Thermal Storage at Torrens Island B Power Station Feasibility Study

Knowledge Sharing Report

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Executive Summary

AGL is committed to transitioning its energy generation portfolio to support a lower carbon future. The Climate Transition Action Plan documents AGL's target to exit coal generation by the end of the financial year 2035 and outlines its emission targets and ambitions to invest in new renewable and firming capacity. Part of AGL's investment strategy is investing in emerging technologies that demonstrate potential solutions to decarbonising its existing energy generation assets.

The AGL Thermal Storage at Torrens Island B Power Station Feasibility Study evaluated the technical and commercial feasibility of integrating a thermal energy storage (TES) solution at Torrens Island B Power Station (TIPS B) and replacing one 200 megawatt (MW) gas-fired generation unit (the Project).

Overview

TES is an emerging technology that essentially stores heat generated from different sources, including grid electricity converted to heat. When used for synchronous electricity generation, a TES solution can provide various system strength services to the electricity grid such as frequency control and grid inertia. The technology was chosen for this Project for its low carbon energy storage potential, providing the ability to store surplus energy (typically produced during daytime periods) to meet later demand (peak demand periods in the early morning and evening).

There are several different types of technologies available in the market which can generate heat. For the purposes of this Project, TES technologies that charge from the grid were the preferred technology because of their relatively simplified method, in comparison to other heat generating technologies.

Two original equipment manufacturers (OEM) were assessed - Kraftblock and MGA Thermal. Each offered the capability of acting as a thermal battery and consisting of three primary phases as summarised below and illustrated in Figure 1:

- **Charge:** The TES is charged from electricity from the grid which runs through a resistive heating circuit converting the electricity to thermal energy and storing it in the thermal block
- **Storage:** Energy is stored in the TES until demand for electricity is required. At this stage, the TES system is on standby until discharge is required

  Discharge: Energy is released from the TES using fans which blow heat transfer fluid (typically air or an inert gas) over the storage. The heat transfer fluid is heated by absorbing heat from the storage material and is ducted towards a heat recovery steam generator (HRSG). The HRSG uses the hot heat transfer fluid to boil water and create steam which run a steam turbine to generate electricity.

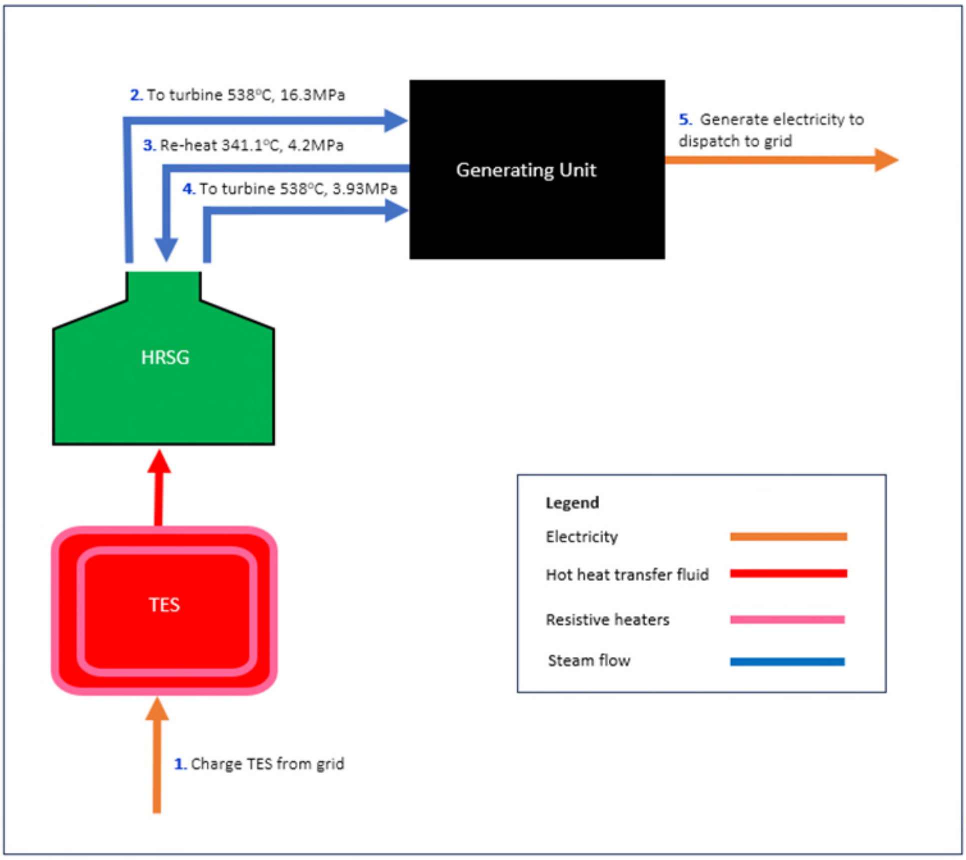


Figure 1 TIPS B integrating TES process overview

Kraftblock technology is a high-temperature energy storage system that stores energy in the form of heat using porous media, which consists of 85% recycled materials.

MGA Thermal technology involves a set of blocks stacked in an insulated enclosure. The blocks consist of a metallic material dispersed as particles within a matrix material that keeps the blocks solid. This matrix is highly conductive and rapidly distributes heat, keeping the particles in place as they melt when heat energy is absorbed. MGA Thermal blocks store massive thermal energy through the solid-liquid phase change, which is released as they cool and the particles solidify.

The key difference between the two technologies was the method by which energy is stored. Kraftblock uses a sensible heat in their storage medium, which is comprised of waste products from industries like the steel and glass industry. This means there is no phase change in the materials when heat is added. Kraftblock TES remains in a solid state and fluctuates between high temperature (charge) and lower temperatures (discharge). MGA Thermal uses a storage medium which is comprised of a metal alloy which is suspended within a matrix material. The metal alloy melts as the heat is absorbed. The matrix material has a higher melting temperature than the internal metal alloy, so the heat can be stored within a solid matrix. The phase change allows both sensible and latent heat to be stored.

Integration

To replace one gas-fired generation unit, Kraftblock and MGA Thermal's technology were studied and evaluated for their capability to be charged with, store and discharge enough thermal energy to produce 1,600MWh of electrical energy on a daily cycle. Thermal energy would be used to produce steam at 538°C and 16.3MPa, suitable for the existing steam turbine generator to produce 200MW for eight hours.

The Project found it was technically feasible to integrate TES into an existing thermal power station, however significant additions to the existing plant is required. This includes providing the following major electrical equipment to enable charging of the TES:

- Two 275kV connection points, each capable of importing 250MW of electricity
- Two large 250MWA three-winding transformers to step down the 275kV transmission voltage to 33kV
- A series of medium sized two-winding transformers to further reduce the voltage from 33kV to the 690V_{AC} utilisation voltage required by the heaters, fans and house load.

A key finding was also the inability of the TES to be integrated to the existing boilers. The boilers at TIPS B are specifically designed with a furnace to combust gas at very high temperatures, transferring heat mainly by radiation and convection to product steam. Heat transfer from the TES occurs at significantly lower temperatures without any combustion process, therefore only allowing convective heat transfer to occur. Consequently, for this site, the technology would require installing HRSGs, which are specifically designed to absorb heat from the TES and transfer it to the water/steam at the required temperature and pressure to drive the turbine.

Technical parameters

The actual heat storage of the TES system is highly efficient at steam generation and both Kraftblock and MGA Thermal's storage systems are expected to discharge approximately 99% of energy used in charging.

However, the heat loss that occurs during the electricity generation process lowers the overall efficiency and therefore the overall useable energy that is discharged to the grid.

Kraftblock's steam production design has an inherently lower efficiency than the MGA Thermal process (around 83% compared to 88% respectively). The reason for this is the Kraftblock system used an open loop cycle for steam production, where the heat transfer fluid (air) is exhausted to the atmosphere after passing through the HRSG heat exchanger. The

MGA Thermal process used a closed loop cycle with inert gas as the heat transfer fluid. The exhaust inert gas from the HRSG is recycled to the thermal storage block, and hence the heat in the exhaust inert gas is re-captured rather than lost to atmosphere. This difference in design results in a HRSG energy efficiency for the MGA Thermal system of 88%.

The open loop cycle was adopted in Kraftblock's method as it allows a greater depth of discharge for the TES, which would lower the volume of thermal storage medium require and therefore lower capital costs.

With the bulk of overall energy loss occurring in the existing steam turbine and generator, the overall round trip efficiency (RTE) for each system was estimated at:

- Kraftblock - approximately 37%
- MGA Thermal – approximately 40%.

Due to the significantly low RTE, the TES storage systems must charge and store a large amount of energy. To produce the required 200MW for eight continuous hours, the TES must produce the equivalent of 1,600MWh of electrical energy as heat, requiring the gross thermal storage volume of 7,467MWh (Kraftblock) and 5,000MWh (MGA Thermal). Of this, the useable thermal energy storage volume was 5,178MWh (Kraftblock) and 3,636MWh (MGA Thermal).

To achieve the desired dischargeable energy, Kraftblock proposed five storage units connecting to five HRSGs in an open loop cycle as shown in Figure 2. Each storage block would have a useable thermal energy storage volume of 1,035.5MWh, capable of producing steam to generate 40MW of power for eight hours.

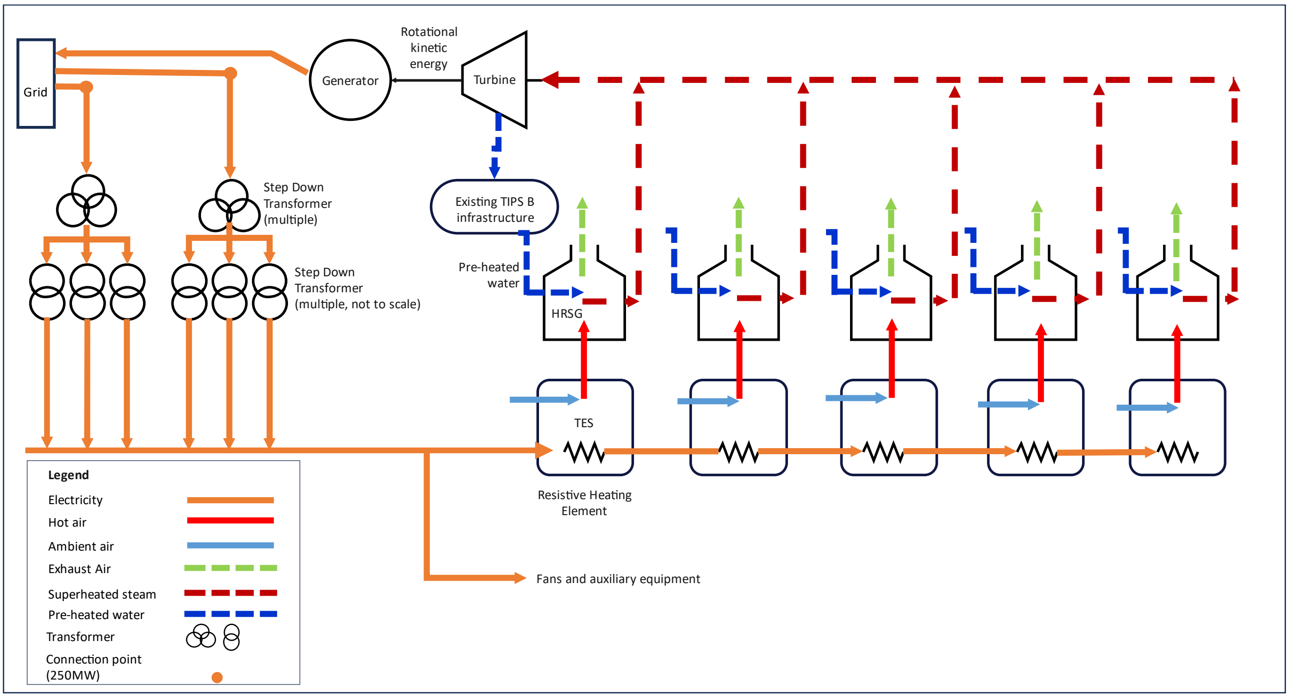


Figure 2 Process overview of integrating Kraftblock TES into TIPS B

MGA Thermal proposed a closed loop cycle involving two storage units with two HRSGs (see Figure 3). The closed loop cycle means the heat transfer fluid (inert gas) is recycled from the outlet of the HRSG to the inlet of the HRSG to ensure any waste heat is recaptured in the TES.

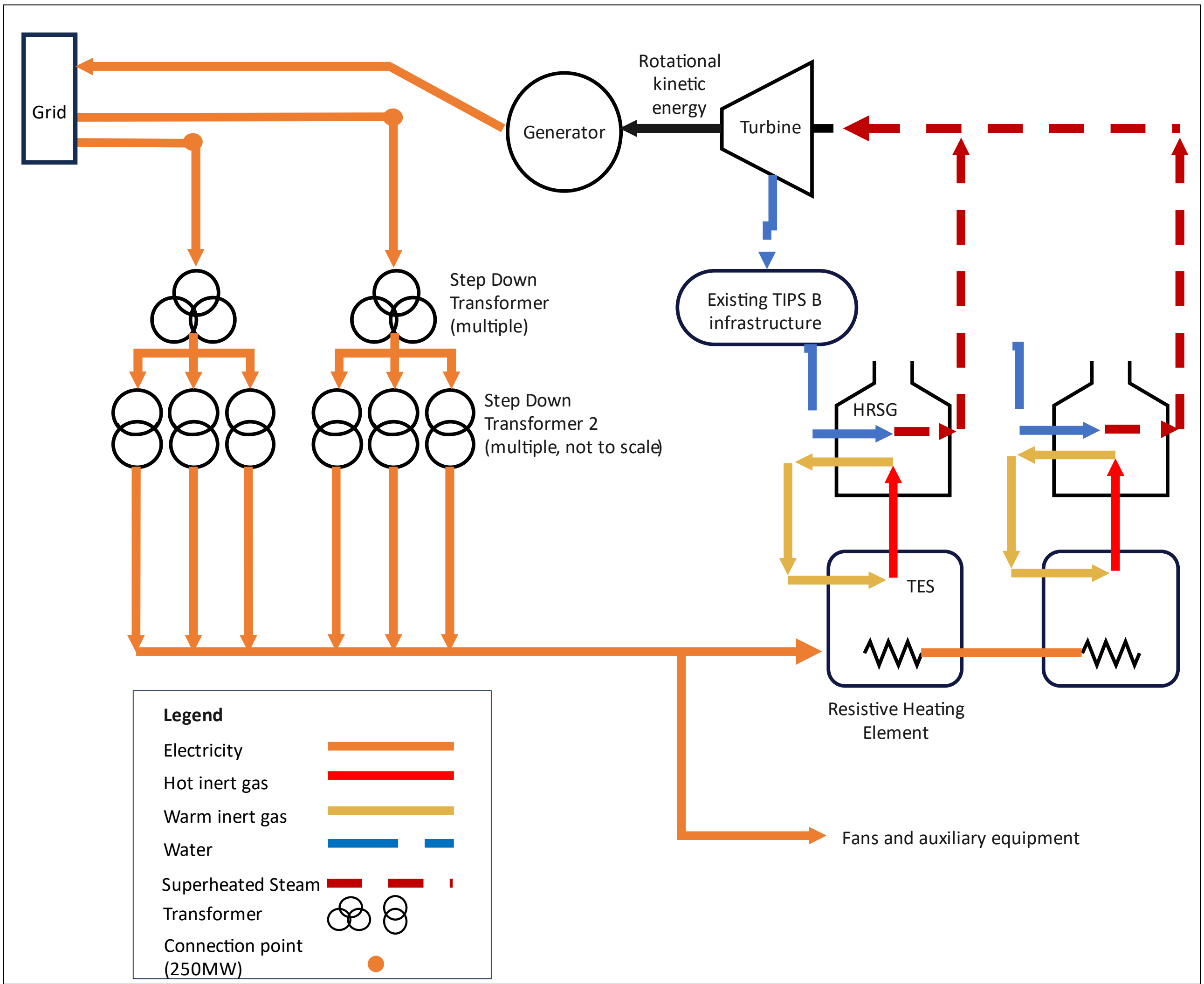


Figure 3 Process overview of integrating MGA Thermal TES into TIPS B

Site considerations

The Project found it is important to locate the TES and HRSGs near the generating units to reduce the distance the steam travels between equipment and thereby minimise flow and heat losses. The ideal location to achieve this at TIPS B would be to install the TES and HRSGs directly behind the generation units. This is where the boilers are currently located and will enable continuity of existing process flow and minimise heat losses.

Both Kraftblock and MGA Thermal's design could suitably be installed on site however the scale of these developments is significant. It is estimated to install either system designs, inclusive of TES, HRSG, associated equipment and additional area as a contingency for potential unforeseen construction works, it will require a footprint size around 18,330m^2 to

25,000m^2. This will require the complete demolition and removal of all four boilers at TIPS B, despite the TES systems being designed to replace only one gas fired generation unit.

Personnel

For the purposes of this Project, Table 1 details the number of jobs estimated for the construction and operation of the TES.

Table 1 Estimated number of new jobs

<table>
<tr><th></th><th>Kraftblock</th><th>MGA Thermal</th></tr>
<tr><td>Construction</td><td>260</td><td>296</td></tr>
<tr><td>Operation</td><td colspan="2">5-10</td></tr>
</table>

Commercial

Preliminary cost estimates for an asset designed to store 1,600MWh of equivalent electrical energy were within the range of $1B to $1.2B. This estimate was made up of construction, electrical equipment, technology costs and a contingency of 30% of the capital cost. On a levelised cost of storage basis, this equated to between approximately $228MWh to $320MWh.

Risk analysis

TES are emerging technologies, with no examples of such technology being integrated in a thermal power station or operating at this scale. Accordingly, the following broad range of project risks were identified:

- **Technology risk –** The TES technologies are relatively young and carry inherent maturity risk. The pilot program would mitigate this risk, proving performance and viability prior to progressing to full scale implementation.
- **Land availability –** A substantial parcel of land would be required to accommodate the large amount of TES needed to meet the required eight-hours of continuous discharge.
- **Regulation –** As a new asset type, the regulation requirements and associated approvals are unknown, raising risk to any deployment, pilot or full-scale project.

Carbon offset

The carbon offset of the proposed TES solutions was determined by measuring the average annual carbon produced each year across the four gas fired units at TIPS B. Based on an average annual energy production over a period from 2018 to 2021, it was estimated that integrating TES at TIPS B has the potential to reduce carbon emissions by approximately 237,209 tonnes per year.

Conclusion

The Project hypothesised that, despite the low energy efficiency of thermal power stations, integrating TES into an established power station could leverage existing infrastructure, reducing the overall capital costs and supporting a commercially viable system.

While the Project found it was technically feasible to integrate TES technology into TIPS B, the following technical matters result in significant increase in costs, design complexities and development constraints, impacting the overall commercial viability of the Project:

- **Low RTE**, heavily impacted by the turbine and generator system, requiring the storage systems to store a significant volume of energy
- **Unable to leverage all the existing infrastructure** at the power station, and in particular, the need to replace the boilers with HRSGs and install a series of transformers, switchboard and associated electrical integration equipment
- **Significant scale of development** requiring an estimated footprint size of around 18,330m^2 to 25,000m^2 to integrate. The scale of this development is significant and includes the installation of the TES, in addition to the HRSGs, ancillary equipment (including transformers) and an additional 15% contingency for potential unforeseen additional construction works.

It is however now evident that the TES designs offer a low carbon method to produce heat and are highly efficient in storing and discharging heat that could otherwise be beneficial to the industrial sectors that use process heat.

There are a broad range of industries that could benefit from this technology as it was found the maximum achievable output temperature of the heat transfer fluid from the TES would influence the type of industrial user who may consider the TES technology. Potential industries include:

Very high temperature (above 650°C):

- Alumina (calcination)
- Iron and steel production
- Ammonia and other chemicals (steam reforming)
- Cement and lime products
- Glass production

Medium temperature (150 – 250°C):

- Food and beverage
- Oil and gas extraction
- Petroleum refining
- Alumina (digestion).

High temperature (250 – 650°C):

- Food and beverage
- Petroleum refining
- Pulp and paper
- Wood and wood products
- Textiles and clothing.
- Steam (Rankine cycle) based electricity generation
- Green hydrogen generation (solid oxide electrolysis)
- Chemical manufacturing.

Low temperature (0-150°C):

- Commercial heating
- Food and beverage
- Agriculture.

The Project did not investigate the feasibility of integrating TES into the operations of any of the above industries, however, the high energy efficiency of the TES, coupled with the low carbon option to produce heat, indicates significant potential opportunities to investigate options for TES to be used as a power to heat application or from the use of waste heat.

Acknowledgement

This project received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program.

The views expressed herein are not necessarily the views of the Australian Government. The Australian Government does not accept responsibility for any information or advice contained within this document.

Abbreviations

The following table describes the significance of various abbreviations and acronyms used throughout the Report.

Abbreviation	Meaning
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AGL	AGL Energy Limited
ARENA	Advancing Renewable Energy Agency
ARP	Advancing Renewable Project
ASX	Australian Securities Exchange
CapEx	Capital Expenditure
CHP	Combined heat and power
CO_2	Carbon Dioxide
EPA	Environmental Protection Agency
EPC	Engineering, Procurement and Construction
ESS	Energy storage system
FCAS	Frequency Control Ancillary Services
FIRM	Fully Integrated Risk Management
GJ	Gigajoule
HP	High pressure
HRSG	Heat Recovery Steam Generator
HSE	Health, Safety and Environmental
I&C	Instrumentation and Controls
IP	Intermediate pressure

Abbreviation	Meaning
LCOS	Levelised cost of storage
MGA	Miscibility Gap Alloy
MW	Megawatt
MWe	Megawatt electric
MWh	Megawatts per hour
NEM	National Electricity Market
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer – refers to Kraftblock and MGA Thermal
OpEx	Operational Expenditure
PPA	Power Purchase Agreement
SME	Subject matter expert
TES	Thermal Energy Storage
The Project	AGL Thermal storage at Torrens Island B Power Station Feasibility Study
The Report	AGL Thermal storage at Torrens Island B Power Station Feasibility Study Knowledge Sharing Report
TIPS A	Torrens Island A Power Station
TIPS B	Torrens Island B Power Station
V_{AC}	Volts Alternating Current

Table of Contents

List of Tables

List of figures

1. Introduction

1.1. Purpose

The purpose of the Thermal Storage at Torrens Island B Power Station Feasibility Study (the Report) is to detail the feasibility findings of integrating a thermal energy storage (TES) system into Torrens Island B Power Station (TIPS B) (the Project). In accordance with item 4.4 of Schedule 1 of the Advancing Renewable Energy Agency (ARENA) Advancing Renewable Project (ARP) funding requirements, the Report details key results to best share knowledge and learnings from the Project.

1.2. Strategic drivers

Four key strategic drivers underpinned the Project, and stemmed from AGL strategy and broader market needs:

1. The need for medium[1] duration energy storage assets as highlighted in the Australian Energy Market Operator (AEMO) Integrated System Plan 2020 (ISP 2020). It is expected that these will play a pivotal role in Australia's transition to renewable energy.
2. Maximising the number of use cases for the heat stored in this asset. Heat underpins many industrial processes as a key utility and an asset that can provide clean, high-grade heat for electricity generation and industrial processes would be of significant value. A TES asset could open decarbonisation pathways for industries.
3. Extracting value from existing assets by repurposing existing infrastructure and skilled workforces, extending the life of existing power stations and reducing the costs of developing new TES projects.
4. Power stations are big employment providers in regional areas, the successful integration of TES assets at these sites could help retain regional jobs and engagement as the energy market transitions to a lower emissions future.

[1] The ISP 2022 refers to medium storage as energy storage with durations between four and 12 hours (inclusive)

1.3. Project objectives

The objectives of the Project were to:

- Investigate the technical feasibility of integrating a TES into an existing power station
- Assess the potential of reducing emissions by implementing a clean industrial heat source
- Evaluate the commercial applicability of integrating a TES into the TIPS B in South Australia
- Size a pilot plant and investigate how it would be implemented to test the co-generation (TES and natural gas) solution.

It was also a Project objective to identify other potential uses for clean industrial heat. A TES asset could be a heat source for electricity generation as well as industrial processes that need high-grade heat and want to decarbonise. As part of this Project, complementary industries and heat processes would be identified because each new use case could enhance the technology's flexibility and value.

1.4. Project partners

The Project was led by AGL Energy Limited (AGL) and involved project partners as detailed in Table 2.

Table 2 Project partners

Organisation	Role	Description
AGL	Project Manager	Responsible for managing the Project including governance, key project activities, deliverables, and cost.
Kraftblock	Project participant	Manufacturer and key project participant of the Kraftblock TES technical, integration and commercial assessments.
MGA Thermal	Project participant	Manufacturer and key project participant of the MGA Block TES technical, integration and commercial assessments.
ARENA	Funding provider	Provision of partial financial support for the Project through its ARP program.

1.4.1. About AGL

Proudly Australian for over 185 years, AGL supplies energy and other essential services to residential, businesses and wholesale customers. AGL is committed to providing its customers simple, fair and accessible essential services as they decarbonise and electrify the way they live, move and work.

AGL operates the largest electricity generation portfolio within the National Electricity Market (NEM) of any Australian Securities Exchange (ASX) listed company. AGL's portfolio comprises coal and gas-fired generation, renewable energy sources such as wind, hydro and solar, batteries and other firming technology, and gas production and storage assets. It is building on its history as one of Australia's leading private investors in renewable energy to now be a leader in the business of transition to a lower emission, affordable and smart energy future in line with the goals of its Climate Transition Action Plan.

1.4.2. About Kraftblock

Kraftblock was founded in 2014 and designs and manufactures thermal storage material which can be used in the decarbonisation of both the industrial and electricity sectors. The Kraftblock technology offers large storage capacity, high temperatures (up to 1,300°C) and an all-in-one solution for power and heat.

Further details on its technology are provided in Section 2.3 of the Report.

1.4.3. About MGA Thermal

Founded in 2019, MGA Thermal is an Australian company which has invented a thermal storage material which is conductive and can rapidly distribute heat. Its Miscibility Gap Alloy (MGA) technology stores and delivers thermal energy while remaining outwardly solid, offering a solution to renewable energy transition.

Further details on MGA Thermal's technology is provided in Section 2.3 of the Report.

1.5. Project structure

The Project was structured in two stages as illustrated in Figure 4.

Stage 1 was a desktop feasibility study into whether the original equipment manufacturer (OEM) of the considered TES could replace the gas use of one of four 200megawatt (MW) units at TIPS B for a period of eight continuous hours.

Stage 2 would proceed if results from Stage 1 had proven feasible, sizing a pilot plant to test the co-generation solution.

This Report details the results and findings from Stage 1 of the Project.

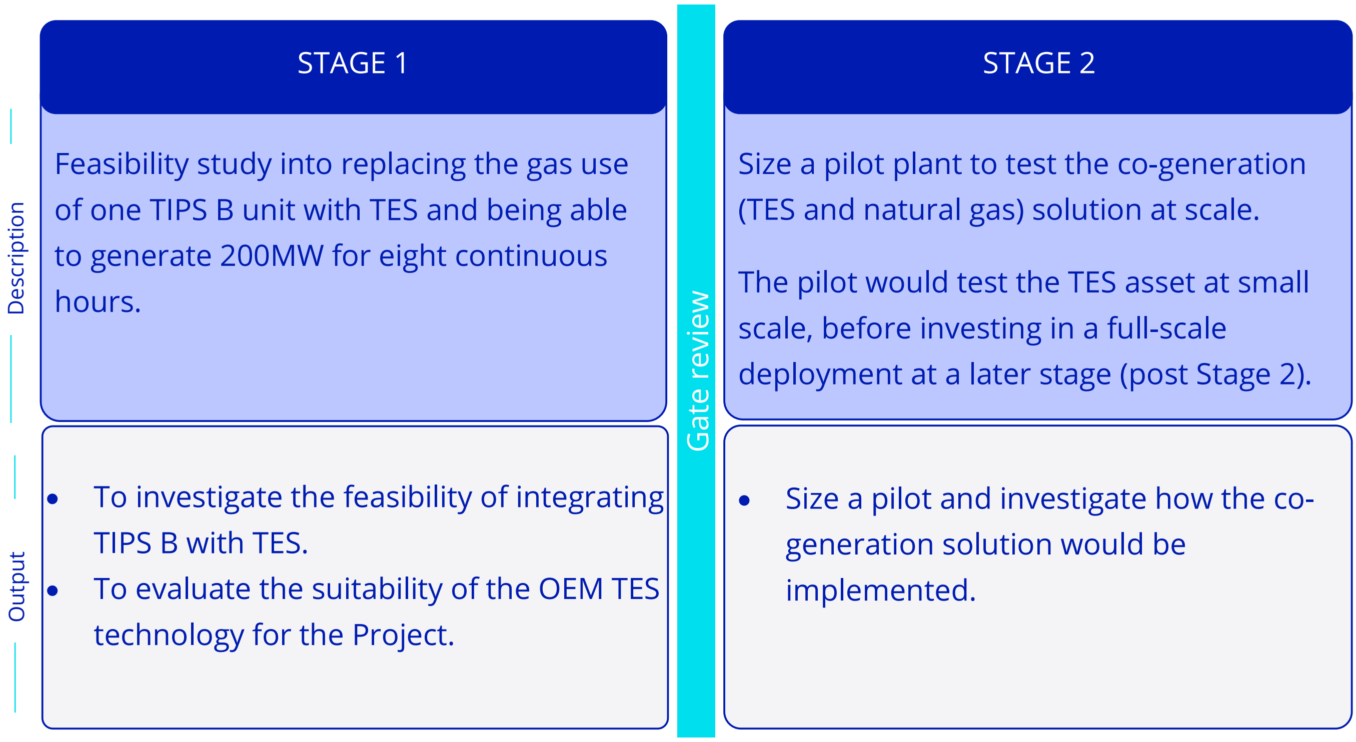


Figure 4 Project methodology

1.5.1. Pilot scale

Sizing the pilot plant would have followed upon progression to Stage 2. However, the decision was made to not progress to this stage – thereby removing the need to size a pilot scale asset.

1.5.2. Full scale

If the Project had progressed to Stage 2 and beyond, a full replacement of a 200MW unit would have been investigated. This full-scale deployment would have involved the removal of the gas required to fire one 200MW TIPS B unit. The purpose of a full-scale deployment would be to act as a competitive energy storage asset in the NEM and to provide process heat to industrial users. The full-scale deployment would have been contingent upon the results of Stage 1 and 2 of the Project.

1.6. Assessment crtieria

Each OEM was assessed against the following criteria:

Table 3 Assessment criteria

Integration capability	Assessment of the electrical and mechanical integration capabilities, evaluating the feasibility of: • Electrical requirements to charge the TES from the grid • Mechanical requirements to discharge from the TES to the grid.
Technical parameters	Assessment of the round trip efficiency (RTE) results, evaluating the potential heat losses, degradation, ramp rates and start times.
Commerciality	Assessment of the potential project costs, evaluating the commercial viability of proceeding with the Project.
Risk	Identification and assessment of the risk, identifying risk across the following categories: • Supply chain • Technology • Site area (footprint) • Health, safety, environment and approvals • Power station reliability.

2. Overview

2.1. Project key features

The Project was a desktop feasibility study to assess two approaches to integrating a TES solution into TIPS B, replacing the gas use of one of four 200 megawatt (MW) units for eight continuous hours. Key features of the Project are summarised in Table 4, with further details provided in subsequent sections.

Table 4 Project key features

Date of the Project	2022 - 2023
Location	Port Adelaide, South Australia
Site	Torrens Island B Power Station
TES technology	• Kraftblock – Sensible heat storage • MGA Thermal – Latent heat storage within a matrix of sensible heat storage material.

2.2. Torrens Island B Power Station

TIPS B is situated on Torrens Island, the site is over 16 hectare and located approximately 25 kilometres north of Adelaide in South Australia. It is a conventional thermal power station with a name plate capacity of 800MW and is designed to burn natural gas in four boilers, each providing steam to a 200MW steam turbine generator set. Figure 5 provides an overview of the Torrens Island A Power Station (TIPS A) and TIPS B, with a site layout also provided in Figure 6.

Figure 5 Torrens Island Power Station A (left) and B (right)

Figure 6 Torrens Island Power Station A and B site layout

TIPS B was identified as the preferred site for the Project based on the following considerations:

Unit availability	TIPS B is scheduled for closure in 2026 which will allow the use of existing generation and connection points.
Market dynamics in South Australia	The South Australian energy market comprises of 70% renewable energy and the State Government aspires to achieve 100% net renewables by 2030 highlighting the strong need for storage solutions.
Proximity to existing industries	TIPS B is located close to existing industries and following its closure will continue as part of AGL low carbon energy hubs.
Availability of skilled personnel at TIPS B	There are qualified personnel at TIPS B with the existing skillsets required to undertake the Project.

2.2.1. Torrens Island B Power Station energy generation overview

Each generating unit at TIPS B uses a conventional steam loop (Figure 7). The conventional steam loop cycle involves burning natural gas in a boiler to generate heat which is then sent to the working fluid (in this case water) causing the water to vaporise and superheat to create superheated steam. The superheated steam is used as the driving force in a steam turbine which turns a generator to produce electricity.

Air is supplied for fuel combustion by a forced draught fan. The hot flue gases are withdrawn from the boiler furnace by another fan after having transferred heat to the steam superheater and economiser, as well as transfer heat to the incoming combustion air in the air heater before venting to the atmosphere via the exhaust stack.

The steam from the boiler transfers the heat energy to the turbine where it is converted to rotational mechanical energy as it passes through the blades attached to the turbine output shaft.

The turbine output shaft is connected to an electrical generator and the electrical energy that is generated is passed to a transformer which raises the voltage for distribution to consumers.

After passing through the turbine, the steam is condensed back to water again in the condenser for re-use in the boiler. Large quantities of cooling water are supplied to the condenser, which is a shell and tube heat exchanger.

In the TIPS B cycle the steam acts as a vehicle to collect the heat released by the fuel in the boiler and to convey it to the generating unit for conversion to electrical energy.

Figure 7 provides a general overview of the energy generation process with a detail process diagram (including heat and mass balance) of the current TIPS B cycle provided in Appendix 1.

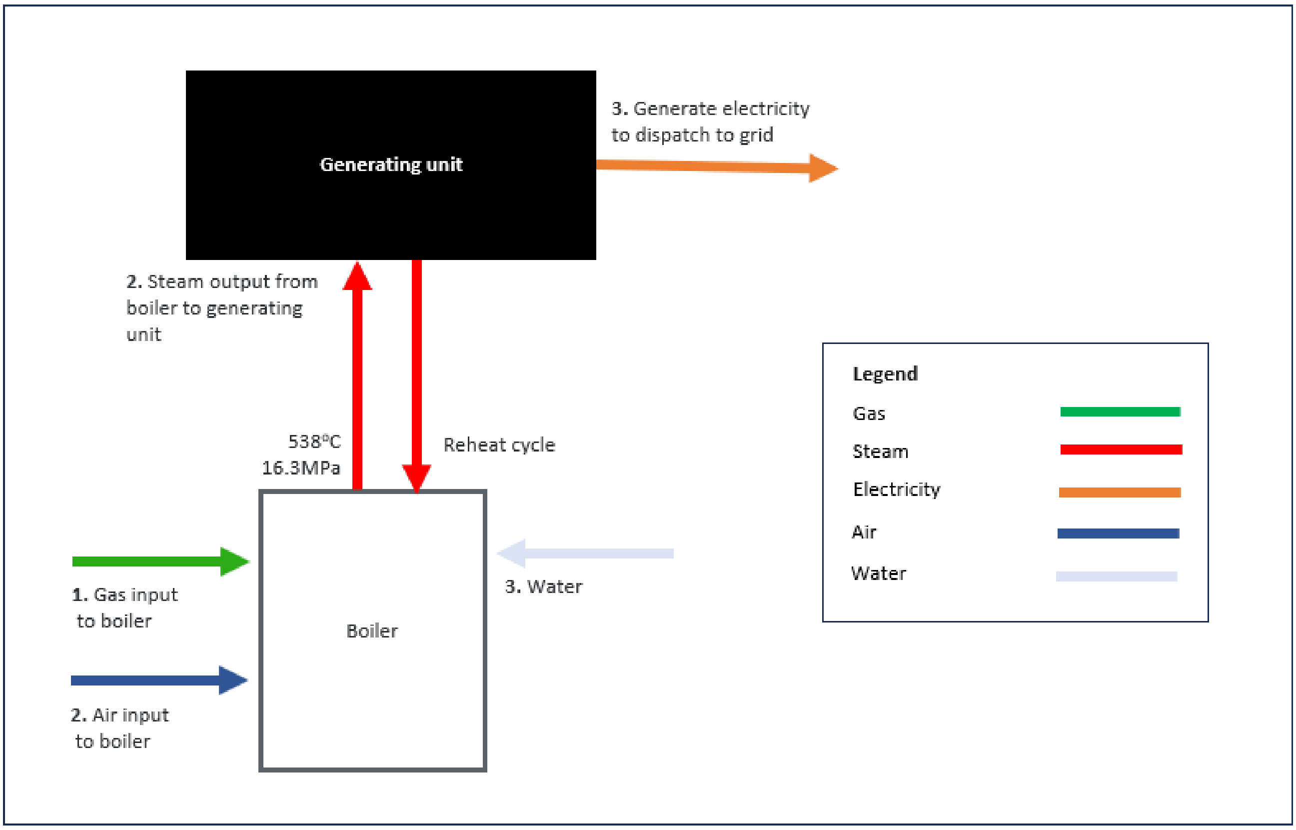


Figure 7 Conventional steam loop overview at TIPS B

2.3. Thermal energy storage technologies

There are several technologies and methods in the market that produce and store heat. These technologies vary in method (heat pumps, resistive heating and combustion of hydrogen-based fuels) and in medium (range from molten salt to volcanic rock).

TES technologies used for the purposes of synchronous electricity generation can provide various system strength services to the electricity grid. These include frequency control and grid inertia. TES technology was chosen for the Project because of its ability to store surplus renewable energy (typically produced during daytime periods) to meet later demand (peak demand periods in the early morning and evening).

The Project hypothesised that integrating TES into an existing thermal power station may reduce energy storage costs relative to comparable assets like pumped hydro, because much of the existing infrastructure, like turbines, could be re-used.

2.3.1. Original equipment manufacturers

TES is an emerging technology, and the bulk of current technical expertise lies with the providers themselves. To leverage this expertise, AGL conducted a global industry-wide search to identify providers whose TES mediums can store heat at temperatures ranging from 500°C-1,200°C. This research informed data and early conclusions on the potential of TES, highlighting:

- There are several different technologies and methods being developed by companies to produce and store heat. They include heat pumps, resistive heating and combusting hydrogen-based fuels to produce heat. Heat storage mediums also vary and range from molten salts to volcanic rocks. However, the simplest method is to charge a TES from grid electricity and storing the energy as heat, using a resistive heating process. The heat should then be stored in a medium that can store and discharge high temperature heat.
- There is increasing interest amongst thermal storage providers to use stored heat for industrial purposes rather than electricity generation.
- The ability to supply industrial processes with heat adds to the value proposition of a TES asset.
- Integrating a TES into an existing thermal power station may reduce energy storage costs relative to a comparable asset, because much of the existing infrastructure could be reused.

Two original equipment manufacturers (OEM), Kraftblock and MGA Thermal, were assessed for the Project. These OEMs were chosen based on meeting the following criterion:

- Have the capability to integrate to a thermal power station
- Have the technology to service electricity generation and additional industrial applications
- Experience in delivering similar projects at pilot scale
- Willing to publicly share information to satisfy the ARENA knowledge sharing requirements.

2.3.2. Kraftblock

Location:	Germany
Year founded:	2014
Heat storage material:	• 85% recycled materials such as slag from the steel and gas industries, with fireproof inorganic binder • Storage units are based on 20-foot container sizes, but a storage unit can be made up of multiple 20-foot containers • Does not require regular maintenance, with thermocouples and pressure sensors to detect anomalies
Heat storage method:	Sensible heat storage[2]
Heat transfer fluid:	Air
Temperature:	Up to 1,300°C
Charging method:	Power to heat or waste heat capture

Figure 8 Kraftblock storage medium illustration

Kraftblock technology is a high-temperature energy storage system that stores energy in the form of heat using porous media.

Kraftblock follows an open-system-approach, meaning the storage can be integrated into different energy systems because the charging and discharging device can be adjusted. This means that the storage can be charged and discharged by different heat-transfer-media, mainly gases and flue gas. This provides Kraftblock with a broad range of applications for its TES.

[2] Sensible heat storage refers to the result of a temperature change of a substance, while the substance remains in the same physical state

Kraftblock use a sensible heat storage whereby there is no phase change in the materials when heat is added. Kraftblock TES remains in a solid state and fluctuates between high temperature (charge) and lower temperatures (discharge).

Use cases

Kraftblock is an emerging technology that has been used in the following cases:

- Kraftblock converted flare gas from the steel industry into high temperature energy, and in doing so heated its workshop during a winter season.
- Kraftblock is working with PepsiCo and Eneco to build the world's largest and highest temperature heat storage system to date. It will consist of 150MW/h gross capacity, be built in five modules, with the first two planned to be operational by the end of 2023.

2.3.3. MGA Thermal

Location:	Australia
Year founded:	2019
Heat storage material:	• Miscibility Gap Alloy (MGA) • Blocks store approximately 300kWh per cubic metre
Heat storage method:	Latent[3] heat storage
Heat transfer fluid:	Inert gas
Temperature limit:	Up to 750°C
Charging method:	Power to heat or waste heat capture

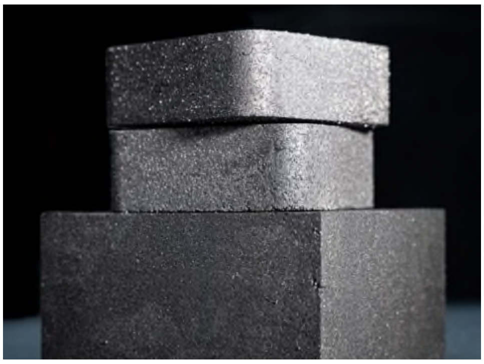


Figure 9 MGA Thermal blocks illustration

MGA Thermal manufactures thermal MGA blocks that store and deliver energy at a constant temperature while remaining outwardly solid. MGA blocks consist of MGA, a matrix material that keeps the block solid while a metallic material is dispersed as particles. It is highly conductive and rapidly distributes heat, keeping the particles in place as they melt when heat energy is absorbed. MGA blocks store massive thermal energy through the solid-liquid phase change, which is released as they cool, and the particles solidify.

[3] Latent heat refers to the energy captured as a result of a substance changing phases

MGA Thermal also uses recycled materials in the manufacturing process. The low thermal expansion helps it cope with thermal shock and its high thermal conductivity means the energy can be inputted and extracted quickly.

MGA Thermal uses a latent heat[4] storage technology, whereby the physical properties of the storage system changes, turning liquid when the storage material is charged and changes back to solid when the energy is discharged.

Use cases

MGA Thermal is targeting a range of applications, typically with a decarbonised energy input from solar, wind, a green Power Purchase Agreement (PPA) or concentrated solar power. The main use for MGA Thermal is for industrial heat and thermal power station application.

MGA Thermal is conducting an ARENA supported pilot project at its manufacturing centre in New South Wales. The pilot demonstrates electric charging of thermal energy storage, discharge on demand via inert gas loop and firmed steam generation in a 5MWh system.

[4] Latent heat refers to the energy captured as a result of a substance changing phases

3. Integration

3.1. Overview

The integration component of the study investigated how the TES assets could be integrated into TIPS B's current steam cycle and considered:

- **Electrical integration:** Examining how grid electricity could be converted to heat and stored.
- **Mechanical integration:** Examining how the stored heat could be used through the current TIPS B generation equipment.

The TES acts as the "thermal battery" that involves three key phases – charging, storing and discharging of energy as explained below and illustrated in Figure 10:

- **Charge** - The TES are charged by grid electricity which runs through a resistive heating circuit to increase the temperature of the thermal blocks. During the charging process, electricity from the grid is converted to thermal energy and stored in the thermal blocks.
- **Storage** - Energy is stored in the TES until demand for electricity is required. As this stage, the TES system is on standby until discharge is required.
- **Discharge** - To discharge energy from the TES, fans are used to blow heat transfer fluid (typically air or inert gas) over the storage material. The heat transfer fluid is heated by absorbing heat from the hot storage material and is then ducted towards a heat recovery steam generator (HRSG). The HRSG uses the hot heat transfer fluid to boil water and create steam. The steam is then used to run a steam turbine with subsequent power generation. Integrating the TES with TIPS B will require the installation of multiple HRSGs which would replace the current boilers at TIPS B. Further information on the use of HRSGs is detailed in Section 3.3.

An overview of this process is provided in Figure 10 with a full process flow diagram, including heat and mass balance, detailed in Appendix 2.

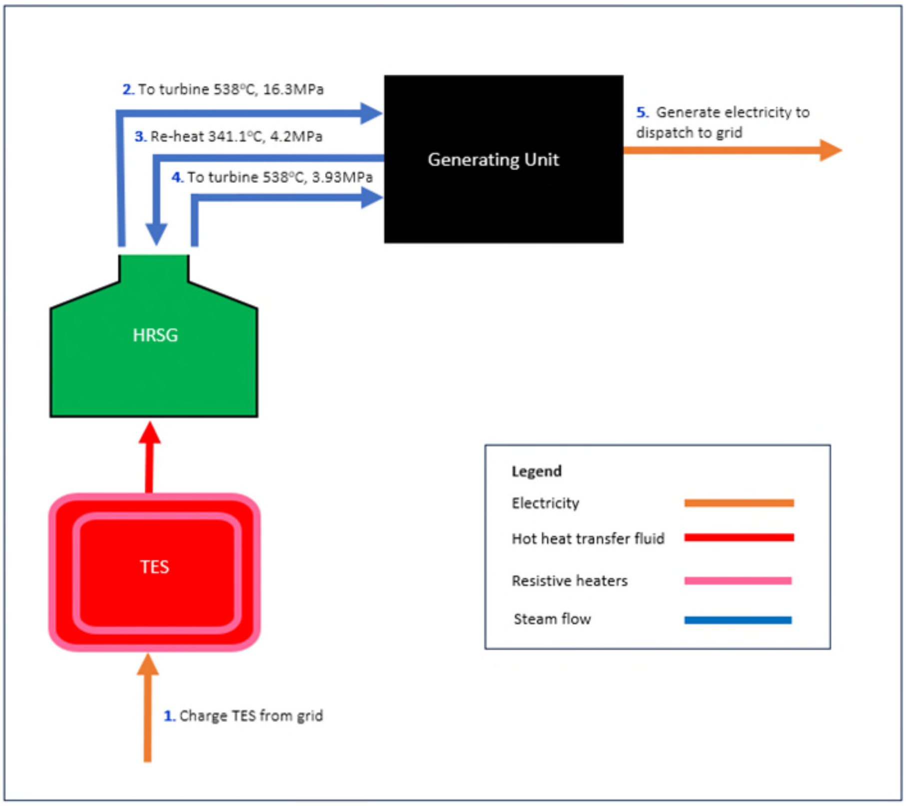


Figure 10 Overview of integrating TES into TIPS B

3.2. Electrical integration

Major infrastructure for the electrical integration of the TES into TIPS B would require:

- The input of grid electricity via two 275kV connection points, each capable of importing 250MW of electricity
- Two large 250MVA three-winding transformers to step down the 275kV transmission voltage to 33kV. This can be reticulated around Torrens Island
- A series of two-winding transformers to further reduce the voltage from 33kV to the 690V_{AC} utilisation voltage required by the heaters, fans and house load.

Figure 11 depicts a simplified view of the electrical integration that would be required.

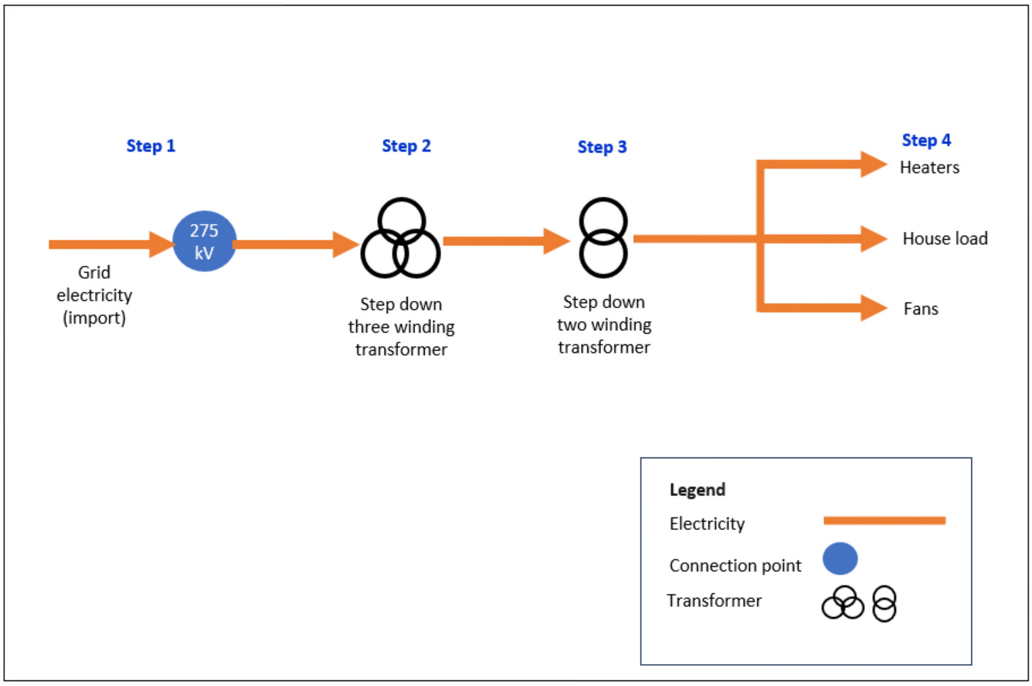


Figure 11 Simplified version | Electrical integration

The electrical integration work required for Kraftblock and MGA Thermal were largely the same. The primary difference between the electrical integration for Kraftblock and MGA Thermal was the auxiliary load drawn by the TES for operation. The main source of auxiliary load drawn is the fans used to circulate their respective heat transfer fluids over the storage material during charging and discharging.

It was also found that the electrical connection points detailed above are currently available at TIPS B and are suitable to connect the TES technology. However, electrical integration will require additional equipment, most notable being a significant number of two-winding transformers and new switchboards.

For further detail on the electrical integration, see the single line diagram provided in Appendix 3.

3.3. Mechanical integration

Preliminary findings show there would be a clear demarcation between the HRSGs and the generating units, indicating the TES can be integrated to the current equipment at TIPS. Figure 12 shows the flow directions and pipe sizes at the potential interface point.

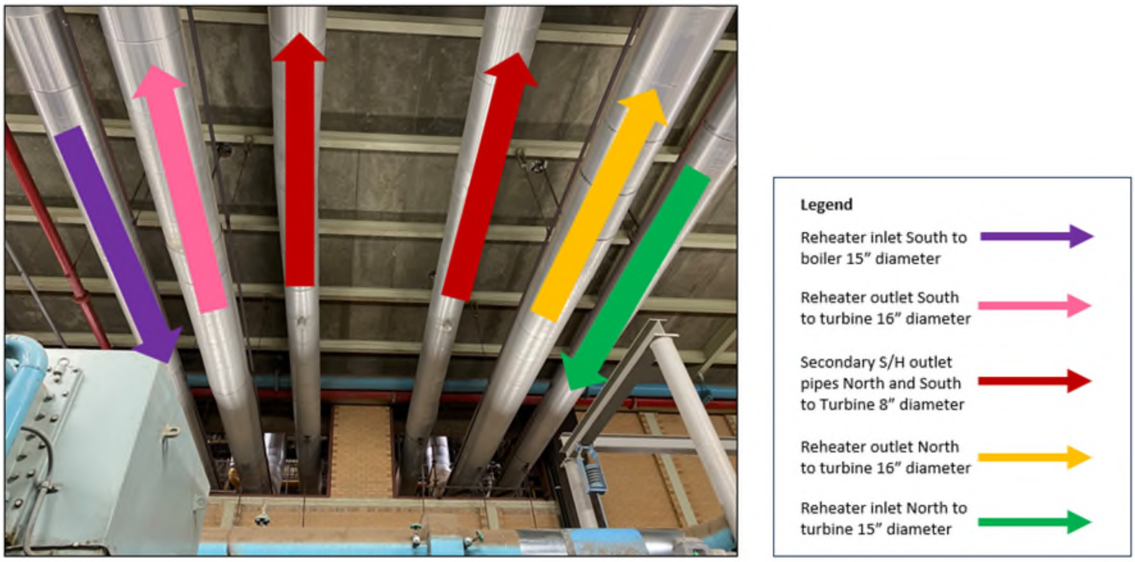


Figure 12 Pipes and flow directions in and out of B1 and B2 unit turbines

A key finding of this Project was that the TES cannot be integrated with the current boilers. The boilers at the TIPS B are designed with a furnace to combust gas and transfer heat through radiative, conduction and convection heat transfer processes, with radiative being the largest component. Heat transfer from the TES largely occurs due to conduction and convection, with little to no radiative heat being transferred via radiation given that there is no high temperature combustion taking place. As a result, the boilers are not suitable to transfer heat from the TES into the working fluid (steam). Consequently, installation of HRSGs is required for TES to be integrated into an existing thermal power station. The HRSGs will take the heat from the TES and put it into water/steam and bring that steam up to the required temperature and pressure conditions to drive the turbine.

While TES are unable to integrate to the existing boilers, the Project identified that some equipment that can remain. Table 5 provides a list of the major equipment that the TES could connect to and maintain in operations.

Table 5 Major equipment that can remain when integrating TES

Equipment	Kraftblock	MGA Thermal
High-pressure turbine (HP), Intermediate-pressure turbine (IP), Low-pressure turbine (LP)	✓	✓
Steam turbine	✓	✓
Generator	✓	✓

Equipment	Kraftblock	MGA Thermal
Condenser	✓	✓
Low Pressure Feed Water Heaters (LP1, LP2, LP3)	✓	✓
Deaerator	✓	✓
Boiler Feed Pump	✓	✓
High Pressure Feedwater Heaters (HP5, HP6, HP7)	✓[5]	✓

3.4. Utility list and availability

The main utility requirements to integrate Kraftblock and MGA Thermal's TES solutions into TIPS B are presented in Table 6.

Table 6 Kraftblock and MGA Thermal utility list

	Kraftblock	MGA Thermal
Electricity for heater operation (MWe)	475	480
Electricity for auxiliary consumption[6] (MWe)	5.3	20
Inert gas initial fill (tonne)	-	266
Inert gas top up (tonne)	-	4.5
Air	Ambient air is used, no restriction on volume.	-
Water for steam production	Approximately equivalent volume and quality of water used as currently used in boilers for steam production.	Approximately equivalent volume and quality of water used as currently used in boilers for steam production.

[5] Although Kraftblock could re-utilise the Feedwater Heaters, it was decided that water preheating would occur within the HRSG, in Kraftblock's design.
[6] Electricity for auxiliary consumption includes electricity to operate fans, house load, heaters etc.

The utilities required for both TESs are readily available onsite at Torrens Island, except for the inert gas which would require a production facility onsite.

3.5. Modular deployment

For the purposes of the Project, modular deployment refers to the phased addition of storage volume, in MWh over time. A modular asset is a design option that allows the expansion of the facility to increase storage capacity as it is needed.

A brief investigation of this approach determined that modular deployment on the TIPS B site poses significant design and engineering challenges for this application. Each of the storage systems are based on an integrated design, for which pressures, flow rates and other vital quantities were specifically determined. A system re-design would be required to allow for any type of modular deployment and future expansion projects.

The Kraftblock and MGA Thermal designs may allow for some level of modularity on a greenfield project.

3.6. Major equipment

The key pieces of major equipment required are thermal storage units, HRSGs, pipes, ducts, and electrical components like transformers of different sizes.

A detailed list of the major equipment required to integrate Kraftblock and MGA Thermal's design is provided in Appendix 4 and 5.

3.7. Conclusion

The Project found it was technically feasible to integrate TES into an existing conventional thermal power station, however this technology will require significant upgrades and modification. While the electrical connection points required to charge the TES are available at TIPS B, the electrical integration will require additional equipment, most notable being a series of two-winding transformers and new switchboards.

A further key modification to integrate TES was the need to remove the existing boilers. As noted above, the heat transfer mechanisms required by the TES are unsuitable for the stored heat to be utilised in the boilers. The TES requires conductive and convective heat transfer process facilitated by the HRSG to allow the existing turbomachinery to be used.

Integration of TES will however involve keeping the following major equipment:

- Steam turbine
- Generator
- Condenser

- Low pressure feed water heaters
- Deaerator
- Boiler feed pump
- High pressure feedwater heaters.

4. Technical parameters

Thermal power stations typically require a low-cost energy source due to the high volumes of energy lost through combustion of fossil fuels and the inherent losses associated with based turbine generator operation. Accordingly, a key focus of the Project was to assess whether energy efficiencies or capital cost savings could be identified through integrating a TES solution into an existing thermal power station with established infrastructure.

This chapter examines the key technical parameters of the TES, detailing the potential RTE efficiencies through adopting Kraftblock and MGA Thermal solutions at TIPS B.

4.1. Start times

The time it takes for the TESs to commence operations is a key measure in evaluating the capability of the technology to produce timely energy and support reliable electricity production. It should be noted that for both TES technologies, the time for the units to charge is almost instant, without any notable delays identified.

The estimated start times of the Kraftblock and MGA Thermal systems are relatively similar for both cold starts (such as when the storage system has not been discharging energy and is in idle) or when it is warm (having recently produced steam). As detailed in Table 7, MGA Thermal is expected to take slightly longer to start than Kraftblock, estimating an additional 20 minutes to start from cold and 10 minutes from warm. However, this difference is marginal and doesn't impact the integration into the existing TIPS B.

Table 7 Kraftblock and MGA Thermal start times

Start time	Kraftblock	MGA Thermal
From cold (minutes)	100	120
From warm (minutes)	20-30	30-40

4.2. Discharge ramp rate

Discharge ramp rate refers to the rate at which the heat into the HRSG can be increased from minimum to maximum load, measuring the ability of the system to reach maximum power output from an idle position.

Due to their designs, the HRSG ramp rates are likely to be better than the capability of the existing generating units. Accordingly, both Kraftblock and MGA Thermal's HRSG ramp rates are estimated to be 15% per minute as detailed in Table 8. This is considered favourable when compared to the existing power station boiler ramp rate of 2.5% per minute.

Table 8 Estimated HRSG ramp rates

	Kraftblock
Ramp rate (%/minute)	15

4.3. Heat wastage

Energy stored in a TES will experience heat loss to the atmosphere resulting from imperfections in thermal insulation and the like. As summarised in Table 9, it is estimated that MGA Thermal will lose approximately 1.3 percentage points (PP) of heat per day more than Kraftblock, however both technologies are expected to incur relatively low heat loss while in storage. It was also understood that the heat wastage difference would likely be mitigated through further design optimisation.

Table 9 Estimated heat loss from Kraftblock and MGA Thermal systems

	Kraftblock	MGA Thermal
Heat loss (%/day)	1.2	1.2

4.4. Degradation

Degradation in energy storage systems involves the gradual decline of capacity and efficiency over time due to chemical and physical changes caused by the charging and discharging phases.

It was estimated that, for both Kraftblock and MGA Thermal, degradation of the energy storage system is low, between 0 to 1% per year. This is based on the advice of the OEMs and is consistent with this type of technology.

4.5. Round trip efficiency

RTE refers to the amount of energy discharged into the grid, compared to the amount of energy stored.

The TES components of the system are highly energy efficient at steam generation (HRSG) and both Kraftblock and MGA Thermal's storage systems are expected to discharge approximately 99% of the energy used in charging.

However, there is heat loss that occurs during the electricity generation (steam turbine) process. This heat loss lowers the overall energy efficiency and hence the useable energy that is discharged to the grid.

The Kraftblock HRSG process had a slightly lower efficiency of approximately 83%, than the MGA Thermal process of approximately 87%. The reason for this is the Kraftblock system uses an open loop cycle for the heat transfer fluid (air), which means any heat in the exhaust air from the HRSG heat exchanger is lost to the atmosphere. The MGA Thermal process uses a closed loop cycle with inert gas. The exhaust inert gas from the HRSG heat exchanger is recycled to the thermal storage block (and hence the heat in the exhaust inert gas is re-captured rather than lost to atmosphere).

The advantage of the open loop Kraftblock design was that it allowed a greater depth of discharge for the thermal storage (because the incoming air is a lower temperature than the warmer exhaust inert gas in the closed loop cycle). A greater depth of discharge was considered to result in a lower volume of thermal storage medium required and therefore lower capital cost.

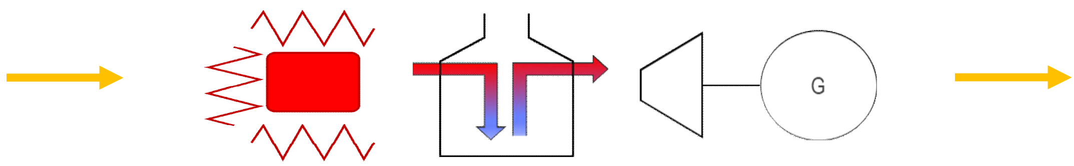
The largest efficiency loss was experienced when the steam is converted to electricity through the generating units. Energy loss in rotating machinery (steam turbine and generator assembly) occurs from several reasons. Firstly, the thermodynamic cycle used in this case is a Rankine Cycle, which is typically 40% efficient however due to the incorporation of steam preheating and reheating, it was 45% in this scenario. Two further sources of energy loss occur through the condenser and energy causing energy losses from the friction in the turbine-generator assembly.

As a result, the overall round trip efficiency for each system was estimated to be:

- Kraftblock- approximately 37%
- MGA Thermal- approximately 40%.

A breakdown of the round trip efficiency for Kraftblock and MGA Thermal is provided in Table 10.

Table 10 Kraftblock and MGA Thermal estimated round trip efficiency

	Energy in	TES	HRSG	Generator units	Energy out
	Electricity from the grid	Electricity to heat	Heat transfer medium (air/inert gas to steam)	Heat to mechanical Mechanical to electrical	Energy to the grid
					
Kraftblock		99%	83%	45%	37%
MGA Thermal		99%	87%	45%	40%

Both TES were assessed based on their capabilities to provide a long duration storage solution while operating under the following plant operating requirements:

- Store the equivalent of up to 1,600MWh of electrical energy as heat
- Discharge heat for eight continuous hours at steam parameters of 538°C and 16.3 Mega pascals (MPa)
- Repeat this process on a 24 hour basis.

Due to the low RTE rates, Kraftblock and MGA Thermal storage systems must charge and store a large amount of energy to produce the required 200MW for eight continuous hours' discharge.

To calculate the gross storage volume, it is important to understand the temperature of the storage material within the TES declines during the discharge cycle resulting in unusable heat. As illustrated in Figure 13, when the temperature reaches below 538°C, the heat coming out of the TES no longer meets the required steam parameters of the TIPS turbines, deeming it unusable heat. Heat that is ~538°C is the minimum temperature of useable energy which can be extracted from the TES. The combined volume of useable and unusable heat makes up the gross thermal energy storage volume.

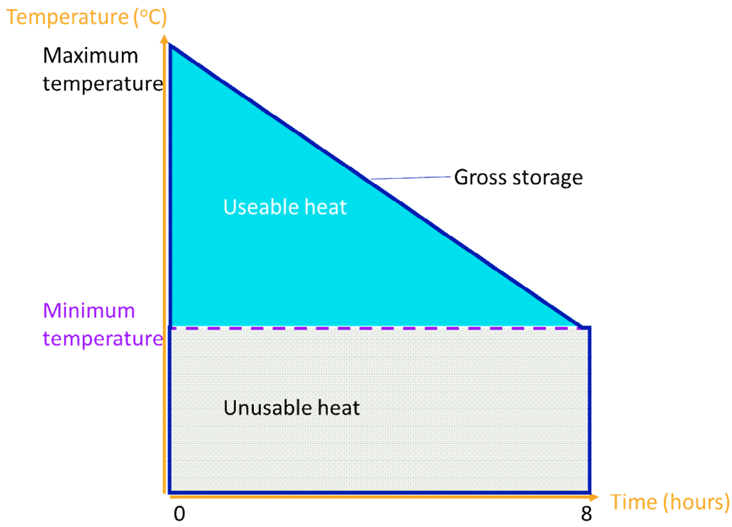


Figure 13 Useable and unusable heat depiction in a TES (during the discharge cycle)

To achieve the desired dischargeable energy, the TES must produce 1,600MWh of electrical energy, requiring useable thermal energy storage volume of 3,900MWh (Kraftblock) and 3,636MWh (MGA Thermal) (detailed in Table 11). This estimate considered the depth of discharge for each storage system which was determined based on the advice of each OEM.

Table 11 Kraftblock and MGA Thermal useable storage volume

	Kraftblock	MGA Thermal
Charge (MWe)	475	480
Discharge (MWe)	200	200
RTE (%)	~37	~40

	Kraftblock	MGA Thermal
Auxiliary load (MWe)	5.3	20

*Assuming maximum RTE achieved

4.6. Kraftblock system design

Kraftblock opted to incorporate an HRSG in an open loop cycle that draws air from the atmosphere through the heat storage medium, transfers that heat to water in the HRSG to create steam. The open loop cycle pushes heat out of an exhaust fan or HRSG chimney and releases waste heat in the atmosphere (not all heat energy can be practically captured in the HRSG). However, the open loop cycle allows a greater depth of discharge from the storage units, thereby reducing the number of units required compared to a closed loop cycle.

Kraftblock's design was a five unit system, coupling five storage modules and HRSGs in an open loop cycle (see Figure 14). Each storage module has a gross thermal energy storage volume of ~1,495MWh and each unit produces 40MW of electrical equivalent capacity from the turbine and generator.

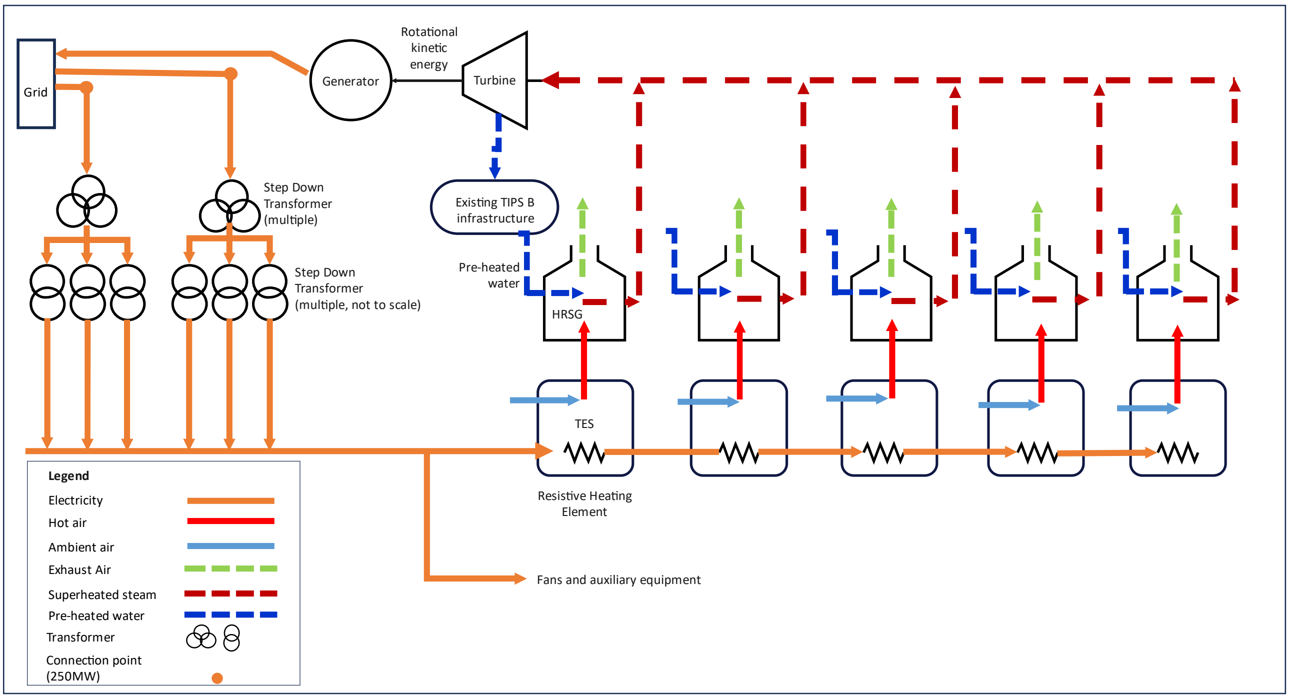


Figure 14 Kraftblock proposed design (not to scale)

4.7. MGA Thermal system design

MGA Thermal designed a closed loop cycle, whereby the heat transfer fluid is not exhausted in the atmosphere after passing through the HRSG, thereby minimising heat loss. A two-unit system was proposed using two storage modules paired with two HRSGs, each capable of supplying the equivalent of 100MW electrical output, the layout is shown in Figure 15. The gross thermal energy stored is approximately 5,000MWh.

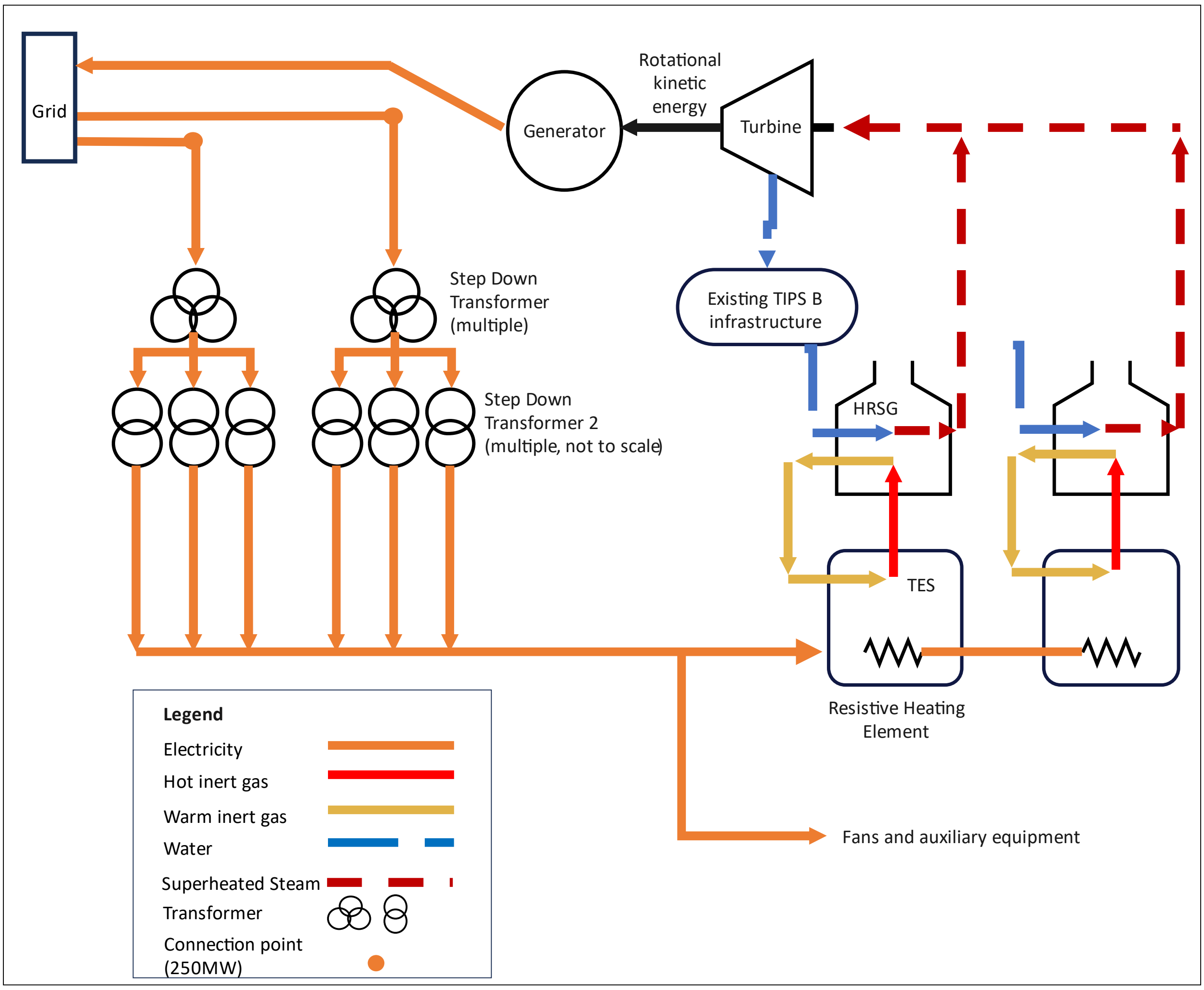


Figure 15 MGA Thermal proposed design, not to scale

4.8. Conclusion

The TES components of the system are highly efficient at steam generation, however the heat loss that occurs during the electricity generation process lowers the overall efficiency and therefore the useable energy that is discharged to the grid.

It is evident that the TES offers a low carbon method to producing heat and is highly efficient in storing and discharging heat that could otherwise be beneficial to industrial sectors that use process heat in their operations. The maximum achievable output temperature of the heat transfer fluid from the TES influences the type of industrial users who may consider the TES technology. This varied from very high temperature (above 650°C), that applicable end users could use for glass, alumina (calcination), iron and steel production to low temperature (150°C or below) that may be utilised for commercial heating, food and beverage and agriculture industries.

Further information on types of different industrial users is detailed in Chapter 7 Industry. It should be noted that the Project did not test the feasibility of utilising TES for industrial uses. However, the high energy efficiency of the TES, coupled with the low carbon option to produce heat, indicates significant potential opportunities to investigate further the options for TES to be used as power to heat application or from the use of waste heat.

5. Site considerations

Due to the low RTE, it is important to locate the TES and HRSGs near the generating units. This system design preference will reduce the distance the steam must travel from the HRSGs to the turbines and therefore minimises the amount of heat lost through the process. It would also be beneficial to locate the TES where the boilers are currently, as this will enable continuity of existing process flow.

5.1. Kraftblock

As detailed in Section 2.3.2, Kraftblock proposed the construction of a five-unit system to achieve the desired gross storage volume of 5,178MWh. It is estimated that each storage system, including the TES, HRSG and ancillary equipment will require approximately 5,000m^2. As a request, the total system is estimated to require a total area size of 25,000m^2 to install (shown in Figure 16).

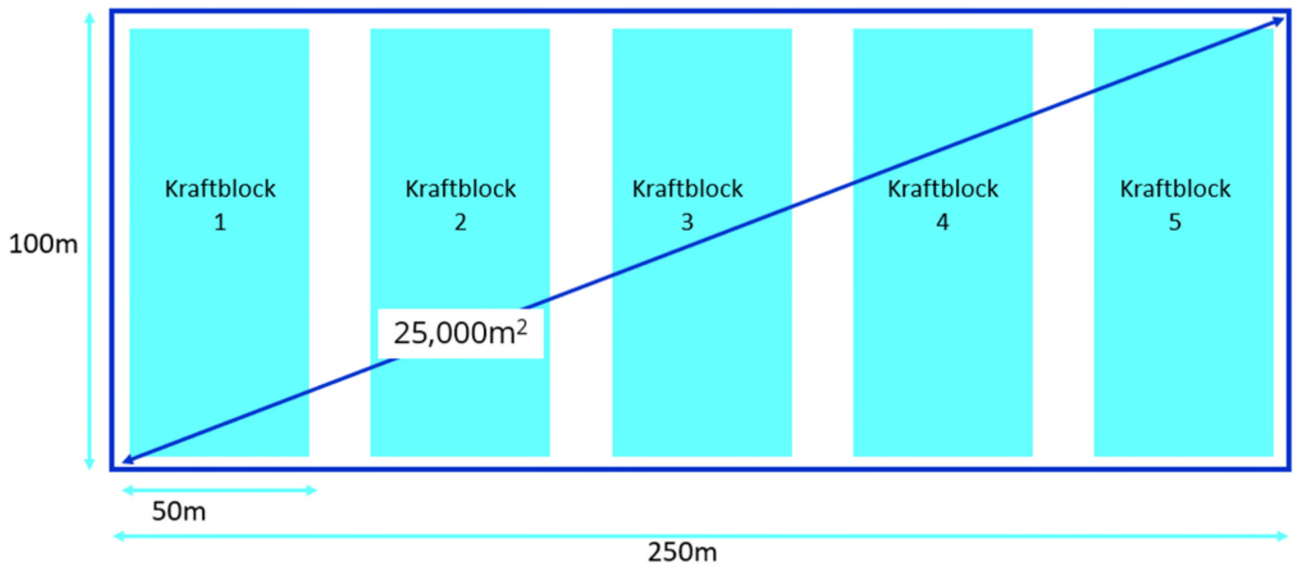


Figure 16 Estimated footprint to install Kraftblock design with HRSG units

5.2. MGA Thermal

MGA Thermal's system involves construction of a two-unit system, each requiring a footprint size of 9,165m^2. To implement the MGA Thermal energy storage system, it is estimated that it will require a total area footprint of 18,330m^2 (shown in Figure 17).

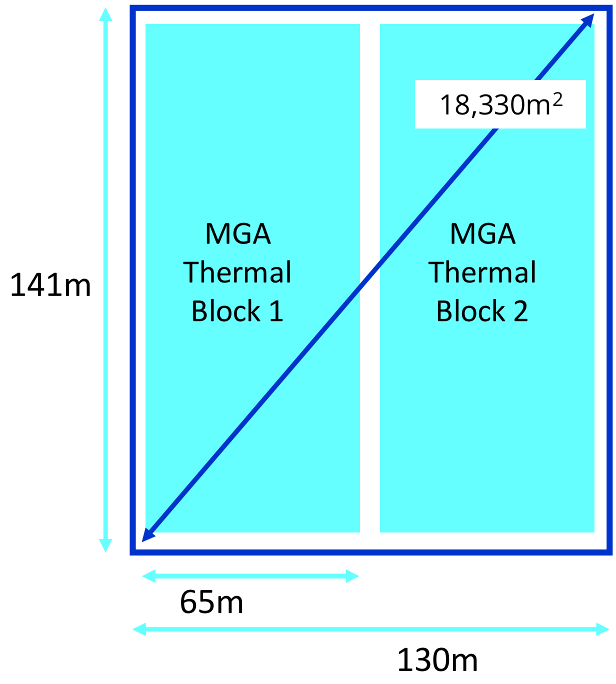


Figure 17 Estimated footprint to install MGA Thermal design with HRSG units

5.3. Asset location

It is important for the TES and HRSGs to be near the generating unit to reduce the travel distance of the steam and thereby minimise heat loss. While several locations were considered, the ideal location is directly behind the TIPS B generation units where the boilers are currently located.

Both Kraftblock and MGA Thermal's proposed system would require the complete demolition and removal of all four TIPS B boilers (shown in Figure 18 and Figure 19).

Figure 18 Preferred sit location for Kraftblock design

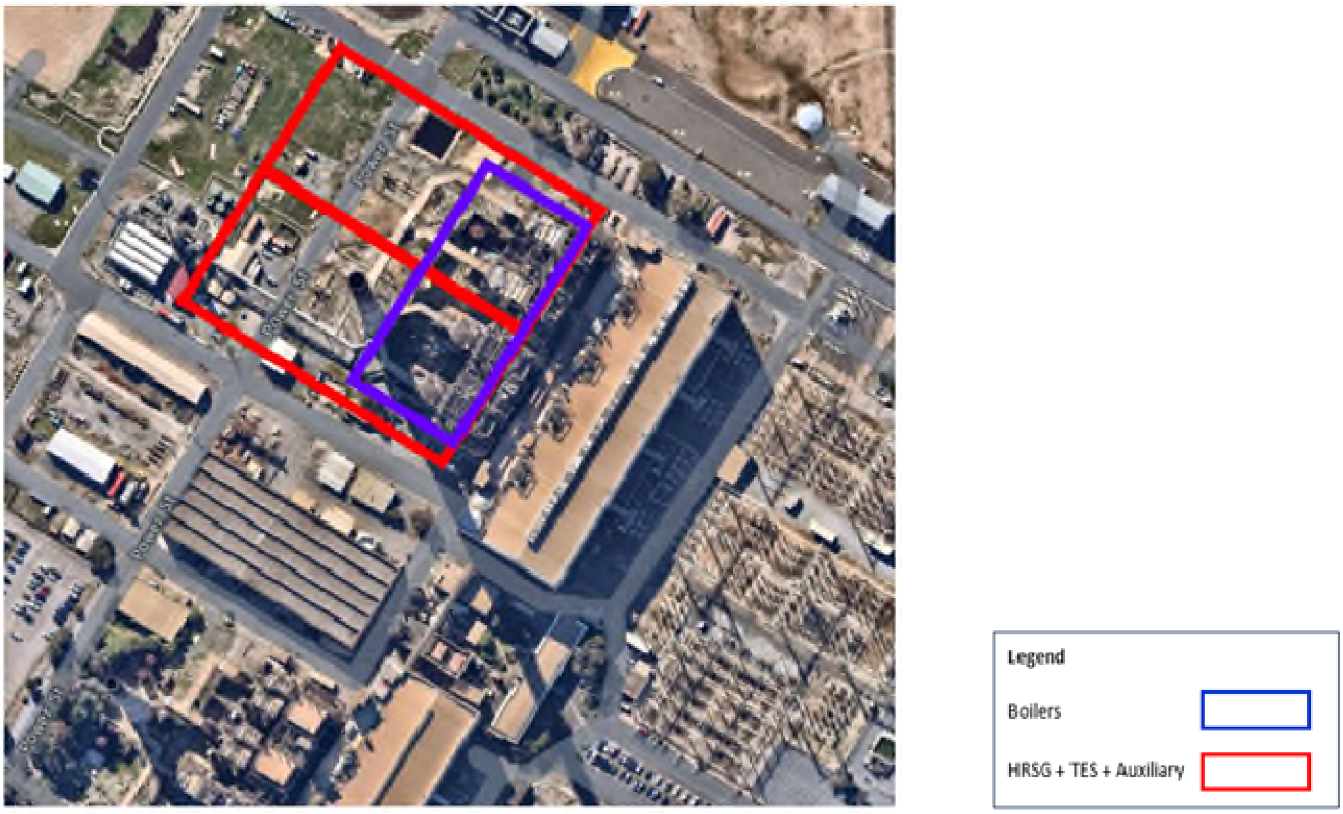


Figure 19 Preferred site location for MGA Thermal design

As both TES technologies are proposed to be located within the Torren Island Power Stations' site and on already disturbed land, minimal additional impact to the flora and fauna in the area would be likely. However, disturbance to existing facilities on site is expected. These impacts are summarised in Table 12.

Table 12 Impact to existing facilities

Asset	Description of impact	Kraftblock	MGA Thermal
TIPS B Boilers	Removal of all boilers from site at TIPS B to provide space for installation of TES and HRSGs.	✓	✓
TIPS B flue stack	Removal of TIPS B flue stack removal to provide space for installation of the TES.	✓	✓
Carbonation plant	Level of impact is currently uncertain however it is likely that installation of the TES would encroach on Air Liquide's carbonation plant.	✓	✓
Shared roadway entry to Torrens Island	Installation of the TES and associated equipment would require existing roads to be rerouted.	✓	✓

5.4. Connection point availability and requirements

Both proposed TES designs would require two connection points. The connection points needed are already established and would require minimal work to upgrade for the Project:

- Three 250MW connection points available from TIPS A
- Two 250MW connection points available from TIPS B.

5.5. Conclusion

The Project found both Kraftblock and MGA Thermal's system design could suitably be installed on the site of Torrens Island Power Station however the scale of these developments is significant.

Despite the TES systems designed to replace one gas-fired generator at TIPS B, both designs will require all four boilers at TIPS B to be demolished to install, rendering the remaining generators inoperable or delaying the implementation of the Project until after all commercial generation at TIPS B has ceased.

6. Personnel

Job creation and retention was a strategic driver for the Project to identify opportunities to maintain a skilled workforce post the closure of the TIPS B. This chapter details the estimated number of potential construction and operations jobs.

6.1. Kraftblock

For the purposes of the Kraftblock system design, it was estimated that it would require the number of construction and operational jobs as detailed in Table 13.

Table 13 Kraftblock construction and operations job estimates

Construction	Assuming a 12-month project duration and five storage units including the process to heat system, fans and connecting duct: • Approximately 110 fitters (mechanical, electrical, crane) required to work on 10 units in parallel. Each unit requires approximately one month for erection. • Approximately 30 fitters required per unit, for the installation of five HRSGs. Approximately two months required to install the predominantly prefabricated parts and components. In total approximately 260 personnel required on a full-time equivalent (FTE) basis for construction. This estimate did not include related piling and foundation work required at site within the civil and foundation work, outside the Kraftblock scope.
Operation (TES only)	• TES operation would require a limited team of experts given the automatic operational mode with remote control of the TES. • Services, inspection maintenance and repair require a limited team due to the predominantly low maintenance equipment and lack of large wear part consuming scope. • Plant operation would require a team of up to approximately three permanent experts (mechanical, electric, boiler). • Service and repair would require a team of approximately up to five skilled generalists, in a part-time, shared service function.

6.2. MGA Thermal

For the purposes of the proposed MGA Thermal TIPS B system design, it was estimated that it would require the number of construction and operational jobs as detailed in Table 14.

Table 14 MGA Thermal construction and operations job estimates

Construction	Assuming a 24-month project duration and a 40-hour work week: • Construction and commissioning were approximated to require 241 FTE roles. • In addition, approximately 45 FTE roles would be required for project management, administration, procurement, engineering and quality control. Total construction and commissioning: 296 FTE positions.
Operation (TES only)	Plant operation would require approximately three FTE operators and two FTE maintenance roles.

7. Industry

With half of the world's energy consumption used for heat production in 2018, and half of this energy used for industrial processes, there is potential to reduce these emissions by implementing a clean heat source. A TES asset that can provide clean, high-grade heat for industrial processes would be of significant value and identifying the use cases for heat stored was a strategic driver of the Project.

This chapter summarises the industrial industries that could also use the heat stored in the TES asset, thereby making the TES technology more flexible and valuable. It should be noted that the Project did not test the feasibility of utilising TES for industrial uses and further work would be required to test this.

7.1. Other types of industrial uses for thermal energy storage

7.1.1. Kraftblock

As part of the Project, Kraftblock investigated industrial partners who could benefit from high temperature heat served from the Kraftblock system design – either as power to heat application or from the use of waste heat.

There are many potential partners given that process heat is applicable to all industries operating with heat above 120°C.

Kraftblock identified the following range of industries with potential for decarbonisation with its TES technology:

- Food and beverage industry (drying, frying, roasting, cooking)
- Commodity industry (drying, pre-heating)
- Building material industry (steam heated autoclaves)
- Pulp and paper industry (drying, heating)
- Chemical/petrochemical industry (drying, heating)
- Steel and non-ferrous metals (use of waste heat)
- Glass industry (use of waste heat)
- Ceramic industry (waste heat from batch processes-preheating)
- Galvanizing industry (heating zinc bath)
- Paint shop industry (drying air)
- Industries' flaring gases: Such flare gas energy could be tapped after an e.g., adiabatic combustion, and be applied as a mobile heat served by trailer mounted containers to a nearby third party.

7.1.2. MGA Thermal

MGA Thermal assessed Australian uses of industrial process heat for compatibility with its TES technology and identified the most critical parameter when determining applicable markets was the maximum achievable output temperature of the heat transfer fluid. This temperature limits the downstream processes the storage can provide energy to. As a result, the temperature can be decreased through various processes to meet requirements and be transferred to different working fluids and pressures through appropriate heat exchangers. It cannot however be increased without additional power input.

MGA Thermal identified the following industry applications by accessible temperature range. MGA Thermal's current TES technology can address heat requirements for the low, medium, high temperature ranges, with development currently underway for the very high temperature uses:

Very high temperature (above 650°C):

- Alumina (calcination)
- Iron and steel production
- Ammonia and other chemicals (steam reforming)
- Cement and lime products
- Glass production

High temperature (250 – 650°C):

- Food and beverage
- Petroleum refining
- Pulp and paper
- Wood and wood products
- Textiles and clothing
- Steam (Rankine cycle) based electricity generation
- Green hydrogen generation (solid oxide electrolysis)
- Chemical manufacturing

Medium temperature (150 - 250°C):

- Food and beverage
- Oil and gas extraction
- Petroleum refining
- Alumina (digestion)

Low temperature (0-150°C):

- Commercial heating
- Food and beverage
- Agriculture.

7.2. Conclusion

There are a broad range of industries that could benefit from this technology as it was found the maximum achievable output temperature of the heat transfer fluid from the TES influences the type of industrial users who may consider the TES technology. Potential industries include:

The Project did not investigate the feasibility of integrating TES into the operations of any of the above industries however the high energy efficiency of the TES, coupled with the low carbon option to produce heat, indicates potential opportunities to investigate the options for TES to be used as a power to heat application or from the use of waste heat.

8. Australian sourcing analysis

8.1. Materials, equipment and services

A component of the Project was for the OEMs to consider the materials, equipment and services which can be procured from Australian based suppliers that have the necessary capability and capacity.

Both Kraftblock and MGA Thermal indicated that they would source the required equipment and materials domestically. Kraftblock also indicated that it would need to set up a production facility within Australia to manufacture the TES. MGA Thermal is an Australian based company with established local production and manufacturing contacts.

The TES systems and components that can be procured in Australia are:

- Process equipment:
  - HRSGs
  - Gas circulation fans
  - Steel fabrication (ducting, piping, TES enclosure)
  - Inert gas generation
  - Instrumentation and Controls (I&C).
- TES system interior:
  - TES storage medium
  - Insulation.
- Electrical:
  - Switchboards and transformers
  - Electric heaters.

9. Commercial

A key activity of the Project was to assess the cost of integrating TES into an existing thermal power station. Note that all values are in Australian dollars (AUD) unless stated otherwise and all costs were indicative only.

Project costs include:

- **Site development costs:** This includes construction (including labour costs) of the TES, HRSG and installation of electrical works, including installation of the 275kV grid connection point to the utilisation voltage at $690V_{AC}$. Site development costs for the TES system designs vary, depending on the scale of development and therefore the associated installation and labour costs.
- **Capital costs:** Capital costs includes costs to design, procure and install the TES system designs, including HRSGs and ancillary equipment. Ancillary equipment includes equipment required to support the TES such as substations, switchgear, circuit breakers, relays, protection systems, control systems, backup power systems, monitoring and communication equipment, protection and safety devices, distribution lines, transformers, and control rooms.
- **Operational costs:** Financial modelling assumed operational expenditure for the Project at 2% of capital costs, increasing with consumer price index (CPI) over the expected life of the asset of 30 years. The method to determining the operational costs was calculated based on OEM input regarding the requirements for the Project.
- **Contingency:** As TES is an emerging technology that carries more risk than mature technologies, a contingency of 30% of was assumed to the total capital cost estimate.

Incorporating the above cost, it is estimated that integrating TES into TIPS B will cost between $1B to $1.2B, inclusive of contingency.

9.1. Levelised cost of storage

The levelised cost of storage (LCOS) can be described as the total lifetime cost of the investment in an electricity storage technology divided by its cumulative delivered electricity. The Project calculated the LCOS for electricity. The Australian Energy Regulator (AER) formula to calculate LCOS was used and is presented below.

$$\mathrm{LCOS} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

The LCOS for the technologies was calculated to be between $220 to $320/MWh.

10. Risk analysis

10.1. Identifying risks

A key activity for this Project was to identify, evaluate and assess the potential risks. Risks associated with the Project were identified through a series of Risk Workshops facilitated using the AGL Fully Integrated Risk Management (FIRM) assessment matrix.

At this early stage in the Project, the aim of the workshops was to identify a longlist of fatal flaws and risks. Project risks were to be assessed, and mitigation strategies developed if the Project proceeded to Stage 2.

10.2. Risk assessment

Risks were identified and grouped into the following categories:

- **Design and technology:** Construction and operational phase risks concerning the TES technology and system design.
- **Engineering:** Technical and engineering risks including those arising from procurement and supply chain.
- **Integration:** Risks regarding integrating the TES to TIPS B.
- **Health and safety:** Construction and operational phase health and safety risks.
- **Environment and stakeholders:** Environmental and stakeholder impact risks.
- **Land availability:** Site risks concerning land availability.
- **Aviation:** Aviation related risks.
- **Other:** Risks that do not fit within the above categories.

10.3. Project and site-specific risks

Table 15 summarises project and site-specific risks. These 17 risks are not specific to any TES technology, but rather summarise general project and key site specific risks.

Table 15 Project and site specific risks

Risk no.	Risk description	Controls
Design and technology		
1.	**Insufficient storage capacity to run unit for required dispatchable eight hours:** There is a risk that the thermal storage will not hold the required capacity to run for eight hours and will have the consequence of not performing as required and a financial/commercial impact.	Ensure that a clear performance specification is developed. Manufacture a prototype and test storge capacity before committing to full scale manufacture / construction. Leverage pilot program performance outcome.
2.	**Bespoke construction:** There is a risk that bespoke design may cause project delays and a potential increase in project costs.	Deliver a pilot project of 5MW with internal stacking of blocks. Follow robust design processes.
Engineering		
3.	**Connection process:** There is a risk that the connection process may be more complicated than expected and cause delays.	Investigate possibilities for other ways to implement independent charging systems.
4.	**Asset age:** There is a risk that the age of the existing unit generators at TIPS B will impact performance reliability and the Project reliability	Work with OEMs to ensure asset age, capability and specifications inform performance reliability targets.

Risk no.	Risk description	Controls
	targets cannot be met.	
5.	**Cost of key resources:** There is a risk that because 500MW of 690VAC requires many transformers, land space and oil, it will increase project costs.	More efficient land use to be key consideration of future design and engineering solutions.
6.	**Supply-chain disruption:** There is a risk that delays and inability to source key supplies and materials are caused due to supply chain disruption and constraints, and that such constraints raise the costs for key Project materials.	Engage with multiple, large-scale suppliers. Use standard equipment where possible. Proactively manage long lead items.
Integration		
7.	**Site integration:** There is a risk that unforeseen integration issues emerge because TES technology is new, causing construction and commissioning delays.	Build a pilot plant to test the system at scale.
Health and safety		
8.	**New regulatory approvals:** There is a risk that the Project could lead to environmental licence amendments for TIPS, or a Major Hazard Facility categorisation, causing delays to Project completion.	Consult with the Environmental Protection Agency (EPA).
Environment and stakeholders		
9.	**Stakeholder management:** There is a risk of unmet internal and external stakeholder needs should appropriate effort not be given to stakeholder engagement including genuine consultation.	Engage early with internal and external stakeholders.

Risk no.	Risk description	Controls
Land availability		
10.	**Physical footprint:** There is a risk that because the TES technology and TIPs infrastructure is best co-located, that there is insufficient space for the design including ancillary plant and laydown area for the equipment required during construction.	Ensure that design post-prototype includes ancillary plant, and computer-aided design (CAD) model is created. Consideration given to efficient build when designating laydown area for equipment required during construction.
Other		
11.	**Changing energy market conditions:** There is a risk that changes in energy market conditions or government policy negatively impacts the potential value delivered by this application of the TES technology.	Monitor energy market and government policy, forecast future uptake of renewables, investigate other uses of the asset, industrial process heat, Frequency Control Ancillary Services (FCAS), Combined Heat and Power (CHP).
12.	**Specialist personnel availability:** There is a risk that the skills and expertise required to operate the retrofitted TIPS B is unavailable due to take up of employment opportunities elsewhere.	Develop and implement a workforce transition plan.

11. Key stakeholders

AGL understands the importance of early and continual stakeholder engagement for the successful delivery of any new project development. We take a tailored approach to community engagement, based on the needs of individual communities and projects.

Through various workshops and engagement throughout the Project, a broad range of stakeholders were identified. Table 16 provides the list of stakeholders who were grouped by government and regulatory bodies, workforce (including unions), site users, Torrens Island workforce, and the Traditional Owners.

Table 16 List of potential key stakeholders

Stakeholder
Government and regulatory agencies
• AEMO • ARENA • Department of Energy and Mining, South Australia Government • Department of Environment and Water, South Australian Government • Department of Trade and Investment, Planning Division, South Australian Government • Deputy Premier of South Australia and State Member for Port Adelaide • Generation Lessor Corporation • Honourable Tom Koutsantonis MP, Minister for Infrastructure and Transport, minister for Energy and Mining, South Australian Government • Port Adelaide Enfield Council • Port Adelaide Enfield Council elected official • SafeWork South Australia • Shadow Minister for Energy and Net Zero, Mining and Defence and Space Industries, South Australia • South Australian Environmental Protection Agency • The Honourable Mark Butler MP, Minister for Health and Aged Care, Commonwealth Government

Stakeholder
Workforce and associated organisations
• Australian Manufacturing Workers' Union • Australian Services Union • Australian Workers' Union • Communications, Electrical and Plumbing Union of Australia • Professionals Australia • TIPS employees
Torrens Island tenants
• Air Liquide • ElectraNet • Origin • SA Power Networks
Traditional owners
Local Kaurna representatives.

12. Carbon offset

The carbon offset of the proposed TES system designs was determined by measuring the average annual carbon produced each year across the four gas fired units at TIPS B, using the following method:

Determine the gas usage	1. Recorded gas usage for all of TIPS B, was averaged across the four generating units
Calculate the CO_2 production values	2. CO2 production values were estimated using the average that burning 1GJ of gas produces approximately 50kg of CO_2

The results of applying the above calculations are summarised in Table 17 which shows, integrating TES at TIPS B has the potential to reduce carbon emissions production by approximately 237,209 tonne per year.

Table 17 Carbon offset overview

Year	Gas Consumed (GJ)	CO_2 total (tonne)
2018	5,535,250	276,763
2019	5,333,000	266,650
2020	4,418,250	220,913
2021	3,690,250	184,513
4,744,187.50 **Average**	5,535,250	237,209

13. Lessons learnt

The Project hypothesised that, despite the low energy efficiency of conventional thermal power stations, integrating TES into an existing power station could leverage existing infrastructure, reducing the overall capital costs and support a commercially viable system.

While the Project found it was technically feasible to integrate TES technology into TIPS B, the following technical matters result in significant increase in costs, design complexities and development constraints, impacting the overall viability:

- Low RTE
- Unable to leverage all existing infrastructure
- Significant footprint required.

Further information on these matters is explained below.

13.1. Low round trip efficiency

The TES components of the system are highly efficient at stream production and both Kraftblock and MGA Thermal's system designs are expected to discharge approximately 99% of energy used in charging.

The different methods proposed by Kraftblock and MGA Thermal had varying impacts on the energy output, however the overall energy efficiency didn't differ too greatly. The open loop system for the heat transfer fluid (air) would result in losing heat in the exhaust air from the HRSG heat exchanges to the atmosphere. Whereas the closed loop cycle allows the heat transfer fluid (inert gas) from the HRSG heat exchanges to be recycled to the thermal storage medium. This difference in system design results in an HRSG efficiency variance of approximately 87% to 83%.

However, the heat loss that would occur during the steam turbine electricity generation process lowers the overall efficiency and therefore also the useable energy that is discharged to the grid.

As a result, the low RTE rates require the storage system designs to absorb (charge) and store a large amount of energy, increasing the scale of development and capital costs. To achieve the required dischargeable energy of 200MW for eight continuous hours, the TES must produce 1,600MW of energy, requiring the gross thermal storage volume of around 7,467MWh to 5,000MWh.

It was however evident that the TES offers a low carbon method to produce heat and are highly efficient in storing and discharging heat that could otherwise be beneficial to industrial sectors that use process heat. The maximum achievable output temperature of the heat transfer fluid from the TES influences the type of industrial users who may consider the TES technology. This varied from very high temperature (above 650°C), where applicable end users could include glass, alumina (calcination), iron and steel production to low temperature (150°C or below) that may be utilised by commercial heating, food and beverage and agriculture industries.

It should be noted that Project did not test the feasibility of utilising TES for industrial uses. However, the high energy efficiency of the TES, coupled with its low carbon potential to produce heat, indicates significant potential opportunities to investigate further the options for TES to be used as a power to heat application or from the use of waste heat.

13.2. Unable to leverage all major infrastructure

It is technically feasible to integrate TES technology into TIPS B and the system design approach to integrate Kraftblock and MGA Thermal didn't differ too greatly. However, significant modifications and additions to the existing equipment will be required.

The Project found the TES is unable to utilise the existing boilers at TIPS because the process by which the boilers absorb heat is not the same as that of the TES. The boilers largely transfer heat to the water through a radiative transfer process, with some conduction and convection. The heat coming out of the TES relies on conduction and convection to be transferred to the water in the HRSG. This means that if heat was extracted from the TES using the transfer fluid (e.g. air or inert gas) and placed into the boiler, the majority of this thermal energy would be lost, as it cannot be effectively transferred into the water in the boiler. As a result, integration requires installation of HRSGs to use the hot heat transfer fluid in the storage system to superheat steam and create the required temperature and pressure conditions for the operation of the steam turbine.

HRSGs are a significant equipment both in terms of size and cost and it was found that for each storage unit proposed, it would also require a HRSG to be installed.

Other major equipment required to be installed included a significant number of transformers and switch board to connect to the grid for thermal charging purposes.

13.3. Significant development footprint

Due to the low RTE, it is important to locate the TES and HRSGs near the generating units. This system design preference would reduce the distance the steam must travel from the HRSGs to the turbines and therefore minimises the amount of heat lost through the process. It would also be beneficial to locate the TES where the boilers are currently located as this would enable continuity of existing process flow.

The Project found the TES system designs could be installed on site at the Torrens Island Power Station, however the scale of these developments were significant requiring the installation of the storage systems, as well as multiple HRSGs and ancillary equipment. In total, including additional area as a contingency for potential unforeseen construction works, installation of the TES system would require a footprint size of around 18,330m^2 to 25,000m^2. To construct it at TIPS B, it will require the complete demolition and removal of all four boilers, despite the systems being designed to replace only one gas fired generation unit.

14. Conclusion

The Project evaluated the feasibility of integrating a TES asset at TIPS B and replacing the use of one 200MW gas-fired generation unit. The objectives of the Project were to:

- Investigate the technical feasibility of integrating a TES in an existing thermal power station
- Assess the potential of reducing emissions by implementing a clean industrial heat source
- Evaluate the commercial applicability of integrating a TES into the TIPS B
- Size a pilot plant and investigate how it would be implemented to test the co-generation (natural gas and TES) solution.

It was also a Project objective to identify other potential uses for clean industrial heat. A TES asset could be a heat source for electricity generation as well as industrial processes that need high-grade heat and want to decarbonise.

The Project assessed two OEMs, Kraftblock and MGA Thermal, testing the following long duration storage capabilities:

- Charge and store the equivalent of up to 1,600MWh of electrical energy as heat
- Discharge heat for eight continuous hours with steam parameters of 538°C at 16.3MPa.

Kraftblock technology provides a high-temperature energy storage system that stores energy in the form of heat using porous media. It consists of 85% recycled materials such as slag from the steel and glass industries with fireproof inorganic binder. Kraftblock use a sensible heat storage whereby there is no phase change in the materials when heat is added. Kraftblock TES remains in a solid state and fluctuates between high temperature (charged) and lower temperatures (discharged).

MGA Thermal technology involves a set of blocks stacked in an insulated enclosure that consist of a metallic material dispersed as particles within a matrix material that keeps them solid while a metallic material is dispersed as particles. This matrix material is highly conductive and rapidly distributes heat, keeping the particles in place as they melt when heat energy is absorbed. MGA blocks store massive thermal energy through the solid-liquid phase change, which is released as they cool and the particles solidify.

Technologies assessed

The Kraftblock and MGA Thermal technologies and methodologies differ but offer the same outcome. The key difference is in the method by which energy is stored. Kraftblock uses a sensible storage medium, which is comprised of offcuts from industries like steel and glass. This means there is no phase change in the materials when heat is added. MGA Thermal uses a storage medium which is comprised of a metal alloy suspended within a matrix material. The metal alloy melts as heat is absorbed. The matrix material has a higher melting temperature than the internal metal alloy, so the heat can be stored within a solid matrix. The phase change allows for the metal alloy to exist at a higher state of energy.

Integration

To replace one gas-fired 200MW generation unit, Kraftblock and MGA Thermal's system designs were tested for their capability to provide long duration storage of 1,600MWh electrical energy over eight continuous hours and to discharge at steam parameters of 538°C at 16.3Mpa.

The Project found it was technically feasible to integrate TES into an existing thermal power station, however significant modification to the existing equipment is required.

Major infrastructure required to connect the grid to the TES include:

- Two 275kV connection points, each capable of importing 250MW of electricity
- Two large 250MVA three-winding transformers to step down the 275kV transmission voltage to 33kV
- A series of medium sized two-winding transformers to further reduce the voltage from 33kV to the 690V_{AC} utilisation voltage required by the heaters, fans and house load.

A key finding was the inability of the TES to be integrated with the existing boilers. The boilers at TIPS B are specifically designed to combust gas in a furnace and absorb heat through a radiation, conduction and convection heat transfer process. Heat transfer from the TES occurs at significantly lower temperatures without any combustion process, therefore only allowing convective heat transfer to occur. Consequently, the technology would require installing HRSGs, which are specifically designed to absorb heat from the TES and transfer it to the water/steam at the required temperature and pressure to drive the turbine.

Technical parameters

The actual heat storage of the TES system is highly efficient at steam production and both Kraftblock and MGA Thermal's storage systems are expected to discharge approximately 99% of energy used in charging. However, a significant amount of energy is lost during the electricity generation processes, causing significantly lower overall usable energy discharge to the grid.

Kraftblock's steam production process design has an inherently lower efficiency than the MGA Thermal process (around 83% compared to 87% respectively). The reason for this is the Kraftblock system used an open loop cycle for steam production, where the heat transfer fluid (air) is exhausted to the atmosphere after passing through the HRSG heat exchanger. The MGA Thermal process used a closed loop cycle with inert gas as the heat transfer fluid. The exhaust from the HRSG is recycled to the thermal storage block, and hence the heat in the exhaust flow is re-captured rather than lost to atmosphere.

The open loop cycle was adopted in Kraftblock's method as it allowed a greater depth of discharge for the TES, would lower the volume of thermal storage medium required and therefore lower capital costs. However, this reduction was offset by the efficiency loss and as a result a lower volume of storage medium was not realised.

Due to the significantly low RTE, the TES storage systems must charge and store a large amount of energy. To produce the required 200MW for eight continuous hours, the TES must produce the equivalent of 1,600MWh of electrical energy as heat, requiring the gross thermal storage volume of 7,467MWh (Kraftblock) and 5,000MWh (MGA Thermal). Of this, the useable thermal energy storage volume ranged from 5,178MWh to 3,636MWh.

Site considerations

The Project found it was important to locate the TES and HRSGs in close proximity to the generating units to reduce the distance the steam must travel between equipment and thereby minimise heat loss. The ideal location to achieve this on TIPS B is to install the TES and HRSG directly behind the generation units where the power station boilers are currently located as this will enable continuity of existing process flow and minimise heat loss.

Both Kraftblock and MGA Thermal's design could suitably be installed on site however the scale of these developments is significant. It is estimated to install either system designs, inclusive of TES, HRSG, associated equipment and additional area as a contingency for potential unforeseen construction works will require a footprint size around 18,330m^2 to 25,000m^2. This will require the complete demolition and removal of all four boilers at TIPS B, despite the TES systems being designed to replace only one gas fired generation unit.

Personnel

Both OEMs estimated the resources required to construct and operate the integrated TES facility. These are preliminary and indicative estimates only and would require revision in future planning stages. Kraftblock estimated approximately 260 FTE would be required for the construction phase, and eight during the operational phase. MGA Thermal estimated approximately 286 FTE would be required during the construction phase and five during operations.

Industry

TES offers a low carbon method for heat production and are highly efficient in storing and discharging heat that could otherwise be beneficial to industrial sectors that use process heat in their operations.

Several industries could benefit from TES technology. These industries are segmented by the heat temperature required for their purposes. Due to the flexibility of TES, it is likely that the technology would be able to replace fossil fuel usage in a number of industries. From a grid stability perspective, industries creating electrical load during periods of high supply would be beneficial with the increasing penetration of renewables in the NEM.

Australian sourcing analysis

Kraftblock and MGA Thermal indicated they would source the equipment and materials required domestically, creating local opportunities including manufacturing supply chain and workforce development.

Commercial

While the Project hypothesised that leveraging existing TIPS infrastructure could reduce capital costs, this was not the case. As not all the existing infrastructure at TIPS B could be utilised, integrating a TES system design would incur significant plant upgrade costs, in addition to capital costs.

It is estimated that integrating TES to TIPS B will cost between $1B to $1.2B and will involve the following costs:

- Site development costs, including the construction of the TES, HRSGs and transformer and installation of electrical works
- Capital costs including costs to design, procure and install the TES system designs, including HRSGs and ancillary equipment
- Operational costs including the cost to operate and maintain the integrated TES facility
- Contingency costs, assuming 30% of the total capital costs.

Risk analysis

General project and site-specific risks were identified and included:

- **Technology risk –** The TES technologies are relatively young and carry inherent maturity risk.
- **Commercial risk –** The preliminary cost estimates and low RTE indicate the Project would need to overcome significant challenges to become commercially viable.

- **Land availability –** A substantial parcel of land is required to accommodate the large amount of TES required. With the desired land at Torrens Island constrained, further design refinements and optimisations would be required during detailed engineering stages.
- **Regulation –** As a new asset type, the regulation requirements and associated approvals are unknown raising a significant amount of risk to any deployment, pilot or full-scale project.

Key stakeholders

Potential key stakeholder groups were identified as follows:

- Government and regulatory bodies
- TIPS employees
- Other site users such as Air Liquide
- Other companies with business operations on Torrens Island
- Traditional owners.

Carbon offset

A carbon offset methodology was used to estimate a CO_2 emission reduction of 237,209 tonne per year if the Project were to proceed. While any emission reduction is favourable, the reduction that could be achieved by the Project does not outweigh the capital expenditure required and RTE achieved.

Conclusion

The Project hypothesised that, despite the low energy efficiency of thermal power stations, integrating TES into an existing power station could leverage existing infrastructure, reducing the overall capital costs and support a commercially viable system.

While the Project found it would be technically feasible to integrate TES technology into TIPS B, the following technical matters results in significant increase in costs, design complexities and development constraints, impacting the overall commercial viability of the Project:

- Low RTE requiring the storage systems to store a significant volume of energy
- Unable to leverage all the existing infrastructure at the power station, and in particular, the need to replace the boilers with HRSGs
- Significant scale of development requiring a footprint size of around 18,330m^2 to 25,000m^2 to install.

It is however evident that the TES offer a low carbon method to producing heat and are highly efficient in storing and discharging heat that would otherwise be beneficial to the industrial sector that use process heat.

There are a broad range of industries that could benefit from this technology. It was found that the maximum achievable output temperature of the heat transfer fluid from the TES influences the type of industrial users who may consider the technology. Potential industries include:

Very high temperature (above 650°C):

- Alumina (calcination)
- Iron and steel production
- Ammonia and other chemicals (steam reforming)
- Cement and lime products
- Glass production

Medium temperature (150 - 250°C):

- Food and beverage
- Oil and gas extraction
- Petroleum refining
- Alumina (digestion)

High temperature (250 – 650°C):

- Food and beverage
- Petroleum refining
- Pulp and paper
- Wood and wood products
- Textiles and clothing
- Steam (Rankine Cycle) based electricity generation
- Green hydrogen generation (solid oxide electrolysis)
- Chemical manufacturing

Low temperature (0-150°C):

- Commercial heating
- Food and beverage
- Agriculture.

The Project did not investigate the feasibility of integrating TES into the operations of any of the above industries however the high energy efficiency of the TES, coupled with the low carbon option to produce heat, indicates significant potential opportunities to investigate the options for TES to be used as a power to heat application or from the use of waste heat.

Appendix 1 TIPS B Heat Balance Diagram at 200MW

Appendix 2 TES Process Flow (including heat and mass balance)

Appendix 3 Single line diagram

Appendix 4 Kraftblock Major Equipment List

Appendix 5 MGA Thermal Major Equipment List