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Quantum Sunlands Partnership
Completion of National Electricity Market Study

Application of Sunlands Co. Technology within the NEM
Potential Retrofitting of Coal Fired Power Stations

Further to our announcement of 23 December 2021, the Company is pleased to announce the completion of the Quantum Sunlands Partnership's (QSP) National Electricity Market Study.

The earlier announcement outlined two key studies, the results of which would provide the Company with important data to assess the scope of the contribution of QSP to the Company's Uley 2 project returns.

The first study consists of certain high temperature test work to confirm the optimum Uley 2 flake specification for QSP's manufacture of thermal storage media for Sunlands Co.'s energy storage cells. The Company recently announced (market release of 3 March 2022), that its engineering partners had selected TU Freiberg's Institute for Non-Ferrous Metallurgy and High Purity Materials (INEMET) to conduct this test work. Further details are expected to be released to the market in the coming weeks.

The second study (NEM Study) is an assessment of Australia's National Electricity Market (NEM) requirement for long duration energy storage and specifically long duration thermal energy storage technology. This category of technologies includes the thermal energy storage cells offered by Sunlands Co. This study was undertaken by Macroeconomics Advisory and has been completed.

Summary of NEM Study Findings

Attached is the NEM Study Preface and Executive Summary of Findings. The study concluded that long duration thermal energy storage technology offers a commercially feasible path to support the National Electricity Market's net zero emissions plan and enables the increasing penetration of solar and wind generation.

This type of technology offers three key advantages in a solar and wind based system:

1. *It provides a means of storing energy in a way that provides relatively cheap long duration back up for intermittent systems;*
2. *It can be used as a replacement for coal and even gas in existing thermal generation facilities thereby;*
   - *retaining the value of existing infrastructure and transmission facilities, avoiding the cost of its replacement;*
   - *continuing to provide the flexibility, security and stabilization services currently delivered by thermal generation facilities; and*
3. *It provides a means of hedging against partial failure of the solar and wind programme.*

The Chief Economist of Macroeconomics Advisory, Stephen Anthony said, "Macroeconomics Advisory, Chief Economist, Stephen Anthony, said "thermal energy storage technologies present a unique advantage – they have the potential to create a bridge for the transition of all generation to achieve AEMO's net zero plan whilst maintaining NEM optionality to implement other and more efficient solutions and technologies.

For the existing conventional thermal power facilities such as coal and gas fired generation, this technology has the potential to deliver a solution that avoids the massive upfront cost of restructuring the grid. Similarly, for renewables generation, it delivers a workable platform to accelerate the increase of renewables without the significant infrastructure costs associated with integrating discrete renewables installations across the NEM."

Scope of NEM Study

The study was conducted within a framework Macroeconomics Advisory determined would deliver meaningful, verifiable results and included the following limitations and assumptions:

- imposing the precondition of commercial feasibility on the long duration thermal energy storage technology;
- identifying a specific market segment within which this technology could be readily deployed (i.e., retrofitting coal fired power stations); and
- assuming that there is no practical impediment to the scalable production of the relevant thermal energy storage media and the associated technology plant and equipment.

Key information regarding the scope of the NEM Study and these assumptions and limitations is outlined below.

(a) Precondition of Commercial Feasibility

Macroeconomics Advisory broadly defined commercially feasibility as the deployment of the technology within the NEM without requiring substantial changes to governmental or regulatory policy, material Commonwealth or State based transfer payments or material changes to NEM infrastructure.

The precondition of commercial feasibility can be satisfied by a type of thermal energy storage technology that meets certain technical requirements, principally, the capability to drive large utility scale steam turbines at the same level as the existing operation of this plant.

Importantly, this precondition reduces the complexity of the analysis and promotes greater certainty in our findings. Various energy storage technologies, well understood by the market, have been commercially deployed across the NEM. However, none of these technologies provide a commercially feasible path within the NEM as a long or very long duration storage solution without significant, and in many cases fundamental change, to governmental or regulatory policy or NEM infrastructure or both.

Sunlands Co. claims its technology meets the principal technical requirement. This is supported by the results of its independent techno-commercial feasibility previously announced to the market (30 June 2020 Quarterly Activity Report released on 31 July 2020) however the technology has not yet been commercially deployed. For the purposes of the study, Macroeconomics Advisory makes no claims about the technical capability of the specific Sunlands Co. technology or that its commercial deployment or operation will achieve the results published in its techno-commercial feasibility.

(b) Defining the NEM Market Segment

Macroeconomics Advisory acknowledged that the assessment of the overall market requirement for long duration and very long storage within the NEM, was too broad and the potential applications too expansive to provide a meaningful assessment.

Confining the market to the application of the technology to the retrofitting of coal fired power stations within the NEM provided a well-defined market capable of delivering meaningful verifiable results.

(c) Scalable Production of Thermal Storage Plant

Macroeconomics Advisory considered that an essential feature of a suitable thermal energy storage technology is the capability of deployment within the relevant market segment consistent with AEMO's emissions reduction milestones. Since the critical input to all thermal energy storage technologies is the thermal storage media, it concluded that the scalable production of this media, including ready access to critical raw materials, would be essential.

For example, based on the thermal process data included within the Sunlands Co.'s techno-commercial feasibility, 100,000 tonnes of coarse flake would be required to replace every 1 GW of coal fired generation.

Macroeconomics Advisory makes no claims regarding the scalable production of this quantity of raw material to produce the required amount of thermal storage media or that the energy storage plant and associated equipment can be produced within the timeline required by AEMO's emissions reduction plan. It has made the general assumption that, regardless of the type of thermal energy storage technology selected, the availability of raw materials and the production profile of the energy storage plant and associated equipment will meet this timeline.

Director, David Trimboli commented that, "the completion of this market study is a key milestone for the Quantum Sunlands Partnership. It demonstrates the transformational value to the national electricity market for long duration thermal energy storage and a massive potential market for QSP."

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QUANTUM SUNLANDS PARTNERSHIP

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Solutions for complex problems

Sunlands' Energy Storage Technology

National Electricity Market Deployment of Large Scale Storage and Generation Solution
Assessment of Grid Network Value and Direct Capital Cost

PREFACE

If emissions reductions targets are to be met, electricity generation will have to be extended beyond its current uses to cover most of the energy required in transport and industry. This may require increasing production from between five and nine times that of existing levels in advanced economies.

Australia plans to make this transition with solar and wind as the primary energy sources, together with a significant amount of confidence in the successful development of emerging technologies. Unlike California and Germany, for example, the execution of Australia's plans does not have the benefit of critical support from an alternative large scale neighboring grid. In this sense Australia is unique amongst large industrial economies.

It is true that Australia has an advantage in solar and wind resources compared with countries such as Japan, Germany or the UK. On the other hand the magnitude and extent of the energy required creates extraordinary economy wide vulnerabilities.

Is this a bet we can afford to make?

The truth is we don't know whether a trajectory based exclusively on solar and wind is optimal or even feasible. Nor can we yet grasp its total economic cost.

The answer to these questions must be based on an assessment of the system as a whole. Many of the current policy statements and reports of regulatory agencies are essentially concerned with answering the question '*how can we facilitate more solar and wind?*' and not with the question, '*what would be the optimal generation mix required for Australia to maintain an efficient economy with low levels of emissions?*' In restricting the analysis, the standard mathematical principles of optimality are violated.

A consequence of this restricted view is that technical and commercial issues associated with the available technologies and their deployment are largely overlooked. In addition there are major issues around expected value and uncertainty that are ignored.

Pursuing a strategy of reliance on solar and wind requires, large scale storage and backup. It is extremely unlikely that the storage capacities needed can be provided by batteries or potential energy such as pumped hydro. Hydrogen is a possibility, but there remains serious questions about its capacity to operate as a major back up source.

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One of the most promising of the available technologies is Sunlands' thermal energy storage. Most of the technologies being developed in this area are scalable and compact but lack the significant high temperature operating ranges essential to driving utility scale steam turbine generators such as those utilised by existing coal fired turbines. Thermal storage technologies capable of such high temperature operating ranges are also likely to be significantly less expensive than alternatives such as pumped hydro and batteries.

Low emissions electricity

Australia is already on a path towards low emissions electricity.

Solar, wind and other renewable technologies are being installed at a world-leading rate. These technologies are projected to provide over half of Australia's total generation by 2030.[24] Led by ultra low-cost solar (Section 2.3.2), an increased share of renewables will be the foundation for a near zero emissions grid by 2050.

The challenge is to ensure our electricity system remains secure, reliable and affordable as the share of variable renewables grows. Storage technologies, like batteries, are already providing short-term firming and other system services. Low-cost, long-duration storage will enable very high shares of renewables and ensure security and reliability (Section 2.3.3). In the meantime, while these technologies mature our existing thermal generation assets will continue to play an important and necessary role in providing affordable and reliable power.

The Sunlands thermal storage technology has been developed to operate at these high temperature operating ranges and consequently can be deployed as storage units to run existing coal fired turbines. This technology offers three key advantages in a solar and wind based system:

1. It provides a means of storing energy in a way that provides relatively cheap long duration back up for intermittent systems;
2. It can be used as a replacement for coal and even gas in existing thermal generation facilities thereby;
   - retaining the value of existing infrastructure and transmission facilities, avoiding the cost of its replacement;
   - continuing to provide the flexibility, security and stabilization services currently delivered by thermal generation facilities; and
3. It provides a means of hedging against partial failure of the solar and wind programme.

This last point is less obvious than the first two but vitally important. Even at the low level of about 20 per cent electricity from intermittent sources, Australia's Energy Security Board (ESB) has warned of risks to energy security and stability and highlights the importance of this point.

Combining thermal and intermittent co-generation creates the type of robust system needed to execute a workable transition to net zero. Such a combined system retains a stable and dispatchable power supply that isn't subject to simultaneous failure across the grid.

Australia is unlikely to have a different experience than the rest of the world. There is a non-zero probability that a system relying substantially on solar and wind without long duration storage of the type offered by the Sunlands technology will prove unfeasible. The detrimental impacts to the economy without long duration storage are foreseeable.

By keeping existing turbines and generation capacity active thermal storage helps build a system with a spread of technologies. Instead of an all or nothing bet we have a dynamic system that will work in almost all contingencies.
For example if:

- it becomes difficult to move solar and wind beyond, say 50 to 70 per cent, of total energy requirements thermal capacity is already in place and does not have to be rebuilt; and
- other technologies such as carbon capture and storage or nuclear turn out to offer a better path

the expense of changing trajectories is reduced because much of the required infrastructure has been retained.

EXECUTIVE SUMMARY OF FINDINGS

The Sunlands Company has proposed an energy storage technology that has the potential to resolve the critical problems facing Australia's grid network in the areas of energy storage, security and stability.

Macroeconomics has been commissioned to provide an independent economic assessment of the Sunlands technology in the Australian market. Since a key application of the technology is the *retrofitting of existing coal fired power generation facilities*, our analysis necessarily examined the implications of the use of existing network infrastructure. Much of this infrastructure is geographically centred at these generation facilities.

Accordingly, our assessment of the technology is summarised as a response to two key questions.

Question A. What is the value of the existing infrastructure retained and utilised by providing an alternative (thermal) energy source for existing coal fired thermal generation facilities?

Question B. What are the capital costs of employing the Sunlands' technology as the energy source (in the form of stored thermal energy) to feed existing steam turbine generator infrastructure?

The mapping of any technology over the trajectory that satisfies AEMO's Net Zero Plan is subject to various uncertainties. Macroeconomics recognised that its assessment involved working with two discrete but connected levels of uncertainty - the trajectory of the technology's deployment over an extended period spanning more than two decades and the limited grid network information available to the market to make both commercial and technical decisions.

Because the level of these uncertainties has the potential to exceed the range of estimates in the figures and projections, we have developed a working model that deals with the main factors raised by these uncertainties. These factors are the techno-economic impacts of long run uncertainty and short term risks and the inherent risks associated with limited grid network information. Macroeconomics dealt with these factors in the model by:

(i) Integrating the costs of long run uncertainty and short term risks into the analysis; and

(ii) Examining the underlying patterns and dynamics of the overall system to address the shortfalls in grid network information.

The approach adopted to deal with the limited information requires an understanding of network trajectories and developments at a macro-level consistent with AEMO's Net Zero Plan. We concluded that this approach provides more reliable results and avoids falling into the trap of false precision by applying unconnected bits of data.

All assumptions and data have been sourced from the Australian Energy Market Operator unless otherwise indicated. In the circumstances where Macroeconomics has derived or adopted an assumption or data, every effort has been made to apply these in a way that does not bias the analysis.

QUESTION A

The value of Sunlands' thermal storage to the grid has been estimated in terms of the benefits it creates as a hedge against risks associated with reliance on a narrow range of unproven technologies and in terms of capital costs avoided.

We estimate that each coal fired station maintained by the Sunlands technology would have an average capital cost avoided of approximately **$7.5 billion** per GW of generation if the costs of maintaining or refurbishing existing facilities were ignored. These costs are not expected to be significant.

We also consider the way in which the value of individual coal fired stations or their equivalent will change depending on the penetration of intermittent sources and the number of thermal stations remaining in operation. On the basis of indirect analysis we estimate that the variations in value range from **$5 billion** per GW of generation when nearly all existing thermal stations are still operating to **$10 billion** per GW of generation or more when only a small number are retained.

Table 1 Summary of Capital Costs Avoided

Item		Value ($bil)	
Transmission			7
New Installation			
	Immediate capital cost	80	
	Add 20 year discounted replacement cost	10	
			90
Back up			
	Immediate capital cost	40	
	Add 20 year discounted capital cost	7	
	Total		47
Other			1
Total			**145**
Applying options value multiplier 1.15			**167**
Average value for each GW maintained			7.5
Range of values from first to number 23 maintained			4.8 – 10.7

Our cost figures are overnight costs and no allowance has been made for the cost of finance.

Taking into account the forecasted growth of intermittent penetration we estimate that there is sufficient almost zero-cost electricity in the system to support sufficient thermal energy storage to replace about half or **12 GW** of coal generation on AEMO's 2050 figures.

After this level of coal generation is displaced, additional investment in renewable generation capacity (solar and wind) would be necessary.

In terms of critical materials, the natural flake graphite required for Sunlands' thermal storage media to operate a 1GW plant indefinitely is 100,000 tonnes of coarse natural flake, roughly equivalent to the amount of coal burnt in the same plant every10 days

QUESTION B

The estimate of capital costs depends on the size and nature of the coal fired unit displacedced and its capacity factor.

We estimate that on available figures for replacing a 1GW unit with full thermal capacity of the Sunlands' technology, the capital cost is likely to be less than **$0.8 billion** if the thermal unit were required to have a run time of 20 hours without energy input. This includes all the costs of retrofitting this technology to the existing thermal units.

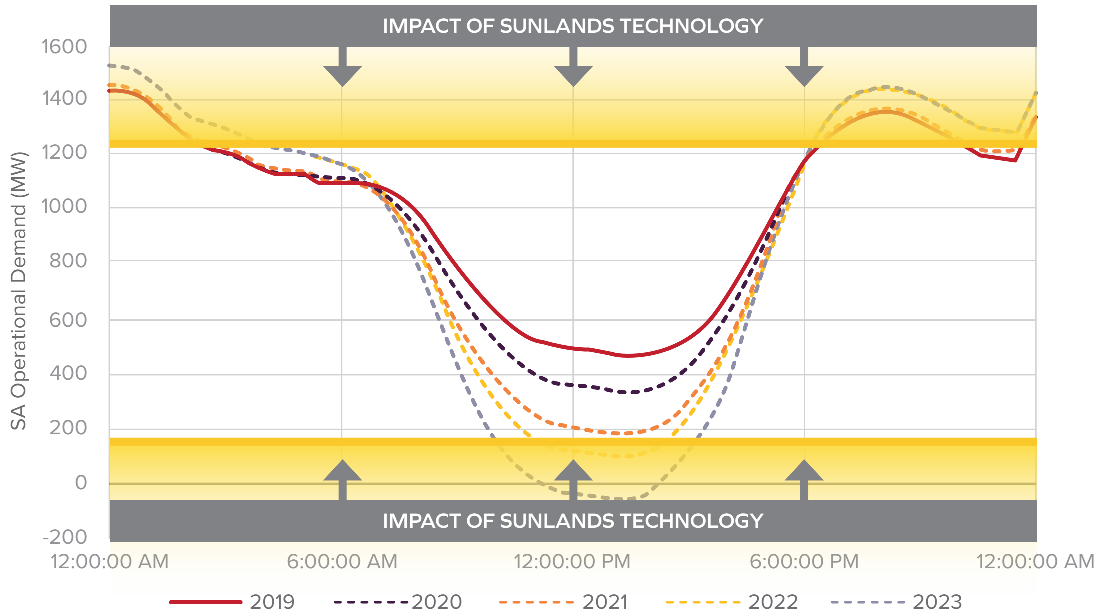
If a 1GW plant were expected to operate closer to today's typical output this would translate to a capacity factor of about 0.5 and the expected cost is likely to be less than **$460 million.**

The estimates adopted for economies of scale are deliberately conservative and are likely to understate the savings attainable i.e., both these figures may be high. We suggest they be treated as the upper bounds for the capital costs.

In respect of the operational costs, and specifically the supply of generation to Sunlands' thermal storage devices, our findings (included in the response to Question A) are that near zero cost renewables generation of up to 12 GW (i.e., half of the current coal generation) will be available. At the efficiencies published by Sunlands, the cost of generation delivered by its technology to the market is significantly less than the $100 per MWh target that forms part of current Federal Government policy.[1]

The implications of the technology's impacts on the market over the duration of its deployment are beyond the scope of our study. For the sake of completeness, we can however make certain observations based on the market's current operation.

Firstly, the deployment of the Sunlands technology, will have the effect of contracting the Duck Curve's peaks and troughs thereby reducing the network arbitrage exploited by current market participants. The benefits to the consumer are self-evident.



https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/data-nem

[1]*Australian Government Department of Industry, Science, Energy and Resources.2020. Technology Investment Roadmap: First Low Emissions Technology Statement. September.*

Secondly, this impact on the Duck Curve is likely to accelerate as the technology's deployment progresses. The undeniable signals to the market transmitted by its deployment will shape the investment decisions of both existing market participants and project sponsors offering renewables generation. That is, as a significant and continuous limiting factor on network arbitrage opportunities, the technology will encourage sustainable growth vectors in renewables generation that are more appropriately matched to grid connected long duration storage.

And thirdly, the network dynamics of the ongoing contraction of the Duck Curve's peaks and troughs will drive adjustments to the network bringing it closer to equilibrium. As a matter of policy, achieving equilibrium must be one of the key objectives. It delivers a level of transparency that both promotes and sustains investment whilst ensuring protection of consumer interests.