Supplementary Submission No 29a

INQUIRY INTO FEASIBILITY OF UNDERGROUNDING THE TRANSMISSION INFRASTRUCTURE FOR RENEWABLE ENERGY PROJECTS

Name: Professor Simon Bartlett

Date Received: 7 August 2023

Additional Submission to Undergrounding Inquiry from Prof Simon Bartlett AM – Part 1

The following additional material is provided to the Undergrounding Inquiry upon their invitation to do so by 8th August:

All solar farms
No wind farms

NSW will need extra power to run in early morning and early eveni keep lights on when solar is not running
Solar PV will not help to keep the lights on in NSW when coal-fired power stations close

1.

Figure A1.7: Medium scenario forecast – day of summer maximum demand 2031/32

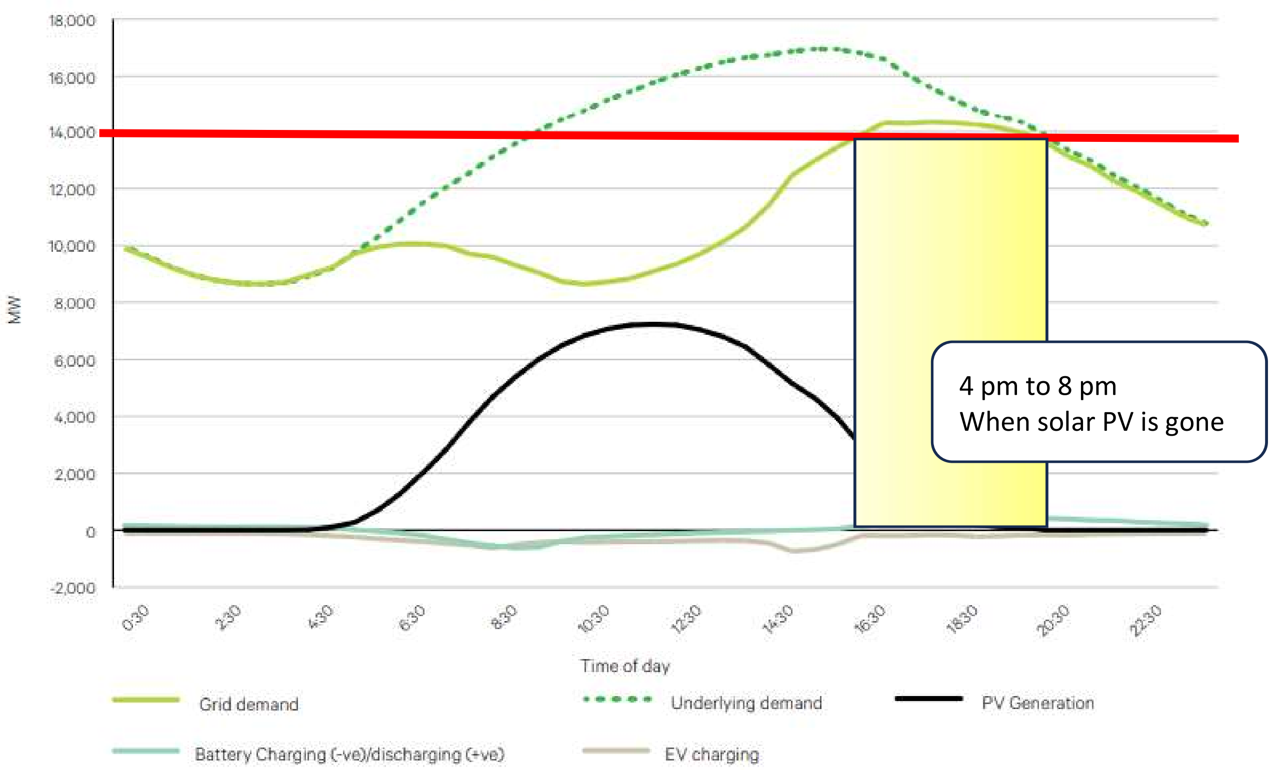
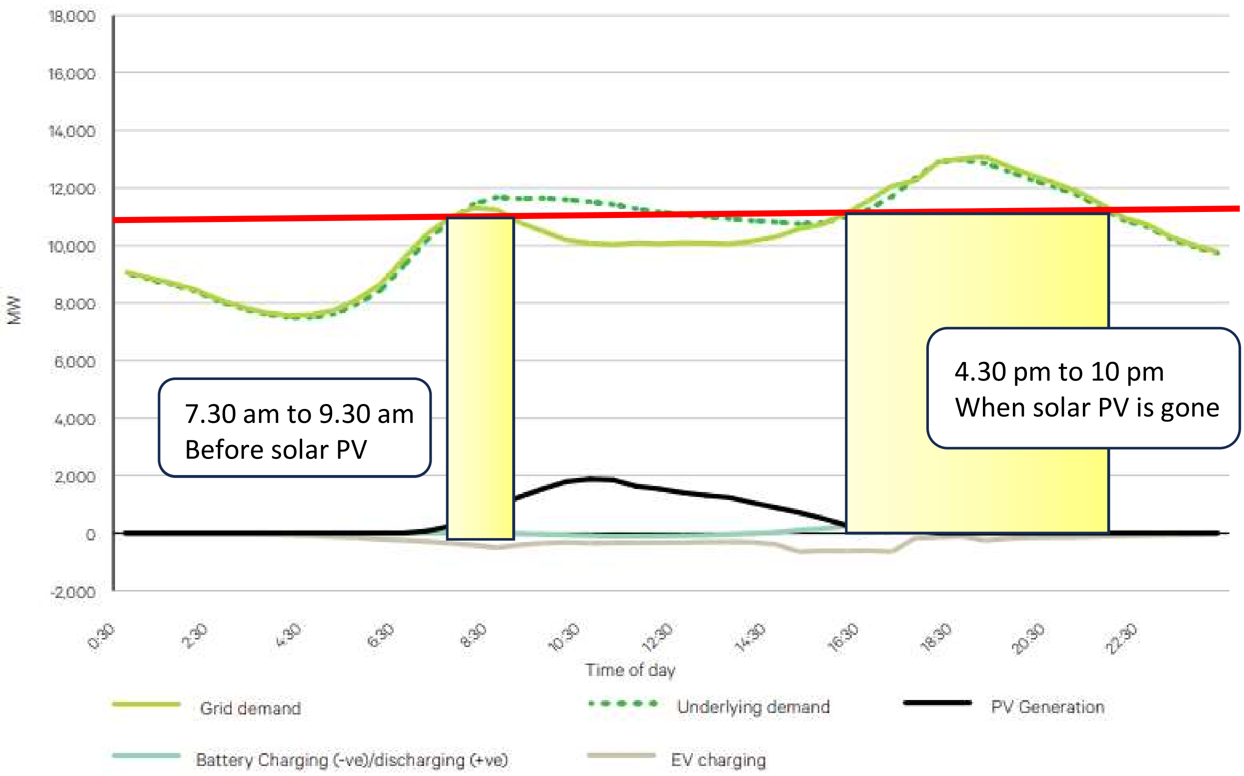
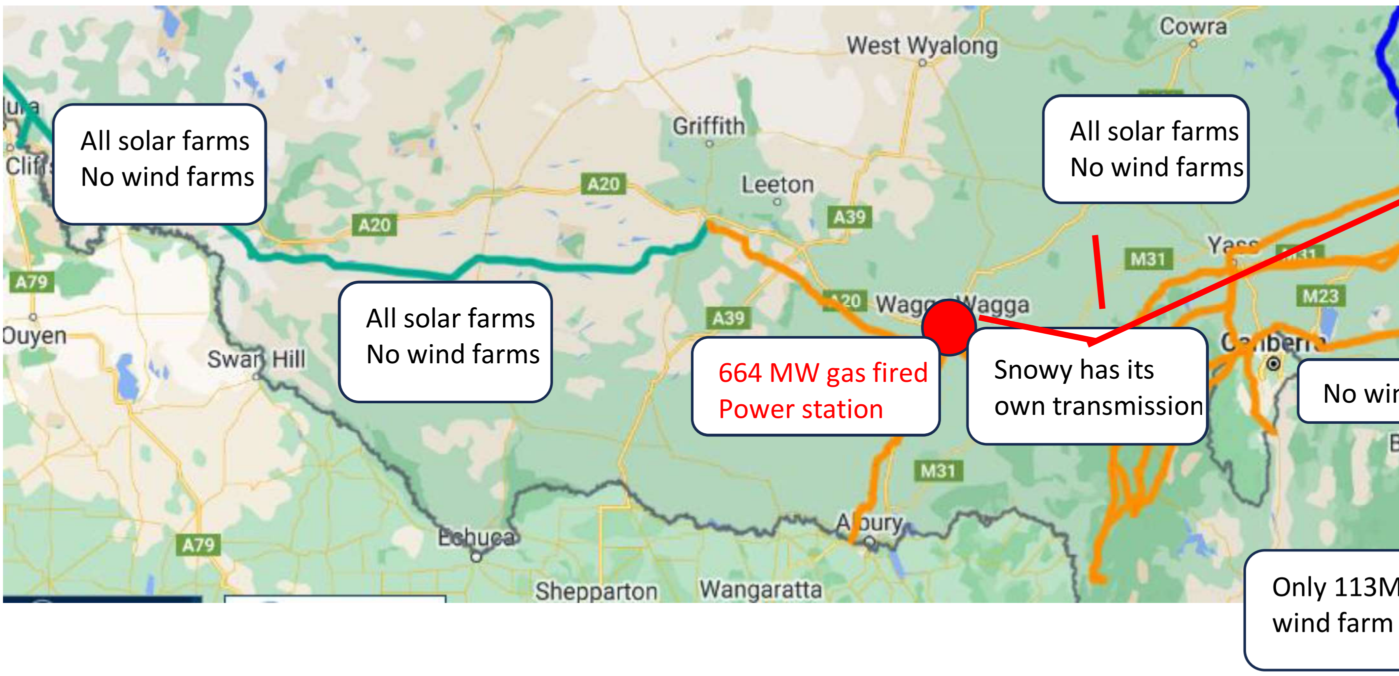


Figure A1.8: Medium scenario forecast – day of winter maximum demand 2031

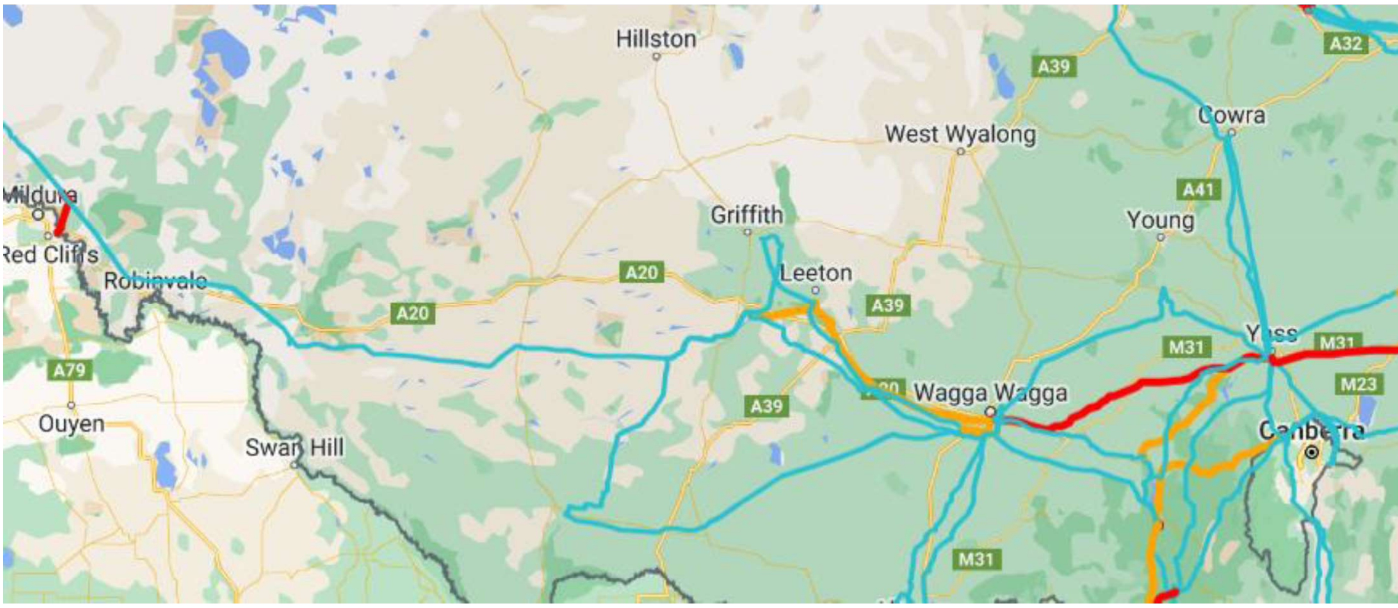


3 Before Snowy 2.0 is finally operating in 2030+ +, at those times Humelink will only transmit gas fired power from Wagga Wagga, but the existing grid can do that anyway. The existing Snowy scheme has its own existing grid and the Snowy scheme only has enough water inflow to run flat out for around 2 to 3 hours every day.



4 Congestion on existing network

The existing Maralan (near Barnaby) to Wagga Wagga 350 kV line is already heavily congested, and so is the Barnaby to Sydney line.



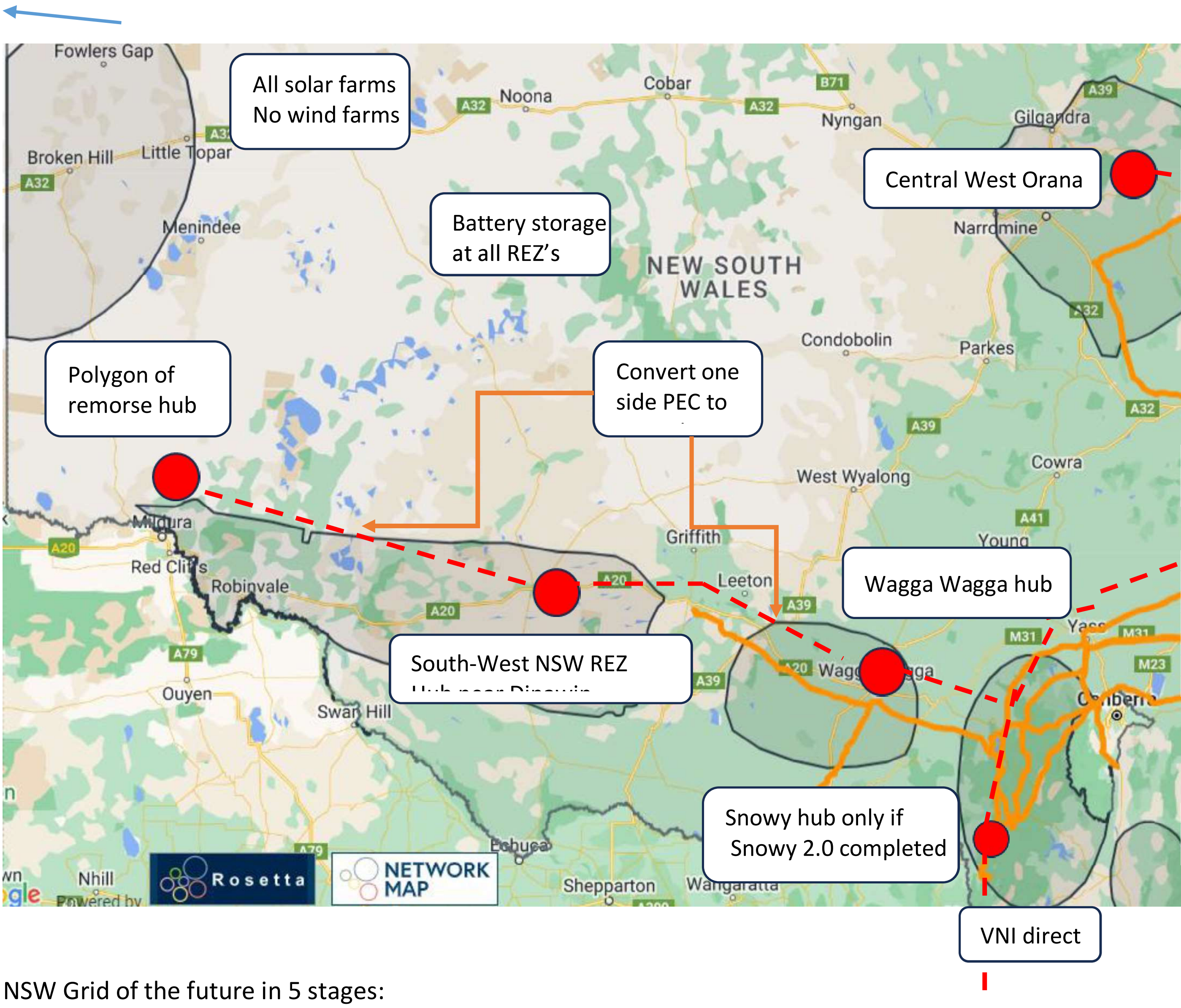
Rather than Humelink, just rebuild the existing Wagga Wagga to Marallan line at twice the capacity on the existing easement? That's needed anyway as the collector line for Humelink or its HVDC replacement.
And Humelink will further congest the Barnaby to Sydney line, this should have been considered when Humelink was planned. TransGrid intend to address that congestion by building the South Sydney Loop by 2027, with a maze of overhead 500kV and 330kV liner from Barnaby to Sydney for $bn's and running thought Sydney's outer suburbs. That will never be approved and must be undergrounded using HVDC in any case.

Option 2 SNW Southern Loop: • Establish a new substation in the locality of South Creek with 2 x 500/330/33 kV, 1,500 MVA transformers. • Connect the new substation in the locality of South Creek into Eraring – Kemps Creek 500 kV lines and Bayswater – Sydney West and Regentville – Sydney West 330 kV lines. • A new 500 kV double-circuit lines from Bannaby to the new substation in the locality of South Creek. • Rebuild the section of existing Bannaby – Sydney West 330 kV line from locality of South Creek to Sydney West to double-circuit line. • Augment the existing Bannaby and Sydney West substations. • Line reactors on 500 kV transmission lines between Bannaby and locality of South Creek. *Provided by Transgrid – see Section 1.2.*	4,500 (This capacity increase is for accommodation of additional new generation south of Bannaby and 1/3 generation from Central-West NSW). REZ N11:2,000	1,550 (2023 dollars)[60] Class 5 (-30,+40%)	125	Medium

All these TransGrid overhead lines must be considered as one project, combining the Southern Loop with Humelink and 500 kV Project Energy Connect. Then, it's obvious the solution is using HVDC from the REZs direct to Sydney, going via Snowy 2.0 but no need for AC/DC connections in between. That distributor role is better done at 330 kV, including upgrading existing 330kV lines on their existing easements is required.

B5. NSW Transmission Grid of the Future

Below is a suggestion for the HVDC backbone for the NSW grid of the future, including the interconnection to Victoria, which should be started right now:



NSW Grid of the future in 5 stages:

(a) Stage 1 : Large battery storage installed at each REZ, typically 8 hour storage
(b) Stage 2 : 3 terminal HVDC VSC Dinawan to Wagga Wagga to Sydney 3,000MW, +_500kV network, by
    (1) Dinawan to Gugga being a DC bi-pole using one side of PEC
    (2) the other side operated as a 1,500MW 330kV distributor line and maintenance bypass for the HVDC circuits
    (3) Wagga Wagga to Sydney can be undergrounded or overhead to suit land use constraints with two independent bi-pole circuits for security
(c) Stage 3 DC from Dinawan to Buronga (Polygon of Remorse) by converting one side of PEC 330kv to HVDC bi-pole (note 500 kV is possible if towers are redesigned). Other side to become an 800MW distributor line, east and west by open-circuiting somewhere midway. TransGrid, ElectraNet and VicGrid can decide what to do with the western part of PEC

(d) Stage 4 If it is ever certain that Snowy 2.0 will be completed (noting it should be abandoned and replaced by much cheaper batteries or gas turbines) build a 2,000MW HVDC 330kV bi-pole from Snowy Mountains to Wagga Wagga.

(e) Stage 5 : If increased interconnection to Victoria is ever justified, build a 3,000 MW HVDC interconnection between Sydney, Snowy Hydro and Melbourne or convert the existing 350 kV AC interconnection to HVDC

6. The capacity and cost of Humelink

The Humelink PACR was published on 29th July 2021, just 2 years ago. Its estimated cost was $bn3.3 and its transmission capacity was claimed to be 2,530MW, with an average cost per MW of capacity of $m1.3/MW. Just 2 years later in July 2023, TransGrid advised the Inquiry and AEMO that the cost of Humelink has increased by 52% to nearly $5.0bn and its capacity has reduced by 13% to 2,200MW. Humelink's average cost/MW has increased by 75% from $m1.3/MW to $m2.3/MW in just two years and before a sod has been turned. This must be a material change of circumstances requiring Humelink to be revisited. There have also been major changes to Snowy 2.0, the reason for Humelink in the first place. Not only has Snowy 2.0 been delayed 4 years in those two years, but it is believed that all six Snowy 2.0 units will not be synchronous machines, crucial to maintaining the stability of Humelink and the NSW power system. Another change in circumstances that must be investigated as HVDC would be far more effective in maintaining power system security than HVAC Humelink.

7 AEMO's latest cost comparison of Humelink vs HVDC

AEMO has just published a cost comparison of Humelink compared with a 2,000MW overhead HVDC between Wagga Wagga and Barnaby. AEMO's cost estimates are shown below and show Humelink at 2,200MW for $bn4.9 and the HVDC at 2,000MW for $bn2.45. The HVDC option is half the cost of Humelink and with Snowy 2.0 delayed and highly uncertain, The HVDC option must be better. It could be undergrounded and still come out on top, especially if taken through to Sydney instead of Southern Sydney Loop. Please note that the comments at the bottom about Humelink being a pre-requisite and a future Wagga Wagga 500 kV substation being required make no sense if the Wagga Wagga converter simply steps down to 330kV instead of 500 kV.

Augmentation options				
Description	**Additional network capacity (MW)**	**Expected cost ($ million)**	**New easement length (km)**	**Lead time**
Option 1 (HumeLink): • New Wagga Wagga 500/330 kV substation and 330 kV double-circuit connection to the existing Wagga Wagga 330 kV substation. • Three new 500 kV transmission lines: - Between Maragle and Bannaby 500 kV substations. - Between Maragle and new Wagga Wagga 500 kV substations. - Between new Wagga Wagga and Bannaby 500 kV substations. • Three 500/330 kV 1,500 MVA transformers at Maragle. • Two 500/330 kV 1,500 MVA transformers at new Wagga Wagga. • 500 kV Line shunt reactors at the ends of Maragle – Bannaby, Maragle – new Wagga Wagga and new Wagga Wagga – Bannaby 500 kV lines. *Provided by Transgrid – see Section 1.2.*	2,200[63] N6+N7: 2,200 (N6: 1,500), N5: 800	4,892[64] (June 2023 dollars) Class 5 (± 50%)	630	Short
Option 2: • A 2,000 MW bi-pole overhead transmission line from locality of Bannaby to locality of Wagga Wagga. • A new 2,000 MW bipole converter station in locality of Bannaby. • A new 2,000 MW bipole converter station in locality of Wagga Wagga. • AC network connection between new HVDC converter station in the locality of Bannaby and the existing Bannaby 500 kV substation. • AC network connection between HVDC converter station in the locality of Wagga Wagga and a future Wagga Wagga 500 kV substation. *Pre-requisite: HumeLink*	2,000 (both directions SNSW to CNSW) N6: 2,000	2,450 Class 5b (± 50%)	260	Long

[62] Uprating of Marulan – Yass and Marulan – Collector – Yass 330 kV transmission lines were included in limit assessment.

[63] Limit from Transgrid's Project Assessment Conclusions Report is 2,570 MW based on a lower Victoria to New South Wales transfer than that used in the ISP.

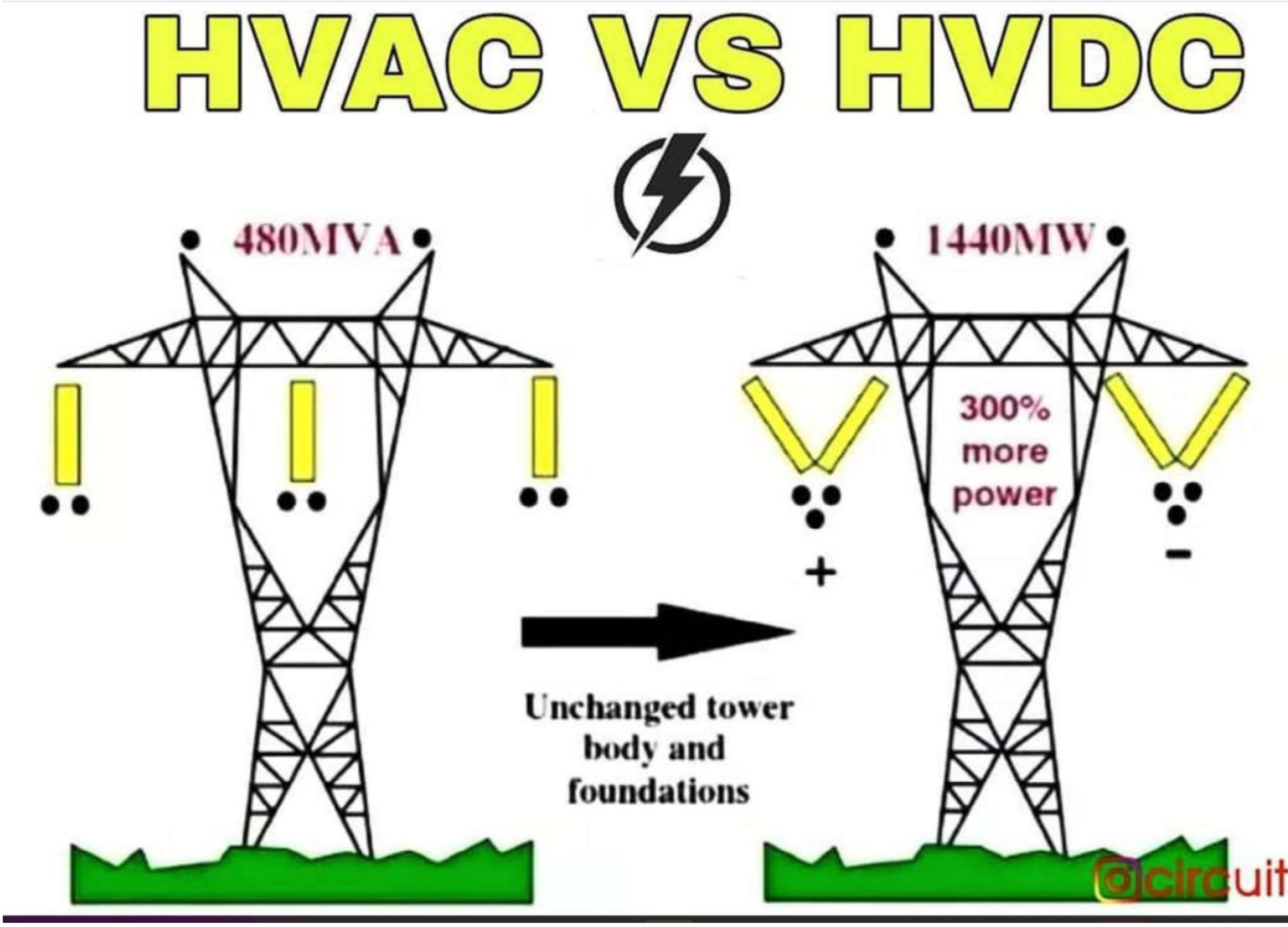
[64] Transgrid. At https://www.transgrid.com.au/media/rxancvmx/transgrid-humelink-pacr.pdf.

8. HVDC in China and Europe

Additional Submission to Undergrounding Inquiry from Prof Simon Bartlett AM – Part 2

The following additional material is provided to the Undergrounding Inquiry upon their invitation to do so by 8th August:

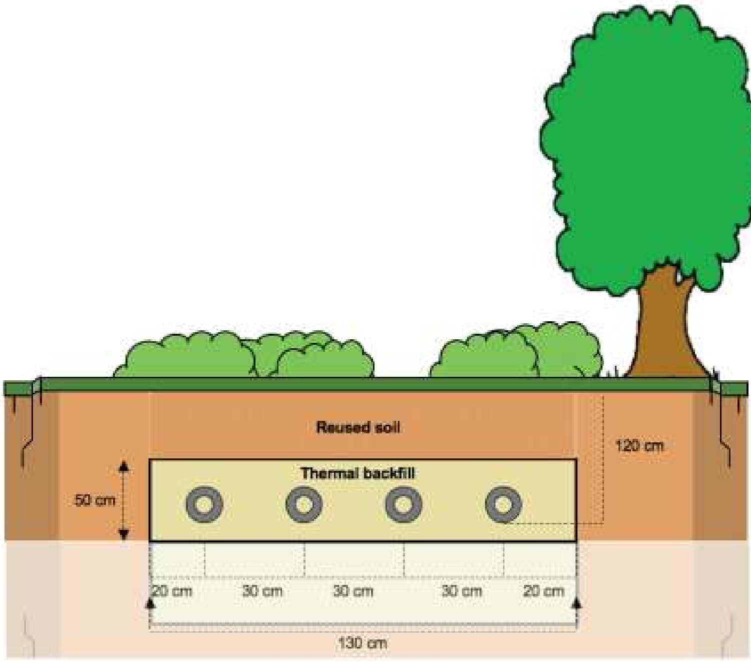
9 HVDC can transmit 3 times the power with the same overhead transmission infrastructure, with the same visual impact



Typical HVDC underground cable arrangement in Europe for 2,000MW 320kV cable system with duplicated bi-poles for security

This is the proposed arrangement for the Preliminary NSW HVDC Grid of the Future in 5 above between Wagga Wagga and Sydney (but using 500 kV HVDC) europacable

2) HVDC: 2 Bipole, 320 kV, 2 GW



For further information please visit our website www.europacable.com or contact:
Dr. Volker Wendt, Director Public Affairs, Europacable, v.wendt@europacable.com

About Europacable
Founded in 1991, Europacable represents 90% of the European wire and cable industry. Our 42 member companies include European multinationals providing global technology leadership, as well as over 200 highly specialized small- and medium sized producers of energy, telecommunication and data cables. In 2009, the industry had a total consumption of €20 billion in wire & cables resulting in the manufacture in Europe alone of some 38 million km of cables. Europacable is listed in the European Commission's transparency register under: 453103789-92.

3,000 MW 500 kV HVDC overhead line

Half the height (39m vs 80 m, only 2 sets of conductors vs 6

much lower visual impact, easement only 50 m wide

7. Integration of HVDC undergrounding into AC transmission networks

Integrating HVDC cables into AC transmission networks offers the following advantages:

- Simple and efficient control of power flow
- No disturbance among the connected network in the event of failure
- No impact to short circuit current
- Interconnection of non-synchronised networks
- Additionally, VSC technology can feed load disconnected by any other network and can help to restart an AC network after a blackout.

8. Cost Aspects of HVDC undergrounding

Overall considerations

Respecting EU competition requirements, Europacable can only provide general statements regarding cost factors of HVDC undergrounding.

Also each project is unique and a full macroeconomic assessment of the cable system should be made that takes into consideration installation costs, life costs, maintenance costs, impact on land / property, environmental protection etc.

Experience of HVDC underground cabling and their cost is currently limited. Based on analysis conducted by Realise Grid[2] in 2010, the cost of HVDC underground cables (two cables, +/- 350 kV, 1,100 MW) is between 1 – 2.5 million euros per km. With that, the cost factor for HVDC underground cables compared to an HVDC overhead line is 2 – 3 times.

Whether HVDC cable or HVDC overhead line, the considerable investment cost for the converter stations required to connect the DC system to the AC transmission grid have to be taken into account.

Consequently, the cost factor for a HVDC cable system compared to a HVDC overhead line system will be considerably lower than the above mentioned factor of 2-3. Example:

Total Cost HVDC Overhead Line	Total Cost HVDC Underground Cable
• Cost for transmission technology: 100 • Cost for converter technology: 300 • **Total Cost: 400**	• Cost for transmission technology: 300 • Cost for converter technology: 300 • **Total Cost: 600**

- Cost factor for transmission technology only of a HVDC cable compared to HVDC overhead line: 3
- Cost factor for total system: 1.5

Principally, Europacable believes that the following two dimensions should be taken into account:

[2] RealiseGrid footnote reference needed!!

Cost of installation:

- The cost of a HVDC cable system will depend on the specific requirements defined for the system. In addition to the cable itself, accessories like joint bays, transition station, converter stations etc. need to be taken into account. Generally speaking, due to the complexity of the technology, installation costs of an HVDC cable solution per km will always be higher than an equivalent distance of overhead line.
- Up to 60% of the installation costs can result from the civil works required for the installation. These depend on the type of soil that the cable is going to be placed in (sand, rocks etc.) as well as other existing infrastructure the route may cross. Europacable member companies will largely work with local contractors to execute the civil works. The installation of the cable system will be implemented by specially trained personnel.

Cost of operation

- The cost of operation of HVDC underground cable is negligible.
- Once in operation, a cable system itself is nearly maintenance free. As with any transmission corridor, the cable route requires regular inspection to prevent any encroachment. A test with +/- 5 kV DC voltage on the cable metal screen in order to check the outer sheath integrity may be performed every second year for precautionary reasons.

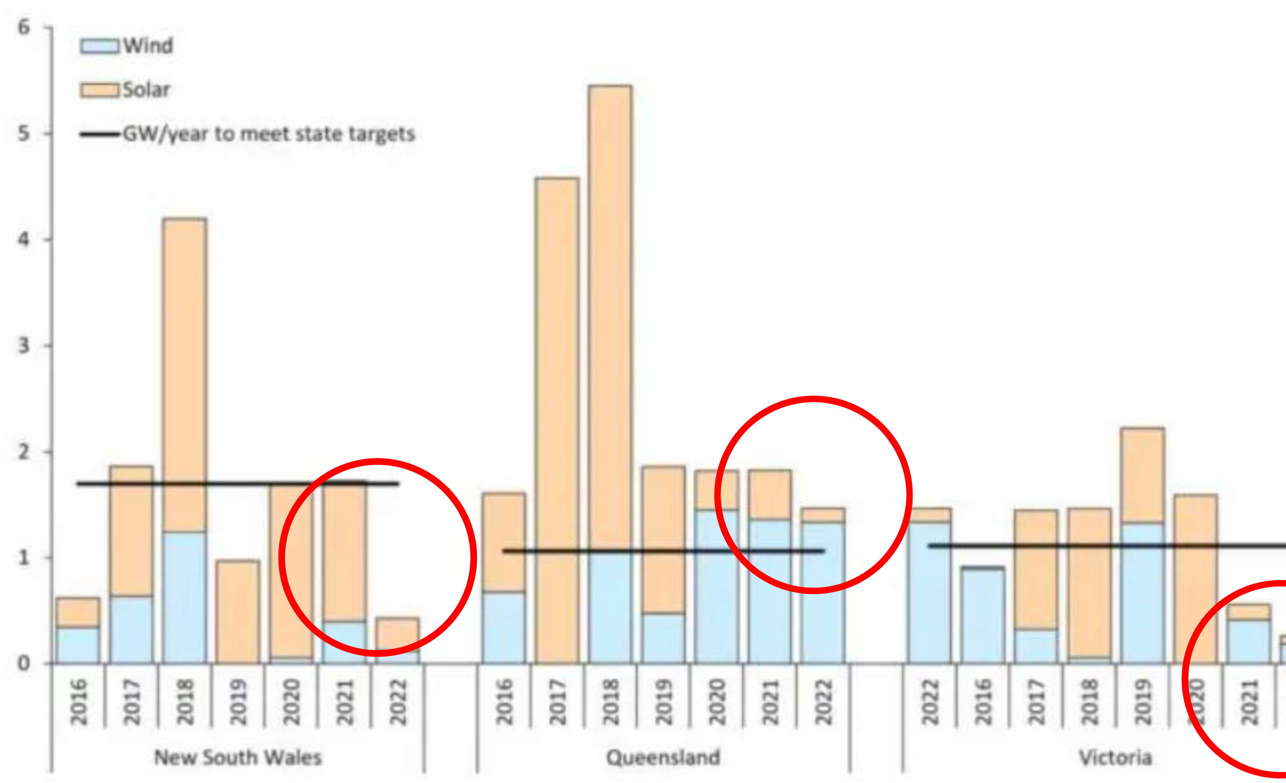
10 The growth in NSW renewables has stalled – must address the cause urgently (congestion on the 330kV and 220 kV networks), much more important than Humelink

TransGrid's failure to upgrade the existing overloaded 220kV and 330 kV rural network is wasting 50% of NSW's best renewable generation and has turned new wind farm investors away from NSW since 2019 and new solar farm investors since 2022. From 2019 onward, virtually all new wind power investments stopped and from 2022 onwards the same thing happened to solar farms. NSW also has extreme congestion in its south-west NSW REZ transmission network. The existing solar farms are wasting half of their potential generation as the can't access the congested grid and have 20% transmission losses.

Only Queensland is still flooded with new wind farm approvals as it has a strong 275/330 kV network near good wind resources in southern Queensland which is already being reinforced. Queensland's solar farm investments also stopped in 2020 as their western rural network also became congested then.

Urgent action is required to upgrade NSW's overloaded 220kV and 330 kV networks by replacing existing weak lines with much stronger 220/330kV lines on their existing easements. This is needed any way to become distributor networks before PEC and Humelink (or their HVDC equivalents) are commissioned. That will also defer the need for the higher capacity lines. TransGrid has forgotten to strengthen the 330 feeder networks running parallel to their 500 kV network between Dinawan and Barnaby.

Figure 3: Annual capacity approved vs capacity required to meet 2030 state targets
Gigawatts (GW)



https://reneweconomy.com.au/wind-and-solar-face-planning-brick-wall-that-threatens-to-derail-switch-from-coal/?fbclid=IwAR3xqY-smvtrBL1ickn-KuQ4Id4S4sqVQiPiANu334DZJHdHm8dooniMY_U_aem_Ac7Xl_5jXVOWpUerzLVLAdTOVXkGc3EhxPWNPfwM4QwXwPsPLcr5fU-TiNbOY5Bwd4c&mibextid=S66gvF

11. **All cost blow-outs in these projects will be paid for by NSW electricity user**

Despite the Australian Energy Regulator AER) posturing about trimming the maximum costs of all these new transmission lines, the electricity rules require ever dollar spent on their construction to be" rolled-into" TransGrid's regulated asset base upon completion of each line. This means that NSW electricity users will pay the full cost of every cost blow-out, interest during construction, and future inflation with a guaranteed profit over the following 50 years. The more the projects cost, the greater the profits so there is no incentive to save on cost. 80% of the profits will go overseas to Abu Dhabi, Kuwait, Quebec and Ontario Canada.

TransGrid will ask AEMO to value the benefits of each projects using the TOOT method (Take one out at a time). This is like valuing one link in a bicycle chain by taking out just one link. The whole chain falls of and the value is the value of the whole bicycle. Humelink, South Sydney loop, PEC, VNI West and Western Renewables Link are the five links in the Sydney to Melbourne 500 kV new interconnector, so it's exactly the same. No matter how much the costs blow out, the TOOT analysis will also say the benefits of all 5 projects justify the cost blowout.

12 A single tower fault on any of the 2,600 towers on these five projects will black-out large parts of NSW and Victoria.

The entire 1,300km 500 kV interconnection will use double circuit 500 kV towers, which support two 500kV circuits on just one transmission tower, one circuit one towers on side and the second circuit on the other. When any tower fails, both circuits will fail, and remain out of service until the damage is repaired.

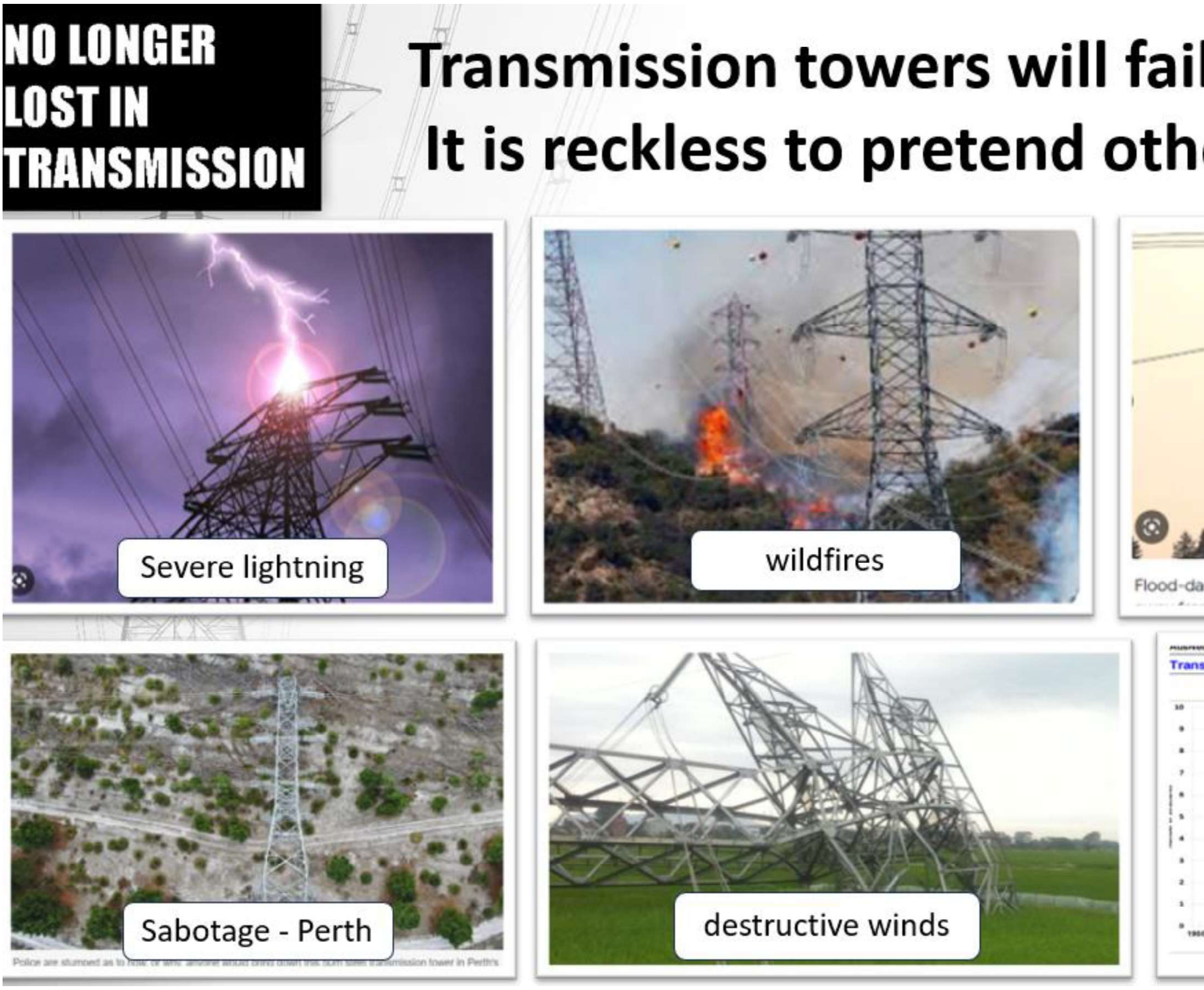
TransGrid and AEMO claim that this is a “non-credible” event and have not allowed for such an event in planning all five sections of the Sydney to Melbourne interconnection. Nor have they allowed for this to happen with PEC from South Australia to NSW.

However, these events happen every year in in Australia due to severe lightning, fierce wildfires, destructive winds, wild-scale flooding and sabotage. Over the last 64 years there have been 37 know transmission tower collapses in NSW averaging one tower collapse every 20 months. When combined with the 50 known tower collapses in Victoria, the total number of known transmission tower collapses in NSW and Victoria is 87 over 64 years which averages one tower collapse every 9 months.

In addition, there have been multiple double circuit failures on this type of tower in NSW due to severe lightning, and bushfires. And in May 2023, unknown parties sabotaged a similar tower in Perth by removing the bolts from the base of the tower causing it to topple over onto the ground. There have also been instances of saboteurs blowing all four legs of a similar tower using high explosives strapped to the tower legs.

These failures do happen and will happen again and again.

We must not use double circuit very high-capacity transmission lines that have no back-up. HVDC underground cables are not vulnerable to any of these above ground weather phenomena



13 Operation and maintenance costs

HVDC underground cablers are virtually maintenance free, other that checking the easement annually for trees growing directly above the cables or someone inadvertently digging deep holes above the cable. In addition, the power electronics in the AC/DC converters will need to be replaced after 20 to 25 years.

Overhead transmission lines and substations and their easements have much higher maintenance and refurbishment/replacement costs

The 0.5% pa assumed in the Humelink PACR, the 0.5% pa assumed in the PEC PACR, the 1% pa assumed in the VNI West PACR and the 1% pa assumed in the ISP are grossly understated and have resulted in these projects delivering a net benefit when they may not otherwise do so. Various explanations have been given by TransGrid and AEMO, however none appear valid. For example, AEMO says they must be right because the RIT-T assessments has assumed 1%. The RIT-T proponents point to the ISP. AEMO says that its only for routine maintenance for transmission lines before they age and need refurbishment and replacement of components. Hey all refer to AER revenue determinations, however in those determinations the refurbishment and replacement expenditure is classified as capital expenditure. They generally exclude easement inspections and maintenance one of the major and fastest growing costs for easement inspections to assess and manage fire risks and treat regrowth which are very substantial. No allowance is included for non-routine expenditure for ageing transmission assets when large expenditures are required to refurbish rusting steel on transmission assets and deteriorating insulation; to replace obsolete substation electronic equipment; and end of life replacement of substation plant, transformers and reactors. These non-routine costs would exceed routine transmission line maintenance by a large amount.

The AER Transmission Network Service Providers Annual Benchmarking can be used to determine the average total annual costs for each company from their submissio0ns to the AER, as follows. Whilst the allocation between capital and operating fund varies because of different accounting practices between Powerlink and the others, the overall annual costs all lie within 3.0% pa and 3.5% pa, except for the outlier ElectraNet**.**

	Total Assets Cost $million	Operating Fund % p.a.	Capital Fund % p.a.	Overall Annual Cost % p.a.
Electranet	$4,760m	2.1% p.a.	3.0% p.a.	5.1% p.a.
Powerlink	$12,000m	1.8% p.a.	1.2% p.a.	3.0% p.a.
AusNet Services	$7,360m	1.2% p.a.	2.1% p.a.	3.3%p.a.
TasNetworks	$2,520m	1.2% p.a.	1.9% p.a.	3.1%p.a.
TransGrid	$11,400m	1.5% p.a.	2.0%p.a.	3.5%p.a.

By assuming only 1% pa instead of 3% pa, the cost of each project has been understated by the equivalent of 15% of its total capital cost. In the case of comparing overhead Humelink (which should have been 3.5% pa instead of 0.5% pa) with underground HVDC (assuming 0.5% pa plus half-life HVDC/AC converter full replacement) the cost of the HVDC undergrounded could be increased by 33% greater than the cost of the overhead line and have the equivalent total life cycle cost in NPV terms. It should also be noted that the AER will automatically pass the actual annual costs through to NSW electricity customers regardless of the incorrect assumption made in the PACR's.

14 China's Revolutionary ZhangBei HVDC Project near Beijing, 2022

China has just completed its ZhangBei HVDC project, for the Beijing Olympics, which demonstrates revolutionary new HVDC technology likely to change electricity transmission globally.

For the first time, it uses a HVDC circuit breaker at the end of each HVDC transmission line. It uses short lengths of HVDC lines (from 78 km to 184 km, connected in a secure mesh arrangement in exactly the same arrangement as HVSC transmission.

The only reason that HVAC won out in the Edison-Tesla-Westinghouse War of Currents in 1870/1880 was because it was not technically possible to change the voltage level (AC used transformers) and to switch off DC (AC used circuit breaker when the current passed through zero). Otherwise HVDC was far superior in every other aspect and is already used in nearly all applications in society.

The AC/DC converter developed 50 years ago solved the first problem and the ZhangBei HVDC network has solved and demonstrated that HVDC can now be switched

The implications for Australia's future transmission grid will be profound. The preliminary HVDC plan shown above is in the absence of HCDC circuit breakers, but is never-the-less superior to using 500 kV AC in NSW, in my opinion.