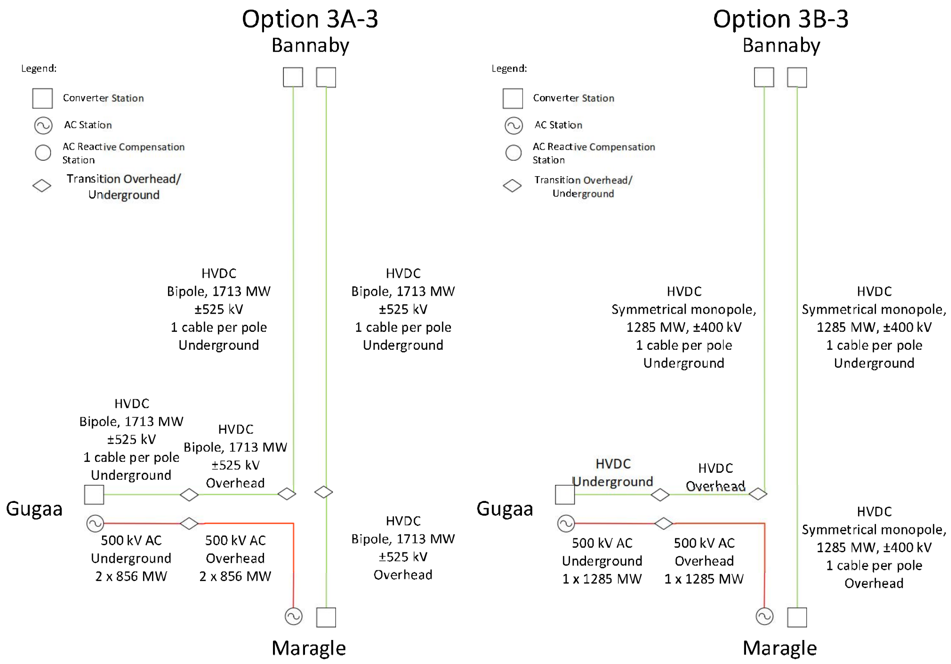



*Figure 3.4 Option 3 preferred solutions*

### Design considerations

Similar to Section 3.2.2, bipole configurations are preferable for the A options and symmetrical monopole configurations are appropriate for the B options.

A combination of AC and DC was chosen as the preferred options, due to the reduced number of converter stations as compared to 3A-1 and 3B-1. The AC underground cable sections would not require reactive compensation stations along the route based on the route length. As well, having HVDC along the entire route is a better technical and economic solution than having converter stations at a mid-point along the line. Including sections of overhead line reduces the costs of the system but affects the reliability as there will be more frequent faults on the overhead lines as compared to the cables.

Options 3A-1 and 3B-1 may be better technical solutions from a power flow control perspective. Power system studies would need to be carried out to determine if the system operation requires controllability of power flow on the path from Maragle to Gugaa.

### Installation considerations

HVDC system considerations will be similar to those in Section 3.2.2 except that transition stations will be required where the overhead line transitions to underground cable. A building may be required at these locations for line fault locator protections, and telecommunications equipment.

As discussed in Section 3.1.2, the energisation of the AC cables will require a significant amount of time, estimated to be 48 to 72 hours per 20 to 40 km segment of cable. This introduces operability issues for configurations with AC cables. By reducing the length of AC cables, the operability of the system is improved.

### Operation considerations

HVDC system considerations will be similar to those in Section 3.2.2; in addition, line fault location equipment will be required to determine if line faults have occurred on the overhead line or the underground cable. In the event that a fault occurs on the overhead line, the HVDC system could be re-started. However, if there is a fault on a cable, the system needs to be taken out of service.

## Maintenance considerations

HVDC system considerations will be similar to those in Section 3.2.2. DC overhead line maintenance will be similar to AC overhead lines of similar voltage.

## Design assumptions

Conductor size calculations for the HVDC cables are detailed in Appendix C. Appendix D provides conceptual design drawings for the HVDC converter stations and HVDC cable trenches and trenchless installation.

## Optimal route

The optimal route for Options 3A and 3B is a combination of the Blowering Deviation route and the Kosciusko route, with the Kosciusko route being the main route and the Blowering Deviation route being followed for the middle portion of the Gugaa to Bannaby circuit.

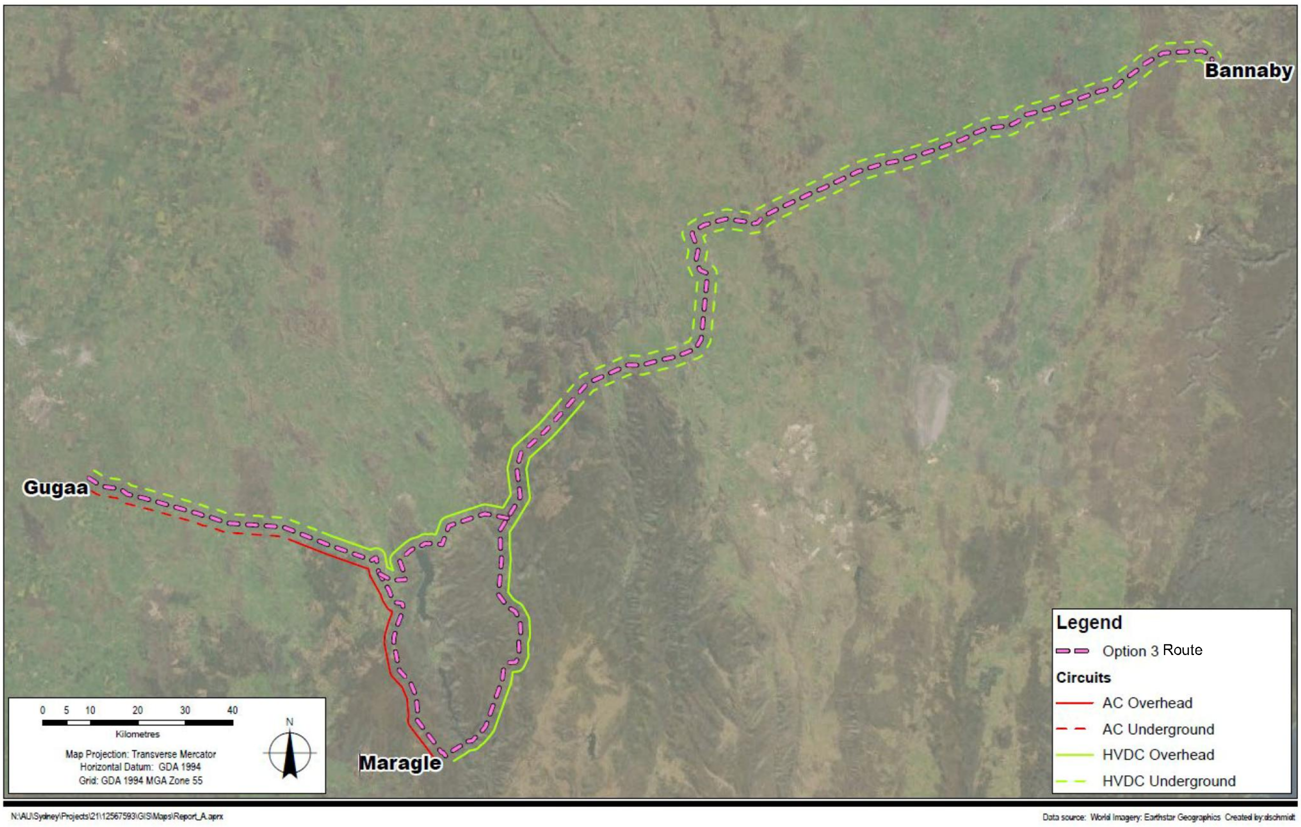



*Figure 3.5 Option 3 optimal route*

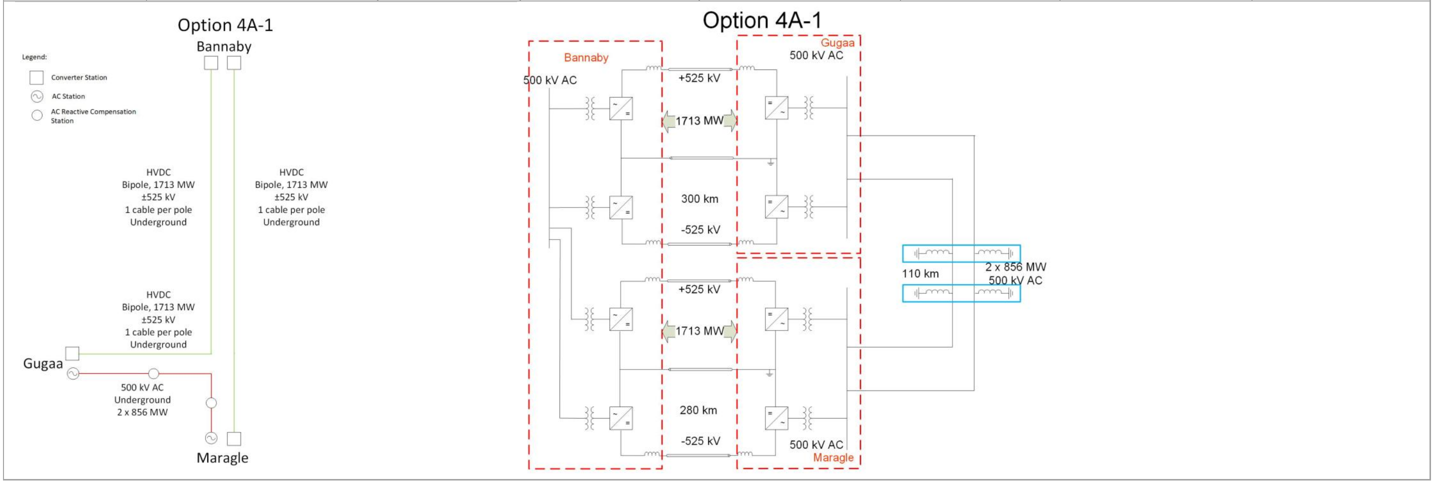
# 3.4 Option 4 – HVDC and HVAC underground and overhead

## 3.4.1 Comparative analysis of sub-options

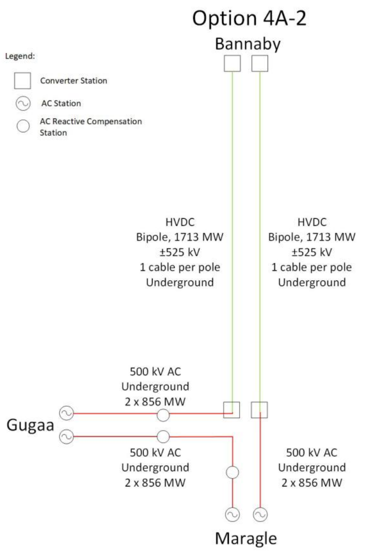
The comparative analysis of the Option 4 sub-options is summarised in Table 3.4. The costs provided in this table are ballpark costs only and do not consider any indirect costs or terrain factors. All sub-options are comparable in cost when considering the accuracy of the estimate.

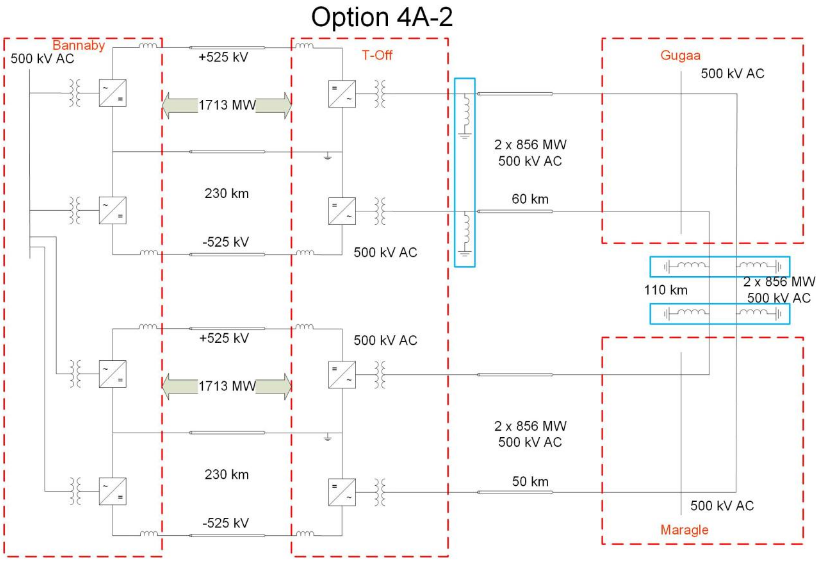
***Table 3.4 Option 4 Comparative Analysis***

| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4A-1 | DC from Bannaby to Gugaa and Bannaby to Maragle consisting of: 2 bipoles, each 1713 MW, ±525 kV, 1 cable per pole<br>AC underground from Gugaa to Maragle | $5.33 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 “Power System Benefits” | 4 converter stations total, 1 cable per pole, 2 reactive compensation stations along AC underground route | No impact due to severe weather events or bushfires. | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal | |

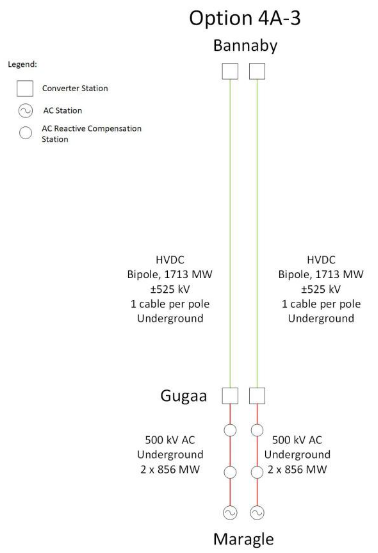


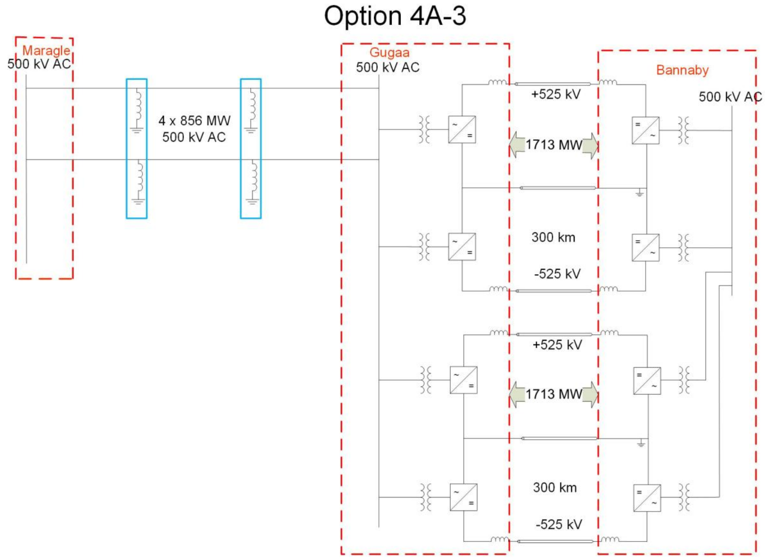
| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4A-2 | DC from Bannaby to T-off consisting of: 2 bipoles, each 1713 MW, ±525 kV, 1 cable per pole<br><br>AC underground cables from T-off to each Gugaa and Maragle, and from Gugaa and Maragle; | $5.50 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 “Power System Benefits” | 4 converter stations total (2 at T-off), 1 cable per pole, 3 reactive compensation stations along AC underground route | No impact due to severe weather events or bushfires. | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal | |



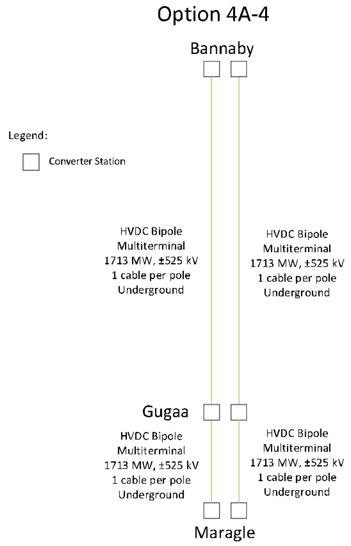



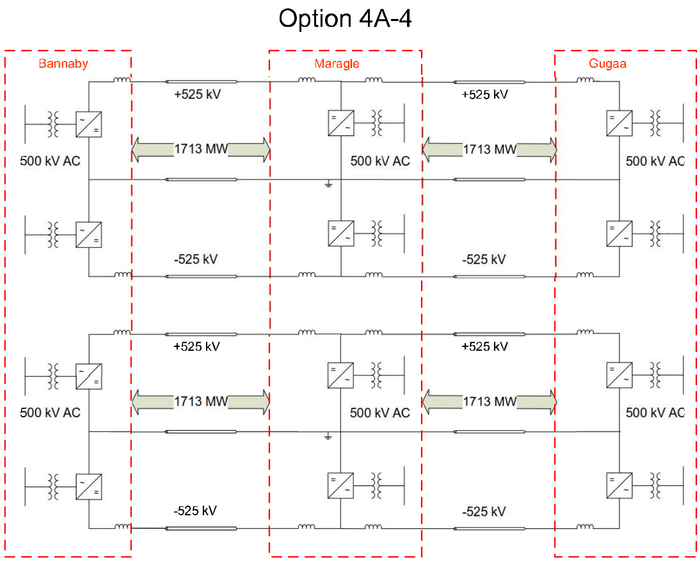
| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4A-3 | DC from Bannaby to Gugaa consisting of: 2 bipoles, each 1713 MW, ±525 kV, 1 cable per pole, AC underground from Gugaa to Maragle | $6.43 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 4 converter stations total, 1 cable per pole, 4 reactive compensation stations along AC underground route | No impact due to severe weather events or bushfires. | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal | |



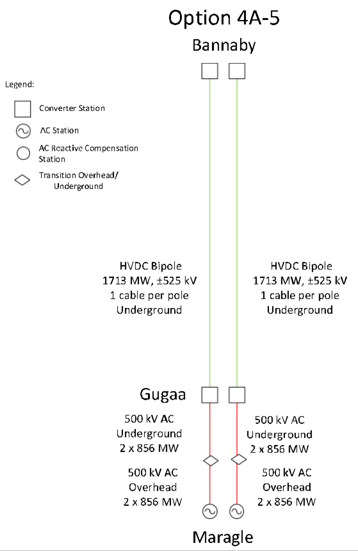



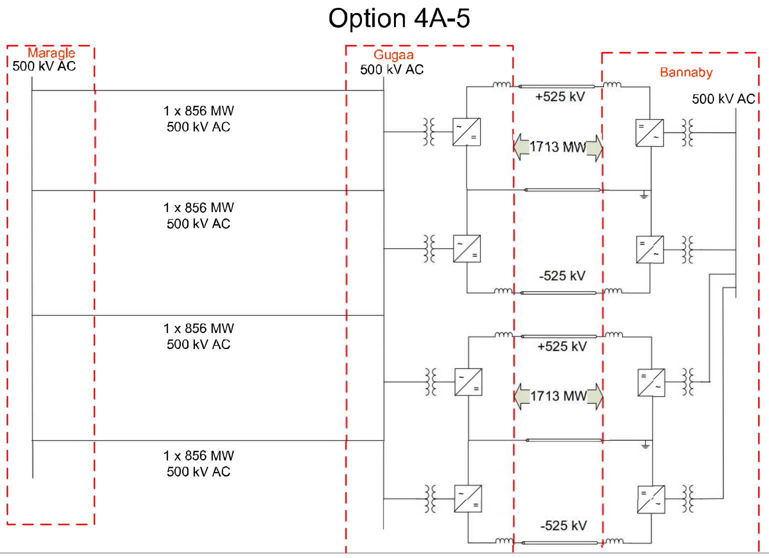
| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4A-4 | DC multi-terminal system from Bannaby to Gugaa, to Maragle consisting of 2 bipolar multi-terminal systems, each 1713 MW, 1 cable per pole; | $6.60 B | More complex controls required, but similar HVDC benefits as other HVDC options | 6 converter stations total, 1 cable per pole | No impact due to severe weather events or bushfires. | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal | |



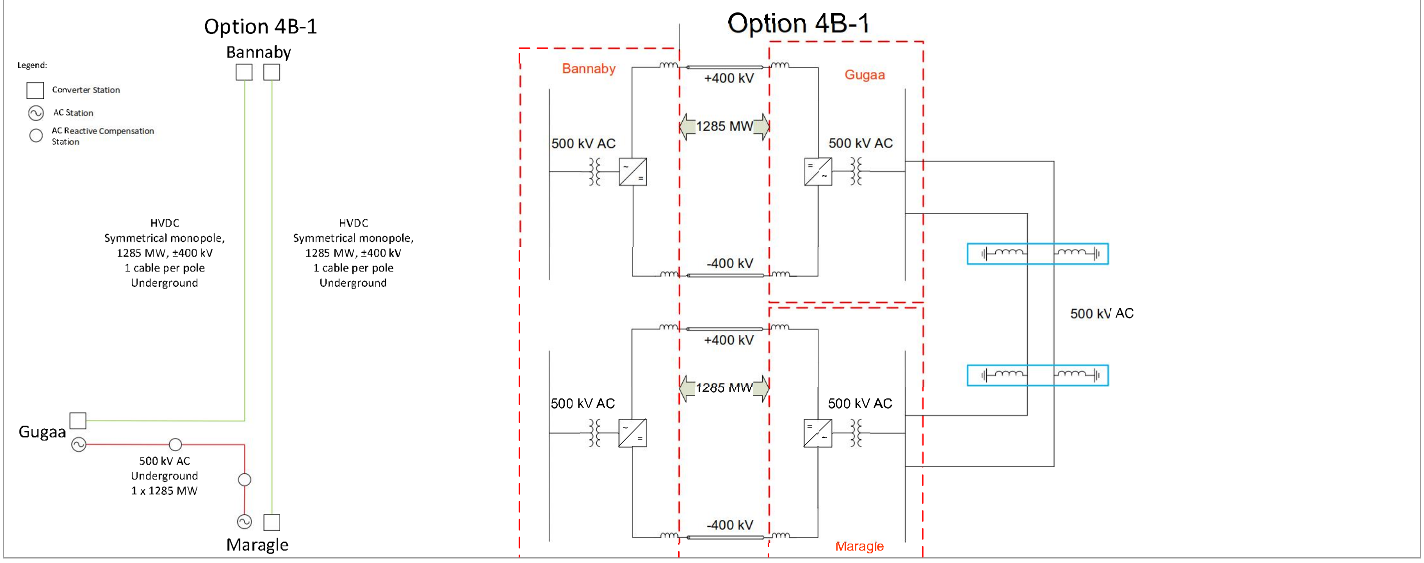



| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4A-5 | DC from Bannaby to Gugaa consisting of: 2 bipoles, each 1713 MW, ±525 kV, 1 cable per pole,<br><br>AC cables and overhead from Gugaa to Maragle AC underground 4 circuits, 2 double circuit overhead lines | $5.77 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 4 converter stations total, 1 cable per pole, 2 transition stations along AC route | The overhead portions of the line will be subjected to severe weather events and other factors outlined in Table 6.10 | Loss of one element only results in loss of half of the bipole rating (856 MW), but still meets 2570 MW transmission capacity at each terminal | Refer to Section 5.5 |

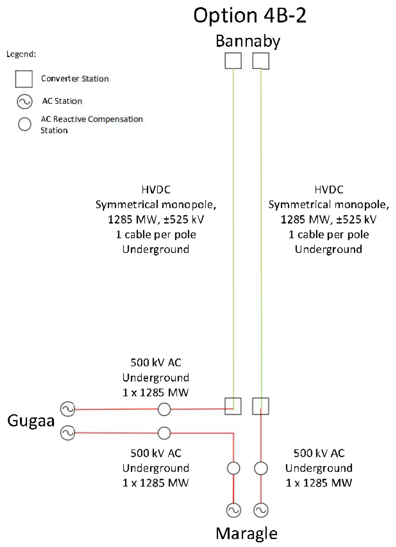


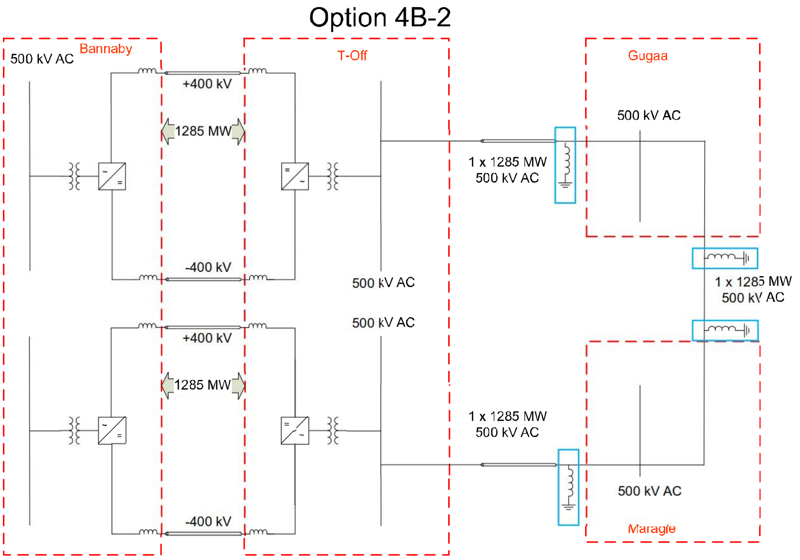



| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4B-1 | DC symmetrical monopoles of 1285 MW from Bannaby to Gugaa and Bannaby to Maragle, AC underground from Gugaa to Maragle<br>2 symmetrical monopoles, each 1285 MW, 1 cable per pole; AC cables of 1285 MW between Maragle and Gugaa | $4.40 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 4 converter stations total, 1 cable per pole, 2 reactive compensation stations along AC underground route | No impact due to severe weather events or bushfires. | Loss of one element results in loss of one symmetrical monopole (1285 MW), but still meets 2570 MW transmission capacity at each terminal | |

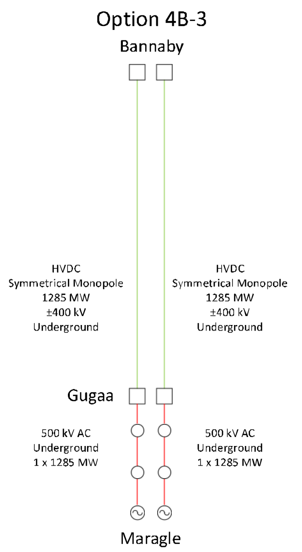


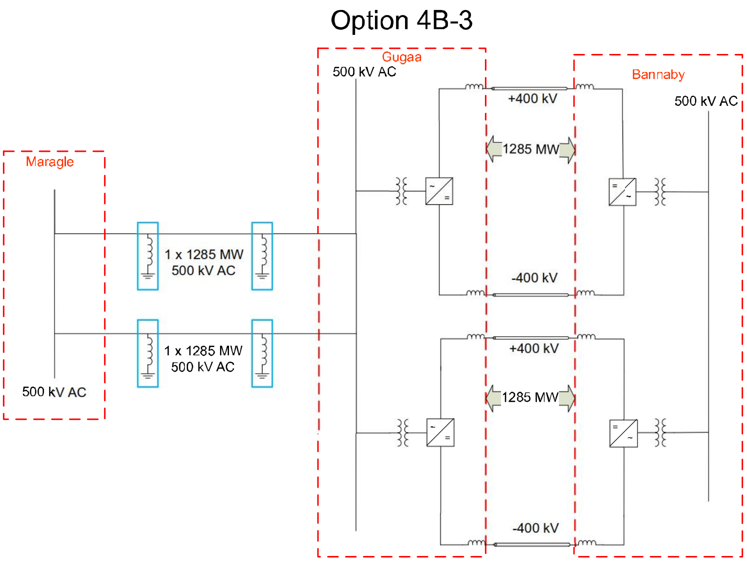
| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4B-2 | DC from Bannaby to T-off; AC cables from T-off to each Gugaa and Maragle, and from Gugaa and Maragle;<br>2 symmetrical monopoles each 1285 MW, AC cables 1285 MW each | $4.27 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 4 converter stations total, 1 cable per pole, 4 reactive compensation stations along AC underground route | No impact due to severe weather events or bushfires. | Loss of one element results in loss of one symmetrical monopole (1285 MW), but still meets 2570 MW transmission capacity at each terminal | |



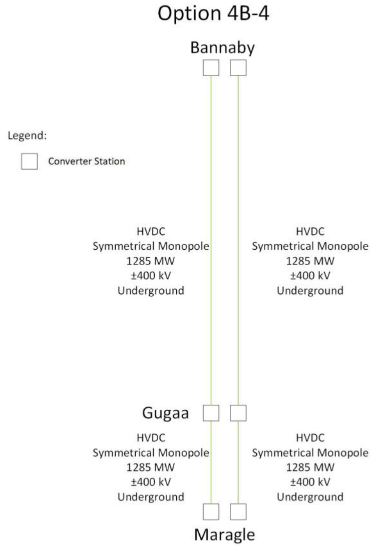



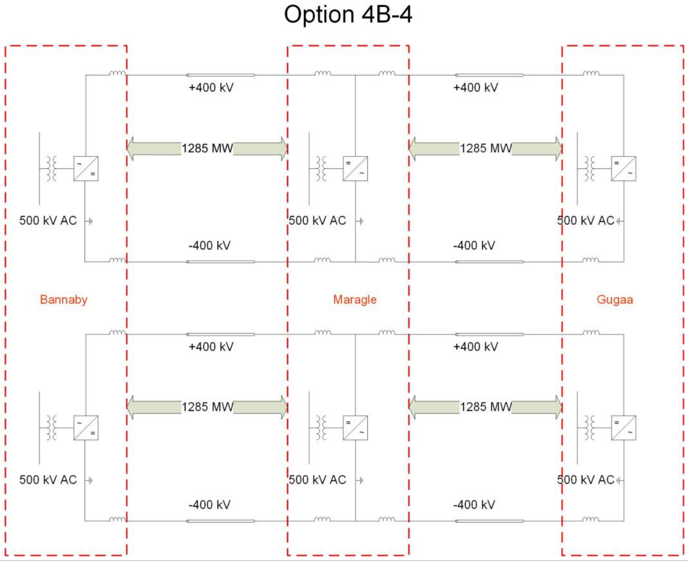
| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4B-3 | DC from Bannaby to Gugaa, AC underground for Gugaa to Maragle; highway route<br>2 symmetrical monopoles each 1285 MW, AC cables 1285 MW each | $5.37 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 4 converter stations total, 1 cable per pole, 4 reactive compensation stations along AC underground route | No impact due to severe weather events or bushfires. | Loss of one element results in loss of one symmetrical monopole (1285 MW), but still meets 2570 MW transmission capacity at each terminal | |



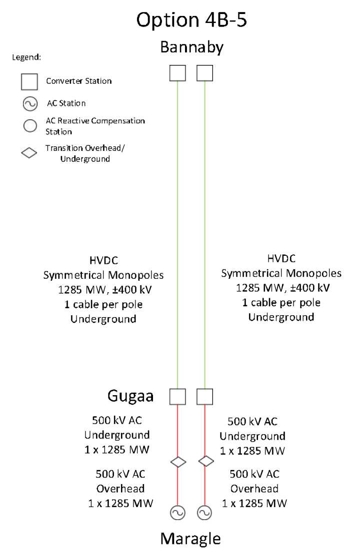



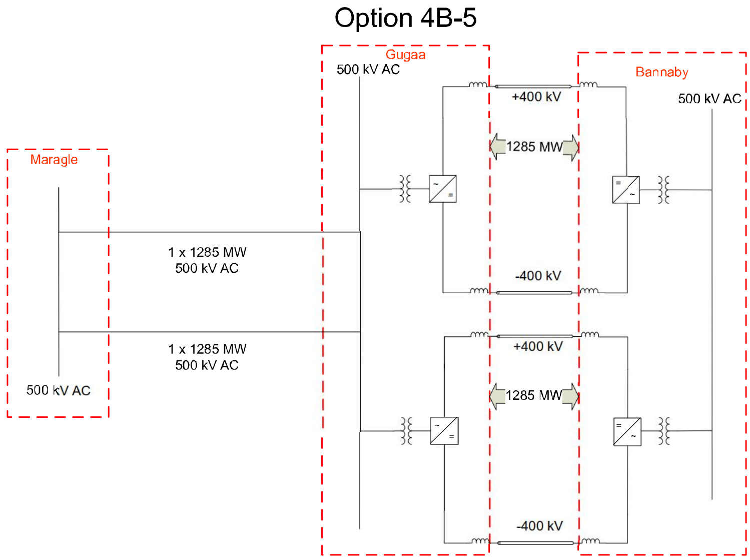
| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4B-4 | DC multi-terminal from Bannaby to Gugaa to Maragle, highway route<br>2 symmetrical monopoles multi-terminal systems each 1285 MW | $5.28 B | More complex controls required, but similar HVDC benefits as other HVDC options | 6 converter stations total, 1 cable per pole | No impact due to severe weather events or bushfires. | Loss of one element results in loss of one symmetrical monopole (1285 MW), but still meets 2570 MW transmission capacity at each terminal | |



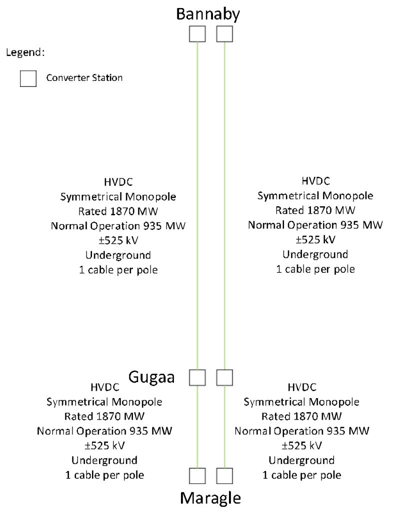
| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4B-5 | DC from Bannaby to Gugaa, AC underground and overhead from Gugaa to Maragle; highway route<br>2 symmetrical monopoles each 1285 MW, AC cables and overhead 1285 MW each | $4.62 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 “Power System Benefits” | 4 converter stations total, 1 cable per pole, 2 transition stations required along AC route | The overhead portions of the line will be subjected to severe weather events and other factors outlined in Table 6.10 | Loss of one element results in loss of one symmetrical monopole (1285 MW), but still meets 2570 MW transmission capacity at each terminal | Refer to Section 5.5 |



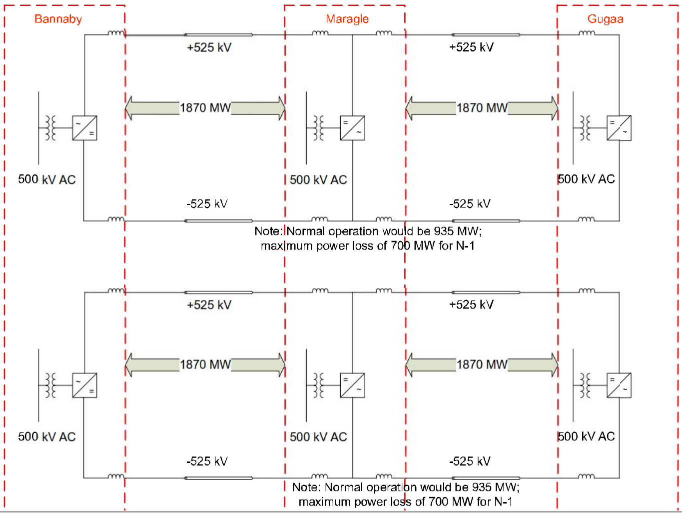



| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4C-1 | Multi-terminal DC from Bannaby to Gugaa to Maragle; highway route<br>2 symmetrical monopole systems each 1870 MW | $5.77 B | More complex controls required, but similar HVDC benefits as other HVDC options | 6 converter stations total, 1 cable per pole, | No severe weather effects | Loss of one element results in loss of one symmetrical monopole, but power drop limited to 700 MW | |

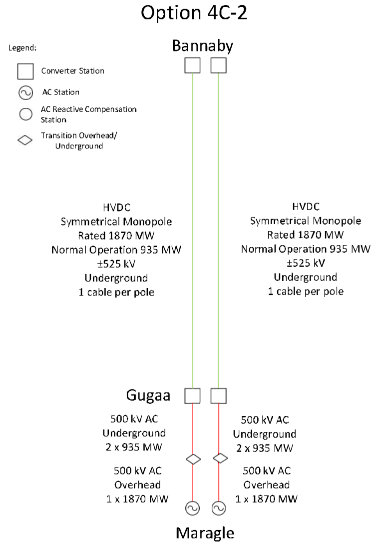
Option 4C-1

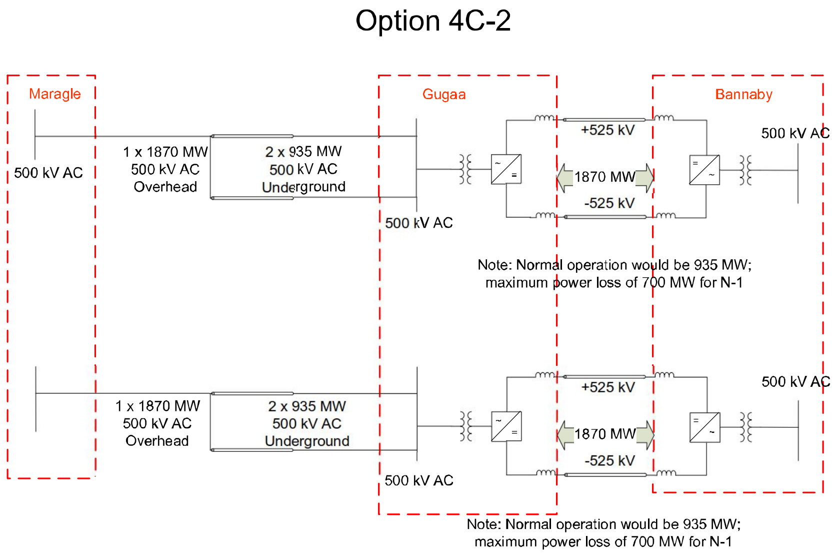



Option 4C-1



| Option | Description | ($) Costs | Benefits | Relative merits | Reliability | Redundancy | Schedule |
|---|---|---|---|---|---|---|---|
| Option 4C-2 | DC from Bannaby to Gugaa; highway route AC underground and overhead from Gugaa to Maragle<br><br>2 symmetrical monopole systems each 1870 MW | $5.11 B | Control of power flows, reactive power support, other HVDC benefits as identified in Table 6.7 "Power System Benefits" | 4 converters stations required; 2 transition stations along AC route | The overhead portions of the line will be subjected to severe weather events and other factors outlined in Table 6.10 | Loss of one element results in loss of one symmetrical monopole, but power drop limited to 700 MW | Refer to Section 5.5 |



### 3.4.2 Preferred solution for option 4

The preferred solutions for Options 4A, 4B, and 4C are shown below (note: these options do not provide the same power system circuit configuration as the Humelink AC overhead configuration).

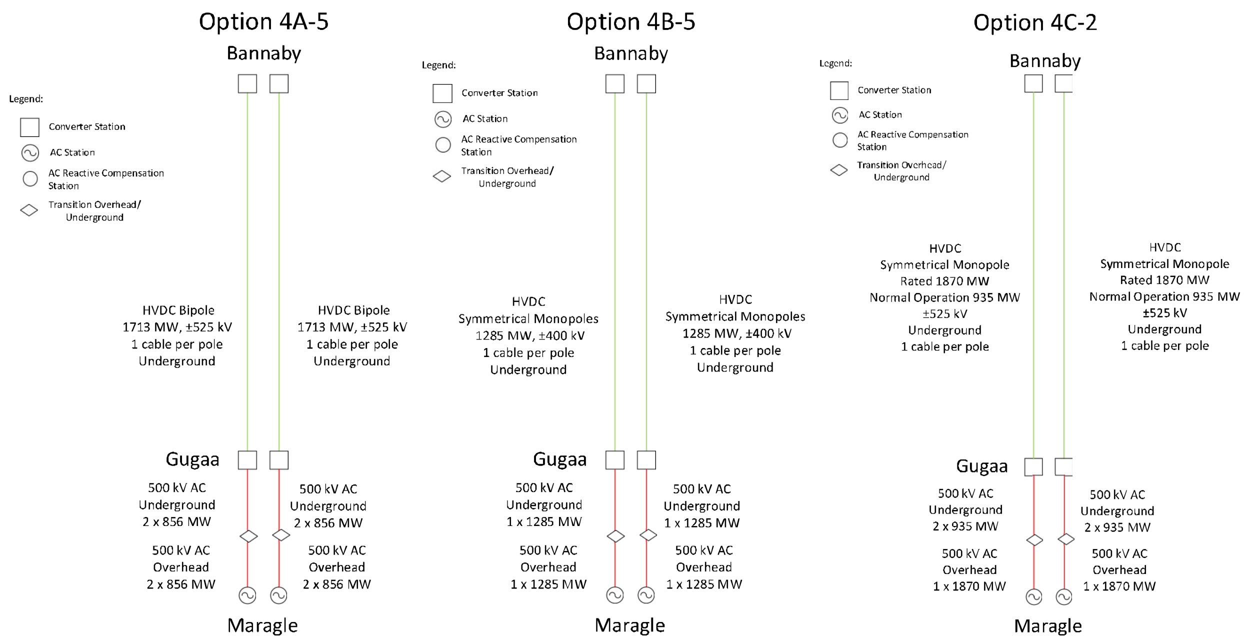



*Figure 3.6 Option 4 preferred solutions*

#### Design considerations

Similar to Section 3.2.2, bipole configurations are preferable for the A options and symmetrical monopole configurations are appropriate for the B and C options.

Adding sections of AC overhead lines reduces the costs of the system but affects the reliability as there will be more frequent faults on the overhead lines as compared to the cables. The preferred configurations are connected in a different configuration to the overall electrical system and thus would have to be studied further to confirm that they meet the system performance requirements.

Options 4A-5, 4B-5, and 4C-2 will each require 4 converter stations. All three options will require approximately 600 circuit km of DC cable, based on the 312 circuit km route for DC underground cables along the Hume highway; this results in nearly 1900 km of DC cables for Option 4A-5 And approximately 1250 km of DC cable for Options 4B-5 and 4C-2. AC overhead lines and AC cables would also be required for these options, with up to 200 circuit km of AC cables. The impacts to the schedule would be similar to Option 2 for the HVDC converters and cables.

#### Installation considerations

Installation considerations would be similar to those discussed in Section 3.2.2.

As discussed in Section 3.1.2, the energisation of the AC cables will require a significant amount of time, estimated to be 48 to 72 hours per 20 to 40 km segment of cable. This introduces operability issues for configurations with AC cables. By reducing the length of AC cables, the operability of the system is improved.

#### Operation considerations

Operational considerations are similar to those discussed in Section 3.2.2.

#### Maintenance considerations

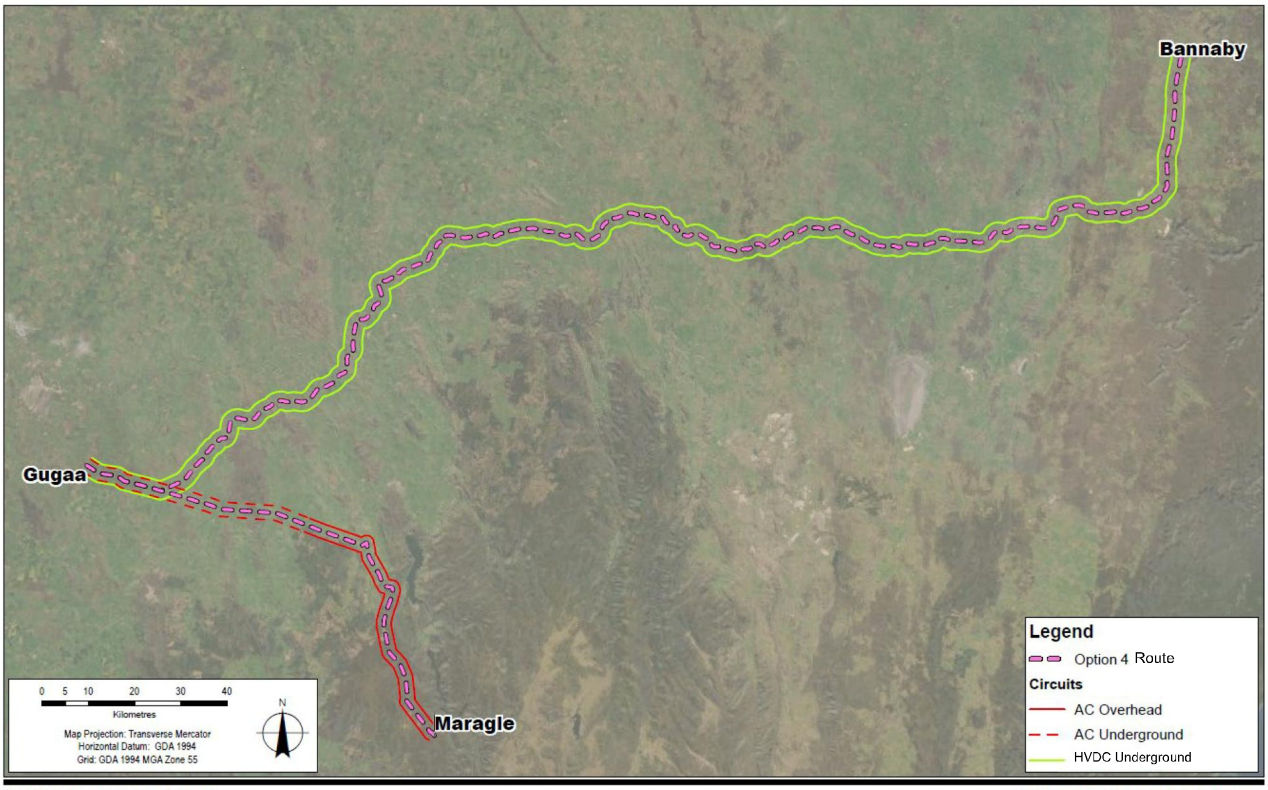
Maintenance requirements would be similar to those discussed in Section 3.2.2 and 3.3.2.

## Design assumptions

Conductor size calculations for the HVDC cables are detailed in Appendix C. Appendix D provides conceptual design drawings for the HVDC converter stations and HVDC cable trenches and trenchless installation.

## Optimal route

Two routes were considered in the analysis: the Tumut North route for Options 4A-1, 4A-2, 4B-1, and 4B-2; the highway route was considered for the circuit between Gugaa and Bannaby for Options 4A-3, 4A-4, 4A-5, 4B-3, 4B-4,4B-5, 4C-1, 4C-2 while the Tumut North route was considered for the Gugaa to Maragle circuit.




N:\AU\Sydney\Projects\21\12567593\GIS\Maps\Report_A.aprx

Data source: World Imagery: Earthstar Geographics Created by:dschmidt

*Figure 3.7 Option 4 Hume Highway route*

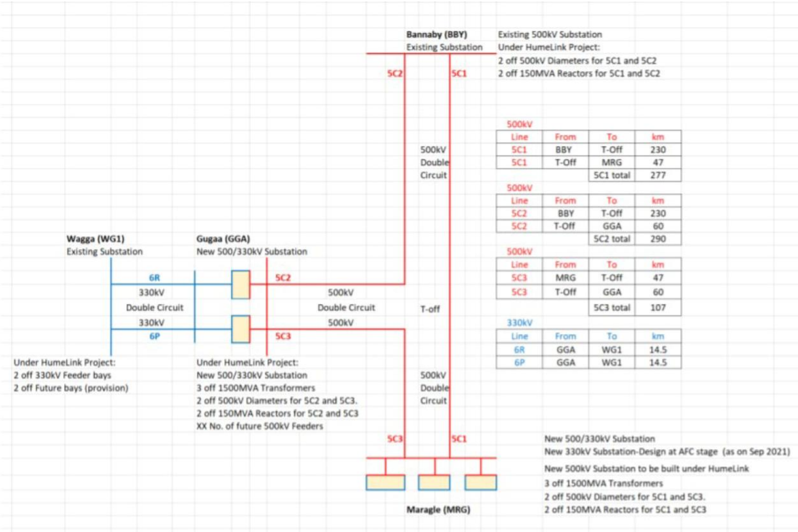
# 3.5 Overhead Line Option

## 3.5.1 Overhead Line Option by Transgrid

The preferred OHL option developed in 2020-21 by Transgrid is detailed in the PACR has been summarised in Table 3.5. The costs provided in this table have been estimated by Transgrid in 2021.

*Table 3.5 OHL Option summary*

| Option | Description | ($) Costs | Schedule |
|---|---|---|---|
| Overhead Line Option | 100% AC Overhead. Double circuir 500kV towers with 4x orange conductors per phase (3259MW) | $3.3 B (all-inclusive cost) | 4-5 years |



# 4. Preferred options cost estimate

## 4.1 Estimate basis

### 4.1.1 Capital cost estimate basis

The capital cost estimates provided in this report should be considered no better than AACE Class 4 estimates. The Transmission Cable (TC) capital estimates are broken down into the following cost components:

- Direct costs
  - Labour
  - Materials
  - Plant & Equipment
  - Engineering & PM
  - Pre-Construction
- Indirect costs
  - Allowances (includes insurances, stakeholder, and community engagement)
  - Distributable's (includes works delivery costs)

Capital intensity figures for fixed and variable components are calculated for each option and expressed in $/km and $/km/MW respectively. The direct and indirect cost components listed above are assigned a percentage of fixity or variability, depending on the nature of the cost component. This is configurable within the estimate model and is displayed below:

*Table 4.1 Cost Component Fixed and Variable Contributions*

| Estimate line item | Fixed ($ / km) | Variable ($ / km / MW) |
|---|---|---|
| Labour | 10% | 90% |
| Materials | 0% | 100% |
| Plant & Equipment | 100% | 0% |
| Engineering & PM | 90% | 10% |
| Pre-Construction | 100% | 0% |
| Distributables | 100% | 0% |

To account for local project factors, the estimate model allows the user to split each option into TC sections and apply Terrain Factors according to the route. The Terrain Factors are as described below:

*Table 4.2 Terrain Factors Guide*

| Factor | Easy | Medium | Difficult |
|---|---|---|---|
| Clearing | Open grassland | Lightly wooded | Thick forest |
| Geotech | Soil, easy to dig | Some incidences of rock | Heavy rock, or inconsistent material |
| Topography | Flat | Low hills | Mountainous |
| Easement Access | Existing access roads nearby | New access roads will be required in some areas | Inaccessible, no existing infrastructure |

The TC capital estimate is impacted by the assigned terrain types. The weighted average Terrain Factor for each TC section is calculated and applied to the relevant cost component capital intensity, these including Labour, Pre-Construction and Distributables. The values of the Terrain Factors are displayed below:

*Table 4.3 Terrain Factors*

| Difficulty | Clearing | Geotech | Topography | Easement Access |
|---|---|---|---|---|
| Easy | 1 | 1 | 1 | 1 |
| Medium | 1.1 | 1.1 | 1.1 | 1.1 |
| Difficult | 1.3 | 1.3 | 1.3 | 1.3 |

Biodiversity Offset and Land costs are calculated for the TCs, TLs, as well as the reactor stations, transition stations (UGOHs) and convertor stations. The base offset rates used are displayed below (as stated in the proposal) and scaled according to the circuit easement width and overall route vegetation cover.

- Biodiversity offset costs: $2,090,000 / km (70 m easement). (Scaled for the easement on each option)
- Land costs: $475,000 / km (70 m easement). (Scaled for the easement on each option)

Additional assumptions include:

- For TCs/TLs constructed in proximity to each other, no cost reduction has been applied.
- For the offset costs, only the easement width and the footprint of required infrastructure (reactor stations, UGOHs and convertor stations) are accounted for.
- For options that require alternative TC/TL line design, the costs of similar GHD benchmark projects have been used.
- TSB has not been included in the cost estimate
- Offset costs are calculated based on the actual easement, which is potentially understated as wider clearing will be required for construction purposes

## HVDC Specific CAPEX Breakdown

The HVDC Cable Cost estimate assumptions include:

- Per km cost estimate is based on an estimate for a theoretical 300km route length.
- 1km between field joints
- Cables are installed by direct burial
- Electrical works includes field joint assembly, termination assembly, cable pulling
- Civil works includes trenching, backfilling, material disposal, thermal backfill material, pre-cast joint bays, HDD conduit installations
- Horizontal Directional Drilling (HDD) required for 5% of the overall route length.
- Each HDD section consists of conduits with an approximate length of 500m.

The estimates are based on reference to recent bids received by Stantec for EuroAsia and Harmony link HVDC projects as well as information received from equipment suppliers. Stantec has also referenced in-house knowledge and experience with HVDC systems and cost factors over the past 55 years, as well as a database of bid and budgetary costs that includes information from over 50 projects.

There is currently high market demand for both HVDC converter equipment and high voltage AC and DC cables across the globe. As a result, contract prices are much higher and project schedules are longer than for previously awarded projects. Since there are a limited number of HVDC converter and cable suppliers, the market demand is and will continue to influence contract prices and project schedules. The suppliers are well positioned to require terms and conditions that are more favourable to reducing their risk. In some instances, suppliers have chosen to not bid projects due to lack of resources to prepare a bid, and/or choosing to pursue more favourable projects. This reduced competition on projects also results in less competitive pricing.

The global demand for HVDC converters and cables is currently not envisaged to relax in the near term, as there continues to be significant advances and investments towards more renewables, bulk transmission, and construction of underground transmission systems to protect against weather events or to comply with environmental and/or permitting restrictions imposed on overhead transmission lines.

More HVDC projects with long-distance underground land cables are being planned.The SouthWest Link in Sweden has 190 km of its 250 km DC route length using underground HVDC cables Two of the German HVDC projects SuedOstLink and Suedlink, will have route lengths using underground HVDC cables of approximately 500 km and 750 km respectively, both using 525 kV underground HVDC cables.

Factors that may affect the cost estimates include:

- Foreign Currency Exchange Fluctuations
  - Changes in the exchange rate of foreign currencies that the HVDC and cable suppliers perform work.
- Commodity Price Fluctuations
  - The Increase in commodity price pressures occurring since 2020 and further volatility which may occur from the activity in China, India, and other emerging economies will impact costs and schedule.
- Suppliers' Manufacturing Plant Loading
  - There is currently a high demand for HVDC converters and cables which is predicted to continue for several years. High loading at HVDC factories will result in higher prices and longer project schedules.
- Labour Rates
  - The significant increase in Labour rates in Australia over the last year will result in higher prices.
- Design Requirements
  - The price could change due to future detailed design requirements being more stringent than those assumed for the preliminary budgetary price
- Local Content
  - The local content requirements have not been accounted for at this time. Pricing will be subject to local labour rates, labour productivity, and costs for materials.

Due to these market conditions, the estimation of HVDC civil and electrical unit rates is difficult and complex. A price range has been determined to be used to more fully encapsulate the potential costs of labour, materials and equipment rates per km.

For example, the proposed Range for option 2a-1 includes:

- Low range: $6.4M AUD per km
- Middle range: $8.3M AUD per km
- High range: $10.8M AUD per km
- Extreme high range: $12.5M AUD per km

The ranges above are based on the factors identified above, the most significant of which are that the HVDC market and cable market in general are experiencing very high demand and inflation rates which are very high.

The Final estimate breakdown for all options 2-4 are based on the middle range numbers.

### 4.1.2 Operating cost estimate basis

The operating cost estimates provided in this report should be considered no better than AACE Class 4 estimates and nominal values only. The operating costs are for the TCs, reactor stations, transition stations and convertor stations only. Operating costs for the substations at the Bannaby, Gugaa, Wagga Wagga and Maragle have not been determined. Electrical losses have been calculated for the TCs and include substation transformer and converter station losses (Converter station loss assumptions have been adjusted for the cases where full bridge converters are being used). Substation transformer/converter station losses have been set to be within 1% of transmitted power, and AC transmission line and AC cable losses to be 0.2% per 100km. DC Transmission cables have been set to 28.5, 27.6 and 30.8 kW/km/circuit for the 1713MW bipoles, 1285MW monopoles and 1870MW monopoles respectively, while the DC transmission lines have been set to 32.4 and 34.7 kW/km/circuit for the 1713MW bipoles, 1285MW monopoles, respectively. These are considered to be reasonable benchmarks.

The Overhead line Operating costs have been provided by Transgrid totalling AUD$50.5 million a year. This includes losses which have been provided by Transgrid and based on our assumed power cost of AUD$70.52/MWh

The cost of power is dependent on the cost of generation. A power cost of AU$70.52/MWh have been derived from US Energy Information Administration (EIA) data and fits within the expected benchmark cost bands for Australian energy costs. This value is configurable within the model.

A basic build-up of labour costs has been used for labour costs in Australia. Sustaining capital has been included as a % of capital cost of aboveground TCs and associated infrastructure. This study has allowed for sustaining capital costs at 0.5% of capital increasing linearly to 1% after 10 years. The operating costs include a capital refresh of 2.5% of capex after 15 years, based on the assumption in CIGRE TB649. The level of sustaining capital is adjustable within in the model.

The operating cost estimate includes a calculation for flights and vehicle hire, as well as a calculation of the ongoing clearing costs of the transmission line.

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### 4.1.3 Capital cost estimate summary

A summary of the capital cost estimates for the preferred options are displayed below. Sections 4.2 – 4.5 contain detailed capital cost breakdown for each preferred option.

***Table 4.4 Capital Cost Estimate Summary Table***

| Variant | Description | Route | Total Capex (AUD) | Life Cycle |
|---|---|---|---|---|
| OHL | Overhead AC (2020 estimate) | 1 - via Tumut North | $3,300,000,000 | 50 years |
| 1A | Underground HVAC | 1 - via Tumut North | $17,140,000,000 | 50 years |
| 2A-1 | Underground HVDC | 1 - via Tumut North | $11,490,000,000 | 50 years |
| 2B-1 | Underground HVDC | 1 - via Tumut North | $8,992,000,000 | 50 years |
| 3A-3 | Overhead in public land, HVAC & HVDC Hybrid | 2/3 – via Blowering and Kosciusko combination | $9,626,000,000 | 50 years |
| 3B-3 | Overhead in public land, HVAC & HVDC Hybrid | 2/3 – via Blowering and Kosciusko combination | $7,464,000,000 | 50 years |
| 4A-5 | HVAC & HVDC Hybrid | 4 - via Hume Highway | $11,450,000,000 | 50 years |
| 4B-5 | HVAC & HVDC Hybrid | 4 - via Hume Highway | $9,053,000,000 | 50 years |
| 4C-2 | HVAC & HVDC Hybrid | 4 - via Hume Highway | $10,420,000,000 | 50 years |

***Table 4.5 Capital Cost Estimate Summary Table – Gugaa to Wagga Wagga***

| Variant | Description | Total Capex (AUD) | Life Cycle |
|---|---|---|---|
| Gugaa to Wagga Wagga | 330kV underground HVAC | $754,000,000 | 50 years |

### 4.1.4 Operating cost estimate summary

The Operating Cost for the first 11 years has been calculated for each preferred option and is displayed below. A detailed breakdown for each option may be found in Appendix F.

*Table 4.6 Operating Cost Estimate Summary Table, AUD millions per annum*

| Variant | YR1 | YR2 | YR3 | YR4 | YR5 | YR6 | YR7 | YR8 | YR9 | YR10 | YR11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| OHL | $50.5 | $50.5 | $50.5 | $50.5 | $50.5 | $50.5 | $50.5 | $50.5 | $50.5 | $50.5 | $50.5 |
| 1A | $51.0 | $52.1 | $53.2 | $53.5 | $53.8 | $54.1 | $54.4 | $54.7 | $54.9 | $69.3 | $55.5 |
| 2A-1 | $84.7 | $84.7 | $87.2 | $89.7 | $91.3 | $93.0 | $94.7 | $96.4 | $98.0 | $99.6 | $101.3 |
| 2B-1 | $80.4 | $82.3 | $84.2 | $85.3 | $86.4 | $87.5 | $88.6 | $89.7 | $90.8 | $91.9 | $93.0 |
| 3A-3 | $109.7 | $118.6 | $127.6 | $129.3 | $130.9 | $132.6 | $134.3 | $135.9 | $137.6 | $139.3 | $140.9 |
| 3B-3 | $101.7 | $108.4 | $115.0 | $116.1 | $117.2 | $118.4 | $119.5 | $120.6 | $121.8 | $122.9 | $124.0 |
| 4A-5 | $93.6 | $98.5 | $103.4 | $105.5 | $107.6 | $109.6 | $111.7 | $113.7 | $115.8 | $117.8 | $119.9 |
| 4B-5 | $88.1 | $93.3 | $98.5 | $99.9 | $101.3 | $102.6 | $104.0 | $105.4 | $106.8 | $108.1 | $109.5 |
| 4C-2 | $89.8 | $95.7 | $101.5 | $103.5 | $105.5 | $107.4 | $109.4 | $111.3 | $113.3 | $115.3 | $117.2 |

*Table 4.7 Operating Cost Estimate Summary Table, AUD millions per annum – Gugaa to Wagga Wagga*

| Variant | YR1 | YR2 | YR3 | YR4 | YR5 | YR6 | YR7 | YR8 | YR9 | YR10 | YR11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gugaa to Wagga Wagga | $35.4 | $35.5 | $35.5 | $35.6 | $35.6 | $35.6 | $35.7 | $35.7 | $35.7 | $37.6 | $35.8 |

## 4.2 Option 1A

The cost estimates for civil installation and cable supply have been benchmarked against the Transgrid 330 kV Powering Sydney's Future project. The respective contractors have also provided estimation guidance on this potential project.

The cost estimate has additionally been benchmarked against a confidential 330 kV Australian project currently in feasibility stage.

Terrain factors applied to Option 1A are as displayed below:

*Table 4.8 Option 1A Terrain Factors*

| Terrain Factor | Clearing | Geotech | Topography | Easement Access |
|---|---|---|---|---|
| **Difficulty** | Easy | Medium | Medium | Medium |

The cost estimate for the preferred solution, Option 1A, is summarised in Table 4.8 below.

*Table 4.9 Option 1A Cost Estimate*

**Case Scenario Capex Breakdown**

| | | |
|---|---|---|
| **Project** | Hume Link - Underground Options Comparative Estimates | |
| **Project Variant** | 1A - Undeground HVAC | |
| **Capex Total** | $ 17,140,000,000 | AUD |
| **Transmission Cable Capex** | $ 15,920,000,000 | AUD |

| **Tranmission Cable** | **TC1** | **TC2** | **TC3** | | |
|---|---|---|---|---|---|
| **Capital Cost** | | | | **Unit** | **Comments** |
| Subtotal | $ 6,958,000,000 | $ 7,428,000,000 | $ 2,751,000,000 | AUD | All in costs (including offsets, convertor stations, reactor stations and UGOHs) |
| Installed Rate per km | $ 25,120,000 | $ 25,350,000 | $ 25,240,000 | AUD/km | |
| Installed Cost per km/MW | $ 9,774 | $ 9,864 | $ 9,822 | AUD/km/MW | |
| Subtotal | $ 6,442,000,000 | $ 6,897,000,000 | $ 2,577,000,000 | AUD | Excludes offsets, convertor stations, reactor stations and UGOHs |
| Installed Rate per km | $ 23,260,000 | $ 23,540,000 | $ 23,640,000 | AUD/km | |
| Installed Cost per km/MW | $ 9,049 | $ 9,159 | $ 9,198 | AUD/km/MW | |
| **Line Design** | | | | **Unit** | **Comments** |
| HVAC/HVDC | HVAC duct bank cable | HVAC duct bank cable | HVAC duct bank cable | - | |
| Voltage | 500 | 500 | 500 | kV | |
| Power/Rating | 2,570 | 2,570 | 2,570 | MW | |
| Circuit configuration | Single circuit | Single circuit | Single circuit | - | |
| Location | NSW | NSW | NSW | - | |
| Country | Australia | Australia | Australia | - | |
| Length | 277 | 293 | 109 | km | |
| Number of Reactor Stations | 7 | 7 | 2 | - | |
| Number of Transition Stations | 0 | 0 | 0 | - | |
| Number of Converter Stations | 0 | 0 | 0 | - | |
| **Cost Basis** | | | | **Unit** | **Comments** |
| Labour | $ 1,557,000,000 | $ 1,667,000,000 | $ 622,600,000 | AUD | |
| Materials | $ 1,170,000,000 | $ 1,252,000,000 | $ 467,800,000 | AUD | |
| Equipment | $ 2,506,000,000 | $ 2,683,000,000 | $ 1,002,000,000 | AUD | |
| Engineering & PM | $ 445,600,000 | $ 477,000,000 | $ 178,200,000 | AUD | |
| Pre-Construction | $ 370,700,000 | $ 396,800,000 | $ 148,200,000 | AUD | |
| Distribs | $ 259,500,000 | $ 277,800,000 | $ 103,800,000 | AUD | |
| Allowances | $ 133,700,000 | $ 143,100,000 | $ 53,470,000 | AUD | |
| **Additional Allowances** | | | | **Unit** | **Comments** |
| Biodiversity Offset Cost | $ 219,800,000 | $ 231,800,000 | $ 85,090,000 | AUD | |
| Land Offset Costs | $ 49,960,000 | $ 52,670,000 | $ 19,340,000 | AUD | |
| Reactor Stations | $ 246,600,000 | $ 246,600,000 | $ 70,450,000 | AUD | |
| Transition Stations | $ - | $ - | $ - | AUD | Also referred to as UGOHs |
| Converter Stations | $ - | $ - | $ - | AUD | |
| **Footprints** | | | | **Unit** | **Comments** |
| Reactor Station | 62,500 | 62,500 | 62,500 | m2 | Per station |
| Transition Station | - | - | - | m2 | Per station |
| Converter Station | - | - | - | m2 | Per station |
| Reactor Station | 437,500 | 437,500 | 125,000 | m2 | Total footprint |
| Transition Station | - | - | - | m2 | Total footprint |
| Converter Station | - | - | - | m2 | Total footprint |

## 4.3 Option 2

### 4.3.1 Option 2A-1

Terrain factors applied to Option 2A-1 are as displayed below:

*Table 4.10 Option 2A-1 Terrain Factors*

| Terrain Factor | Clearing | Geotech | Topography | Easement Access |
|---|---|---|---|---|
| **Difficulty** | Easy | Medium | Medium | Medium |

The cost estimate for the preferred solution, Option 2A-1, is summarised in Table 4.11 below.

*Table 4.11 Option 2A-1 cost estimate*

**Case Scenario Capex Report**

| | | |
|---|---|---|
| **Project** | Hume Link - Underground Options Comparative Estimates | |
| **Project Variant** | 2A-1 | |
| **Capex Total** | $ 11,490,000,000 | AUD |
| **Transmission Line Capex** | $ 7,717,000,000 | AUD |

| **Tranmission Cable** | **TC1** | **TC2** | **TC3** | | |
|---|---|---|---|---|---|
| **Capital Cost** | | | | **Unit** | **Comments** |
| Subtotal | $ 4,431,000,000 | $ 4,624,000,000 | $ 2,431,000,000 | AUD | All in costs (including offsets, convertor stations, reactor stations and UGOHs) |
| Installed Rate per km | $ 16,010,000 | $ 15,790,000 | $ 22,210,000 | AUD/km | |
| Installed Cost per km/MW | $ 9,345 | $ 9,216 | $ 12,970 | AUD/km/MW | |
| Subtotal | $ 3,143,000,000 | $ 3,326,000,000 | $ 1,248,000,000 | AUD | Excludes offsets, convertor stations, reactor stations and UGOHs |
| Installed Rate per km | $ 11,350,000 | $ 11,350,000 | $ 11,410,000 | AUD/km | |
| Installed Cost per km/MW | $ 6,628 | $ 6,628 | $ 6,659 | AUD/km/MW | |
| **Line Design** | | | | **Unit** | **Comments** |
| HVAC/HVDC | HVDC direct buried cable | HVDC direct buried cable | HVDC direct buried cable | - | |
| Voltage | 525 | 525 | 525 | kV | |
| Power/Rating | 1,713 | 1,713 | 1,713 | MW | |
| Circuit configuration | Bipole | Bipole | Bipole | - | |
| Location | NSW | NSW | NSW | - | |
| Country | Australia | Australia | Australia | - | |
| Length | 277 | 293 | 109 | km | |
| Number of Reactor Stations | 0 | 0 | 0 | - | |
| Number of Transition Stations | 0 | 0 | 0 | - | |
| Number of Converter Stations | 2 | 2 | 2 | - | |
| **Cost Basis** | | | | **Unit** | **Comments** |
| Labour | $ 1,072,000,000 | $ 1,134,000,000 | $ 423,800,000 | AUD | |
| Materials | $ 805,400,000 | $ 852,300,000 | $ 318,400,000 | AUD | |
| Equipment | $ 686,600,000 | $ 726,500,000 | $ 271,500,000 | AUD | |
| Engineering & PM | $ 211,300,000 | $ 223,500,000 | $ 83,520,000 | AUD | |
| Pre-Construction | $ 175,700,000 | $ 186,000,000 | $ 69,480,000 | AUD | |
| Distribs | $ 126,600,000 | $ 134,000,000 | $ 53,900,000 | AUD | |
| Allowances | $ 65,220,000 | $ 69,010,000 | $ 27,770,000 | AUD | |
| **Additional Allowances** | | | | **Unit** | **Comments** |
| Biodiversity Offset Cost | $ 147,200,000 | $ 155,400,000 | $ 61,220,000 | AUD | |
| Land Offset Costs | $ 33,450,000 | $ 35,330,000 | $ 13,910,000 | AUD | |
| Reactor Stations | $ - | $ - | $ - | AUD | |
| Transition Stations | $ - | $ - | $ - | AUD | |
| Converter Stations | $ 1,107,000,000 | $ 1,107,000,000 | $ 1,107,000,000 | AUD | |
| **Footprints** | | | | **Unit** | **Comments** |
| Reactor Station | - | - | - | m2 | Per station |
| Transition Station | - | - | - | m2 | Per station |
| Converter Station | 84,000 | 84,000 | 84,000 | m2 | Per station |
| Reactor Station | - | - | - | m2 | Total footprint |
| Transition Station | - | - | - | m2 | Total footprint |
| Converter Station | 168,000 | 168,000 | 168,000 | m2 | Total footprint |

## 4.3.2 Option 2B-1

Terrain factors applied to Option 2B-1 are as displayed below:

***Table 4.12 Option 2B-1 Terrain Factors***

| Terrain Factor | Clearing | Geotech | Topography | Easement Access |
|---|---|---|---|---|
| **Difficulty** | Easy | Medium | Medium | Medium |

The cost estimate for the preferred solution, Option 2B-1, is summarised in Table 4.13.

***Table 4.13 Option 2B-1 cost estimate***

| Case Scenario Capex Report | | |
|---|---|---|
| **Project** | Hume Link - Underground Options Comparative Estimates | |
| **Project Variant** | 2B-1 | |
| **Capex Total** | $ 8,992,000,000 | AUD |
| **Transmission Line Capex** | $ 6,407,000,000 | AUD |

| Tranmission Cable | TC1 | TC2 | TC3 | | |
|---|---|---|---|---|---|
| **Capital Cost** | | | | **Unit** | **Comments** |
| Subtotal | $ 3,495,000,000 | $ 3,656,000,000 | $ 1,841,000,000 | AUD | All in costs (including offsets, convertor stations, reactor stations and UGOHs) |
| Installed Rate per km | $ 12,630,000 | $ 12,480,000 | $ 16,820,000 | AUD/km | |
| Installed Cost per km/MW | $ 9,827 | $ 9,713 | $ 13,090 | AUD/km/MW | |
| Subtotal | $ 2,605,000,000 | $ 2,757,000,000 | $ 1,045,000,000 | AUD | Excludes offsets, convertor stations, reactor stations and UGOHs |
| Installed Rate per km | $ 9,412,000 | $ 9,412,000 | $ 9,545,000 | AUD/km | |
| Installed Cost per km/MW | $ 7,325 | $ 7,325 | $ 7,428 | AUD/km/MW | |
| **Line Design** | | | | **Unit** | **Comments** |
| HVAC/HVDC | HVDC direct buried cable | HVDC direct buried cable | HVDC direct buried cable | - | |
| Voltage | 400 | 400 | 400 | kV | |
| Power/Rating | 1,285 | 1,285 | 1,285 | MW | |
| Circuit configuration | Symmetrical Monopole | Symmetrical Monopole | Symmetrical Monopole | - | |
| Location | NSW | NSW | NSW | - | |
| Country | Australia | Australia | Australia | - | |
| Length | 277 | 293 | 109 | km | |
| Number of Reactor Stations | 0 | 0 | 0 | - | |
| Number of Transition Stations | 0 | 0 | 0 | - | |
| Number of Converter Stations | 2 | 2 | 2 | - | |
| **Cost Basis** | | | | **Unit** | **Comments** |
| Labour | $ 888,700,000 | $ 940,400,000 | $ 351,300,000 | AUD | |
| Materials | $ 667,700,000 | $ 706,500,000 | $ 264,000,000 | AUD | |
| Equipment | $ 569,200,000 | $ 602,300,000 | $ 225,000,000 | AUD | |
| Engineering & PM | $ 175,100,000 | $ 185,300,000 | $ 69,240,000 | AUD | |
| Pre-Construction | $ 145,700,000 | $ 154,200,000 | $ 57,600,000 | AUD | |
| Distribs | $ 105,000,000 | $ 111,100,000 | $ 51,070,000 | AUD | |
| Allowances | $ 54,070,000 | $ 57,210,000 | $ 26,310,000 | AUD | |
| **Additional Allowances** | | | | **Unit** | **Comments** |
| Biodiversity Offset Cost | $ 128,100,000 | $ 135,400,000 | $ 52,140,000 | AUD | |
| Land Offset Costs | $ 29,110,000 | $ 30,770,000 | $ 11,850,000 | AUD | |
| Reactor Stations | $ - | $ - | $ - | AUD | |
| Transition Stations | $ - | $ - | $ - | AUD | |
| Converter Stations | $ 732,700,000 | $ 732,700,000 | $ 732,700,000 | AUD | |
| **Footprints** | | | | **Unit** | **Comments** |
| Reactor Station | - | - | - | m2 | Per station |
| Transition Station | - | - | - | m2 | Per station |
| Converter Station | 41,400 | 41,400 | 41,400 | m2 | Per station |
| Reactor Station | - | - | - | m2 | Total footprint |
| Transition Station | - | - | - | m2 | Total footprint |
| Converter Station | 82,800 | 82,800 | 82,800 | m2 | Total footprint |

## 4.4 Option 3

### 4.4.1 Option 3A-3

Terrain factors applied to Option 3A-3 are as displayed below:

*Table 4.14 Option 3A-3 Terrain Factors*

| Terrain Factor | Clearing | Geotech | Topography | Easement Access |
|---|---|---|---|---|
| **Difficulty** | Easy | Medium | Medium | Medium |

The cost estimate for the preferred solution, Option 3A-3, is summarised in Table 4.15.

*Table 4.15 Option 3A-3 cost estimate*

| | | |
|---|---|---|
| **Case Scenario Capex Report** | | |
| **Project** | Hume Link - Underground Options Comparative Estimates | |
| **Project Variant** | 3A-3 | |
| **Capex Total** | $ 9,626,000,000 | AUD |
| **Transmission Line Capex** | $ 6,061,000,000 | AUD |

| **Tranmission Cable** | **TC1** | **TC2** | **TC3** | **TC4** | | |
|---|---|---|---|---|---|---|
| **Capital Cost** | | | | | **Unit** | **Comments** |
| Subtotal | $ 6,117,000,000 | $ 401,700,000 | $ 901,000,000 | $ 2,206,000,000 | AUD | All in costs (including offsets, convertor stations, reactor stations and |
| Installed Rate per km | $ 15,350,000 | $ 5,987,000 | $ 20,480,000 | $ 13,280,000 | AUD/km | |
| Installed Cost per km/MW | $ 8,959 | $ 3,497 | $ 11,960 | $ 7,755 | AUD/km/MW | |
| Subtotal | $ 4,526,000,000 | $ 229,600,000 | $ 859,700,000 | $ 445,900,000 | AUD | Excludes offsets, convertor stations, reactor stations and UGOHs |
| Installed Rate per km | $ 11,350,000 | $ 3,422,000 | $ 19,540,000 | $ 2,685,000 | AUD/km | |
| Installed Cost per km/MW | $ 6,628 | $ 1,999 | $ 11,410 | $ 1,567 | AUD/km/MW | |
| **Line Design** | | | | | **Unit** | **Comments** |
| HVAC/HVDC | HVDC direct buried cable | HVAC | HVAC duct bank cable | HVDC | - | |
| Voltage | 525 | 500 | 500 | 525 | kV | |
| Power/Rating | 1,713 | 1,712 | 1,712 | 1,713 | MW | |
| Circuit configuration | Bipole | DCST | Double circuit | Bipole | - | |
| Location | NSW | NSW | NSW | NSW | - | |
| Country | Australia | Australia | Australia | Australia | - | |
| Length | 399 | 67 | 44 | 166 | km | |
| Number of Reactor Stations | 0 | 0 | 0 | 0 | - | |
| Number of Transition Stations | 2 | 0 | 1 | 1 | - | |
| Number of Converter Stations | 2 | 0 | 0 | 2 | - | |
| **Cost Basis** | | | | | **Unit** | **Comments** |
| Labour | $ 1,544,000,000 | $ 113,100,000 | $ 205,500,000 | $ 147,300,000 | AUD | |
| Material | $ 1,160,000,000 | $ 32,830,000 | $ 154,400,000 | $ 110,600,000 | AUD | |
| Equipment | $ 988,700,000 | $ 16,420,000 | $ 330,800,000 | $ 94,310,000 | AUD | |
| Engineering & PM | $ 304,200,000 | $ 12,870,000 | $ 58,810,000 | $ 29,020,000 | AUD | |
| Pre-Construction | $ 253,100,000 | $ 33,490,000 | $ 46,590,000 | $ 24,140,000 | AUD | |
| Distribs | $ 182,300,000 | $ 13,780,000 | $ 42,030,000 | $ 26,750,000 | AUD | |
| Allowances | $ 93,920,000 | $ 7,097,000 | $ 21,650,000 | $ 13,780,000 | AUD | |
| **Additional Allowances** | | | | | **Unit** | **Comments** |
| Biodiversity Offset Cost | $ 209,700,000 | $ 140,200,000 | $ 32,850,000 | $ 352,200,000 | AUD | |
| Land Offset Costs | $ 47,660,000 | $ 31,870,000 | $ 7,465,000 | $ 80,040,000 | AUD | |
| Reactor Stations | $ - | $ - | $ - | $ - | AUD | |
| Transition Stations | $ 11,420,000 | $ - | $ 1,000,000 | $ 5,712,000 | AUD | |
| Converter Stations | $ 1,323,000,000 | $ - | $ - | $ 1,323,000,000 | AUD | |
| **Footprints** | | | | | **Unit** | **Comments** |
| Reactor Station | - | - | - | - | m2 | Per station |
| Transition Station | 100 | - | 100 | 100 | m2 | Per station |
| Converter Station | 84,000 | - | - | 84,000 | m2 | Per station |
| Reactor Station | - | - | - | - | m2 | Total footprint |
| Transition Station | 200 | - | 100 | 100 | m2 | Total footprint |
| Converter Station | 168,000 | - | - | 168,000 | m2 | Total footprint |

## 4.4.2 Option 3B-3

Terrain factors applied to Option 3B-3 are as displayed below:

*Table 4.16 Option 3A-3 Terrain Factors*

| Terrain Factor | Clearing | Geotech | Topography | Easement Access |
|---|---|---|---|---|
| **Difficulty** | Easy | Medium | Medium | Medium |

The cost estimate for the preferred solution, Option 3B-3, is summarised in Table 4.17

*Table 4.17 Option 3B-3 cost estimate*

**Case Scenario Capex Report**

| | | |
|---|---|---|
| **Project** | Hume Link - Underground Options Comparative Estimates | |
| **Project Variant** | 3B-3 | |
| **Capex Total** | $ 7,464,000,000 | AUD |
| **Transmission Line Capex** | $ 4,826,000,000 | AUD |

| Tranmission Cable | TC1 | TC2 | TC3 | TC4 | | |
|---|---|---|---|---|---|---|
| **Capital Cost** | | | | | **Unit** | **Comments** |
| Subtotal | $ 4,863,000,000 | $ 338,300,000 | $ 625,600,000 | $ 1,637,000,000 | AUD | All in costs (including |
| Installed Rate per km | $ 12,200,000 | $ 5,042,000 | $ 14,220,000 | $ 9,857,000 | AUD/km | offsets, convertor stations, |
| Installed Cost per km/MW | $ 9,495 | $ 3,924 | $ 11,060 | $ 7,671 | AUD/km/MW | reactor stations and |
| Subtotal | $ 3,752,000,000 | $ 166,200,000 | $ 581,300,000 | $ 326,700,000 | AUD | Excludes offsets, convertor |
| Installed Rate per km | $ 9,412,000 | $ 2,477,000 | $ 13,210,000 | $ 1,967,000 | AUD/km | stations, reactor stations |
| Installed Cost per km/MW | $ 7,325 | $ 1,928 | $ 10,280 | $ 1,531 | AUD/km/MW | and UGOHs |
| **Line Design** | | | | | **Unit** | **Comments** |
| HVAC/HVDC | HVDC direct buried cable | HVAC | HVAC duct bank cable | HVDC | - | |
| Voltage | 400 | 500 | 500 | 400 | kV | |
| Power/Rating | 1,285 | 1,285 | 1,285 | 1,285 | MW | |
| Circuit configuration | Symmetrical Monopole | SCST | Single circuit | Symmetrical Monopo | - | |
| Location | NSW | NSW | NSW | NSW | - | |
| Country | Australia | Australia | Australia | Australia | - | |
| Length | 399 | 67 | 44 | 166 | km | |
| Number of Reactor Stations | 0 | 0 | 0 | 0 | - | |
| Number of Transition Stations | 2 | 0 | 1 | 1 | - | |
| Number of Converter Stations | 2 | 0 | 2 | 2 | - | |
| **Cost Basis** | | | | | **Unit** | **Comments** |
| Labour | $ 1,280,000,000 | $ 69,900,000 | $ 111,800,000 | $ 107,900,000 | AUD | |
| Material | $ 961,500,000 | $ 20,220,000 | $ 83,990,000 | $ 81,060,000 | AUD | |
| Equipment | $ 819,600,000 | $ 15,280,000 | $ 202,600,000 | $ 69,100,000 | AUD | |
| Engineering & PM | $ 252,200,000 | $ 11,450,000 | $ 74,110,000 | $ 21,260,000 | AUD | |
| Pre-Construction | $ 209,800,000 | $ 34,260,000 | $ 65,760,000 | $ 17,690,000 | AUD | |
| Distribs | $ 151,100,000 | $ 9,973,000 | $ 28,420,000 | $ 19,600,000 | AUD | |
| Allowances | $ 77,850,000 | $ 5,138,000 | $ 14,640,000 | $ 10,100,000 | AUD | |
| **Additional Allowances** | | | | | **Unit** | **Comments** |
| Biodiversity Offset Cost | $ 183,400,000 | $ 140,200,000 | $ 35,320,000 | $ 349,600,000 | AUD | |
| Land Offset Costs | $ 41,680,000 | $ 31,870,000 | $ 8,027,000 | $ 79,460,000 | AUD | |
| Reactor Stations | $ - | $ - | $ - | $ - | AUD | |
| Transition Stations | $ 10,200,000 | $ - | $ 1,000,000 | $ 5,100,000 | AUD | |
| Converter Stations | $ 876,400,000 | $ - | $ - | $ 876,400,000 | AUD | |
| **Footprints** | | | | | **Unit** | **Comments** |
| Reactor Station | - | - | - | - | m2 | Per station |
| Transition Station | 100 | - | 100 | 100 | m2 | Per station |
| Converter Station | 41,400 | - | 41,400 | 41,400 | m2 | Per station |
| Reactor Station | - | - | - | - | m2 | Total footprint |
| Transition Station | 200 | - | 100 | 100 | m2 | Total footprint |
| Converter Station | 82,800 | - | 82,800 | 82,800 | m2 | Total footprint |

# 4.5 Option 4

## 4.5.1 Option 4A-5

Terrain factors applied to Option 4A-5 are as displayed below:

*Table 4.18 Option 4A-5 Terrain Factors*

| Terrain Factor | Clearing | Geotech | Topography | Easement Access |
|---|---|---|---|---|
| Difficulty – Gugaa - Maragle | Easy | Medium | Medium | Medium |
| Difficulty – Bannaby - Maragle | Easy | Easy | Easy | Easy |

The cost estimate for the preferred solution, Option 4A-5, is summarised in Table 4.19.

*Table 4.19 Option 4A-5 cost estimate*

**Case Scenario Capex Report**

| | | |
|---|---|---|
| **Project** | Hume Link - Underground Options Comparative Estimates | |
| **Project Variant** | 4A-5 | |
| **Capex Total** | $ 11,450,000,000 | AUD |
| **Transmission Line Capex** | $ 8,439,000,000 | AUD |

| Tranmission Cable | TC1 | TC2 | TC3 | | |
|---|---|---|---|---|---|
| **Capital Cost** | | | | **Unit** | **Comments** |
| Subtotal | $ 8,952,000,000 | $ 1,989,000,000 | $ 511,400,000 | AUD | All in costs (including offsets, convertor stations, reactor stations and UGOHs) |
| Installed Rate per km | $ 14,350,000 | $ 20,260,000 | $ 4,237,000 | AUD/km | |
| Installed Cost per km/MW | $ 8,375 | $ 11,830 | $ 4,949 | AUD/km/MW | |
| Subtotal | $ 6,340,000,000 | $ 1,897,000,000 | $ 201,800,000 | AUD | Excludes offsets, convertor stations, reactor stations and UGOHs |
| Installed Rate per km | $ 10,160,000 | $ 19,320,000 | $ 1,672,000 | AUD/km | |
| Installed Cost per km/MW | $ 5,931 | $ 11,290 | $ 1,953 | AUD/km/MW | |
| **Line Design** | | | | **Unit** | **Comments** |
| HVAC/HVDC | HVDC direct buried cable | HVAC duct bank cable | HVAC | - | |
| Voltage | 525 | 500 | 500 | kV | |
| Power/Rating | 1,713 | 1,712 | 856 | MW | |
| Circuit configuration | Bipole | Double circuit | DCST | - | |
| Location | NSW | NSW | NSW | - | |
| Country | Australia | Australia | Australia | - | |
| Length | 624 | 98 | 121 | km | |
| Number of Reactor Stations | 0 | 0 | 0 | - | |
| Number of Transition Stations | 0 | 2 | 0 | - | |
| Number of Converter Stations | 4 | 2 | 0 | - | |
| **Cost Basis** | | | | **Unit** | **Comments** |
| Labour | $ 1,816,000,000 | $ 458,400,000 | $ 58,900,000 | AUD | |
| Material | $ 1,816,000,000 | $ 344,400,000 | $ 14,760,000 | AUD | |
| Equipment | $ 1,548,000,000 | $ 738,100,000 | $ 29,530,000 | AUD | |
| Engineering & PM | $ 476,200,000 | $ 131,200,000 | $ 19,990,000 | AUD | |
| Pre-Construction | $ 297,700,000 | $ 109,200,000 | $ 60,240,000 | AUD | |
| Distribs | $ 255,400,000 | $ 76,420,000 | $ 12,110,000 | AUD | |
| Allowances | $ 131,600,000 | $ 39,370,000 | $ 6,237,000 | AUD | |
| **Additional Allowances** | | | | **Unit** | **Comments** |
| Biodiversity Offset Cost | $ 330,500,000 | $ 73,280,000 | $ 252,300,000 | AUD | |
| Land Offset Costs | $ 75,110,000 | $ 16,660,000 | $ 57,330,000 | AUD | |
| Reactor Stations | $ - | $ - | $ - | AUD | |
| Transition Stations | $ - | $ 2,000,000 | $ - | AUD | |
| Converter Stations | $ 2,207,000,000 | $ - | $ - | AUD | |
| **Footprints** | | | | **Unit** | **Comments** |
| Reactor Station | - | - | - | m2 | Per station |
| Transition Station | - | 100 | - | m2 | Per station |
| Converter Station | 84,000 | - | - | m2 | Per station |
| Reactor Station | - | - | - | m2 | Total footprint |
| Transition Station | - | 200 | - | m2 | Total footprint |
| Converter Station | 336,000 | - | - | m2 | Total footprint |

## 4.5.2 Option 4B-5

Terrain factors applied to Option 4B-5 are as displayed below:

*Table 4.20 Option 4B-5 Terrain Factors*

| Terrain Factor | Clearing | Geotech | Topography | Easement Access |
|---|---|---|---|---|
| **Difficulty – Gugaa - Maragle** | Easy | Medium | Medium | Medium |
| **Difficulty – Bannaby - Maragle** | Easy | Easy | Easy | Easy |

The cost estimate for the preferred solution, Option 4B-5, is summarised in Table 4.21.

*Table 4.21 Option 4B-5 cost estimate*

**Case Scenario Capex Report**

| | | |
|---|---|---|
| **Project** | Hume Link - Underground Options Comparative Estimates | |
| **Project Variant** | 4B-5 | |
| **Capex Total** | $ 9,053,000,000 | AUD |
| **Transmission Line Capex** | $ 6,836,000,000 | AUD |

| **Tranmission Cable** | **TC1** | **TC2** | **TC3** | | |
|---|---|---|---|---|---|
| **Capital Cost** | | | | **Unit** | **Comments** |
| Subtotal | $ 7,069,000,000 | $ 1,373,000,000 | $ 608,600,000 | AUD | All in costs (including offsets, convertor stations, reactor stations and UGOHs) |
| Installed Rate per km | $ 11,330,000 | $ 13,980,000 | $ 5,042,000 | AUD/km | |
| Installed Cost per km/MW | $ 8,816 | $ 10,880 | $ 3,924 | AUD/km/MW | |
| Subtotal | $ 5,256,000,000 | $ 1,281,000,000 | $ 299,000,000 | AUD | Excludes offsets, convertor stations, reactor stations and UGOHs |
| Installed Rate per km | $ 8,423,000 | $ 13,050,000 | $ 2,477,000 | AUD/km | |
| Installed Cost per km/MW | $ 6,555 | $ 10,150 | $ 1,928 | AUD/km/MW | |
| **Line Design** | | | | **Unit** | **Comments** |
| HVAC/HVDC | HVDC direct buried cable | HVAC duct bank cabl | HVAC | - | |
| Voltage | 400 | 500 | 500 | kV | |
| Power/Rating | 1,285 | 1,285 | 1,285 | MW | |
| Circuit configuration | Symmetrical Monopole | Single circuit | SCST | - | |
| Location | NSW | NSW | NSW | - | |
| Country | Australia | Australia | Australia | - | |
| Length | 624 | 98 | 121 | km | |
| Number of Reactor Stations | 0 | 0 | 0 | - | |
| Number of Transition Stations | 0 | 2 | 0 | - | |
| Number of Converter Stations | 4 | 0 | 0 | - | |
| **Cost Basis** | | | | **Unit** | **Comments** |
| Labour | $ 1,505,000,000 | $ 308,100,000 | $ 125,700,000 | AUD | |
| Material | $ 1,505,000,000 | $ 231,500,000 | $ 36,380,000 | AUD | |
| Equipment | $ 1,283,000,000 | $ 496,000,000 | $ 27,490,000 | AUD | |
| Engineering & PM | $ 394,800,000 | $ 88,180,000 | $ 20,590,000 | AUD | |
| Pre-Construction | $ 246,700,000 | $ 73,360,000 | $ 61,630,000 | AUD | |
| Distribs | $ 211,700,000 | $ 55,310,000 | $ 17,940,000 | AUD | |
| Allowances | $ 109,100,000 | $ 28,490,000 | $ 9,242,000 | AUD | |
| **Additional Allowances** | | | | **Unit** | **Comments** |
| Biodiversity Offset Cost | $ 288,100,000 | $ 73,280,000 | $ 252,300,000 | AUD | |
| Land Offset Costs | $ 65,480,000 | $ 16,660,000 | $ 57,330,000 | AUD | |
| Reactor Stations | $ - | $ - | $ - | AUD | |
| Transition Stations | $ - | $ 2,000,000 | $ - | AUD | |
| Converter Stations | $ 1,460,000,000 | $ - | $ - | AUD | |
| **Footprints** | | | | **Unit** | **Comments** |
| Reactor Station | - | - | - | m2 | Per station |
| Transition Station | - | 100 | - | m2 | Per station |
| Converter Station | 41,400 | - | - | m2 | Per station |
| Reactor Station | - | - | - | m2 | Total footprint |
| Transition Station | - | 200 | - | m2 | Total footprint |
| Converter Station | 165,600 | - | - | m2 | Total footprint |

### 4.5.3 Option 4C-2

Terrain factors applied to Option 4C-2 are as displayed below:

*Table 4.22 Option 4C-2 Terrain Factors*

| Terrain Factor | Clearing | Geotech | Topography | Easement Access |
|---|---|---|---|---|
| Difficulty – Gugaa - Maragle | Easy | Medium | Medium | Medium |
| Difficulty – Bannaby - Maragle | Easy | Easy | Easy | Easy |

The cost estimate for the preferred solution, Option 4C-2, is summarised in Table 4.23

*Table 4.23 Option 4C-2 cost estimate*

| Case Scenario Capex Report | | |
|---|---|---|
| Project | Hume Link - Underground Options Comparative Estimates | |
| Project Variant | 4C-2 | |
| Capex Total | $ 10,420,000,000 | AUD |
| Transmission Line Capex | $ 7,587,000,000 | AUD |

| Tranmission Cable | TC1 | TC2 | TC3 | | |
|---|---|---|---|---|---|
| **Capital Cost** | | | | **Unit** | **Comments** |
| Subtotal | $ 7,809,000,000 | $ 1,989,000,000 | $ 616,600,000 | AUD | All in costs (including offsets, convertor stations, reactor stations |
| Installed Rate per km | $ 12,510,000 | $ 20,260,000 | $ 5,109,000 | AUD/km | |
| Installed Cost per km/MW | $ 6,692 | $ 10,830 | $ 2,732 | AUD/km/MW | |
| Subtotal | $ 5,383,000,000 | $ 1,897,000,000 | $ 307,000,000 | AUD | Excludes offsets, convertor stations, reactor stations and UGOHs |
| Installed Rate per km | $ 8,627,000 | $ 19,320,000 | $ 2,544,000 | AUD/km | |
| Installed Cost per km/MW | $ 4,613 | $ 10,330 | $ 1,360 | AUD/km/MW | |
| **Line Design** | | | | **Unit** | **Comments** |
| HVAC/HVDC | HVDC direct buried cable | HVAC duct bank cable | HVAC | - | |
| Voltage | 525 | 500 | 500 | kV | |
| Power/Rating | 1,870 | 1,870 | 1,870 | MW | |
| Circuit configuration | Symmetrical Monopole | Double circuit | SCST | - | |
| Location | NSW | NSW | NSW | - | |
| Country | Australia | Australia | Australia | - | |
| Length | 624 | 98 | 121 | km | |
| Number of Reactor Stations | 0 | 0 | 0 | - | |
| Number of Transition Stations | 0 | 2 | 0 | - | |
| Number of Converter Stations | 4 | 0 | 0 | - | |
| **Cost Basis** | | | | **Unit** | **Comments** |
| Labour | $ 1,542,000,000 | $ 458,400,000 | $ 121,900,000 | AUD | |
| Material | $ 1,542,000,000 | $ 344,400,000 | $ 30,090,000 | AUD | |
| Equipment | $ 1,314,000,000 | $ 738,100,000 | $ 37,770,000 | AUD | |
| Engineering & PM | $ 404,400,000 | $ 131,200,000 | $ 25,110,000 | AUD | |
| Pre-Construction | $ 252,700,000 | $ 109,200,000 | $ 64,310,000 | AUD | |
| Distribs | $ 216,800,000 | $ 76,420,000 | $ 18,420,000 | AUD | |
| Allowances | $ 111,700,000 | $ 39,370,000 | $ 9,491,000 | AUD | |
| **Additional Allowances** | | | | **Unit** | **Comments** |
| Biodiversity Offset Cost | $ 330,500,000 | $ 73,280,000 | $ 252,300,000 | AUD | |
| Land Offset Costs | $ 75,110,000 | $ 16,660,000 | $ 57,330,000 | AUD | |
| Reactor Stations | $ - | $ - | $ - | AUD | |
| Transition Stations | $ - | $ 2,000,000 | $ - | AUD | |
| Converter Stations | $ 2,020,000,000 | $ - | $ - | AUD | |
| **Footprints** | | | | **Unit** | **Comments** |
| Reactor Station | - | - | - | m2 | Per station |
| Transition Station | - | 100 | - | m2 | Per station |
| Converter Station | 84,000 | - | - | m2 | Per station |
| Reactor Station | - | - | - | m2 | Total footprint |
| Transition Station | - | 200 | - | m2 | Total footprint |
| Converter Station | 336,000 | - | - | m2 | Total footprint |

# 4.6 330kV from Gugaa to Wagga Wagga

The cost estimate for the 330kV line from Gugaa to Wagga Wagga is summarised in Table 4.24.

*Table 4.24 Gugaa to Wagga Wagga*

| | | |
|---|---|---|
| **Case Scenario Capex Report** | | |
| **Project** | Hume Link - Underground Options Comparative Estimates | |
| **Project Variant** | 330kV - Gugaa to Wagga Wagga | |
| **Capex Total** | $ 753,957,497 | AUD |
| **Transmission Line Capex** | $ 726,475,355 | AUD |

| **Tranmission Cable** | **TC1** | **TC2** | | |
|---|---|---|---|---|
| **Capital Cost** | | | **Unit** | **Comments** |
| Subtotal | $ 376,978,749 | $ 376,978,749 | AUD | All in costs (including offsets, convertor stations, reactor stations and UGOHs) |
| Installed Rate per km | $ 25,131,917 | $ 25,131,917 | AUD/km | |
| Installed Cost per km/MW | $ 10,053 | $ 10,053 | AUD/km/MW | |
| Subtotal | $ 363,237,677 | $ 363,237,677 | AUD | Excludes offsets, convertor stations, reactor stations and UGOHs |
| Installed Rate per km | $ 24,215,845 | $ 24,215,845 | AUD/km | |
| Installed Cost per km/MW | $ 9,686 | $ 9,686 | AUD/km/MW | |
| **Line Design** | | | **Unit** | **Comments** |
| HVAC/HVDC | HVAC direct buried cable | HVAC direct buried cable | - | |
| Voltage | 330 | 330 | kV | |
| Power/Rating | 2,500 | 2,500 | MW | |
| Circuit configuration | Single circuit | Single circuit | - | |
| Location | NSW | NSW | - | |
| Country | Australia | Australia | - | |
| Length | 15 | 15 | km | |
| **Cost Basis** | | | **Unit** | **Comments** |
| Labour | $ 106,054,286 | $ 106,054,286 | AUD | |
| Materials | $ 98,507,347 | $ 98,507,347 | AUD | |
| Plant & Equip | $ 81,851,342 | $ 81,851,342 | AUD | |
| Engineering & PM | $ 23,911,618 | $ 23,911,618 | AUD | |
| Pre-Construction | $ 19,891,477 | $ 19,891,477 | AUD | |
| Distribs | $ 21,794,261 | $ 21,794,261 | AUD | |
| Allowances | $ 11,227,346 | $ 11,227,346 | AUD | |
| **Additional Allowances** | | | **Unit** | **Comments** |
| Biodiversity Offset Cost | $ 11,196,429 | $ 11,196,429 | AUD | |
| Land Offset Costs | $ 2,544,643 | $ 2,544,643 | AUD | |

# 5. Schedule

## 5.1 Schedule basis

The concept schedules are split into 4 items, these being "Procurement", "Civil", "Installation" and "Commissioning". Durations have been calculated on information received from contractors on other projects. The logic used in determining the schedule assumes:

- Cable installation lags civil installation, commencing progressively as sections of civil installation completed
  - Overall cable installation completion lags civil installation completion by approximately 12 months
- Construction durations do not allow for any hold points or forced majeure delays
- Constructions durations are based on:
  - 20 trenching and civil crews working 6 days per week, per circuit
  - 5 cable install and jointing crews working 6 days per week, per circuit
  - All 3 circuits are constructed concurrently

The schedule could be accelerated but should be discussed with experienced contractors capable of delivering projects of this size. However, the local market may have insufficient resources and the project may need to investigate sourcing labour and equipment internationally to accelerate the timeline. Competing projects in the region may prevent acceleration and/or create cost pressures due to resource shortages. It is recommended that a contracting strategy is developed early on to ensure there is a sufficient pool of contractors to deliver this major project on schedule and cost effectively.

Specific assumptions made for the Options 2, 3, and 4 schedules are as follows:

- Project schedule for overhead transmission line portions were not included. It was assumed that the overhead transmission lines would be installed in parallel with the cable works and that it would not impact the overall schedule.
- Procurement includes:
  - System studies – approximately 6 months duration.
  - Development of technical specification – approximately 6 months duration.
  - Preparation of bids by suppliers – approximately 4 months duration.
  - Bid evaluation / negotiations / contract award – approximately 2 months duration.
- Cable manufacturing:
  - Assumed no pre-qualification or Type testing would be required for DC cables (i.e., test certificates would already be available for the project cable ratings).
  - Assumed that cable supplier factories are available and not fully booked on other projects.
  - Assumed one factory can produce approximately 200 km of cable/year.
  - For HVDC bipole configurations, assumed the pole cables would be manufactured on vertical continuous vulcanizing (VCV) extrusion line whereas the dedicated metallic return cable would be manufactured on a catenary continuous vulcanizing (CCV) line at a much faster rate, thereby not impacting the project schedule.
  - Assumed two factories would manufacture cable for the following options: 2A-1, 2B-1, 3A-3, 3B-3, 4A-5, 4B-5, 4C-1.

– DC cable installation works for Options 2A-1, 2B-1, 3A-3, 3B-3, 4A-5, 4B-5, 4C-1:
  - Cables installed by direct burial (civil and electrical works combined).
  - Direct burial rate of 1.5 circuit km / month / installation crew. Assumed 10 installation crews working in parallel on various route sections.
  - Land joint assembly of approximately 1 week to install joints per location (including set up and take down). Assumed 5 jointing crews working in parallel with cable installation works.
  - Termination assembly of approximately 1 week to install terminations per location. Assumed 4 termination crews working in parallel with cable installation works.

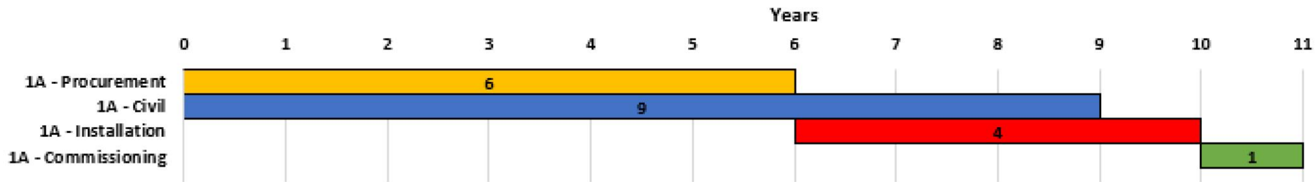
– Transportation of DC cable to site:
  - Duration depends on the cable factory location.

– Assumed that cable manufacturing, transportation to site, and installation would be done in parallel for various cable lots.

– Project duration for configurations with 4 converter stations was assumed to be 4.5 years from contract award to commercial operation. Project duration for configurations with 6 converter stations was assumed to be 5.5 years from contract award to commercial operation.
  - Commissioning times have been allowed to accommodate the complexity of the systems.

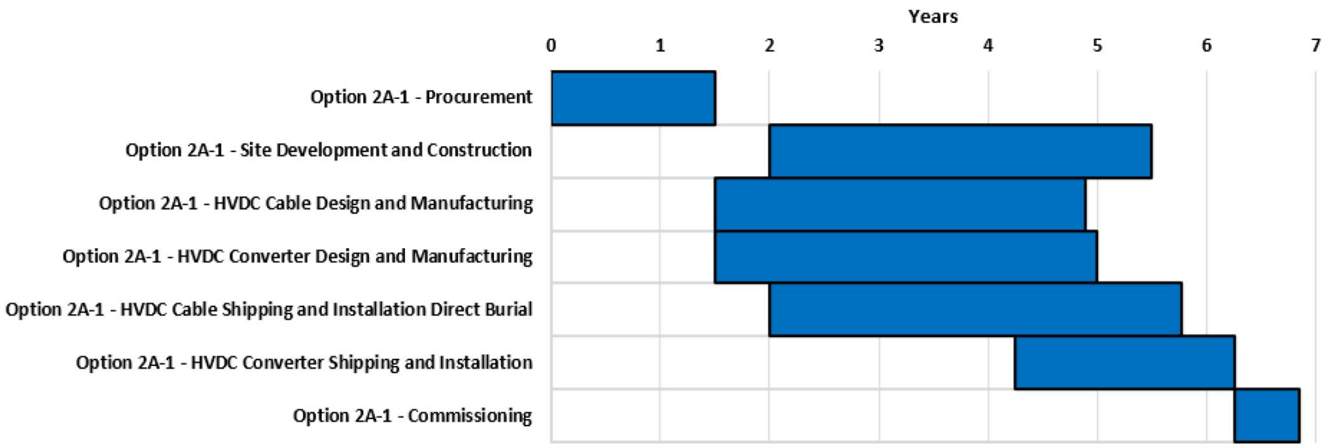
Section 5.2 through to **Error! Reference source not found.** outline the schedule breakdown for each of the preferred options.

# 5.2 Option 1A

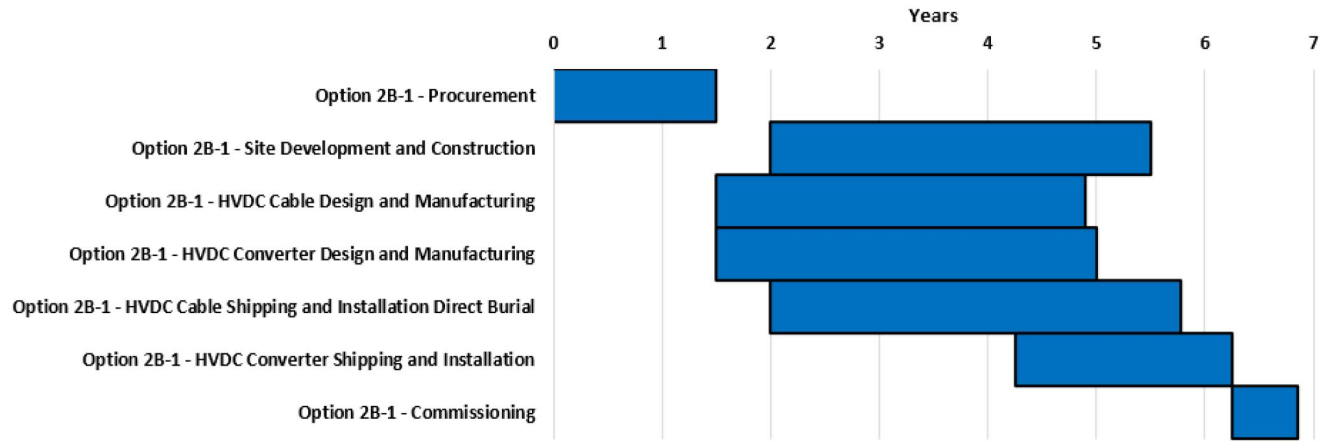



# 5.3 Option 2

## 5.3.1 Option 2A-1

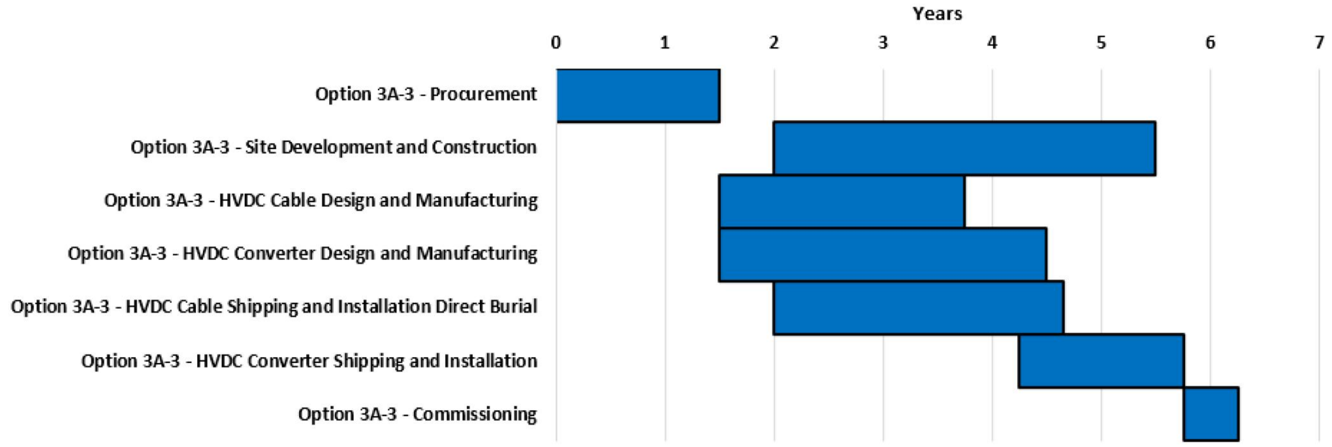


### 5.3.2 Option 2B-1

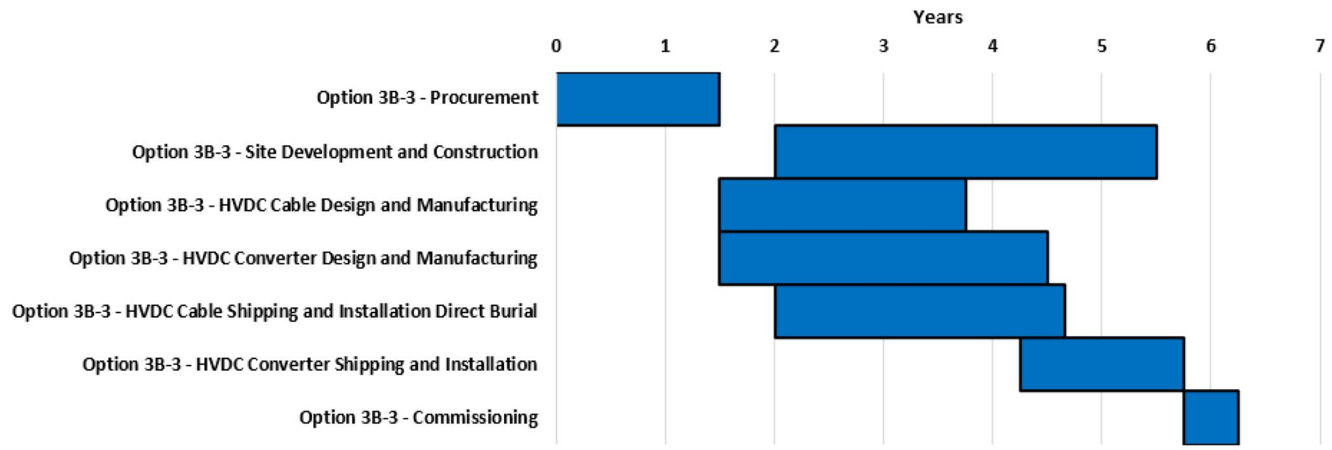



## 5.4 Option 3

### 5.4.1 Option 3A-3

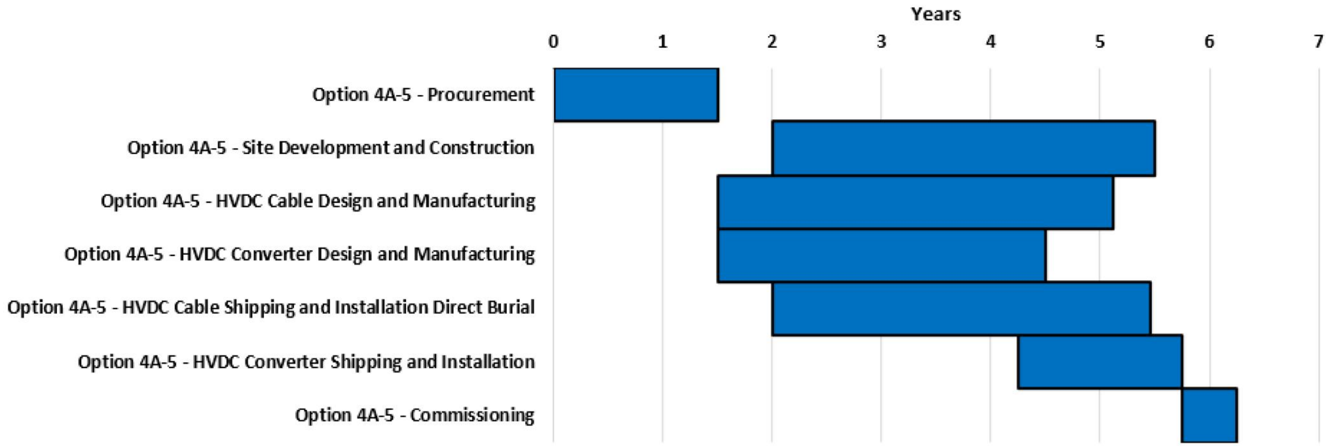



### 5.4.2 Option 3B-3

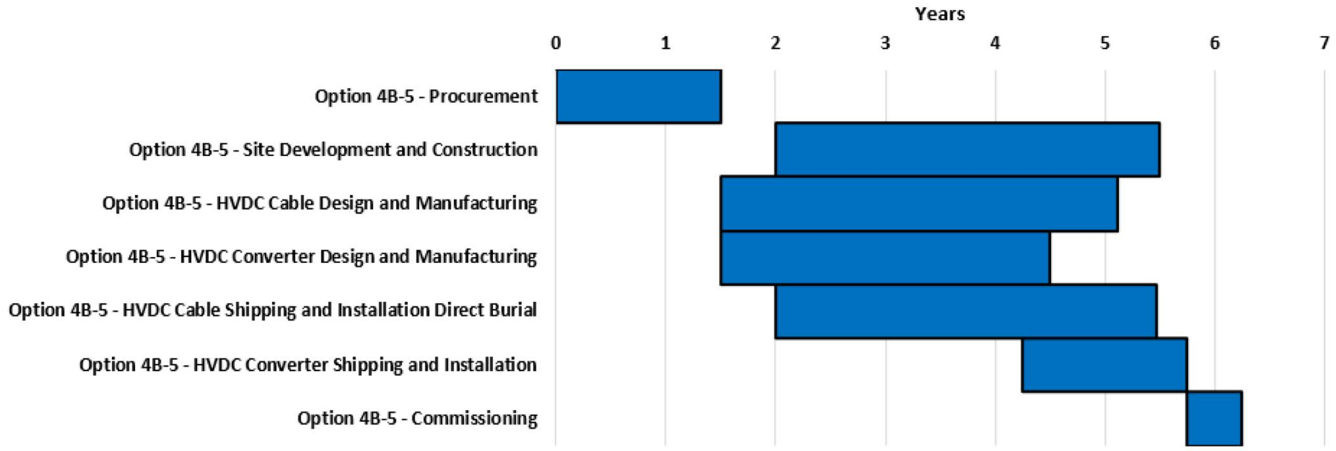


## 5.5 Option 4

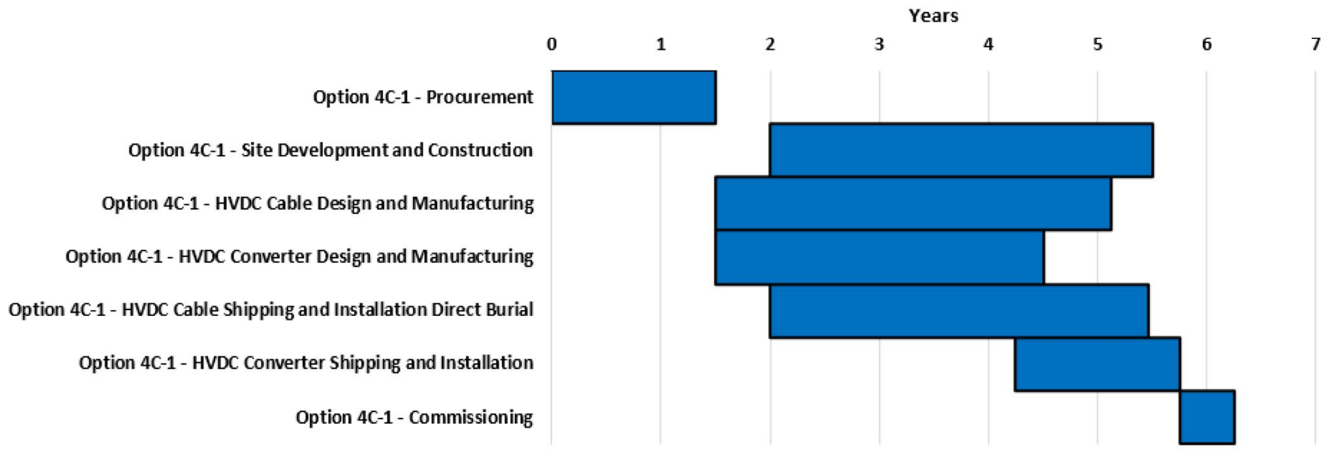
### 5.5.1 Option 4A-5




### 5.5.2 Option 4B-5




### 5.5.3 Option 4C-2



## 5.6 Overhead Line Option

The OHL option developed by Transgrid estimated a schedule of 4-5 years.

# 6. Non-market Benefits Comparison Table

Some of the environmental, agricultural, operational and construction, non-market benefits are discussed for each of the 8 preferred options and the Overhead line option in Table 6.1 to Table 6.10

*Table 6.1 Comparison table Environmental/agriculture community benefits – Environmental Impact*

| Attribute | Overhead Line Option | Option 1 | Option 2A-1 and Option 2B-1 | Option 3A-3 and Option 3B-3 | Option 4A-5, Option 4B-5 and Option 4C-2 |
|---|---|---|---|---|---|
| Environmental Impact (Post Construction) | **Positives:**<br>The route selected has a low likelihood of impacting known areas of very high indigenous values (AHIMS sites) or known historical heritage items.<br><br>**Negatives:**<br>Greater ongoing, routine operational and maintenance impacts will occur within overhead sections to ensure safe access for infrastructure maintenance and to avoid encroachment of vegetation.<br><br>Greater likelihood of direct and indirect impacts to fauna with overhead transmission due to collision with lines, habitat fragmentation or degradation due to ongoing maintenance of the easement. | **Positives:**<br>There will be low ongoing operation and maintenance impacts (e.g., vegetation clearing) due to undergrounding unless a fault occurs.<br><br>The route selected has a low likelihood of impacting known areas of very high indigenous values (AHIMS sites) or known historical heritage items. | **Positives:**<br>There will be low ongoing operation and maintenance impacts (e.g., vegetation clearing) due to undergrounding unless a fault occurs.<br><br>The route selected has a low likelihood of impacting known areas of very high indigenous values (AHIMS sites) or known historical heritage items. | **Positives:**<br>The route selected has a low likelihood of impacting known areas of very high indigenous values (AHIMS sites) or known historical heritage items.<br><br>Underground sections will have low ongoing operation and maintenance impacts (e.g., vegetation clearing) unless a fault occurs.<br><br>**Negatives:**<br>Greater ongoing, routine operational and maintenance impacts will occur within overhead sections to ensure safe access for infrastructure maintenance and to avoid encroachment of vegetation.<br><br>Greater likelihood of direct and indirect impacts to fauna with overhead transmission due to collision with lines, habitat fragmentation or degradation due to ongoing maintenance of the easement.<br><br>This route has a higher proportion of bushfire prone land in overhead sections, increasing the risk of fire spread within the State Forest and National Park<br><br>The optimal route traverse's high biodiversity value landscape containing threatened species (National Park) which could be directly or indirectly impacted.<br><br>This option has the largest potential for construction noise, air quality, and light to disturb fauna within the State Forest and National Park.<br><br>**Opportunities for impact reduction:**<br>There is an opportunity to span overhead lines across ridge tops, reducing impacts to biodiversity. | **Positives:**<br>Underground sections will have low ongoing operation and maintenance impacts (e.g., vegetation clearing) unless a fault occurs.<br><br>The route selected Utilises existing highway corridors which reduces environmental impacts. Least potential for construction noise, air quality, and light to disturb fauna due to use of existing highway route.<br><br>**Negatives:**<br>Greater ongoing, routine operational and maintenance impacts will occur within overhead sections to ensure safe access for infrastructure maintenance and to avoid encroachment of vegetation.<br><br>Greater likelihood of direct and indirect impacts to fauna with overhead transmission due to collision with lines, habitat fragmentation or degradation due to ongoing maintenance of the easement.<br><br>Largest number of Aboriginal and non-aboriginal heritage constraints occur along the highway route.<br>Greater potential exposure of contaminated soils while trenching due to historical land use. |

*Table 6.2 Comparison table Environmental/agriculture community benefits – Productive efficiency of Agriculture and Communities*

| Attribute | Overhead Line Option | Option 1, Option 2A-1 and Option 2B-1 | Option 3A-3, Option 3B-3, Option 4A-5, Option 4B-5 and Option 4C-2 |
|---|---|---|---|
| Productive efficiency of agriculture and communities (Post Construction) | **Positives:**<br>Opportunity to use land for cropping within the easement<br><br>**Negatives:**<br>Aerial spraying: Powerlines pose a significant risk to aerial spraying.<br><br>Removal of agricultural land from production for converter stations, transition stations and transmission towers.<br><br>Machinery height restrictions apply when moving under the OHL<br><br>Earthing requirements for metallic structures adjacent to the OHL for example fences, sheds. | **Positives:**<br>Reduction in visual impact to agricultural land due to undergrounding.<br><br>**Negatives:**<br>Soil compaction: Re-filling the diggings and use of machinery may cause changes to the ideal soil compaction – creating reduced land capability if not addressed.<br><br>Buried at depth: Depending on the depth, there could be a significant safety risk for farm workers who plan on increasing efficiency through large capital works e.g., digging dams/bore holes.<br><br>Limiting the future use of land: The land may be marked for future construction, mining or capital works that would no longer be possible.<br>Limited or conditional opportunity to use land for cropping within the easement<br>Biosecurity: The digging and implementation throughout the project would mean dealing with soil stockpiles and machinery moving between properties – posing a significant risk to the spread of weeds, pests or diseases causing increased management costs and/or loss of production. | The underground impacts will be the same as those discussed in option 1. The overhead benefits are detailed below.<br><br>**Positives:**<br>Opportunity to use land for cropping within the easement<br><br>**Negatives:**<br>Aerial spraying: Powerlines pose a significant constraint to aerial spraying.<br><br>Removal of agricultural land from production for converter stations, transition stations and transmission towers.<br><br>Machinery height restrictions apply when moving under the OHL<br><br>Earthing requirements for metallic structures adjacent to the OHL for example fences, sheds. |

*Table 6.3 Comparison table Environmental/agricultural community benefits – Electromagnetic Fields and Electromagnetic Compatibility*

| Attribute | Overhead Line Option | Option 1 | Option 2A-1 and 2B-1 | Option 3A-3 and Option 3B-3 | Option 4A-5, Option 4B-5 and Option 4C-2 |
|---|---|---|---|---|---|
| Electromagnetic fields (EMF) and electromagnetic compatibility (EMC) Impacts. Including the assessment of exposure, taking into account limits for static. (Post Construction)<br>Note: Overhead lines are a source of two fields: the electric field (produced by the voltage) and the magnetic field (produced by the current). Underground cables eliminate the electric field altogether as it is screened out by the sheath around the cable, but they still produce magnetic fields.<br><br>Cables are typically installed 1m below ground, whereas the conductors of an overhead line are typically more than 10m above ground, so the magnetic field directly above such a cable is usually higher than that directly below the equivalent overhead line. However, as the individual cables are installed much closer together than the conductors of an overhead line, this results in the magnetic field from cables falling more quickly with distance than the magnetic field from overhead lines.<br><br>*ICNIRP (International Commission on Non-Ionizing Radiation Protection) | **Negatives:**<br>High time varying electric and magnetic fields are present beneath overhead AC line sections.<br>Study required to confirm compliance with applicable standards and guidelines. | **Positives:**<br>Time varying magnetic fields above AC cable routes are lower than overhead equivalent arrangement, and time varying electric fields are contained within cable and are lower than overhead equivalent arrangement.<br><br>. | **Positives:**<br>Static magnetic fields from DC cables are typically within the same range as the earth's magnetic fields. Static electric fields from DC cables are blocked by the cable's metallic sheath.<br>Static magnetic field limits are significant multiples of any limits for time varying electric and magnetic fields – General public limits for DC static magnetic fields are 400 mT (ICNIRP 2009), whereas general public limits for 50 HZ AC magnetic fields are 0.2 mT (ICNIRP 2010). | **Positives:**<br>AC Underground: sections share the same positives as Option 1.<br><br>DC OH line section: Magnetic fields below DC OH lines are more favourable than AC OH Lines - less likely to induce hazardous charge in metallic objects below lines.<br><br>DC Underground: Static magnetic fields from DC cables are typically within the same range as the earth's magnetic fields. Static electric fields from DC cables are blocked by the cable's metallic sheath.<br>Static magnetic fields above DC cable routes have less onerous safety limits than time-varying (AC) equivalent arrangement.<br><br>For OH and underground arrangements, static magnetic field limits are significant multiples of any limits for time varying electric and magnetic fields – General public limits for DC static magnetic fields are 400 mT (ICNIRP 2009), whereas general public limits for 50 HZ AC magnetic fields are 0.2 mT (ICNIRP 2010).<br><br>**Negatives:**<br>High time varying electric and magnetic fields are present beneath overhead AC line sections. | **Positives:**<br>Underground sections share the same positives as Option 1.<br><br>DC Underground: Static magnetic fields from DC cables are typically within the same range as the earth's magnetic fields. Static electric fields from DC cables are blocked by the cable's metallic sheath.<br>Static magnetic fields above DC cable routes have less onerous safety limits than time-varying (AC) equivalent arrangement.<br><br>For OH and underground arrangements, static magnetic field limits are significant multiples of any limits for time varying electric and magnetic fields – General public limits for DC static magnetic fields are 400 mT (ICNIRP 2009), whereas general public limits for 50 HZ AC magnetic fields are 0.2 mT (ICNIRP 2010).<br><br>**Negatives:**<br>High time varying electric and magnetic fields are present beneath overhead AC line sections.<br>Study required to confirm compliance with applicable standards and guidelines. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | Study required to confirm compliance with applicable standards and guidelines.<br><br>Corona discharge around DC OH lines less favourable than AC OH lines, increasing noise, and interference to TV and radio signals. | |

*Table 6.4 Comparison table Environmental/agricultural community benefits – Community Benefits*

| Attribute | Overhead Line Option | Option 1 | Option 2A-1 and 2B-1 | Option 3A-3 and Option 3B-3 | Option 4A-5, Option 4B-5 and Option 4C-2 |
|---|---|---|---|---|---|
| Community benefits (visual amenity, audible noise, etc.) (Post Construction) | **Positives:**<br>Lower Capital cost<br><br>**Negatives:**<br>Increased visual impact from construction of transition stations along route.<br><br>Increased visual impact from overhead lines. | **Positives:**<br>Reduced visual impact from undergrounding network infrastructure resulting in improved amenity.<br><br>Moderately improved public and wildlife safety by reducing accidental contact with energised infrastructure.<br><br>No operational noise.<br><br>Lowest density of sensitive receivers (residences) along this route that will be subject to air quality, noise, light, and traffic impacts.<br><br>Least likely to impact known areas of very high indigenous values (AHIMS sites) or known historical heritage items.<br><br>**Negatives:**<br>Increased visual impact from construction of reactor stations along route. | **Positives:**<br>Reduced visual impact from undergrounding network infrastructure resulting in improved amenity.<br><br>Greatest public and wildlife safety by eliminating accidental contact with energised infrastructure.<br><br>Lowest density of sensitive receivers (residences) along this route that will be subject to air quality, noise, light and traffic impacts.<br>Least likely to impact known areas of very high indigenous values (AHIMS sites) or known historical heritage items.<br><br>**Negatives:**<br><br>DC converter stations may have higher audible noise than AC substations and require a significant amount of land. | **Positives:**<br>Undergrounded areas will have reduced visual impact from network infrastructure resulting in improved amenity.<br><br>Moderately improved public and wildlife safety by reducing accidental contact with energised infrastructure, in underground areas.<br>Low likelihood of impacting known areas of very high indigenous values (AHIMS sites) or known historical heritage items.<br><br>**Negatives:**<br>Increased visual impact from construction of transition stations along route.<br><br>DC converter stations may have higher audible noise than AC substations and require a significant amount of land.<br><br>Increased visual impact from overhead lines in National Park and other public areas. | The impacts will be the same as those discussed for the option 3's. With additional impacts detailed below.<br><br>**Positives:**<br>Lowest density of airstrips along this route.<br><br>**Negatives:**<br>Highest likelihood of impacting known areas of very high indigenous values (AHIMS sites) or known historical heritage items. |

*Table 6.5 Comparison table Operational and construction benefits – Bushfire Risk*

| Attribute | Overhead Line Option | Option 1, 2A-1 and 2B-1 | Option 3A-3 and Option 3B-3 | Option 4A-5, Option 4B-5 and Option 4C-2 |
|---|---|---|---|---|
| Bushfire Risk (including impacts of bushfire on transmission network) (Post Construction) | **Negatives:**<br>Overhead lines (and transition stations) are above ground. Increasing the risk for bushfire ignition.<br><br>Overhead lines can restrict access for bushfire fighting as opposed to underground lines, which would have no or negligible impact.<br><br>Bushfires spreading through forest (native and plantation) in severe weather conditions can cause major damage to overhead transmission lines, particularly where uphill fire spread exacerbates fire intensity. Line route sections to the west of Talbingo and Blowering reservoirs have the greatest exposure to high intensity fire potential. Much of this area was impacted by the 2019/20 Black Summer bushfires.<br><br>Bushfires spreading through forest (native and plantation) in severe weather conditions can cause major damage to property and seriously endanger the lives of those living in the area and firefighters<br><br>**Notes to consider:**<br>It is very rare for overhead 500kV transmission lines to start bushfires. None of the 2009 Black Saturday bushfires or 2019/20 Black Summer bushfires were started by transmission lines. Electricity-caused fires associated with these events were from overhead distribution lines which have a very different (higher) bushfire risk profile to 500kV lines.<br>Whilst it is very rare for overhead 500kV lines to experience faults causing bushfire ignition, the risk is not zero. Whilst rare, 330kV overhead lines are known to have caused bushfire ignition.<br><br>During the 2019/20 Black Summer bushfires, 330kV overhead transmission lines within cleared easements in the Southern NSW/Snowy Mountains region suffered extensive bushfire damage (damaged and broken insulators; damaged and downed conductors among other damage) from fires burning at very high intensity through forest vegetation adjacent to cleared easements. Steep land areas above Talbingo Reservoir along the route section through the Lobbs Hole Ravine area and in the upper Goobragandra valley have extreme fire behaviour potential. Challenging accessibility issues in remote sections of KNP (relative to pine plantations and open agricultural areas) limit possibilities for fire control. | **Positives:**<br>Full undergrounding of all circuits results in there being negligible potential for bushfire ignition.<br><br>Full undergrounding of all circuits results in there being negligible potential for above ground bushfire to impact and damage undergrounded assets. | **Positives:**<br>Underground sections contain the same positives outlined in Option 1.<br><br>**Negatives:**<br>Overhead line sections through public land (and transition stations) are above ground. Increasing the risk for bushfire ignition.<br><br>Overhead lines can restrict access for bushfire fighting as opposed to underground lines, which would have no or negligible impact.<br><br>Overhead line sections through public land (and transition stations) are above ground. Bushfires spreading through forest (native and plantation) in severe weather conditions can cause major damage to overhead transmission lines, particularly where uphill fire spread exacerbates fire intensity.<br><br>Bushfires spreading through forest (native and plantation) in severe weather conditions can cause major damage to property and seriously endanger the lives of those living in the area and firefighters | **Positives:**<br>Underground sections contain the same positives outlined in Option 1.<br><br>**Negatives:**<br>Overhead line sections through public land (and transition stations) are above ground. Increasing the risk for bushfire ignition.<br><br>Overhead lines can restrict access for bushfire fighting as opposed to underground lines, which would have no or negligible impact.<br><br>Overhead line sections through public land (and transition stations) north from Maragle are above ground. Bushfires spreading through forest (native and plantation) in severe weather conditions can cause major damage to overhead transmission lines, particularly where uphill fire spread exacerbates fire intensity. Line route sections to the west of Talbingo and Blowering reservoirs have the greatest exposure to high intensity fire potential. Much of this area was impacted by the 2019/20 Black Summer bushfires.<br><br>Bushfires spreading through forest (native and plantation) in severe weather conditions can cause major damage to property and seriously endanger the lives of those living in the area and firefighters |

*Table 6.6 Comparison table Operational and construction benefits – Community and Environment during Construction*

| Attribute | Overhead Line Option | Option 1 | Option 2A-1 and Option 2B-1 | Option 3A-3 and 3B-3 | Option 4A-5, Option 4B-5 and Option 4C-2 |
|---|---|---|---|---|---|
| Impacts on the community and environment (During Construction). | **Positive:**<br>Overhead line can be completed faster and with lower:<br>– Impacts to Traffic<br>– Earthworks<br>– Cultural heritage risks<br>– Interruption to land use<br>– Impacts to community<br><br>**Negatives:**<br>Largest interaction with agricultural land along this route<br><br>Largest proportion of private land impacted with this route.<br><br>Additional earthworks required to create access paths for construction of towers and conductor installation (The earthworks required will depend on the accessibility of the area, can range from minimal to significant) | **Positives:**<br>Underground sections over public land will have less impacts on community<br><br>**Negatives:**<br>Longer construction duration for undergrounding resulting in extended community impacts which will be subject to air quality, noise, light and traffic management.<br><br>Larger above ground construction footprint for undergrounding<br><br>Larger construction footprint and impacts to visual amenity from the construction of reactor stations.<br><br>Largest interaction with agricultural land along this route<br><br>Largest proportion of private land impacted with this route.<br><br>Removal of agricultural land from production: While constructing open holes and implementing infrastructure such as land for reactor stations, there will be both direct and indirect removal of agricultural land from production. The working area containing machinery and access will directly take agricultural land out of use in the short term. Indirectly, and a specific issue for the area, livestock will not be able to use surrounding areas unless fencing is done around the working areas.<br><br>**Negatives relevant to all options UG sections:**<br>Disturbance/loss of infrastructure: Damage to roads, fences, yards, and other infrastructure will be necessary to implement the proposed works that will need to be replaced/compensated. Further, permanent structures such as sheds may need to be relocated. Potential disturbance to other services (gas, water, telecommunications) due to undergrounding<br>Impeded access: Access will be limited both internally and externally to certain farms. Infrastructure, such as yards and water, will also be an issue, considering the large working space that will be necessary and isolation of some parts of the farm from others. The change in access across farm and availability of farmland will cause management issues.<br>Use of local skill and supplies: Agricultural production in the area may not be able to access the machines and workers | **Positives:**<br>Underground sections over public land will have less impacts on community<br><br>**Negatives:**<br>Longer construction duration for undergrounding resulting in extended community impacts which will be subject to air quality, noise, light and traffic management.<br><br>Larger above ground construction footprint for undergrounding<br><br>Largest interaction with agricultural land along this route<br><br>Largest proportion of private land impacted with this route.<br><br>Removal of agricultural land from production: While constructing open holes and implementing infrastructure such as land for reactive compensation stations, there will be both direct and indirect removal of agricultural land from production. The working area containing machinery and access will directly take agricultural land out of use in the short term. Indirectly, and a specific issue for the area, livestock will not be able to use surrounding areas unless fencing is done around the working areas.<br><br>Further negatives under option 1 '**Negatives relevant to all options UG sections'** | **Positive:**<br>Overhead line sections of the route can be completed faster and with less removal of agricultural land. These areas are generally on public property and hence will have low community impacts and less environmental impacts than the underground equivalent<br><br>Overhead line sections can be completed faster and with lower:<br>– Impacts to Traffic<br>– Earthworks<br>– Cultural heritage risks<br>– Interruption to land use<br>– Impacts to community<br><br>**Negative:**<br>Overhead line: Additional earthworks required to create access paths for construction of towers and conductor installation (The earthworks required will depend on the accessibility of the area, can range from minimal to significant)<br><br>Route option contains the most difficult terrain with slopes >50% which may impede access for construction.<br><br>The route travers's higher biodiversity value landscape that could be directly or indirectly impacted. A Biodiversity Offset Strategy will be required which will potentially incur greater costs than other options.<br><br>There is a higher social and cultural attachment to green spaces and protected areas.<br><br>Increased bushfire risk from hot works during construction (covered above).<br><br>Removal of agricultural land from production: While constructing open holes, poles and wires, in addition to land for converter stations and transition stations, there will be both direct and indirect removal of agricultural land from production. The working area containing machinery and access will directly take agricultural land out of use in the short term. Indirectly, and a specific issue for the area, livestock will not be able to use surrounding areas unless fencing is done around the working areas.<br><br>Further negatives under option 1 '**Negatives relevant to all options UG sections'** | **Positive:**<br>Overhead line sections can be completed faster and with lower:<br>– Impacts to Traffic<br>– Earthworks<br>– Cultural heritage risks<br>– Interruption to land use<br>– Impacts to community<br><br>The route option selected makes construction accessibility simplified along highway, reduces impacts to environment and community.<br><br>**Negative:**<br>Overhead line: Additional earthworks required to create access paths for construction of towers and conductor installation (The earthworks required will depend on the accessibility of the area, can range from minimal to significant)<br><br>Highest density of sensitive receivers (residences) along this route that will be subject to air quality (from airborne dust, emissions from vehicles and equipment), noise (from equipment and activities), light (from equipment) and traffic impacts.<br>Largest number of Aboriginal and non-aboriginal heritage constraints occur along the highway route.<br>Greater potential exposure of contaminated soils while trenching due to historical land use.<br><br>Removal of agricultural land from production: While constructing open holes, poles and wires, in addition to land for converter stations and transition stations, there will be both direct and indirect removal of agricultural land from production. The working area containing machinery and access will directly take agricultural land out of use in the short term. Indirectly, and a specific issue for the area, livestock will not be able to use surrounding areas unless fencing is done around the working areas.<br><br>Further negatives under option 1 '**Negatives relevant to all options UG sections'** |

| | | | | | |
|---|---|---|---|---|---|
| | | necessary for ongoing works if they are being used on this project.<br>Dust and noise generation: Large linear works on agricultural land have created complaints on the effects of noise and dust generation on the productive capability of surrounding land. | | | |

*Table 6.7 Comparison table Operational and construction benefits – Power System Benefits*

| Attribute | Overhead Line Option | Option 1 | Option 2A-1 and Option 2B-1 | Option 3A-3 and Option 3B-3 | Option 4A-5, Option 4B-5 and Option 4C-2 |
|---|---|---|---|---|---|
| Power system benefits, including additional reactive power capability, potential for improvements to network stability and system security, and benefits of controllable (Post Construction)<br><br>** For each of the HVDC Options 2 – 4, Voltage Source Converter HVDC (VSC) has been assumed rather than HVDC classic technology, Line Commutated Converter (LCC), due to VSC being more suited to integrating with weak AC systems*<br><br>*A discussion of contingency criteria is included in Appendix E. | | **Positives:**<br>HVAC allows for the transfer of inertia from one region to another, which will be beneficial in the future.<br><br>**Negatives:**<br>The need for significant compensation equipment when using HVAC highlights the lack of power system benefits available to the rest of the network in this option.<br><br>There is a risk of the introduction of new inter-area power system oscillations (small signal stability) which would present a considerable challenge to AEMO and ultimately Transgrid to manage.<br>The existing three modes of inter-area oscillation would need to be re-evaluated, potentially requiring setting changes on power system stabiliser equipment across the NEM.<br><br>The large compensation reactors will provide little additional reactive power capability to the power system outside the new interconnection. | **Positives:**<br><br>VSC HVDC technology provides the following benefits:<br>- High energy availability<br>- Precise control of power<br>- Connection of unsynchronized systems<br>- Minimum contributions to short circuit levels<br>- Long distance transmission without intermediate reactive compensation<br>- Reduction of system losses and congestion<br>- Range of control modes, including frequency control<br>- Independent control of active and reactive power<br>- Damping of power swings and oscillations<br>- Firewall for grid disturbances<br>- STATCOM operation<br>- Black-start capability<br>- Operation with AC systems that have low short circuit levels<br>- Support to the AC system during AC system faults<br><br>**Negatives:**<br>Loss of one element for Option 2A-1 results in a loss of power of 856 MW.<br>Loss of one element for Option 2A-B results in a loss of power of 1285 MW. | **Positives:**<br>HVDC benefits are the same as those in the option '2s'.<br><br>**Negatives:**<br>For the HVDC paths. The addition of the DC overhead line introduces complexity into the system due to fault location requirements and more frequent faults on the overhead section.<br><br>Less control of power flows between the 3 terminals than for Option 2 due to the AC circuit between Maragle and Gugaa.<br><br>Loss of one element for Option 3A-3 results in a loss of power of 856 MW.<br><br>Loss of one element for Option 3B-3 results in a loss of power of 1285 MW. | **Positives:**<br>HVDC benefits are the same as those in the option '3s'.<br><br>**Negatives:**<br>For the HVDC paths. The addition of the DC overhead line introduces complexity into the system due to fault location requirements and more frequent faults on the overhead section.<br><br>Less control of power flows between the 3 terminals than for Option 2 due to the AC circuit between Maragle and Gugaa.<br><br>less operational flexibility with this configuration than the configurations in option 3 since there is no direct connection between Maragle and Bannaby.<br><br>Loss of one element for Option 4A-5 results in a loss of power of 856 MW.<br><br>Loss of one element for Option 4B-5 results in a loss of power of 1285 MW.<br><br>Loss of one element for Option 4C-2 results in a loss of power of 700 MW. |

*Table 6.8 Comparison table Operational and construction benefits – Operation and Maintenance work*

| Attribute | Overhead Line Option | Option 1, Option 2A-1 and Option 2B-1. | Option 3A-3, Option 3B-3, Option 4A-5, Option 4B-5 and Option 4C-2. |
|---|---|---|---|
| Operation and maintenance works along the cable route. (Post Construction) | **Positives:**<br>Less difficult to find and fix faults along the TLs | **Positives:**<br>Lower ongoing operation and maintenance costs, due to lower likelihood of faults occurring.<br><br>Less likely to be impacted due to external factors (i.e., falling trees, wildlife, bushfires, vehicles).<br><br>**Negatives:**<br>Faults along the cable line can take a long time to fix (days to weeks). | **Positives:**<br>**For underground sections:**<br>Lower ongoing operation and maintenance costs, due to lower likelihood of faults occurring.<br><br>Less likely to be impacted due to external factors (i.e., falling trees, wildlife, bushfires, vehicles).<br><br>**For overhead sections:**<br>Less difficult to find and fix faults along the TLs<br>No 'preventative maintenance program' and 'repair preparedness strategy' required. |

*Table 6.9 Comparison table Operational and construction benefits – Human Safety*

| Attribute | Overhead Line Option | Option 1, Option 2A-1 and Option 2B-1 | Option 3A-3, Option 3B-3, Option 4A-5, Option 4B-5 and Option 4C-2 |
|---|---|---|---|
| Human safety (aerial operations personnel, agricultural machinery operators, line workers at heights and the public) (Post Construction) | **Negatives:**<br>– Potential for interruption of aerial operations<br>– Risk of accidents due to falling trees or under passing vehicles etc.<br>– Risk of accident due to working at heights<br>– Chance of interruptions to power supply during extreme weather conditions<br><br>**Notes for Overhead line sections:**<br>Human safety in the design of transmission lines is a large consideration and is implemented in such a way. Some of the Design aspects which consider human safety are listed below:<br>– For the personnel involved in the construction and maintenance, structures are designed to have easy access to climb and work at height such as providing the structures with step bolts to climb and platforms as part of structure to provide facility to stand while doing the maintenance such as washing the insulators.<br>– For the public passing nearby or crossing under the lines, the transmission lines are designed to provide sufficient airgap clearances to avoid the impact of electrical and magnetic fields on the public to avoid any sort of health impacts on them as well.<br>– For the operators of vehicles and machinery, the design of transmission lines defines the height of vehicles allowed to move under the line to avoid any sort of health impact on the operators.<br>– All the above-mentioned clearances are maintained as per the requirements of the regulatory authorities and locally accepted standards, which are cross verified with the proper calculations as well.<br><br>These aspects of the design provide the following benefits:<br>– Reduction in the impact of electrical and magnetic fields.<br>– Reduction in the negative psychological impact on the public, workers and operators of the machinery working or passing nearby and under the live lines.<br>– Reduction in the risk of electrocution of the public and workers.<br>– Reduction in the overall medical and health maintenance cost for the personnel working within the vicinity of live transmission lines.<br>– Increase in the confidence to attract more labour to get involved in the works of transmission lines. | **Positives:**<br>Power supply likely to stay uninterrupted in extreme weather conditions such as Storm, heavy wind, least fire hazards.<br><br>Accidents are less due to circumstances such as falling trees or under passing vehicles.<br><br>Least interruption with Aerial operations.<br><br>Least interference with the Radio, Television, and other communication signals.<br><br>No requirements for working at heights (less risk to human personnel).<br><br>**Negatives:**<br>Potential risk to safety of public if they dig into a cable.<br><br>**Note:**<br>The underground cable trenches will have a warning tape installed close to the top of the trench and some type of mechanical protection above the cables.<br><br>Transgrid is a member of the Dial Before You Dig service, which provides information to the public on the location of underground infrastructure. | **Positives:**<br>The underground non-market benefits will be the same as those detailed in the underground options (option 1 and 2).<br><br>**Negatives:**<br><br>Potential risk to safety of public if they dig into a cable. (Underground cable).<br><br>Negatives relevant to Overhead line sections include:<br>– Potential for interruption of aerial operations<br>– Risk of accidents due to falling trees or under passing vehicles etc.<br>– Risk of accident due to working at heights<br>– Chance of interruptions to power supply during extreme weather conditions<br><br>**Notes for Overhead line sections:**<br>Human safety in the design of transmission lines is a large consideration and is implemented in such a way. Some of the Design aspects which consider human safety are listed below:<br>– For the personnel involved in the construction and maintenance, structures are designed to have easy access to climb and work at height such as providing the structures with step bolts to climb and platforms as part of structure to provide facility to stand while doing the maintenance such as washing the insulators.<br>– For the public passing nearby or crossing under the lines, the transmission lines are designed to provide sufficient airgap clearances to avoid the impact of electrical and magnetic fields on the public to avoid any sort of health impacts on them as well.<br>– For the operators of vehicles and machinery, the design of transmission lines defines the height of vehicles allowed to move under the line to avoid any sort of health impact on the operators.<br>– All the above-mentioned clearances are maintained as per the requirements of the regulatory authorities and locally accepted standards, which are cross verified with the proper calculations as well.<br><br>These aspects of the design provide the following benefits:<br>– Reduction in the impact of electrical and magnetic fields.<br>– Reduction in the negative psychological impact on the public, workers and operators of the machinery working or passing nearby and under the live lines.<br>– Reduction in the risk of electrocution of the public and workers.<br>– Reduction in the overall medical and health maintenance cost for the personnel working within the vicinity of live transmission lines.<br>– Increase in the confidence to attract more labour to get involved in the works of transmission lines. |

*Table 6.10 Comparison table Operational and construction benefits – Reliability of Power Supply*

| Attribute | Overhead Line Option | Option 1, Option 2A-1 and Option 2B-1 | Option 3A-3, Option 3B-3, Option 4A-5, Option 4B-5 and Option 4C-2 |
|---|---|---|---|
| Reliability of power supply. (Post Construction) | **Positives:**<br><br>Negligible risk of flooding affecting power supply for overhead sections.<br><br>**Negatives:**<br><br>Higher probability of power supply interruptions due to falling trees, vehicle accidents, wildlife etc.<br><br>Higher chance of power supply interruptions in extreme weather conditions.<br><br>Need to perform tree and vegetation cutting to prevent interactions between plants and transmission lines.<br><br>**For further Overhead line section notes see Column** ' Option 3A-3, Option 3B-3, Option 4A-5, Option 4B-5 and Option 4C-2'<br><br>**Notes for Overhead line sections:**<br><br>Reliability during the operation of transmission lines is one of the main design parameters to keep the continuous supply of power within the allowed limit of outages.<br>To maintain the power transfer reliability of transmission lines, number of allowed outages are taken from the locally accepted standards and regulatory authorities.<br>To achieve the power transfer within the specified number of outages, the transmission lines are designed to avoid the lightening impulse voltages, switching impulse voltages, failure of components of transmission lines such as failure of structures, insulators, foundations, fittings, hardware and conductor, and cascading failures.<br>To avoid the outages due to overvoltage caused by lightning and switching impulse, the transmission lines are designed with proper earthing and lightning protection design by maintaining the proper earthing of structures, design of required earth wire installed at the required shielding angle.<br>To avoid the failure of components of transmission line in severe weather cases such as extreme wind conditions, thunderstorms and tornados, the components are designed at proper strength and strength coordination is used between the components of transmission line -foundation, structures, insulators, conductors, fittings, hardware and earth wires in such a way that the failure of components should not cause the failure of overall transmission line.<br>To avoid the cascading failure, the transmission lines are designed in different parts and tension structures are placed at standard distances mostly after each 30 structures to avoid the cascading failures which can cause the overall failure of transmission lines.<br>There are multiple non-market benefits which can described as follows.<br>It provides benefit to plan the usage of power within the limits of outages for the end consumers.<br>It reduces the operations and maintenance cost by achieving the required reliability for the transmission lines.<br>In case of failure of transmission lines, the improvement in reliability helps in preparation of good risk response.<br>It helps in synchronization of overall electrical supply system of transmission lines to improve the uninterrupted power supply. | **Positives:**<br>Underground cables will have higher reliability and lower failure rates than overhead lines.<br><br>Uninterrupted power supply during extreme weather conditions<br><br>Underground cables are unlikely to be affected by falling trees and passing vehicles, hence maintaining reliable power supply.<br><br>**Negatives:**<br>Extremely low chance of flooding to impact the cables (Detailed design of the cable would need to take this into consideration)<br><br>**Notes:**<br>In case of flooding, special design of UG cables is required because in rare cases water can permeates as well in underground cables so depending on the chemical resistance and moisture levels cable designs are considered. In addition, the cable terminations are prone to more danger in case of floods. | The underground portion will consist of the non-market benefits detailed in the underground options in option 1 and 2.<br><br>The Overhead non-market benefits include:<br>**Positives:**<br><br>Negligible risk of flooding affecting power supply for overhead sections.<br><br>**Negatives:**<br><br>Higher probability of power supply interruptions due to falling trees, vehicle accidents, wildlife etc.<br><br>Higher chance of power supply interruptions in extreme weather conditions.<br><br>Need to perform tree and vegetation cutting to prevent interactions between plants and transmission lines.<br><br>For additional comments on overhead line section refer to 'Notes for Overhead line sections' under Overhead line option column |

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|---|---|---|---|
| | Proper estimation of reliability of transmission lines helps in determining the probability of failure of structures in severe weather cases which can help in detailed cost benefit analysis including the assessment of required easements to access the transmission lines during maintenance.<br>With detail requirements of reliability, optimized structure design can be achieved which can help in overall cost-benefit.<br>To achieve the required reliability of transmission lines, anti-cascading design analysis is conducted on transmission lines to install the tension structures after a specific length of transmission lines which can avoid the overall failure of transmission lines and benefits the surrounding structures and assets.<br>With proper earth design of transmission lines to gain a specific reliability, touch and step voltage design analysis is conducted on the basis of cost-benefit values that can have positive impact on the health benefits of the public passing nearby, touching the structures and workers performing the live line maintenance. | | |