Attachment D
Snowy 2.0 cyclic energy storage capacity is considerably less than 350 GWh

A key justification for Snowy 2.0 is its claimed cyclic energy storage capacity of 350 GWh.

As stated in the Main Works EIS:

> *"Snowy 2.0 will increase the generation capacity of the Snowy Scheme by almost 50%, providing an additional 2,000 megawatts generating capacity, and making approximately 350,000 megawatt hours (175 hours of energy storage) available to the National Electricity Market."*

> *"Snowy 2.0,* ***being a closed system****, can move water between reservoirs and not rely on natural inflows that may vary seasonally, offering valuable seasonal storage and insurance against drought risk. This is because* ***Snowy 2.0's pumping capabilities work in a 'closed' system - water is recycled between the two dams so the same water can be used to generate power more than once, making the most of available water [bold emphasis added]****."*

Snowy 2.0 is portrayed as a 'green battery' cycling the same water back and forth between its upper and lower reservoirs (Tantangara and Talbingo, respectively) and capable of generating 2,000 MW for 7 days straight (350 GWh).

No information has been provided on how this figure of 350 GWh has been determined. Though it would appear to be based on utilising the full active storage volume of the upper (headwater) reservoir (Tantangara), which is stated to be 239 gigalitres (GL):

> *"The period of full and continuous operation when headwater reservoir is full is 175 hrs (which equates to 7.3 days)."* (Snowy 2.0 FID Market Modelling)

This Paper contends that Snowy 2.0's recyclable energy storage capacity is considerably less than 350 GWh. Depending on the operating regime for Tantangara Reservoir the recyclable storage capacity could vary between about 40 and 200 GWh - i.e. 20 to 100 hours at 2,000 MW. Generation beyond this amount would result in discharging to Blowering Reservoir where water is 'lost' from Snowy 2.0 and therefore not recyclable.

1. Snowy 2.0 is unlikely to ever generate 2,000 MW for 7 days

The capability of generating at full capacity for 175 hours is claimed to be a distinguishing benefit of Snowy 2.0 over other energy storages.

However, it has not been demonstrated how often such a situation might arise in the National Electricity Market where Snowy 2.0 would be called upon to generate continuously at 2,000 MW for 175 hours.

NPA contends that it is a capability that would probably never be called upon to deliver, certainly not for a few decades and then only very rarely, if ever.

Even with high penetration wind and PV in a few decades, it is most unlikely that Snowy 2.0 would ever be called upon to generate 350 GWh at one time. It would be highly unlikely for the spot price to stay at a sufficiently high level over a week to make it financially worthwhile to generate continuously.

It is anticipated that Snowy 2.0 's usual operation would be to generate and pump over a few hours a day, extending beyond that only occasionally. In other words, it would be difficult to achieve additional incremental commercial value from having 175 hours of storage compared to that achieved with a smaller storage amount.

Further evidence of the limited generation expectations of Snowy 2.0 is the Feasibility Study prediction that prior to 2040 Snowy 2.0 will operate at full capacity for less than 87 hours per year[1].

Snowy 2.0 would rarely be called upon, or would it be economic, to operate for any more than some hours at a time, rather than days or a week.

Whilst Snowy 2.0 might have an energy reserve of up to 350 GWh, it would rarely or ever be called upon to deliver that amount of energy at once.

2. Energy storage capacity of pumped hydro determined by volume of recyclable water

The energy storage capacity of a pumped hydro storage scheme is defined by the fixed volume of water that can be recycled between the two reservoirs. In a closed system this is set by the capacity of the smaller reservoir[2]:

> *"the energy generating capacity of a pumped storage scheme is set by the water storage capacity of the lesser of the two water storage volumes".*

In the case of Snowy 2.0, the smaller reservoir, Talbingo, has only two-thirds the active storage capacity of Tantangara (160 GL versus 239 GL nominal). One-third of Tantangara water will not fit in Talbingo.

If Snowy 2.0 were a closed system its energy generating capacity would be determined by the generating capacity of two-thirds of Tantangara's 239 GL – i.e. 240 GWh (2/3x350).

However, Snowy 2.0 is not a closed system, contrary to the Snowy Hydro quote at the beginning of this Paper. In Snowy 2.0's case its recyclable energy generating capacity is substantially less than that determined by the volume of the smaller reservoir (Talbingo), due to complexities from integration with the existing Tumut Scheme (as explained later).

3. Tantangara does not have 239 GL of active storage

Much of the Snowy Scheme infrastructure was based on design principles of the US Bureau of Reclamation where, in the case of reservoirs, the minimum operating levels were determined by design lives of 100 years and the condition of vegetation in the catchment. For Tantangara, the

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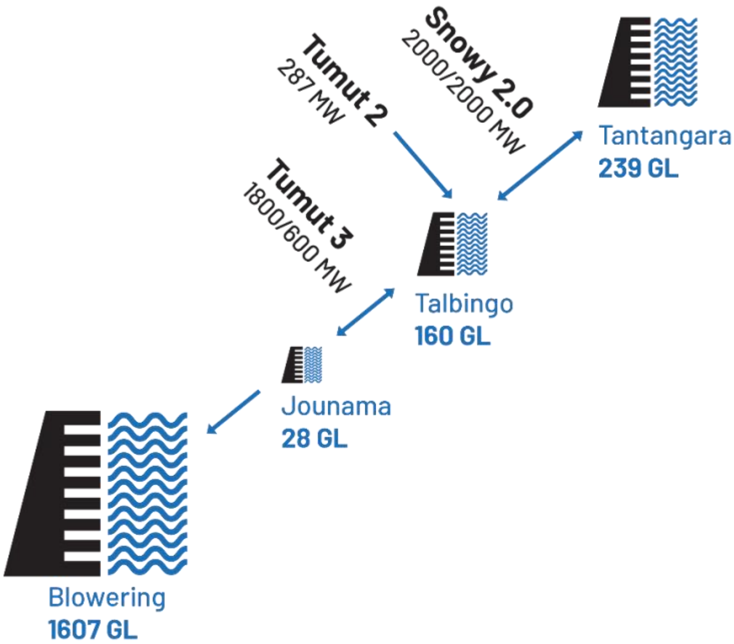
[1] *"A key consideration for the power waterway diameter selection was the average permissible velocity in a concrete lined tunnel (generally accepted to be 6m/s). Prolonged operation at such high velocities may lead to a deterioration by scouring of the power waterway's concrete surfaces due to high local turbulence at surface irregularities. This analysis consequentially must be matched to the independent market expert's modelling of the Project's operation profile, which shows that in any given year prior to 2040, the Project will be operated at full capacity for less than 87 hours per year. At this stage of the Project's due diligence efforts, this is deemed acceptable."* Snowy 2.0 Feasibility Study (page 16 of Summary)

[2] "ROAM report on Pumped Storage modelling for AEMO 100% Renewables project" 24 September 2012 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.434.9204&rep=rep1&type=pdf

vegetation was considered to be pristine and the 100 years of estimated sedimentation amounted to 15 GL (i.e. the difference between the total storage of 254 GL and active storage of 239 GL – the so-called 'dead storage').



Schematic of Tumut and Snowy 2.0 Reservoirs (using Snowy Hydro's stated volumes)

As Tantangara Reservoir is 60 years old, theoretically 60% of the estimated sedimentation would have occurred by now (i.e. 9 GL). Though it is likely that sedimentation has accelerated in recent years due to the ever-increasing numbers of feral horses trampling the catchment and destroying the previously pristine environment.

In practice most sediment impinges as an alluvial fan into the active storage area and does not settle into dead storage at the base of the reservoir below the minimum operating level. This is expected to be the case with the gently sloping topography of Tantangara.

A further reduction in Tantangara's active storage of about 3 GL will result from the dumping of over 4,000,000 cubic metres of excavated spoil from the Snowy 2.0 tunnels.

So, the active storage of Tantangara is likely to be at least 12 GL less than 239 GL (i.e. <227 GL).

4. Tantangara would normally be kept below full supply level

Like most storages, Tantangara is usually never kept completely full, to avoid spilling from high inflow events due to rain and melting snow. In the past, Tantangara has averaged about one-third full.

However, its level will have to increase to full supply if Snowy 2.0 is to deliver its maximum energy reserve capacity.

The consequent increased risk of spilling is largely mitigated by the ability of Snowy 2.0 to turbine large inflows down to Talbingo. Though there would be times when generation would be limited or not permitted due to full storages downstream and the need to manage releases from Blowering to pre-SMA levels. In such a scenario, it would be necessary to divert Tantangara inflows to

Eucumbene. But, due to the limited diversion capacity (1.6 GL/day), there would need to be air space reserved in Tantangara to avoid spilling.

So, in practice Tantangara would probably be kept slightly below full supply level.

If that reserve space margin was say 5% (12 GL) this would reduce the maximum stored volume to 215 GL [239-12-12 = 215GL].

In a wet sequence with full or very high storage levels in Blowering, the storage level in Tantangara would need to be even lower in order to manage local inflows thus greatly reducing the energy reserve storage capacity.

5. What is the energy storage after adjustments to Tantangara storage volume?

The total reductions in storage volume from the above adjustments is 24 GL:

- Sedimentation 9 GL
- Spoil dumping 3 GL
- Headspace 12 GL

Hence the resulting active storage capacity is approximately 215 GL (239-24 = 215 GL).

If the claimed 350 GWh energy storage capacity is based on an active storage volume of 239 GL, a reduced storage volume of 215 GL would result in a lower energy storage capacity of 315 GWh (215/239x350 = 315 GWh) i.e. ~10% less than the claimed 350 GWh.

However, some expert analysts have suggested that the original 350 GWh figure could be slightly understated and that 350 GWh could be delivered with slightly less than 239 GL.

This Paper has taken a conservative approach and assumed the full 350 GWh can be generated from an active storage volume of 215 GL. Also, to reduce confusion in the analysis, the Paper has retained the stated storage volunme for Tantangara of 239 GL.

Of course, the deliverable energy capacity is reduced when Tantangara is further below 215 GL and is zero when Tantangara is at minimum operating level.

6. Talbingo will also have less active storage capacity than stated (160 GL)

Sedimentation into Talbingo Reservoir over the 50 years since its construction in 1971 is not known. Also, as with Tantangara, over 4,000,000 cubic metres of excavated spoil is to be dumped in Talbingo Reservoir.

Hence, Talbingo's active storage capacity will be (slightly) less than its original 160 GL.

(It would have been prudent of Snowy Hydro to have undertaken surveys of both Talbingo and Tantangara to determine their present-day capacities, particularly as the maximum storage capacities are relevant in determining the operating and financial performance of Snowy 2.0.)

7. But the most relevant issue is that the water in Tantangara can’t fit in Talbingo

As noted earlier, Talbingo Reservoir has only two-thirds the active storage capacity of Tantangara (160 GL versus 239 GL nominal) and one-third of Tantangara water will not fit in Talbingo (slightly less if calculated with an actual storage volume of 215 GL).

Hence, based on the storage volume of the ‘lesser reservoir’, Talbingo, the theoretical energy storage capacity of Snowy 2.0 is about 240 GWh - i.e. 120 hours at 2,000 MW [160/239x350 = 234GWh].

Even in the most fortuitous (and unlikely) of circumstances, if both Talbingo and Jounama Reservoirs happened to be empty, the energy capacity of Snowy 2.0 is 275 GWh [(160+28)/239x350 = 275GWh]. But in this case the full energy storage capacity of Tumut 3 (60 GWh) is not available, resulting in a net storage availability of Snowy 2.0 of 215 GWh (275-60 = 215 GWh).

In the most favourable of circumstances, when Tantangara Reservoir happened to be full and Talbingo/Jounama empty at a time when Snowy 2.0 was called upon to generate continuously at 2,000 MW for 7 days, about 15% of Tantangara water (39 GL) would not fit in Talbingo/Jounama and would be ‘lost’ from the Snowy 2.0 system and flow into Blowering Reservoir [239-160-28 = 39GL = 16% of 239GL].

8. Talbingo is rarely empty, hence even more of Tantangara’s volume can’t fit

Snowy 2.0 is not a ‘closed system’, with exclusive use of Talbingo, which is the lower reservoir of Tumut 2 hydro power station and the upper reservoir of Tumut 3 pumped hydro station (1,800 MW of generation and 600 MW of pumping). Hence, Snowy 2.0 will need to be integrated into the existing Tumut Scheme (Tumut 1, Tumut 2 & Tumut 3).

Historically, levels in Talbingo Reservoir have been kept as high as possible to optimise the operation of Tumut 3. The higher the level of Talbingo the greater amount of energy is stored and the higher is the efficiency of generation. As stated in the Main Works EIS:

> *“Water levels [in Talbingo] are typically maintained at the dam crest level for around six months of the year and lower water levels tend to occur in late winter or spring, although this pattern shifts from year to year.”*

Historically, the spare capacity in the Tumut 3 Talbingo/Jounama system has been approximately equal to the capacity of Jounama Pondage (28 GL). Simplistically, if Talbingo was full, Jounama would be emptied, to allow for Tumut 3 generation. If Jounama was full, Talbingo’s level would be targeted at 28 GL below full supply to allow for Tumut 3 pumping. If Jounama was half full, Talbingo’s level would be targeted at 14 GL below full supply to allow for Tumut 3 pumping and generation.

If the current operating regime were maintained, with spare capacity in Talbingo/Jounama of about 28 GL, then emptying a full Tantangara would result in about 210 GL (85%) of Tantangara water not fitting in Talbingo/Jounama and being lost from the Snowy 2.0 cycle to Blowering [239-28 = 211GL = 87% of 239GL].

If the operating regime were changed to say keep Talbingo/Jounama about half full, then emptying a full Tantangara would result in about 145 GL (60%) of Tantangara water not fitting in Talbingo/Jounama and being lost from the Snowy 2.0 cycle to Blowering [239-80-14 = 145GL = 60% of 239GL].

9. If Snowy 2.0 were built, would Talbingo would be kept close to full

Whilst Talbingo's level could be reduced to provide 'space' for Snowy 2.0 Tantangara water, this would reduce the energy storage and efficiency of Tumut 3.

As Tumut 3 has 60 GWh of storage when Talbingo is full, any reduction in Talbingo water levels would reduce that capacity, which can be delivered at 1,800 MW for up to 33 hours. A reduction would also (marginally) reduce the efficiency of Tumut 3.

Another reason to keep Talbingo close to full is that a call on Snowy 2.0 to generate for 7 days would normally be most unlikely. Also, Tumut 3 can very quickly generate and create space in Talbingo for Snowy 2.0 water, though this still means discharging water to Blowering, beyond whatever spare capacity there was in Jounama at the time.

So, if the current operational arrangement remains largely intact, the available capacity for Snowy 2.0 before water is lost to Blowering would be approximately 28 GL.

This volume equates to a recyclable energy storage capacity for Snowy 2.0 of about 40 GWh (28/239x350) – i.e. 20 hours at 2,000 MW.

This doesn't mean that Snowy 2.0 would be constrained to generating for only 20 hours at 2,000 MW (28 GL of water). It just means that generation beyond that amount would result in Tantangara water being discharged into Blowering and lost to Snowy 2.0. This could be as much as 210 GL if Tantangara was emptied, having started near full supply level.

Discharging into Blowering is normally not an issue from an operational perspective, except of course in wet years when Blowering is full and the Tumut stations are prevented from generating to minimise flooding of the Tumut River below Blowering. But it does mean that the lost water needs to be replenished from Eucumbene via Tumut 1 & 2 stations for pumping back up to Tantangara.

10. What happens if levels in Talbingo were reduced to accommodate Snowy 2.0

An alternate operating regime could be to reduce the water stored in Talbingo/Jounama:

Half full

In this case emptying a full Tantangara would result in 94 GL of Tantangara water 'fitting' in Talbingo and 145 GL being lost from the Snowy 2.0 cycle to Blowering.

This equates to a recyclable energy storage capacity for Snowy 2.0 of about 140 GWh (94/239x350). Though it halves the energy capacity of Tumut 3 from 60 GWh to 30 GWh, so the net storage is about 110 GWh.

Almost empty

At the extreme, the water stored in Talbingo/Jounama could be reduced to 28 GL.

This would allow 160 GL of Tantangara water to be accommodated in Talbingo. This equates to a recyclable energy storage capacity for Snowy 2.0 of about 235 GWh (160/239x350).

In this case the energy capacity of Tumut 3 is reduced from 60 GWh to 10 GWh, so the net energy storage is 185 GWh (235-50).

Emptying a full Tantangara would result in 79 GL of Tantangara water being lost from the Snowy 2.0 cycle to Blowering.

11. The cyclic energy storage capacity of Snowy 2.0 is considerably less than 350 GWh

The capacity of Snowy 2.0, based on the amount of water that can be "*recycled between the two dams"*, as per the quote and definition, is not simply determined by the capacity of Tantangara Reservoir (350 GWh), as claimed by Snowy Hydro.

If based on the active storage volume of the 'lesser reservoir', Talbingo, the theoretical energy storage capacity is about 240 GWh [160/239x350 = 234GWh].

But, due to the use of Talbingo by Tumut 3, determination of the practical recyclable energy storage capacity of Snowy 2.0 is more complex and depends on the integrated operating regime. Any reductions in Talbingo levels to accommodate Tantangara water will reduce the energy capacity of Tumut 3 and hence needs to be factored into the analysis.

At one extreme, if the current operating regime were maintained (i.e. Talbingo kept full), the recyclable energy storage capacity of Snowy 2.0 is 40 GWh. Emptying a full Tantangara would result in about 210 GL (85%) of Tantangara water not fitting in Talbingo/Jounama and being lost from the Snowy 2.0 cycle to Blowering.

At the other extreme, if Talbingo/Jounama were reduced to 28 GL, the minimum level to keep Tumut 3 operational, the recyclable energy storage capacity for Snowy 2.0 is about 235 GWh. But in this case the energy capacity of Tumut 3 is reduced from 60 GWh to 10 GWh, so the net energy storage is 185 GWh (235-50). Emptying a full Tantangara would result in 79 GL of Tantangara water being lost from the Snowy 2.0 cycle to Blowering.

So, the recyclable energy storage capacity of Snowy 2.0 is within a range of about 40 – 200 GWh, depending on the operating regime adopted for Talbingo levels. This equates to between 20 and 100 hours generation at 2,000 MW.

This is the capacity that could be provided in a drought situation where no make-up water was available.

12. It will take months to replenish Tantangara

A further major constraint on Snowy 2.0's purported pumping/generating cycling is that whenever Tantangara Reservoir is emptied down to its minimum operating level it will take many months to refill.

In theory, if Snowy 2.0 pumps were run at 2000 MW, Tantangara could be refilled in about 11 days of continuous 24 hour/day pumping (allowing for a 30% loss factor). But this would not be possible as there would be insufficient water in Talbingo, being two-thirds the capacity of Tantangara. It does not make economic sense to generate at Tumut 1 & 2 to refill Talbingo at the same time as Snowy

2.0 was pumping, thus limiting the amount of water from Tumut 1 & 2 to non Snowy 2.0 pumping periods.

Usually it would not be financially viable to run Snowy 2.0 pumps for more than 5-8 hours/day at 2000 MW (i.e. when the spot price is 'cheap'). It could well be less hours/day, as if Tantangara were emptied it is likely to be during a period when wholesale prices were high due to stresses within the National Electricity Market (NEM) that triggered extended Snowy 2.0 generation in the first place.

To run a plausible best-case scenario, if Snowy 2.0 pumped for 6 hours/day at 2,000 MW, it would take about 45 days to fill Tantangara, at just over 5 GL/day. Coincidentally, 5 GL/day is about the maximum rate at which water from Eucumbene can be transferred to Talbingo via Tumut 1 and Tumut 2 generating for 12 hours/day, which is likely to be the maximum daily period for economical generation. So, 45 days is the minimum time it would take to refill Tantangara, ignoring any direct inflows to Tantangara and avoiding any net drawdown of Talbingo.

This best-case scenario assumes no generation by Snowy 2.0 during that 45-day period. But it is likely to be profitable to run Snowy 2.0's generators for at least some of those days, especially if the NEM remained under stress and prices were high. Obviously, any generation depletes the water pumped back to Tantangara. Also, any period of generation requires 1.4 times that period for pumping at the same MW rate, to replenish the water used, due to losses in the pumping cycle. The net amount of water pumped back up to Tantangara would be determined by the prevailing electricity price spreads.

So, in practice it would be expected to take many months (3+) to fill Tantangara and for Snowy 2.0's full capacity to be 'available' again.

Another relevant point to note is that any unavailability or breakdown of the Tumut 1 or Tumut 2 generators or the Snowy 2.0 pumps would extend the time to refill Tantangara.

In reality, if Tantangara were ever emptied it is a once-a-season shot.

And it will require 500 GWh of pumping energy to re-fill.

13. Summary

Accounting for reductions in the storage of Tantangara Reservoir from sedimentation, dumping excavated spoil from Snowy 2.0 and providing a small operating margin to minimise spilling from high inflow events, would reduce the maximum energy that can be generated by approximately 10%.

However, the energy storage capacity of a pumped storage scheme is determined by the fixed volume of water that can be recycled between the two reservoirs. In Snowy 2.0's case that means the nominal capacity is determined by the water storage volume of Talbingo Reservoir (i.e. a bit under 160 GL). This would result in an energy storage capacity, in theory, of about 230 GWh.

But Snowy 2.0 is not a closed system. If Snowy 2.0 is constructed, Talbingo Reservoir will have multiple uses and the cyclable energy storage capacity, as determined by the amount of water that can be recycled between its two reservoirs, is substantially less.

If the current operation of Talbingo and Tumut 3 is largely retained (i.e. Talbingo kept close to full), in order to maintain the energy reserves of Tumut 3, the available space in Talbingo/Jounama will continue to be approximately 28 GL. This results in a recyclable storage capacity for Snowy 2.0 of approximately 40 GWh. Any Snowy 2.0 generation beyond 40 GWh would result in up to 190 GL

(85%) of Tantangara water being discharged to Blowering where it is lost to Snowy 2.0 and cannot be recycled.

However, if the operating regime was taken to the other extreme and Talbingo/ Jounama were left with a minimum amount of water to run Tumut 3 (28 GL) to accommodate the maximum amount of Tantangara water via Snowy 2.0, the recyclable energy capacity of Snowy 2.0 is approximately 200 GWh. Any Snowy 2.0 generation beyond 200 GWh would result in up to 79 GL (30%) of Tantangara water being discharged to Blowering where it is lost to Snowy 2.0 and cannot be recycled.

Also, emptying Tantangara would be a once-a-season shot, as it would take many months (3+) to refill.