*Submission by **Oscar Archer**, **PhD**, addressing part 1.(a) of the Terms of Reference:*

"That a select committee, to be known as the Select Committee into the Resilience of Electricity Infrastructure in a Warming World, be established to inquire into and report on, by 10 February 2017, the following matters: the role of storage technologies and localised, distributed generation to provide Australia's electricity networks with the resilience to withstand the increasing severity and frequency of extreme weather events driven by global warming."

Preamble

The Federal Senate is to be commended on the formation of the Select Committee and its efforts to gather knowledge regarding the potential of energy storage technologies in the context of Australia's response to the climate challenge.

This submission is intended to bring the Committee's attention to three fundamental, critical challenges faced by battery storage technologies at the device scale, and one which broadly dictates the economics at grid scale.

Conventional lithium ion battery technologies have begun to dominate the market[1] thanks to versatility in a growing range of applications and an expansion of manufacturing capacity which has boosted global economies of mass production. Lithium is also the lightest metal with the highest ionisation potential. Thus, lithium ion cells present the ideal illustration of the fundamental ceiling on electrochemical energy storage, and will be referred to by default.

Density

The first ionisation potential of lithium is 5.39 electron volts, which translates to a hypothetical change in energy for the equation

$$\mathrm{Li} \rightarrow \mathrm{Li}^{+} + e^{-}$$

of 520 kilojoules per mole (kJ/mol). (A mole is the mass of a pure substance relative to its atomic weight. To illustrate, 1 mole of carbon – twelfth on the periodic table of elements – is equivalent to 12 grams.)

A typical lithium ion cell stores electricity by adding electrons to lithium ions at the anode of the cell (the reverse of the above equation).

Consequently, there is a concrete upper limit for battery capacity based on the amount of lithium contained in the battery. In practice, it is markedly lower than the “textbook” figure given above. The dominant method for increasing capacity in marketable lithium ion cells is to increase cell density. The latest reported research shows density could be doubled (or more) relative to current technology, however this requires new chemistries which are a long way away from mass production[2] and the cost declines exhibited by that current technology.

The result is a tension between: incumbent, market dominating lithium ion batteries which are already produced at a large (and growing) scale, suitable for many uses and requiring only marginal improvements to adequately meet even more uses; and all-new battery technologies which could potentially supply the step change in density, material requirements, scalability and overall cost (by at least an order of magnitude relative to present costs) which is recognised as technically necessary for economical, widespread deployment at grid-scale – the scale needed to displace fossil fuels for meaningful climate action. This ultimate factor is illustrated in figure 1 below: considering that 520 kJ is the equivalent of just over 144 watt hours (Wh), the economical storage of energy via lithium ion battery systems is still far from the density advantage of conventional liquid fuels.

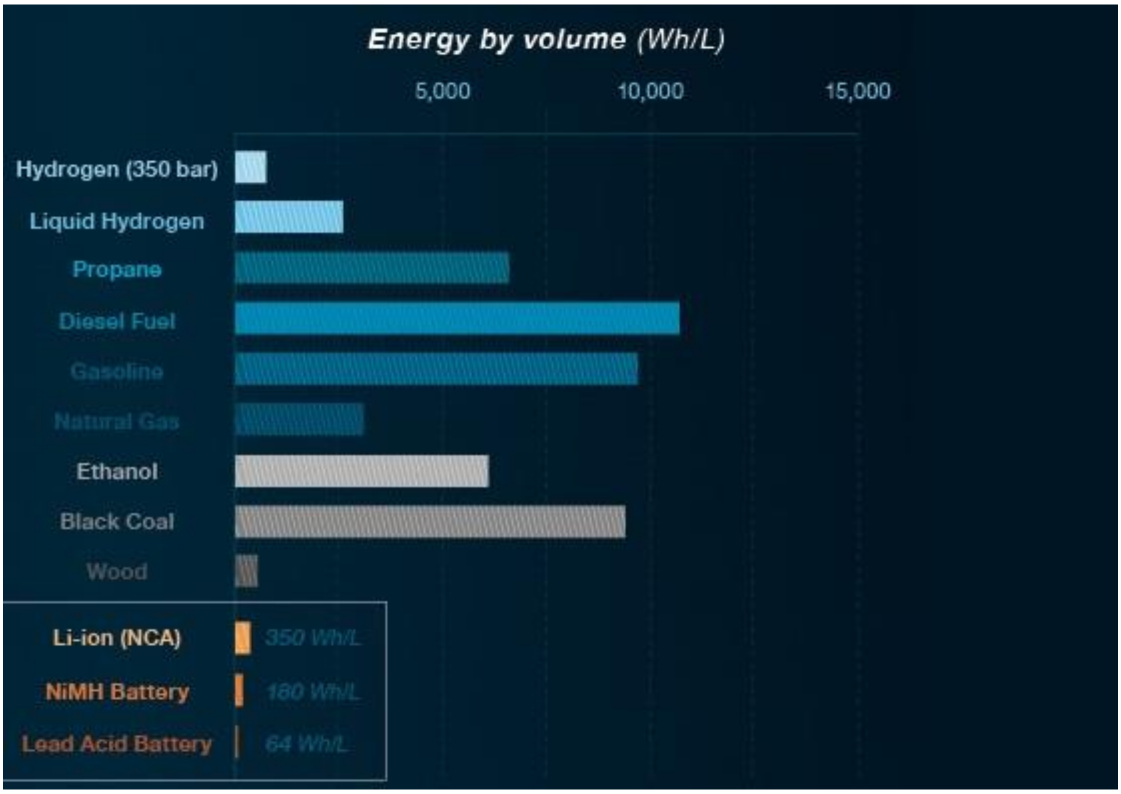

Figure 1 (from https://goo.gl/FYnXSG)

Lifespan

The highly engineered and pure chemistry within lithium ion cells is necessary to achieve their versatile capacity and output characteristics with acceptable safety, depending on specific application. However, this chemistry unavoidably degrades over time, largely based on charge/discharge cycling. In some cases, such as small domestic storage units this results in limited manufacturers' warranty periods, typically 10 years. In cases of feasibility studies for grid-scale storage applications, this service lifespan is included as an assumption. Although 15 years is sometimes chosen, 10 years is a sensible assumption for economical operation, as was specified in the on-going ESCRI study,[3] the first comprehensive assessment of non-hydro storage technology in Australia, supported by ARENA.

In any case, this lifespan is considerably shorter than normally expected for capital infrastructure which may be important for achieving plentiful, economically competitive and decarbonised future energy supplies. To illustrate, analysis by Parsons Brinkerhoff[4] for the South Australian Nuclear Royal Commission set the debt period of power station operation at 20 years. Nobody expects modern lithium ion batteries, constantly charging and discharging, to operate for this long, let alone the 60 years expected of new nuclear plants.

Alternative storage technologies such as pumped hydroelectric, compressed air energy storage and vanadium flow batteries, as well as thermal storage without transformation to electrical supply, present demonstrated or promising solutions to the lifespan limit. However, deployment may be geographically limited or economies of scale as yet unrealised, and none receive anything like the current focus enjoyed by lithium ion.

Moore's Law

The US Department of Energy reports that modelled costs in dollars per kilowatt hour of capacity for lithium ion batteries have fallen from about $1000 in 2009 to $230 in 2015.[5] This sort of trend is sometimes naively attributed to Moore's Law, which frames it as a predictable and constant cost decline such that batteries will be a fraction of their current price in the near future.

Moore's Law specifically relates to the predictable increase in the number of transistors per area for printed circuits, and thus decrease in costs, which halve roughly every 18 months. It has enabled a revolution in affordable information technology, but it is not transferable to other, non-transistor-based manufacturing, which must rely on normal economies of scale and learning rates.[6]

The US DOE is working with private industry with the aim of halving the current cost of battery capacity by 2022, a fundamentally different timescale to that of Moore's Law. This laudable objective should be viewed against the fundamental ceiling to storage capacity – the energy per mass/volume which lithium ions can store – as discussed above.

Actual Demand

The electrical demand for a region describes a daily "load curve", typically peaking in the evening. The maxima and minima (in megawatts) vary subtly from day to day, and more dramatically across seasons, and also more recently due to intermittent "behind the meter" distributed supply (almost entire rooftop PV solar).

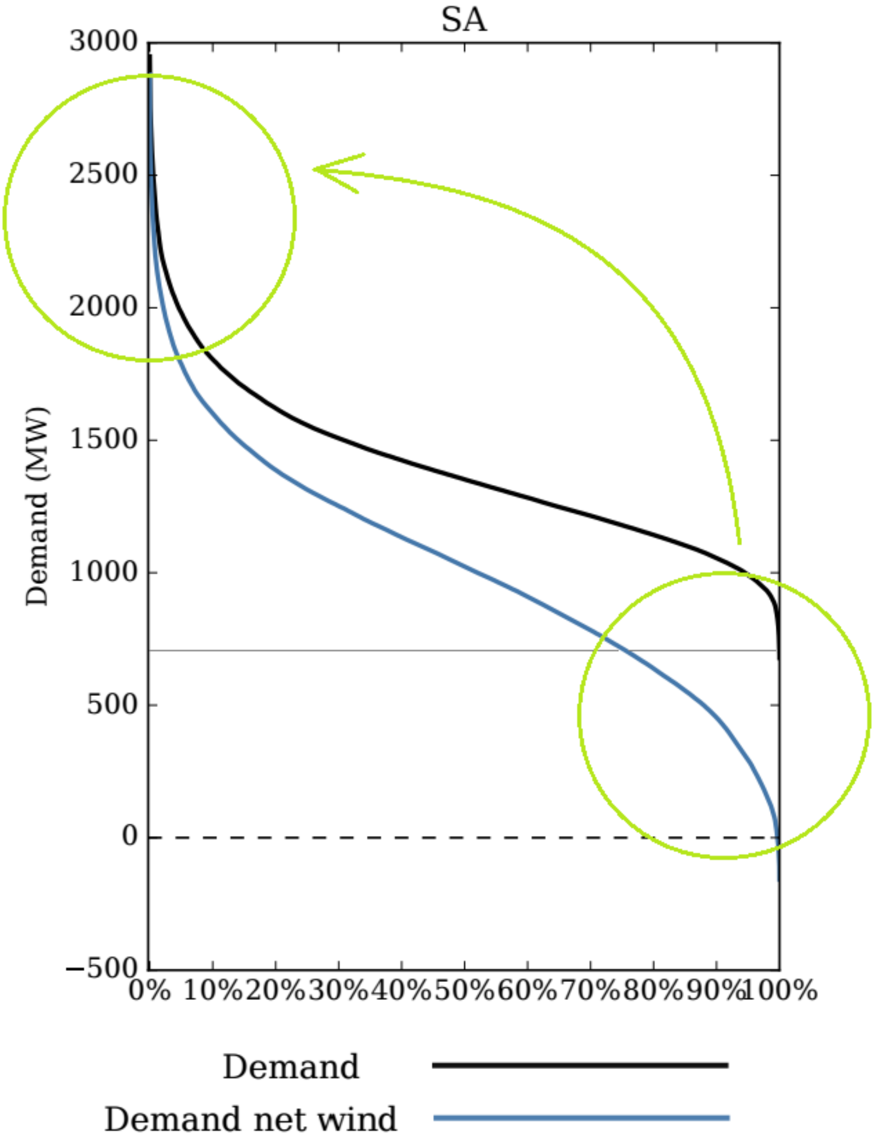

Figure 2 (adapted from https://goo.gl/Gnsu0t appendix A)

The individual time increments of the load curve (5 or 30 minutes for the Australian markets) can be rearranged according to magnitude, as shown for 2015 in South Australia in figure 2. The highest load for the year is at 0% and the lowest at 100%. The black line is referred to as the “duration curve” for the region and illustrates two important things:

Firstly, all else being equal, South Australia required roughly 700 MW of constant “baseload” supply (thin grey line). In a conventional market this is provided by scheduled generators with low short run costs which bid their output in at low prices, obviously doing so for most or 100% of the year and therefore covering their long run costs.

Secondly, demand peaked to around 3,000 MW for a small percentage of 2015, which had to be met by marginal, flexible, scheduled generators with high short run costs. The prices they bid for their output must be very high to cover their long run costs since they spend most of the year running at low output or not at all.

The blue curve is known as the “residual load curve”. The megawatts between the two curves were supplied by wind energy in 2015. The larger area towards 100%, compared to the narrower wedge towards 0% (and practically nothing at the topmost point) illustrates that wind output is not closely correlated with regular South Australian demand.

An obvious potential solution is to imagine this wind energy paired with battery storage, but doing so must increase the cost of wind energy since such batteries must be paid for. Although wind output isn’t correlated with demand, every MW of stored wind energy which can be held then discharged during peak demand (when the market will pay the most) will provide the best return on investment to the operators and investors of the storage capacity (green circles).

There are two potential consequences of this market-driven arrangement. Firstly, megawatts will be moved from the large “100% area” to the narrow “0% wedge”. The further towards 100%, and the higher the volume of storage, the more residual “baseload” will tend to be revealed, resulting in increased profitable annual operation of scheduled “baseload” generators. Secondly, once sufficient supply has been shifted, the peak and off-peak market prices will tend to equilibrate, providing less profit for any further energy storage capacity additions.

It follows that the widespread expectation of adding sufficient storage capacity to meet most or all load when intermittent sources are not producing (night/overcast days *and* low wind), and in particular through off-peak, low demand periods, is unrealistic in any sort of modern competitive market. A critical, honest and *quantitative* examination must be made at the national policy level of the extent and realism of the fundamental market redesign required to enable such notions in practice, bearing in mind that nothing resembling such a market exists today anywhere in the world.

Further Reading

Sisternes et al., The value of energy storage in decarbonizing the electricity sector, Applied Energy 2016, 175, 368-379
http://dx.doi.org/10.1016/j.apenergy.2016.05.014

Safaei and Keith, How much bulk energy storage is needed to decarbonize electricity? Energy Environ. Sci. 2015, 8, 3409-3417
http://dx.doi.org/10.1039/C5EE01452B

References

1. https://www.asme.org/career-education/early-career-engineers/me-today/dawn-the-lithiumion-battery-era
2. https://blogs.scientificamerican.com/plugged-in/beyond-the-hype-what-s-the-future-of-batteries/
3. https://arena.gov.au/project/energy-storage-for-commercial-renewable-integration/
4. http://nuclearrc.sa.gov.au/app/uploads/2016/05/WSP-Parsons-Brinckerhoff-Report.pdf
5. https://energy.gov/articles/6-charts-will-make-you-optimistic-about-america-s-clean-energy-future
6. https://www.greentechmedia.com/articles/read/why-moores-law-doesnt-apply-to-clean-technologies