Market Context Report – MGA Thermal Energy Storage Application in Australia

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1 Abstract

This report shares key rationale for the ARENA funded MGA Thermal Energy Storage Project in the context of the Australian renewable energy landscape. The report draws on published data to identify the key uses of heat and energy in Australia, and assesses which of these are suitable to be supplied with decarbonised energy through the use of MGA Thermal's thermal storage technology. High level economic benchmarks of the existing solutions are compared against that of projected MGA systems in terms of the Levelised Cost of Energy (LCOE) and Levelised Cost of Heat (LCOH) as indicators of economic viability.

2 Introduction

2.1 Context - Australia's Energy Landscape

The Paris Agreement calls for greenhouse gas (GHG) emissions to reach net zero by 2050 in order to limit global warming to 1.5°C above preindustrial levels. Presently, the energy sector accounts for around three-quarters of global GHG emissions, making the decarbonisation of this sector one of the keys to avoiding the worst effects of climate change (IEA, 2021). As of 2019, Australia ranked 9th in the world for CO2 emissions per capita (World Bank, 2023), with higher relative emissions than other first world countries including the United States, China, Russia and the United Kingdom.

According to a study conducted by ITP Thermal in 2019, approximately 42% of Australia's total energy consumption is used in industry, with 51% of that being used for process heating, and 21% as electricity (Figure 1). Despite efforts to reduce emissions, the vast majority of this energy is still supplied by the combustion of fossil fuels in the form of coal and natural gas (ITP Thermal, 2019).

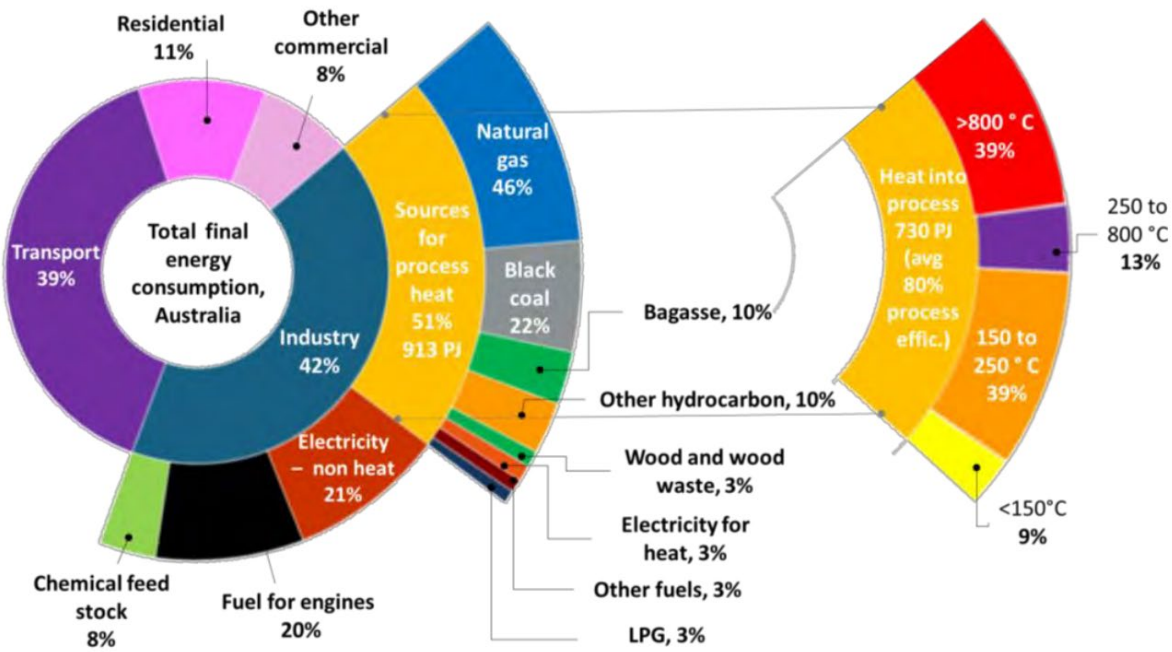

Figure 1: Breakdown of industrial process heat use in Australia. Image reproduced with permission (ITP Thermal, 2019).

As costs of variable renewable generation continue to drop, electrification of industrial processes is rapidly becoming a major avenue to achieve decarbonisation. Renewable generation is accelerating to meet this demand - it's projected to realise a 1.5°C scenario by 2050, there will be an estimated fivefold increase in total renewables supply, and twofold increase in total electricity supply (IEA, 2021).

However, as industrial processes are switched to run on low-cost renewable energy, the requirement to match fluctuating generation to demand is becoming a bottleneck. Unlike the combustion of fossil fuels, the supply of energy from both wind and PV is intermittent – which can lead to large fluctuations in the price of electricity, and at worst can lead to an inability to meet demand altogether. Either outcome can be catastrophic for industries with limited ability to control the power usage of their process.

Thermal Energy Storage (TES) has the ability to draw in renewable energy from multiple sources and dispatch both heat and electricity over medium to long durations (2 - >72h), positioning it as a major renewable enabling technology in this space. For processes involving heat, the capital and ongoing cost of TES can be far lower than alternative technologies. The levelised cost of heat from renewable – powered TES has recently been benchmarked by the Long Duration Energy Storage Council to be the lowest among the various options for firmed supply, including not only the low emission solutions of hydrogen boilers and Li-ion powered electric boilers, but also the incumbent fuel based alternatives such as gas and biomass boilers (LDES Council, 2022). This means that adoption of TES for many processes provides not only a rapid means of decarbonisation, but also a rapid economic return on investment to the user.

2.2 Thermal Energy Storage Technology Overview

Simply put, thermal energy storage systems rely on the ability of materials to hold heat as a means of storing energy. A TES system typically consists of an insulated vessel containing a specifically selected thermal energy storage medium. The system is ‘charged’ with an input of heat either by circulating a heat transfer fluid through the storage medium or by an embedded electric heating system, and discharged either by circulation of a working fluid or by circulating the storage media itself (for example in the case of molten salt based systems).

The choice of energy storage media used is the most apparent differentiator between the various thermal energy storage offerings, as it has many flow on effects to the performance and relevant applications of the TES system. Sensible heat thermal energy storage systems rely on the energy contained in a material measurable as a change in temperature, while latent heat systems rely on a reversible phase change such as melting or boiling to store energy.

Typically, sensible heat systems may be characterised by low material costs, low energy storage densities, and simplicity of system, as they handle a material of a continuous phase only (i.e., solid at all times in operation, whether fully charged or fully discharged). Some sensible heat based storage alternatives in current use include sand, alumina, molten salt, concrete and graphite.

Meanwhile, latent heat thermal energy storage systems store energy not only in the form of a material temperature change, but also as a material phase change. The use of latent heat as an energy storage mechanism can significantly increase the energy storage capacity of the system. However, it typically also increases complexity, as a material must be interfaced with when in both solid and molten, or molten and gaseous states. Thus such systems are typified by higher energy densities (stored energy per unit volume), but also increased complexity. Importantly, they are also tailored to a specific operating temperature (the melting or boiling temperature of the storage media). This means that heat can be delivered at a constant temperature as the material undergoes the phase change, creating a constant heat output of the system regardless of state of charge. Some examples of latent heat thermal energy storage materials with various melting temperatures are aluminium (660°C), silicon (1414°C), water/ice (0°C) and paraffin wax (~40°C).

2.3 Thermal Energy Storage Using MGA

MGA Thermal is unique in the TES marketplace in offering a purpose-engineered thermal energy storage medium, the Miscibility Gap Alloy (MGA). This material is a composite consisting of discrete particles of a phase change material, encapsulated inside a continuous solid matrix, and formed into solid modular blocks. In operation, when a block of MGA is heated and cooled, the phase change particles melt and freeze (providing latent heat), however their containment in the matrix material ensures that macroscopically the material remains solid. The result of this is a material which exhibits the high energy storage density and stable temperature output of a phase change material, with the safety and ease of integration of a continuously solid sensible heat storage material.

Figure 2: Render of the MGA Thermal TESS

To facilitate the use of MGA blocks as a TES medium, MGA Thermal have developed a Thermal Energy Storage System (TESS) (pictured above) which uses modular MGA blocks to store input energy and deliver high temperature heat and/or electricity on demand. The MGA TESS is charged using electrical energy provided by variable renewable sources, via a resistive electric heating system. This heating system is designed to accept electricity from wind, PV, or aggregated electricity from the grid. Input energy is captured as heat by MGA blocks within an insulated vessel, and once stored, charge can be maintained for periods of days to weeks at large scale with minimal loss. This stored energy can be dispatched on demand via an inert gas heat transfer loop, coupled either directly to an industrial process for heat input, or used to generate electricity through a power cycle.

This system lends itself to applications requiring energy in daily cycles over periods of 4 -24 hours, a longer duration than can currently be met by battery storage systems and shorter than that suitable for economical green hydrogen or pumped hydroelectric storage.

3 Application case studies and LCOE benchmarking

3.1 Overview of relevant applications

The most critical parameter when determining applicable markets of a thermal energy storage system is the maximum achievable output temperature of the heat transfer fluid. This temperature limits the downstream processes the storage can provide energy to; the temperature can be decreased through various processes to meet requirement, as well as being transferred to different working fluids and pressures through appropriate heat exchangers, however it cannot be increased without an additional power input. In the case of the MGA TES, the bulk of the system's energy is stored in a phase change occurring at 660°C, and the storage system is capable of dispatching heat transfer fluid at temperatures up to 650°C for the duration of its discharge cycle. This temperature range enables the production of high pressure superheated steam for both industrial use and power generation, which is central to many energy and emission intensive applications.

Applicable use case temperatures are superimposed with the accessible temperature range of the MGA TESS in Figure 3.

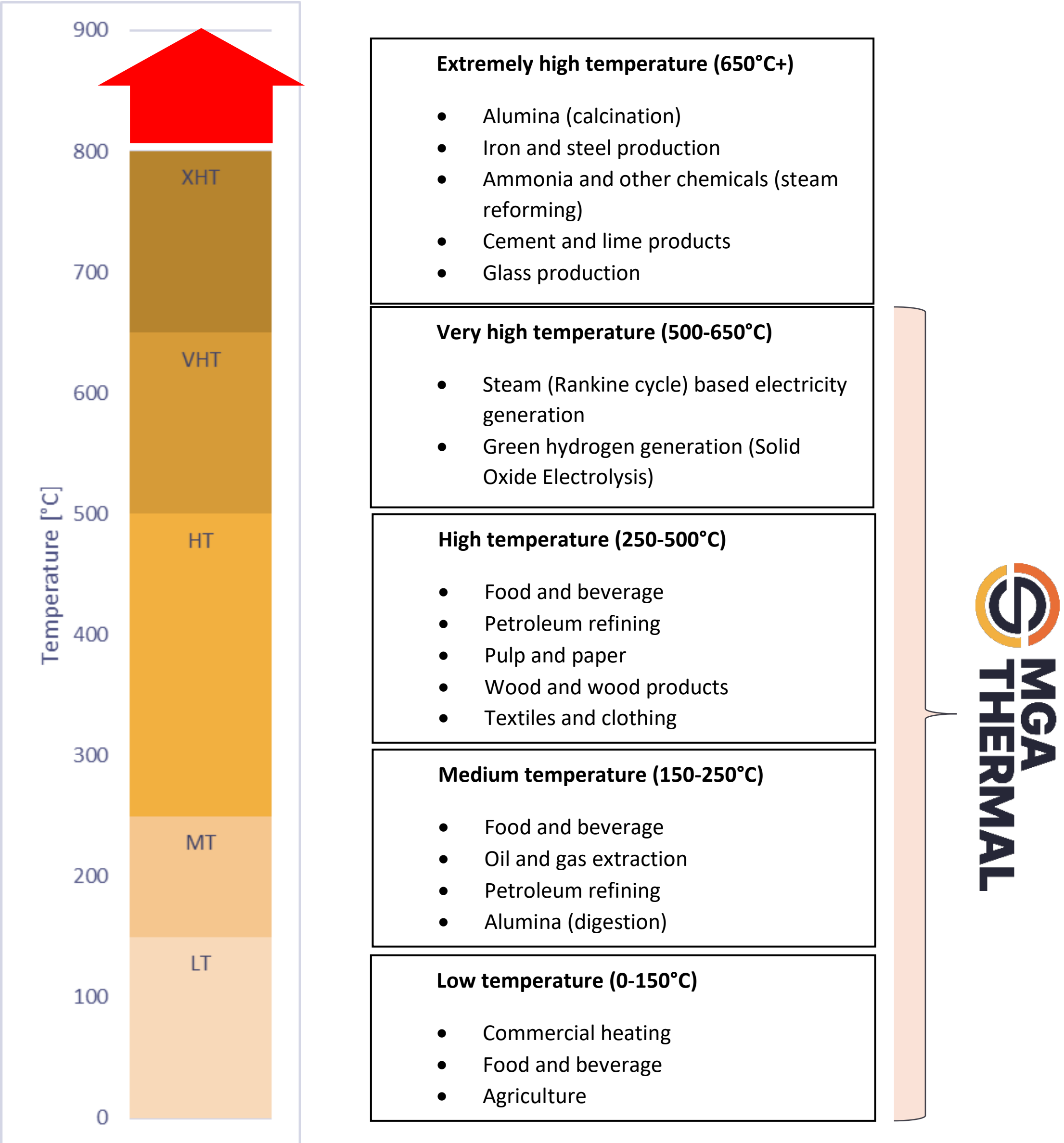

Figure 3: Summary of key heat use cases and their applicability to the MGA TESS

A subset of the key applications in Australia which will be examined as Case Studies for the MGA Thermal Energy Storage Project are detailed in Table 1:

End-use	Description	Benchmarks
Firmed renewable process steam	Behind-the-meter solar PV, charging TES to produce high temperature steam for industrial heating applications (chemicals, polymers, food processing, etc.) This may involve injection of steam into pre-existing process equipment.	Gas boiler, green hydrogen boiler, biomass boiler, electric boiler with Li+ ion battery energy storage
Combined heat and power	Behind-the-meter solar PV, storing as thermal energy and utilising back-pressure steam turbines to convert thermal energy into electricity with waste heat as usable process steam.	CHP biomass boiler
Utility scale grid energy storage by retrofitting thermal power stations (brown field)	Grid-connected PV and wind, capturing and storing at times of excess supply / low spot price using pre-existing HV grid connections at thermal power stations. Dispatching electricity from thermal storage by repurposing existing power generation infrastructure (turbines, generators and grid connections) to distribute back onto the grid as required.	Pumped hydro-electric storage, long duration utility scale Li+ ion battery energy storage.

3.2 LCOE methodology and assumptions

The Levelised Cost of Energy and Levelised Cost of Heat (LCOE and LCOH) metrics are used in the power industry to describe the total lifetime cost of a generating asset, normalised against its total lifetime generated energy or heat. As a result of their simplicity, the metrics fail to account for many important parameters such as time or duration of dispatch, however they do provide a high level comparison of the relative cost of different technologies. LCOE or LCOH benchmarking have been used here to demonstrate economic viability for each of the four use cases identified in Table 1.

The basic formula used to calculate LCOE (and LCOH):

$$LCOE\ or\ LCOH = \frac{\sum annualised\_costs}{\sum annual\_dispatched\_energy}$$

With the costs considered in this report:

- Upfront capital cost annualised over project lifetime (30 years)[1]
- Ongoing operation and maintenance (O&M) costs[2]
- Cost of charging energy

In all of the cases considered, the Levelised Cost of Storage (LCOS) is the LCOE or LCOH minus the cost of charging energy. The capital cost of the TES system has been scaled for each use case. The

[1] Calculated using a weighted average cost of capital of 5.5%
[2] Annual O&M cost assumed to be 1% of system CAPEX

capital cost items taken into account in this analysis capture all necessary system components down-stream of a 400 or 690 V site electrical supply of sufficient amperage, and include:

- Charging infrastructure (electric heaters)
- Process equipment (any necessary discharge heat exchangers, utilities and inert gas supply)
- Enclosure and support
- Pipework, valves and fittings
- Instrumentation and control system
- Storage media (MGA blocks)
- Power cycle, generator and ancillaries (as required for the application)

System details and assumptions specific to each application are detailed in the following sections, along with LCOE benchmarking results.

3.3 Firmed renewable process steam

As outlined in Section 2, industrial heating is one of Australia's largest energy uses, and a difficult area to decarbonise. A large proportion of industrial heat is currently used as steam. If provision of this steam can be achieved by renewable means, then the industry can be decarbonised without changing processes, just substituting the type of boiler.

In this case study, options are examined for a 10 MW (thermal), 24 hour steam supply – corresponding to a large industrial boiler. The LCOH of the following alternatives has been compared:

- **Electrically charged MGA TES steam generation system**
  - Supplied with energy from behind-the-meter solar, priced at $40 AUD/MWh
  - Daily operating regime: 8 h charging while discharging steam (32 MW electrical input), 16 h discharging from storage
- **Natural gas boiler** – data from (McKinsey, 2021)
  - Carbon tax of $30 /T CO2 (ACCU price) on emitted CO2
  - Gas price of $15 AUD /GJ.
- **Hydrogen boiler** –data from (LDES Council, 2022),
  - Green hydrogen priced at $3.84 AUD per kg
- **Biomass boiler** – data from (ITP Thermal, 2019)
  - Biomass (wood pellets) priced at $11 /GJ
  - No price on CO2 emissions – although burning biomass releases CO2, it is typically assumed that this biomass has been recently gathered from the atmosphere through photosynthesis, and is thus carbon-neutral. If the biomass is not generated on site of use, then the emissions of transportation need to be considered – these can be considerable due to the fuel's often low calorific value.
- **Electric boiler with Li+ battery energy storage** – data from (LDES Council, 2022)
  - Supplied with energy from behind-the-meter solar, priced at $40 AUD/MWh

Industrial heat pumps can also be used as a highly efficient means of steam production. They have been omitted from this comparison for two reasons:

1) They're only applicable to low temperature steam production (< 160°C)

2) They do not contain storage – so the user is still exposed to intermittency of renewables or high spot price unless combining a heat pump with battery or thermal storage.

If the application does allow for the use of steam at low temperatures, heat pumps have been predicted by the LDES Council to have a Levelised Cost of Heat of $36-51 AUD/MWh when paired with Li-ion battery storage, or $22-36 AUD/MWh[3] when paired with TES (LDES Council, 2022)

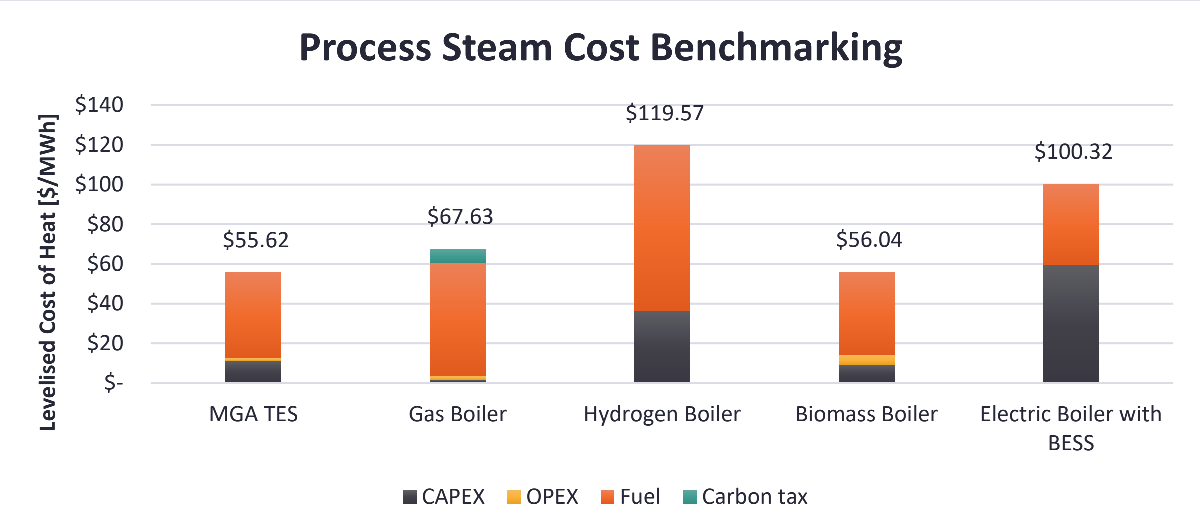

Figure 4: LCOH comparison of firmed process steam technologies

Besides a competitive LCOH, the key benefits of MGA TESS in this use case are:

- Ability to charge using a variety of metered or behind-the-meter energy supplies
- Integration with processes including other waste heat sources on site
- Stable output temperature over the length of dispatch
- No reliance on fuel supply chain (e.g., Biomass or hydrogen transport and storage)
- No exhaust stream – in combustion based applications this can have repercussions on site location and necessitate positioning the boiler away from other processes
- Strong economy of scale

3.4 Combined heat and power

The high steam outlet temperature of MGA Thermal Energy Storage allows for conversion into electricity using steam Rankine cycle technology. Through the use of a back-pressure turbine, the waste heat from this power cycle may be usable as process steam. In this way, the storage system can simultaneously provide Combined Heat and Power (CHP).

Both the MGA system and biomass system considered here are for 10 MW (thermal) process heat provision, with a CHP stage simultaneously generating electricity. In such systems, the ratio between heat and electricity is governed by the efficiency of the power cycle. To maintain consistency with the costing data of (ITP Thermal, 2019), a 15% efficient back-pressure power cycle has been used in

[3] Prices 25-35 and 15-25 USD/MWh for BES and TES respectively, from (LDES Council, 2022) with 0.69c used as AUD-USD exchange rate.

this analysis. Output electricity has been costed at $50 /MWh, and deducted from the input fuel cost as a revenue stream to achieve a single LCOH estimate. In this way, the system can be thought of as dispatching electricity at $50 /MWh, and heat at the LCOH indicated.

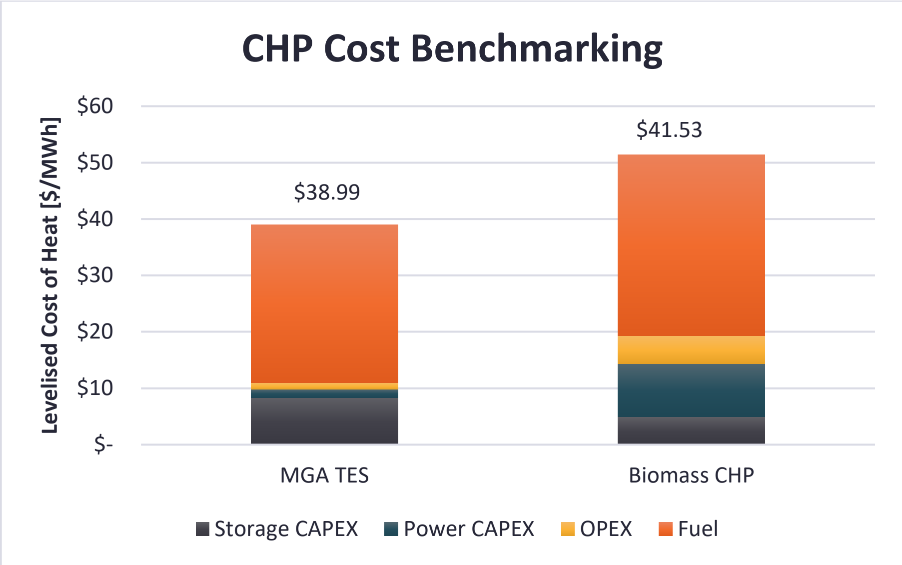

Figure 5: LCOH comparison of firmed CHP solutions

LCOH estimates are competitive between the two technologies, with MGA TESS having the benefit of energy supply from behind-the-meter solar, and no reliance on biomass supply. A slightly higher heating efficiency also decreases fuel cost, as the TES system has no exhaust stream of combustion by-products. Implementing the TES at larger scales is expected to decrease LCOH further still.

The provision of electricity in this cost scenario at $50 /MWh demonstrates the high potential for CHP to provide decarbonised electricity in situations where a large heat load is also required. This represents a marginal cost increase of only $10 /MWh over the feed-in energy price of $40 /MWh, despite the firming of that energy from an intermittent to continuous supply.

3.5 Retrofitting thermal power stations

The grid-scale MGA Thermal Energy Storage can capture and store excess renewable electricity on the grid at times of high VRE generation / low or negative market spot price. When located on the site of an existing thermal power station, the pre-existing grid connection may be utilised to avoid the capital cost of transformers. Like other scenarios, the TES dispatches stored energy as steam on demand, however in this case that steam may be dispatched into pre-existing power generation infrastructure (turbines, cooling tower, grid connection) from brown-field thermal power stations. The large majority of the power station is therefore repurposed as a renewable energy storage and dispatch facility, allowing for large-scale, cost-efficient renewable energy storage.

This application has been benchmarked against decarbonised alternatives for utility scale, grid connected renewable energy dispatch. The core technologies in this space are pumped hydro-electric storage, and to a lesser extent, grid connected Li+ ion battery systems.

Scenarios have been developed for a 500 MW (electrical), 16 hour dispatch system, with charging energy costed at $25 /MWh. The following assumptions have been made on each case:

- **Electrically charged MGA TES steam generation system**
  - Power block efficiency downstream of the TES system has been assumed to be 42%
  - 30-year asset lifetime
  - 8 hours daily charging, 16 hours daily discharging
- **Li+ion battery energy storage**
  - 90% round trip efficiency
  - 15-year lifetime
  - No degradation over lifetime
  - Capital cost $308 AUD /kWh (NREL, 2021) including all system components, necessary grid connections and ancillaries
- **Pumped hydro-electric energy storage**
  - 80% round-trip efficiency
  - 30-year lifetime
  - Capital cost $200 AUD /kWh[4]

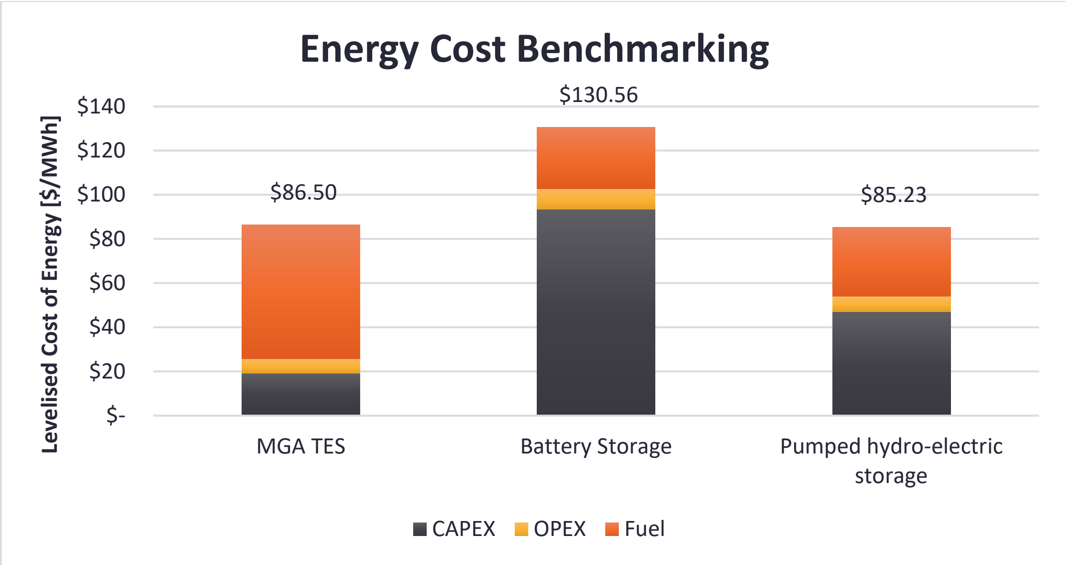

Figure 6: LCOE comparison of utility scale storage solutions

When incorporated into a brown-field thermal power station site, utility scale MGA Thermal storage is expected to exhibit a lower capital cost than both Li+ ion based battery energy storage and pumped hydro-electric storage systems. However due to the lower round trip efficiency than alternatives, the contribution of fuel (charging) cost to LCOE is large. A positive spot price for charging energy has been used in this model, however it should be observed that the trend as VRE penetration on the grid increases, is that the frequency of low or negative spot prices also increases, potentially decreasing the average fuel cost significantly below that applied here.

It should also be noted that the energy dispatched in this regime relies on synchronous generation, and inherently contributes stability to the grid. While this is also the case for pumped hydro-electric

[4] Interpolation between PHES costs at 12 hours, 24 hours capacity, (CSIRO, 2021)

dispatch, it is not the case for batteries. As LCOE is a cost metric, the value of grid stabilisation and other ancillary services as a potential revenue stream is not realised in this analysis.

Finally, there is the potential to incorporate CHP (as examined in Section 3.4) into utility scale systems such as this, while still using significant pre-existing plant. If this can be achieved, the large waste heat stream of the power cycle can be utilised to meet industrial process heat requirements of neighbouring industries.

4 Summary and final comments

The economic viability of MGA Thermal energy storage in the Australian energy landscape has been examined in this report using LCOE and LCOH metrics to benchmark against alternate technologies across a series of key use cases. Competitive LCOE and LCOH indicate that the technology holds potential as a means of rapidly decarbonising hard to abate industry, and firming renewable energy on the grid at utility scale, by simple integration with pre-existing assets. This integration and utilisation of standard technology is the key to rapid and cost-effective adoption of renewable energy in order to meet climate targets and prevent catastrophic global warming scenarios.

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