THE EMERGING ROLE OF THERMAL ENERGY STORAGE IN DECARBONISING INDUSTRIAL PROCESS HEAT

17 JUNE 2026

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Australian National University

Acknowledgement of country

We acknowledge and celebrate the First Australians on whose traditional land we meet, the Ngunnawal and Ngambri people and pay our respect to elders past and present.

[Tjabal Indigenous Higher Education Centre | Australian National University (anu.edu.au)]

[Bandalang Studio | The homepage for the Indigenous Engineering Design Studio in the School of Engineering. (anu.edu.au)]

Outline

Overview of how TES can be integrated with industrial processes

- Heat use by industry
- Options for decarbonised heat supply, and why choose TES?
- Classes of thermal energy storage systems
- Sensible heat storage
  - Hot water
  - Molten salt
  - Particle-based
  - Packed-bed
- Latent heat storage
- Thermochemical storage
- System components (heaters) and thermal integration with processes
- Case studies: examples of deployed TES systems

The HILT CRC program

- What it is, who are the partners
- Key activities
- Some research highights

Case study: the modified hot blast stove for retrofit to alumina calcination

- Introduction to alumina calcination
- How to integrate TES
- The modified HBS concept
- Integrated system modelling and TEA
- Design improvements

Concluding remarks

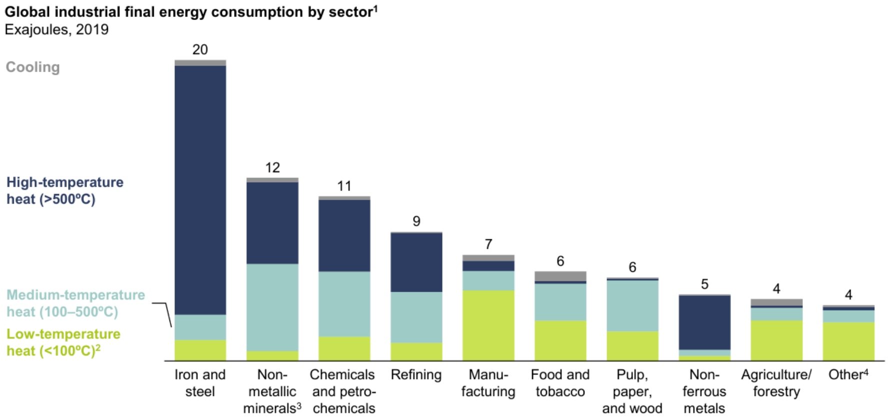
- CST vs PV/wind or grid electricity with TES

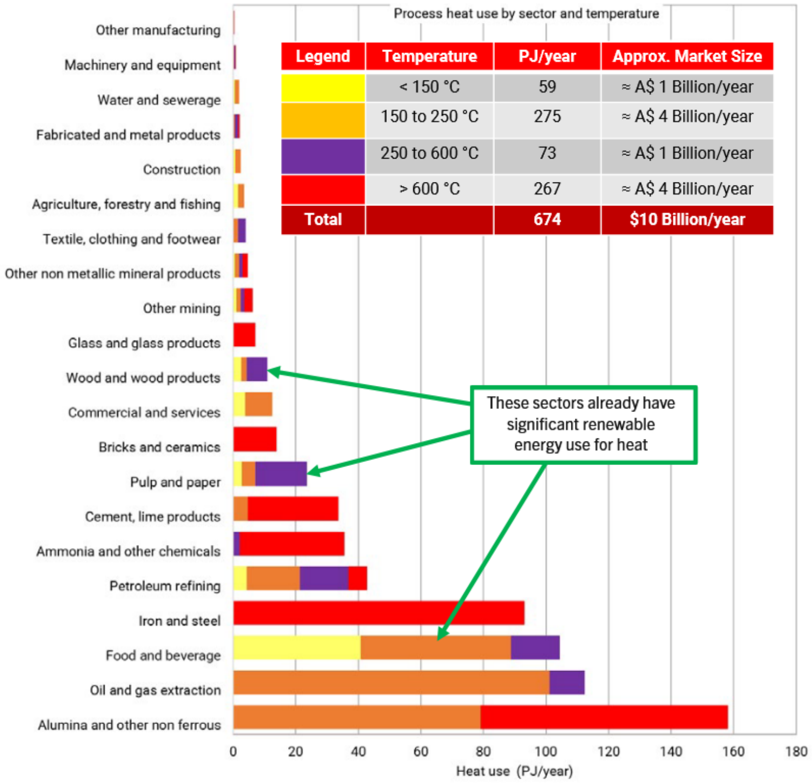
Heat use by industry

Australia

- Alumina refineries are the largest users of heat in Australia
- Globally, the iron and steel sector dominates, largely due to use of coking coal to heat iron ore in blast furnaces.
- Heat needs are across a wide range of temperatures, depending on the industrial process

Global



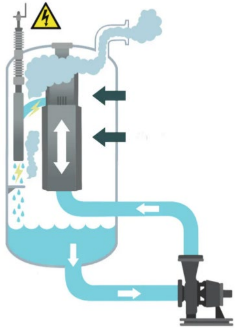


Legend	Temperature	PJ/year	Approx. Market Size
	< 150 °C	59	≈ A$ 1 Billion/year
	150 to 250 °C	275	≈ A$ 4 Billion/year
	250 to 600 °C	73	≈ A$ 1 Billion/year
	> 600 °C	267	≈ A$ 4 Billion/year
Total		674	$10 Billion/year

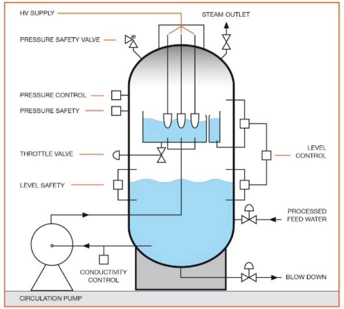
Sources: LDES, McKinsey & Company, 2022, ITP Thermal, 2025

Options for decarbonised heat supply

- Electric boilers
- Electric heaters
- Mechanical vapour recompression
- Heat pumps
- Thermal energy storage (TES)
  - Electrically heated
  - Concentrating solar thermal
  - Waste heat recovery



Jet-type electrode boiler

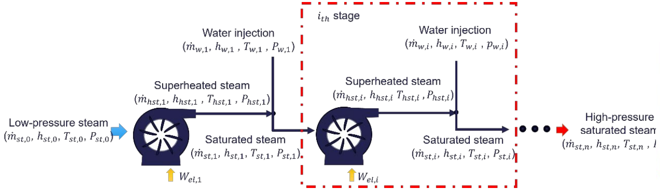


Immersion-type electrode boiler

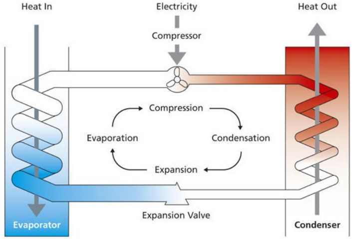
Resistance boiler

Why choose TES?

- **Lower operating costs by charging during low price periods** on the wholesale electricity market and using storage to ride through high price periods
- **Buffer for variable renewable sources of energy**, like photovoltaic (PV) solar or wind, minimising curtailment
- **Buffer in cases of highly variable demand-side energy use** (e.g. abattoirs)



Schematic diagram of a n-stage MVR system

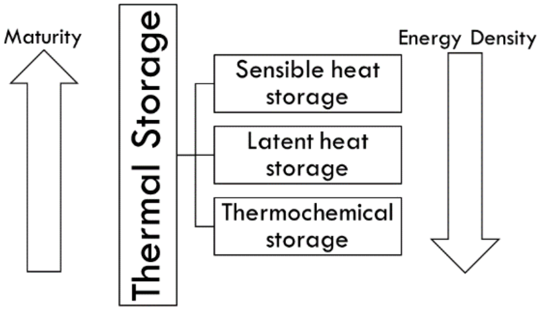


Vapour compression heat pump cycle

Sources: CTI, PARAT, AB&Co, Bosch, Heat pumps UK, IEA 2023, Yang, Jafari and Arjomandi 2024

Classes of thermal energy storage systems

Sensible heat storage	Latent heat storage	Thermochemical storage
• Involves storing heat in a material by changing its temperature	• Involves making a material change physical phase, usually from solid to liquid and vice versa	• Involves storing energy by driving a reversible chemical reaction



Sources: Kuravi et al., 2013

Hot Water TES

- The **simplest and most widely deployed** form of sensible heat storage is hot water at up to 90°C
- **Heat pump installations often include hot water storage** to provide buffering in applications including breweries, dairies, food production, etc.
- Larger scale hot water storage is also feasible, with district heating systems storing hot water at up to 90°C in huge pits to provide seasonal storage

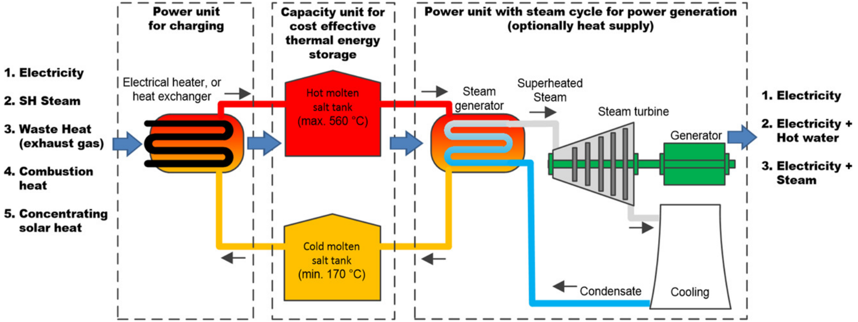
Hot water storage coupled to a heat pump system at the Nestle confectionery plant in Halifax, UK

Water pit thermal energy storage system in Høje Taastrup

Sources: Pearson, Sifnaios and Jensen

Molten salt TES

- A **commercially mature** sensible heat storage technology is 'two tank' molten salt storage, which uses a nitrate salt mixture
- This mode of operation is **efficient in its use of the storage media**, as virtually all of the salt is pumped between the hot and cold tanks
- **Electrically heated molten salt systems are now being deployed** at large scale.
- However, **for smaller scale industrial applications, operational complexity may be a barrier**, particularly managing the risk of salt freezing.



Typical configuration used for power generation

Two-tank molten salt storage at the Noor CSP plant, Morocco. Photo: Coventry

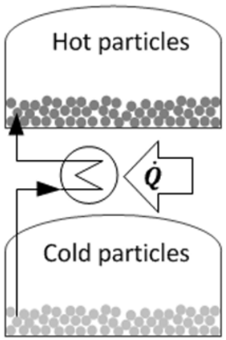
Project	Capacity	Status
Jinta Zhongguang 1 00MW CSP + 600MW PV Project	20 MW	Operating
SPIC CSP + PV Integrated Project	20 MW	Operating
Qinghai-Hanan DC Transmission Project	3×35 MW	Operating
Luneng Fukang Multi-energy Integration Project	20 MW	Construction
Jixi Base Lugu DC Baicheng 100MW CSP Project	20 MW	Construction
Delingha 2000 MW Multi-energy Integration Project	4×25 MW	Construction
Luneng Haixi Golmud 50 MW CSP Project	25 MW	Construction

Examples of molten salt electric heater deployment by Cosin Solar

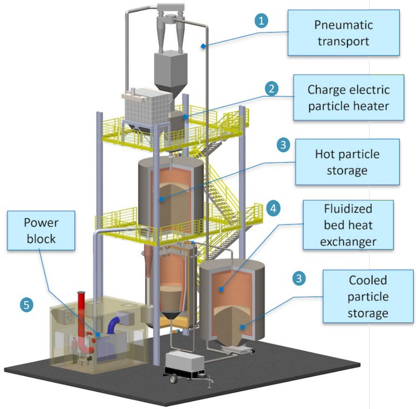
Sources: Bauer, Odenthal and Bonk, 2021, Cosin Solar (personal communication)

Particle-based TES

- **Solid storage materials are stable at higher temperatures** than liquid storage materials, and therefore of interest for medium- and high-temperature TES.
- Particles have some special properties. Beds of **particles can be 'fluidised' by injection of air, behaving more like liquids than solids** in terms of heat transfer and transport.
- However, heat transfer rates are not as high, and new technologies are still being developed for heat exchange to particle systems, hence **the technology is less mature**



Two-tank storage with particles



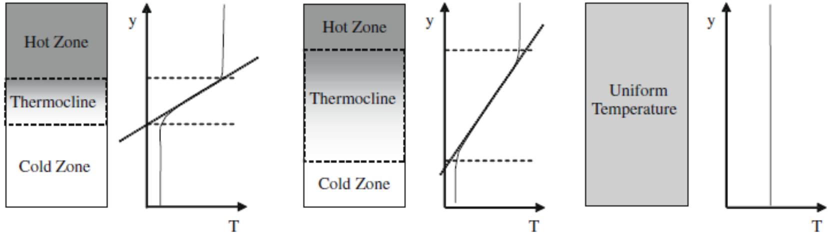
Particle storage concept developed by NLR

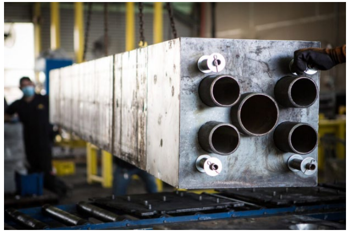
Magaldi's fluidised bed TES system (single tank)

Sources: Kraemer, Magaldi, Bauer, 2021

Packed bed TES

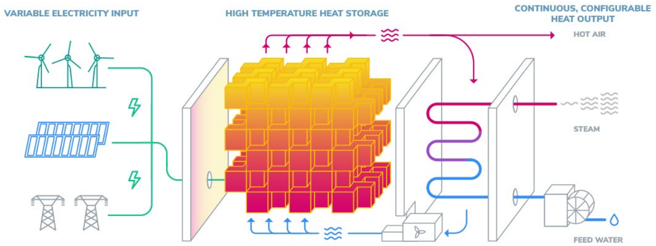
- Packed bed TES is a class of sensible energy storage system consisting of a **packed bed of solid storage materials through which a heat transfer fluid is circulated.**
- Many recent start-up companies use packed bed TES technology because:
    - It is **relatively simple to operate**, e.g. the storage material is static
    - It can **be modularised relatively easily**
- One challenge is that it is **difficult to utilise all the storage material effectively** due to thermal gradients, particularly where heat transfer properties of the fluid are poor (e.g. air)





Brenmiller, storage in crushed rock, electrical or process fluid charging, water/steam discharging

Graphite Energy, storage in graphite, radiative electric charging, water/steam discharging

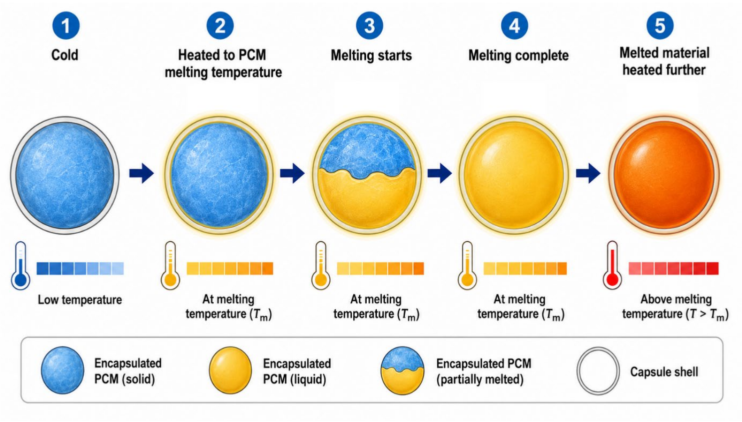


Rondo, storage in alumina-silicate ceramic bricks, radiative electric charging, air discharging

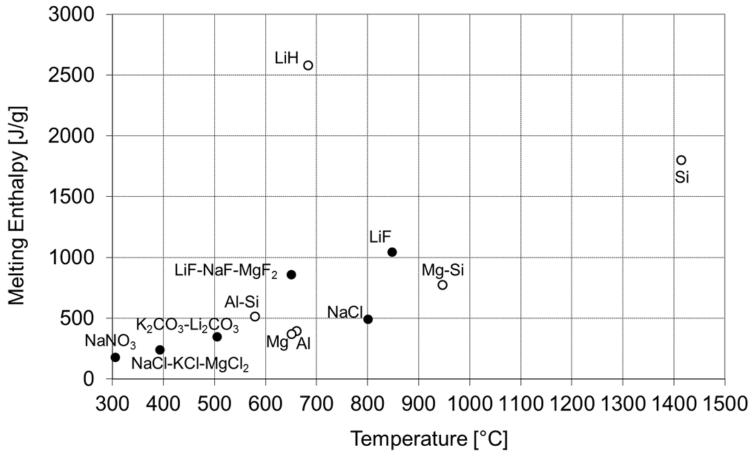
Sources: Rondo, Brenmiller, Graphite Energy, Haller et al., 2009,

Latent heat storage

- Latent heat storage offers **higher energy density compared to sensible heat storage**
- **1414 Degrees :** the SiBox storage technology is capable of delivering hot air at 900°C using Si-based alloys
- **MGA Thermal:** technology based on a 'miscibility gap alloy' i.e. a solid graphite matrix containing aluminium alloy particles (which melts at 577°C).
- With these two companies as notable exceptions, in general (despite much R&D) **PCM technology has been slow to progress commercially.**



SiBricks (left) and MGA blocks (right) from 1414 Degrees and MGA thermal, respectively



Sources: Purohit and Sistla, 2021, 1414 Degrees, MGA Thermal, Bauer, 2021

Thermochemical storage

- Thermochemical storage has both **high energy density**, and the potential **to deliver energy at very high temperature** for heavy industry applications
- To date **complexity and cost have been barriers to testing and deployment beyond laboratory and small demonstration scale.**
- One example of current commercial development is **Tempo Energy,** who are using a proprietary mixed metal oxide (composition not revealed) capable of delivering heat between 900-1450°C

Physical phases of reaction	Material Group	Material	T_r (1 bar) [°C]	$\Delta h_{r,educt}$ [kJ/mol]
Solid-gas	Hydroxides	$Ca(OH)_2 \leftrightarrow CaO + H_2O$	505	104
Solid-gas	Ammonium salt	$NH_4HSO_4 \leftrightarrow NH_3 + H_2 + SO_3$	467	337
Solid-gas	Salt hydrates	$MgSO_4 \cdot 7H_2O \leftrightarrow MgSO_4 + 7H_2O$	122	411
		$CaCl_2 \cdot 2H_2O \leftrightarrow CaCl_2 \cdot H_2O + H_2O$	174	48
		$CuSO_4 \cdot 5H_2O \leftrightarrow CuSO_4 \cdot H_2O + 4H_2O$	104	226
		$CuSO4 \cdot H_2O \leftrightarrow CuSO_4 + H_2O$	205	73
Solid-gas	Peroxide salts	$BaO_2 \leftrightarrow BaO + ½O_2$	782	75
		$KO_2 \leftrightarrow ½ K_2O + ¾ O_2$	668	101
Solid-gas	Metal oxides	$6 Mn_2O_3 \leftrightarrow 4 Mn_3O_4 + O_2$	960	32
		$2 Co_3O_4 \leftrightarrow 6 CoO + O_2$	900	200
Solid-gas	Carbonates	$CaCO_3 \leftrightarrow CaO + CO_2$	896	167
		$BaCO_3 \leftrightarrow BaO + CO_2$	1497	212
Solid-gas	Metal hydrides	$MgH_2 \leftrightarrow Mg + H_2$	293	79
		$Mg_2NiH_4 \leftrightarrow Mg_2Ni + 2H_2$	253	128
Gas-gas		$NH_3 \leftrightarrow ½N_2 + 1.5H_2$	195	49
		$CH_4 + H_2O \leftrightarrow CO + 3H_2$	687	205
		$CH_4 + CO_2 \leftrightarrow 2CO + 2H_2$	687	247
Hybrid cycles	Sulphur cycle	$\underline{\mathbf{H_2SO_4}} \leftrightarrow SO_3 + H_2O$ $SO_3 \leftrightarrow SO_2 + ½O_2$ $SO_2 + ⅔H_2O \rightarrow ⅔H_2SO_4 + ⅓\underline{\mathbf{S}}$ $S + O_2 \rightarrow SO_2$	170 400 140 1250	132 99 55 297

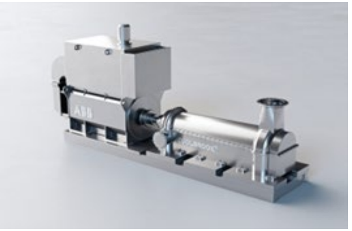
Sources: Bayon et al., 2021, Edwards and Materić, 2012, Bauer, 2021, Tempo Energy

Charging – electrical heaters

- Industrial heat market dominate by LV heaters
- **MV heaters are in demand by large-scale users of heat**, to minimise transformer cost/space
- **New technologies are being developed which may be very beneficial for TES** systems including inductive heaters and turbomachinery

Category	Heating principle	Example vendors	Materials used	Temp. limit	Integration with TES
Insulated resistance heaters – gas heating	Resistive heating in sheathed elements	Vulcanic, SAN Electro Heat	Metal sheath about metallic resistive wire (e.g. NiCr), packed powder insulation (e.g. MgO, BN)	<750°C (LV) <600°C (MV)	Internal or external heating, through radiation conduction or convection
Insulated resistance heaters – fluid heating	Resistive heating in sheathed elements	HC Thermal, Cosin Solar	Metal sheath about metallic resistive wire (e.g. NiCr)	<750°C (LV) <600°C (MV)	Convective external heating of a heat transfer fluid, through immersion in thermal oil or molten salt
Non-insulated resistance heaters	Bare wire, coil, or rod resistive element	Storworks, Rondo, E2S, Antora	FeCrAl alloy coils/wires, stainless steel	~900-1300°C (MV) <2400°C (LV)	Typically integrated into the TES system, combined radiative/convective heating
Conductive ceramics or metal oxides	Direct resistance heating through conductive materials	Electrified Thermal Solutions. Tempo Energy	Semiconductor-doped refractory bricks, mixed metal oxides	~1500-1800°C	Current passed directly through the TES medium to do the heating
Induction heaters	Induction	Siemens Energy	Electrically conductive tube (material not specified) containing heat transfer fluid.	~700-1000°C	External fluid heater (e.g. molten salt or oil)
Turbomachinery	Supersonic gas friction heating	Coolbrook, Siemens Energy	No resistive elements; uses kinetic heating	~1000-1400°C	External gas heater

Insulated resistance heater bank for air heating (Source: SAN Electro Heat)

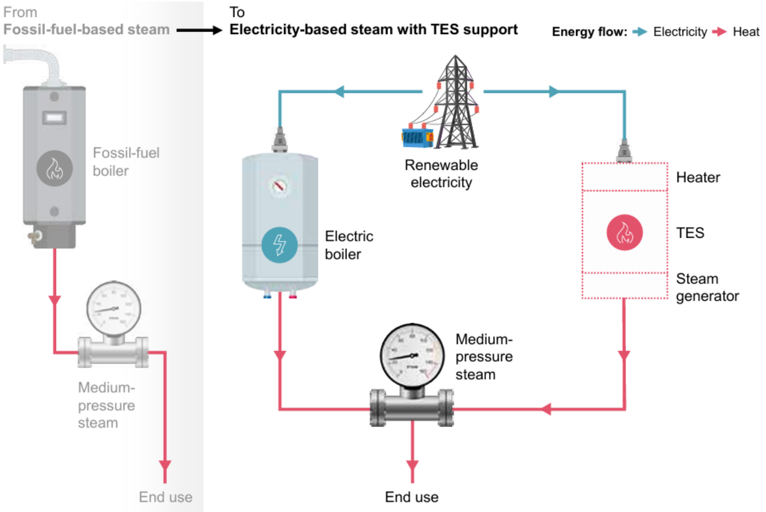


Turbomachinery heater (Source: Coolbrook)

Source: ANU/South32 study / HILT CRC.

Discharging – thermal integration with processes

- **Steam networks** are among the most straightforward and widely applicable integration pathways for TES.
- **Other process rely on hot air** e.g. drying, calcination, roasting, curing, and thermal treatment.
- Many packed bed TES systems provide hot air, but could also **be a preheate**r upstream of a conventional flow heater, **or the final stage of the heating** process after it.



Integration of TES into a steam network

[14]*Source: LDES, McKinsey & Company*

Case study 1 – Graphite Energy / Mars Petcare

- Graphite Energy TES unit supplies steam to the Mars Petcare manufacturing facility in Wodonga
- The 5 MWh unit uses resistance heaters to convert low-cost grid electricity into heat, which is stored at temperature up to ~700°C
- Water passed through tubes in the hot graphite absorbs heat and is converted to superheated steam at approximately 150-200°C
- There will be an 18 MW CST system (parabolic trough) installed in parallel to the TES in the next phase of the project.

Graphite Energy Green Steam™ system at Mars Petcare Wodonga.

Sources: ABC News, Mars, Bowler

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Case study 2 – MGA Thermal Pilot plant

- In 2025, MGA Thermal commissioned a pilot-scale TES system at Tomago, NSW, based on their miscibility gap alloy technology
- The facility delivers steam at conditions designed to replicate operational requirements of industries including alumina refining, chemicals processing and large-scale manufacturing
- The pilot has electrical charging and thermal discharging capacity both of 500kW, and storage capacity of 5 MWh_{th}

Sources: MGA Thermal

Case Study 3 – Kyoto Heatcube / KALL Ingredients

- In Oct 2025, Kyoto commissioned a TES system to supply steam to KALL Ingredients' corn processing facility in Tiszapüspöki, Hungary
- The system is a multi-tank molten salt technology called Heatcube
- Storage capacity is 56 MWh_{th}. It is charged electrically with 10 MW_e capacity, and supplies steam at capacity of 7 MW_{th}
- The system was delivered under a long-term Heat-as-a-Service model

Sources: Kyoto Group

Case Study 4 – Rondo / Holmes Western Oil

- In Oct 2025, Rondo started operating its first large-scale thermal battery, a 100 MWh system at the Holmes Western Oil Corporation facility in California
- Rondo's Heat Battery converts electricity into stored thermal energy using high-temperature refractory bricks
- A key enabler of the project was Holmes Western's ability to self-supply renewable electricity. The company owns sufficient land adjacent to its facility to operate on-site solar photovoltaic generation in an islanded, behind-the-meter configuration, avoiding exposure to retail tariffs.

Sources: Canary Media, California Air Resources Board, Rondo

Case Study 5 –Jinta Zhongguang hybrid PV/CSP

- In 2025, Cosin Solar's Jinta Zhongguang 100 MW CSP + 600 MW PV project demonstrated integration of molten salt thermal energy storage with both solar thermal and electrically driven charging
- The plant is equipped with a 20 MW molten-salt electric heating system operating at 6.3kV, enabling electricity-to-heat conversion directly into the molten salt inventory
- During periods where there is more PV than can be exported, the heater takes excess electricity, storing it in molten salt tanks for conversion back to electricity at a later time via the 100 MW steam turbine system.

Cosin Solar's 6.3 kV high-temperature molten salt heater (Source: unpublished direct communication with Cosin).

Sources: Cosin Solar website

Case Study 6 – Eco-Tech Ceram waste heat recovery

- Eco-Tech Ceram has deployed their 1.3 MWh_{th} ceramic storage technology to recover waste heat from a firing kiln, and supply it to adjacent clay product dryers
- Waste heat sourced at 500°C from the kiln exhaust and charges the ceramic storage bed.
- Heat is discharged from storage via the air to the dryers.

Sources:Py-Renaudie

Case Study 7 – Antora Energy / Big Stone Project

- Located in South Dakota, Project Big Stone supplies 50 MW steam to a large bioethanol production site
- The technology is a modular system based on graphite blocks, operating at very high temperature.
- Big Stone deploys more than 200 units, with total storage capacity 5 GWh
- Antora reports zero capital investment from the energy offtaker. The project is structured around a long-term heat offtake agreement with third-party project financing, rather than direct customer ownership.

Antora Energy

WHO WE ARE – HILT CRC

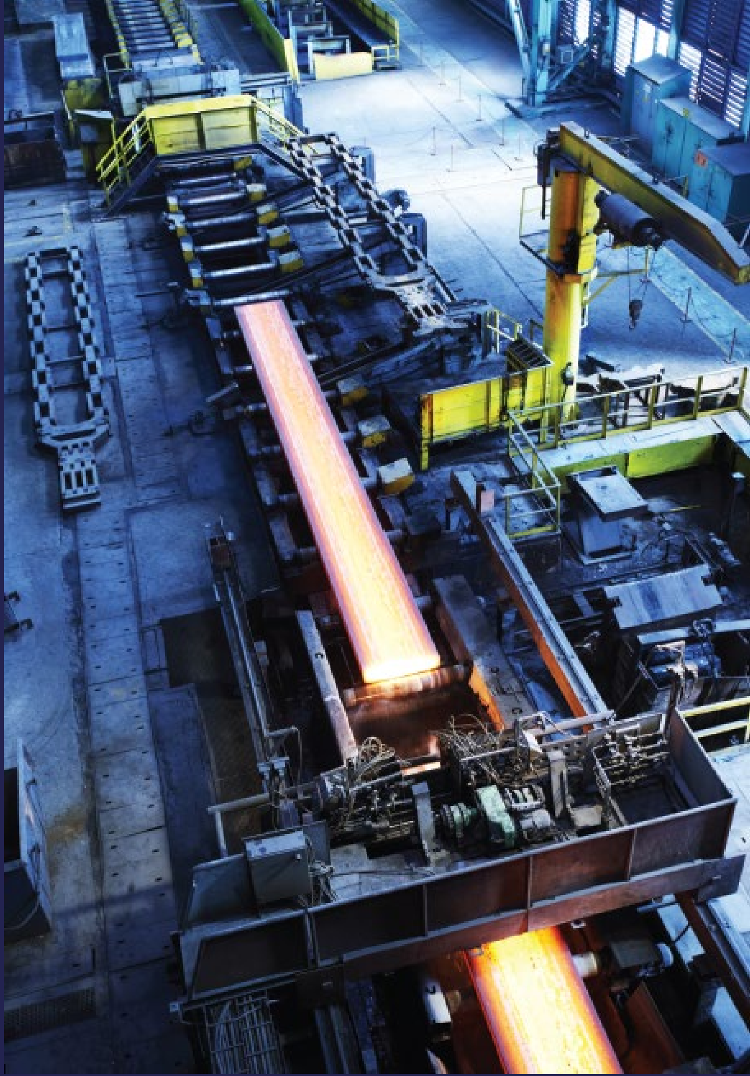
A collaborative research centre established in 2021 with total funding of AUD$200M.

Our mission: To accelerate and de-risk decarbonisation for heavy industry.

We do this by linking industry, research and governments on local, national and international scales.

Our strategic outcomes are:

- Research with impact
- Collaborative ecosystem
- Trusted voice
- Upskilled workforce



AN INTERNATIONAL EFFORT LED FROM AUSTRALIA

PILBARA

The world's biggest iron ore region, with plans to harness its outstanding renewable energy resources for additional, value-added exports.

Fortescue, Hancock Iron Ore, BHP, Rio Tinto

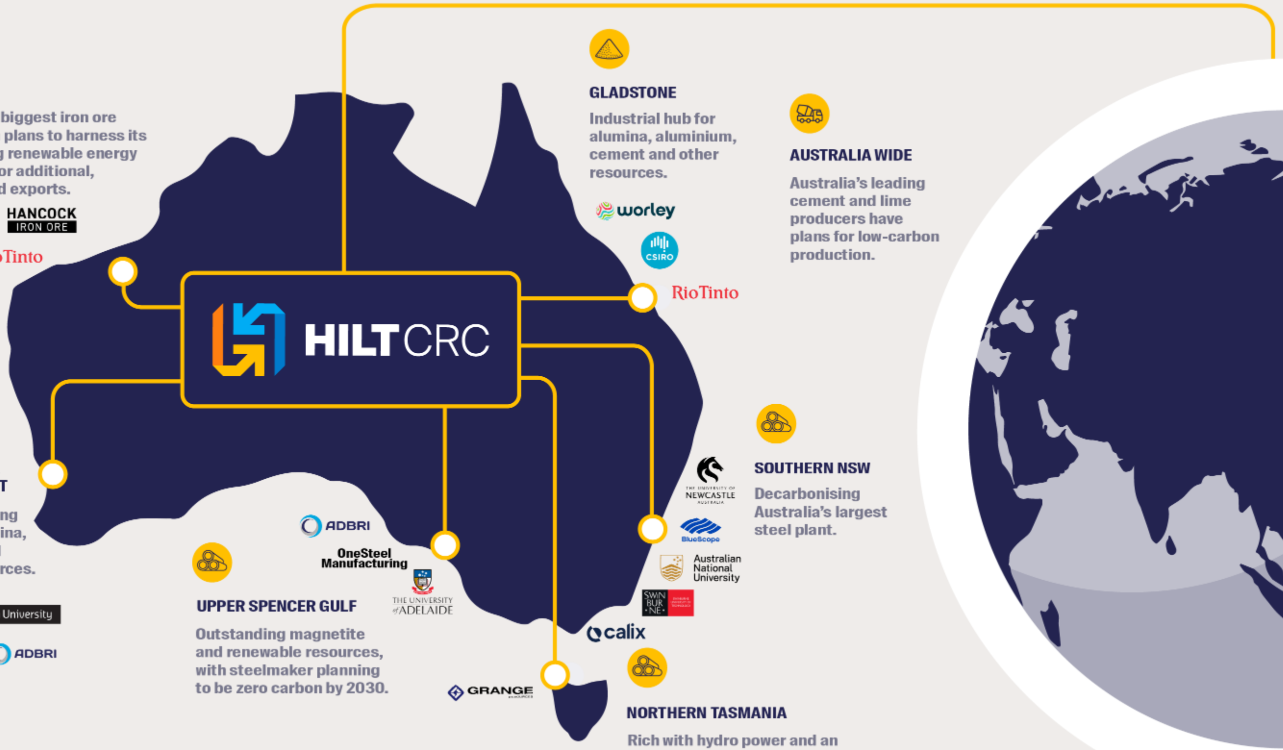
GLADSTONE

Industrial hub for alumina, aluminium, cement and other resources.

Worley, CSIRO, Rio Tinto

AUSTRALIA WIDE

Australia's leading cement and lime producers have plans for low-carbon production.



KWINANA & SOUTH WEST

World-leading hub of alumina, cement and other resources.

Curtin University, South32, Adbri

UPPER SPENCER GULF

Outstanding magnetite and renewable resources, with steelmaker planning to be zero carbon by 2030.

Adbri, OneSteel Manufacturing, The University of Adelaide, Grange Resources

SOUTHERN NSW

Decarbonising Australia's largest steel plant.

The University of Newcastle Australia, BlueScope, Australian National University, Swinburne University of Technology, Calix

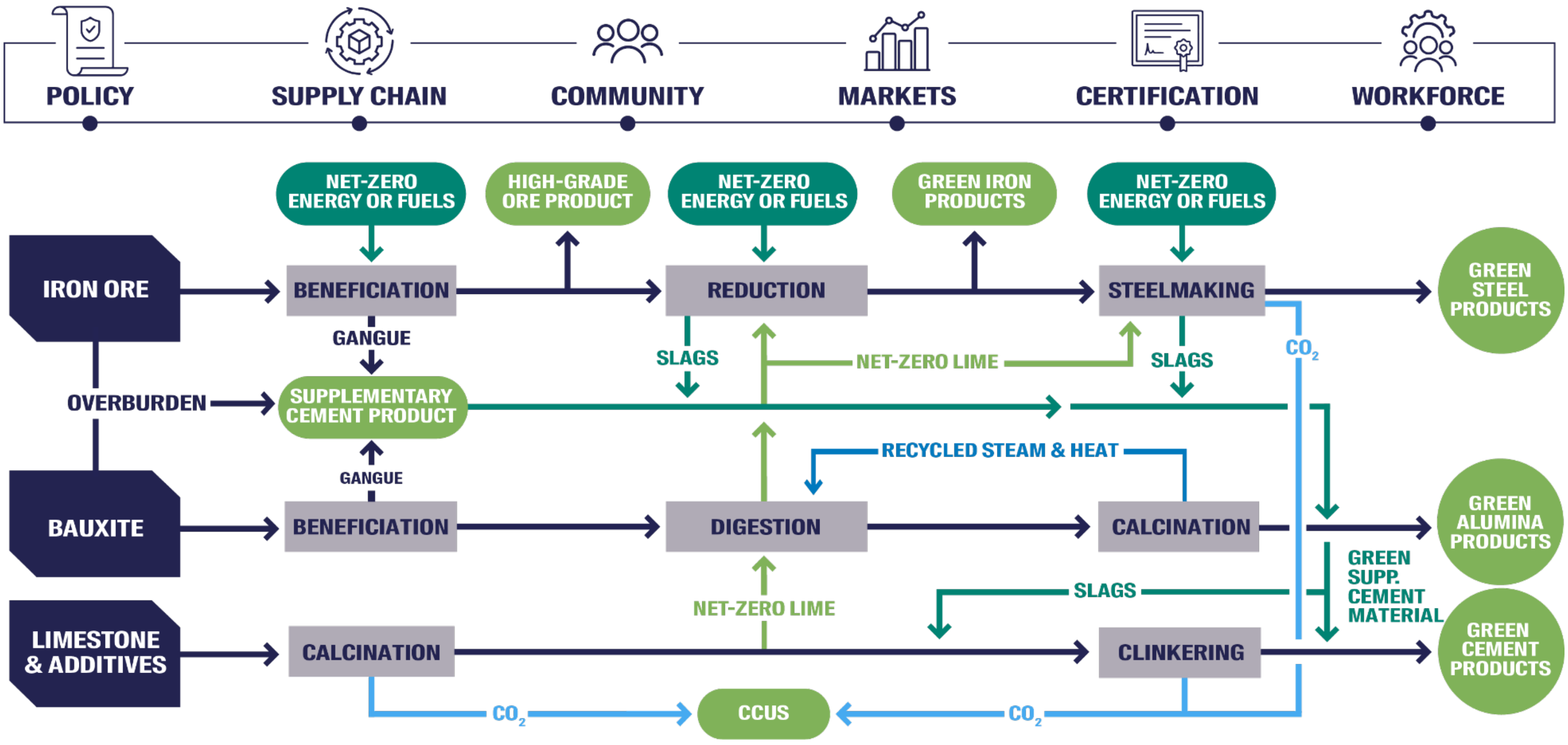
NORTHERN TASMANIA

Rich with hydro power and an iron pellet exporter, the region has plans for hydrogen.

Mission Innovation Net-Zero Industries Mission, UNIDO, worldsteel Association, IRENA, Hydro, World Economic Forum, iea, EGA Emirates Global Aluminium, POSCO Holdings, Magaldi Dependable technologies, Mitsubishi Heavy Industries Australia, Primetals Technologies, Arizona State University, Victoria University of Wellington Te Herenga Waka, DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center, Sandia National Laboratories, International Aluminium, Sumitomo SHI FW, IDRIC, DICMaPI, UC University of Canterbury, Heliós

Iron & Steel | Alumina | Cement & Lime

PATHWAYS TO DECARBONISE HEAVY INDUSTRY



KEY RESEARCH HIGHLIGHTS

RP1.015
Hydrogen direct flash reduction

Up to 95% metallisation for hematite–goethite ores demonstrated in Calix's Zesty™ reactor. Project insights helped inform ARENA's $49 million funding for Calix's 30 ktpa demonstration plant.

RP1.011-ARENA
Upgrading iron ore using leaching

An alkaline-leaching flowsheet produced a calcined concentrate of ~67% Fe (DRI/EAF grade). If commercially feasible, this enables use of these ores for green iron.

RP1.012-ARENA
Prevention of sticking in H_2DRI production

Tests showed Australian hematite–goethite fines can be successfully reduced at 700–800 °C without sticking, de-risking Pilbara ores for future green-iron pathways.

RP1.013
AlumiNEXT™

Built full SysCAD models for two refinery reference cases with input from 5 producers, providing a framework to evaluate low-carbon options.

RP1.014
De-risking electric smelting furnace

Experiments and modelling defined optimal operating zones, slag chemistries and feed preparation to minimise energy use and maximise recovery.

RP2.007
Hydrogen burners for cement and iron

A new low-NOx multi-fuel burner was developed and test for pellets, capable of firing natural gas, syngas or hydrogen, enabling lower-emissions fuel choices.

RP2.012
Opportunities for bioenergy in Australian heavy industry

Syngas was shown to be technically viable and, in some cases, cost-competitive with natural gas for pelletising and calcination in some locations and hence a viable low-carbon fuel option.

RP2.014
Low-cost reliable green electricity

Modelling of on-site solar and batteries for heavy-industry operations shows 34–85% emissions cuts and cost-competitiveness with gas once carbon costs are included.

RP2.017
Thermal energy storage

Process models integrated thermal energy storage (TES) into alumina and iron-ore value chains and a new concept was assessed for low-cost clean heat.

RP3.004
Hydrogen burners for cement and iron

Analysis indicates Australian green-iron via hydrogen is more viable when domestic hydrogen costs are ~$0.50/kg lower than China's; ESF technology choice is also pivotal..

RP3.006
Green certification

Policy briefs and practical tools developed to prepare for embedded-emissions accounting and Guarantee of Origin consultations, informing trade and potential green premiums.

RP3.007
Energy infrastructure

Energy-supply models, reference scenarios and hub-location demand assessments progressed, informing cost-optimised infrastructure options for low-carbon energy.

RP3.008
Policy roadmap

Synthesis of domestic and international policy mechanisms completed and options report prepared on policy measures to support decarbonisation.

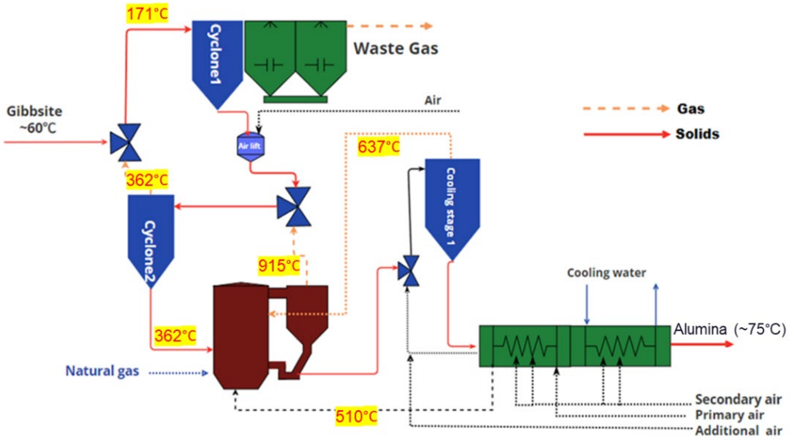
28 Projects completed
21 Active projects
34 Active HDR students

$6.9M funding secured
26 Journal publications
2 Patent applications filed

HILT CRC TES project case study: modified hot blast stove retrofitted to alumina calciners

- Australian alumina production is about 17.5 Mt/year. Replacing fossil heat with renewables plus TES would abate about 11.8 Mt CO_2-e per year, almost 3% of Australia's annual GHG emissions.
- Most existing alumina plants have circulating fluidized bed (CFB) calciners.
- How can TES be integrated with a CFB calciner?

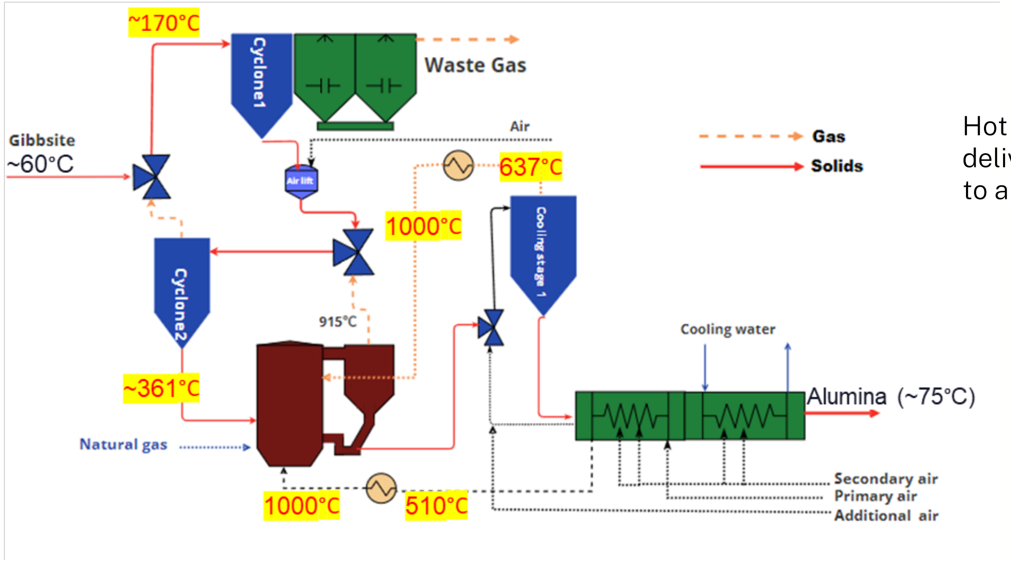
Outotec's 5th Gen CFB alumina calciner



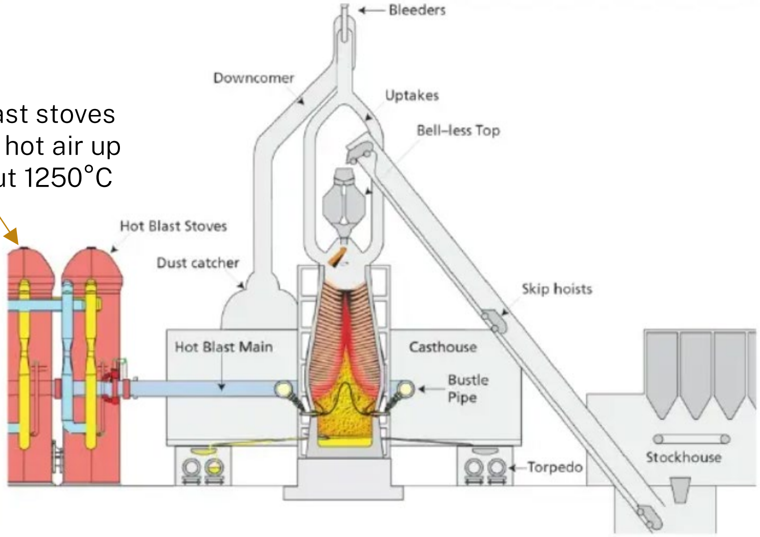
Flowsheet of the 2nd Gen Outotec CFB alumina calciner

Understanding the process

- Hot air can be added to the calciner at ~1000°C to displace natural gas combustion
- What TES technology can deliver such hot air?
- What are the limitations?



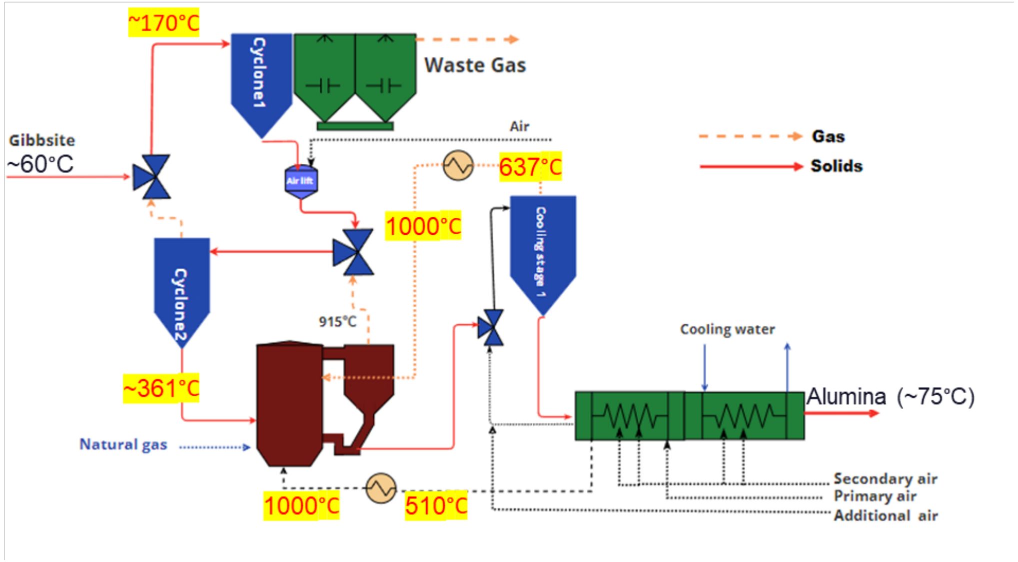
Hot blast stoves deliver hot air up to about 1250°C



Source: Geerdes

Understanding the process

- Hot air can be added to the calciner at ~1000°C to displace natural gas combustion
- What TES technology can deliver such hot air?
- What are the limitations?



Supporting structure has a maximum temperature limit

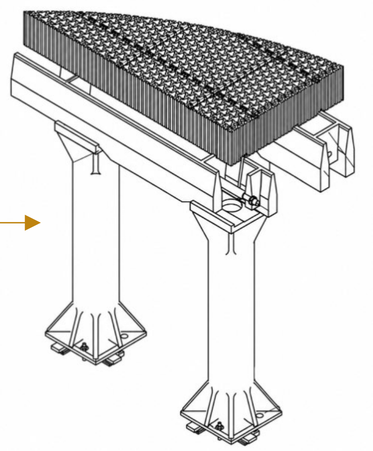


Image: CN112063787A (modified)

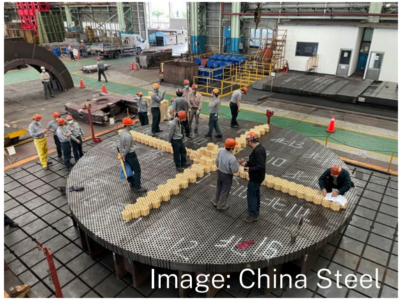
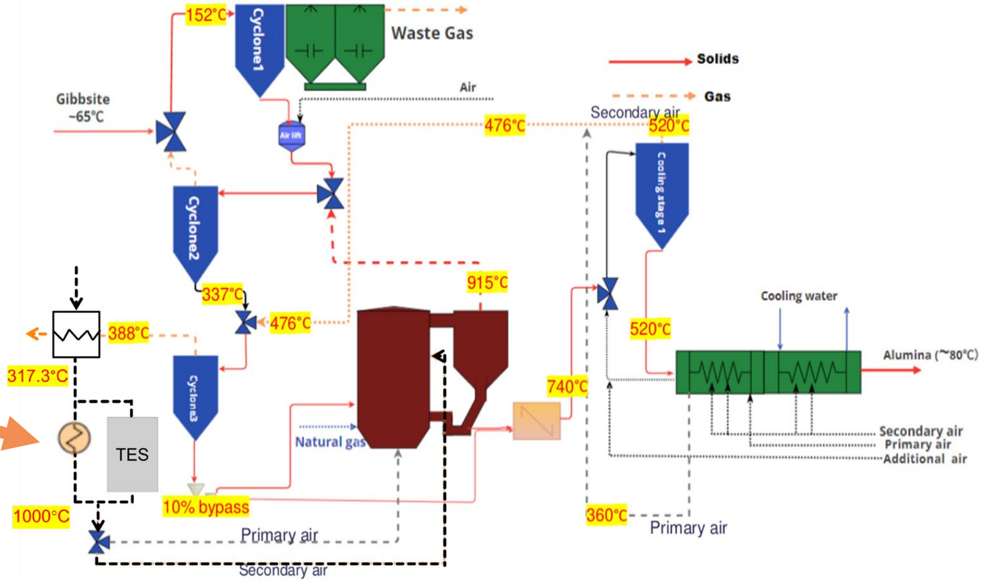


Image: China Steel

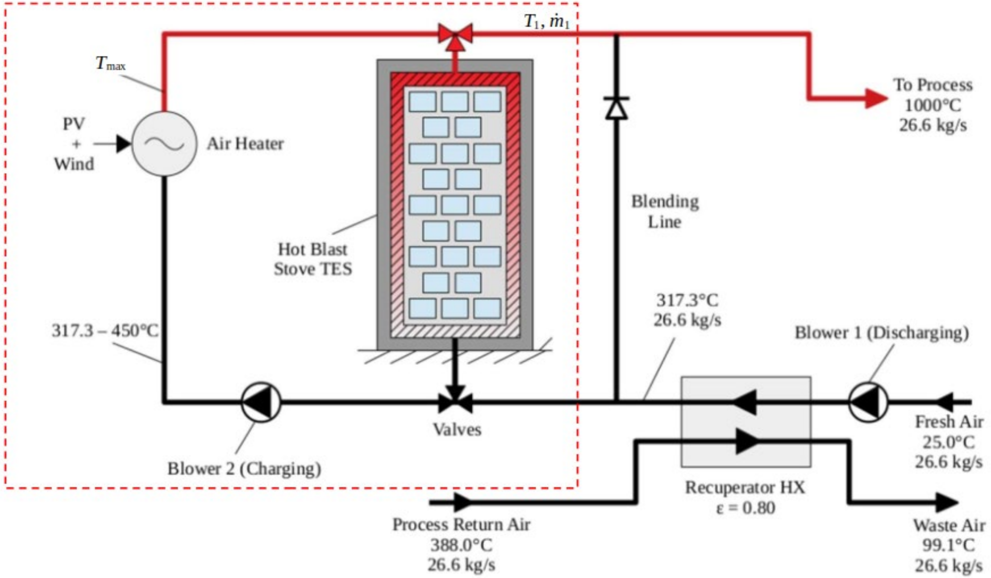
Modifying the flow sheet to suit the TES system

- Flow sheet modified to bring down the return air temperature
- Process modelling indicates 33% reduction in natural gas usage

Hot blast stoves at Port Kembla (abc.net.au)



Modified hot blast stove concept

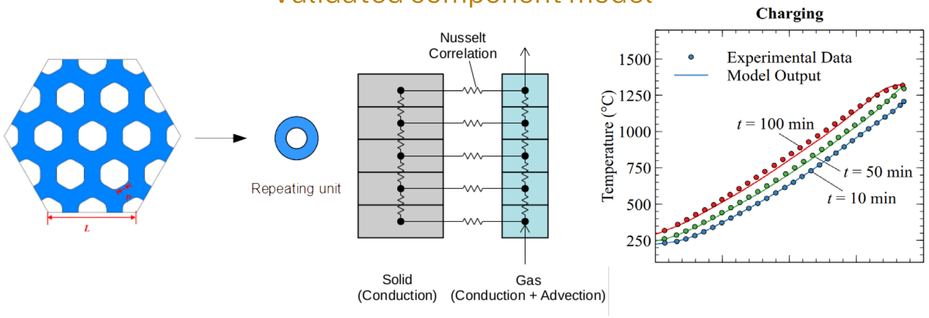


Case study parameters

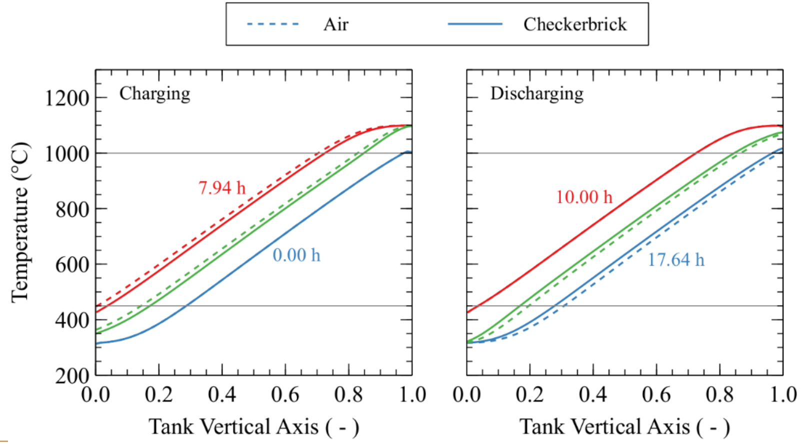
Parameter	Value	Notes
Heat demand rate (MJ/s)	20.4 MW	Based on 26.6 kg/s of hot air at 1000°C and a return of 317.3°C
Discharging mass flow rate (kg/s)	26.6 kg/s at 1000°C 23.0 kg/s at 1100°C	If the TES outlet temperature is above 1000°C, the discharge flow rate is reduced and cold air from the return line is blended in such that the process always receives air at 26.6 kg/s and 1000°C
Heater output rate (MJ/s)	40.8 MW	Heater Multiple = 2.0
Charging mass flow rate (kg/s)	23.0 kg/s at 317.3°C 27.3 kg/s at 450°C	The heater input air flow rate is adjusted to produce an air outlet stream at 1100°C.
Minimum TES top temperature (°C)	1000°C	TES stops discharging if the top outlet is below 1000°C
Maximum TES bottom temperature (°C)	450°C	TES stops discharging if the bottom temperature is above 450°C. This is to preserve the supporting structure of the HBS.
Height of HBS	35 m	Fixed as a constant
Diameter of HBS	Varied	The diameter of HBS is varied based on the material storage capacity
Porosity	0.3232	Kerui K37 brick, 0.02 m for hole diameter and 37 holes

Integrated system modelling

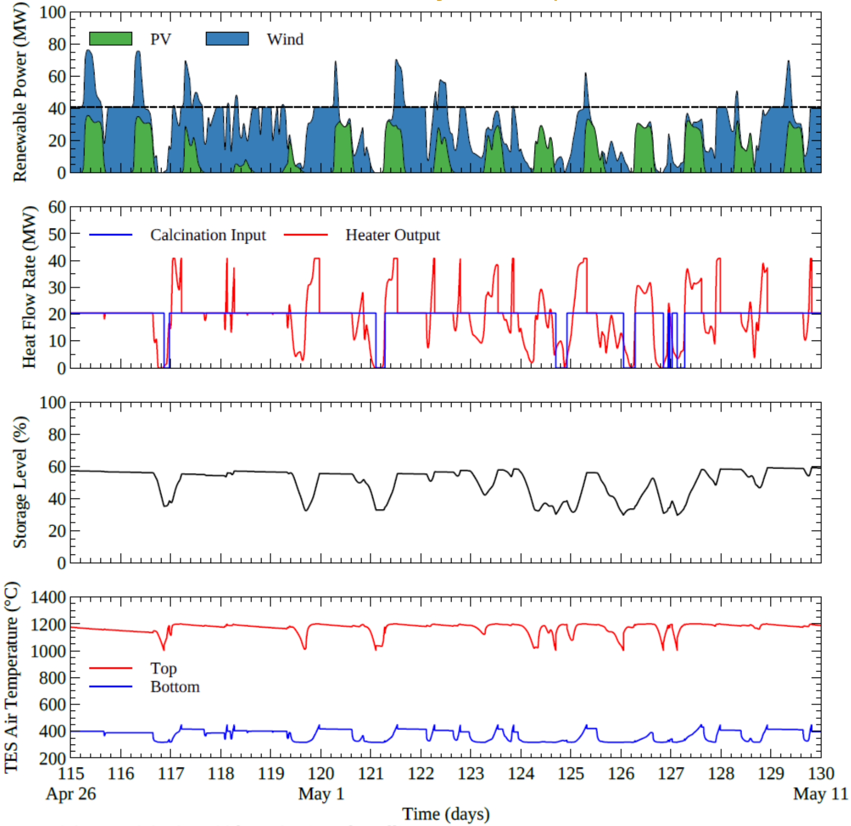
Validated component model



Temperature profile within the checker bricks and air channels



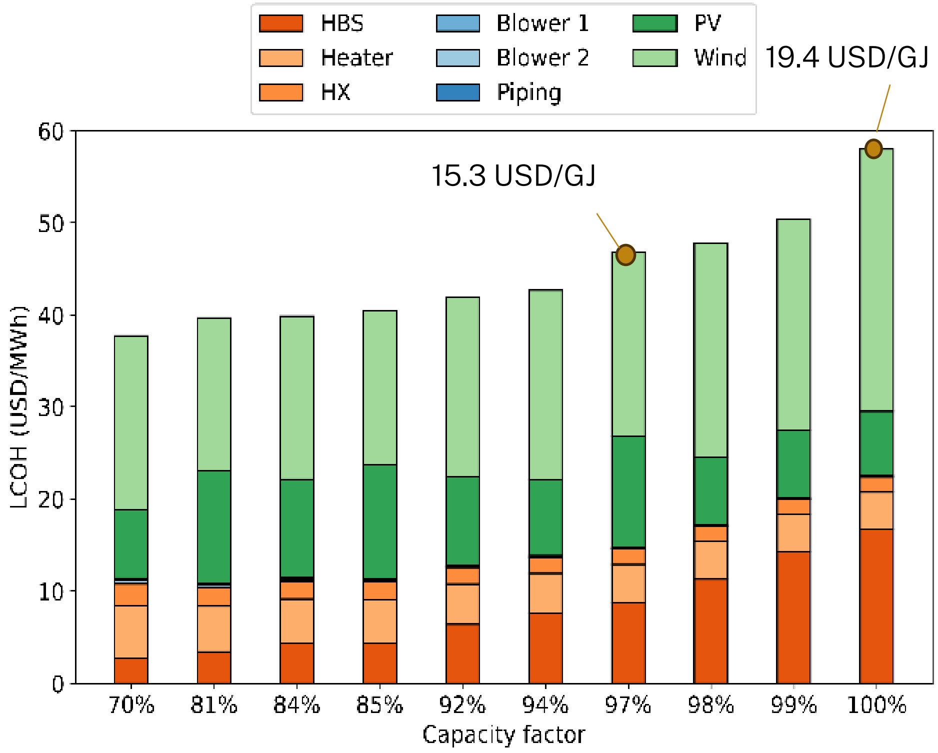
Simulation of full system operation



HM = 2.0, *RM* = 2.0, *ISH* = 20 h, TES = 1-Tank Mullite

Technoeconomic analysis

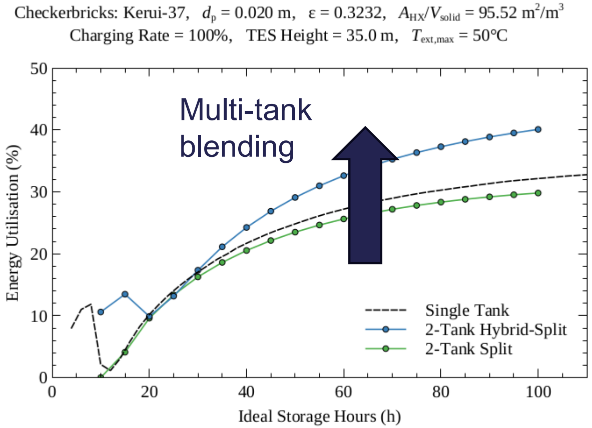
- Levelised Cost of Heat (LCOH) rises with capacity factor, particularly approaching 100% capacity factor
- At 97% CF, LCOH is 15.3 USD/GJ

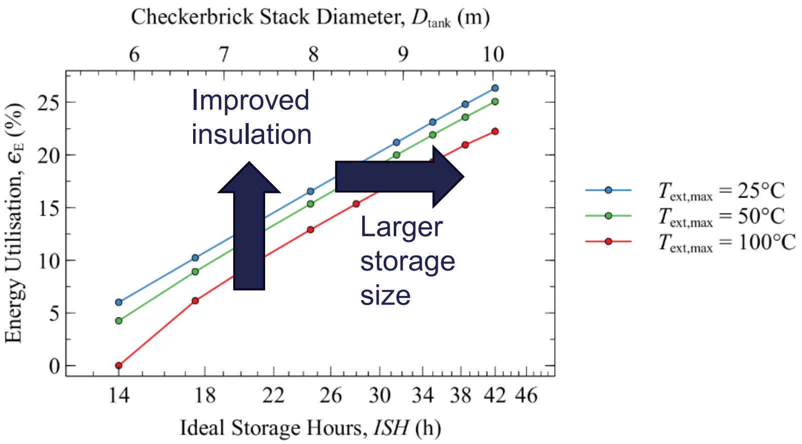


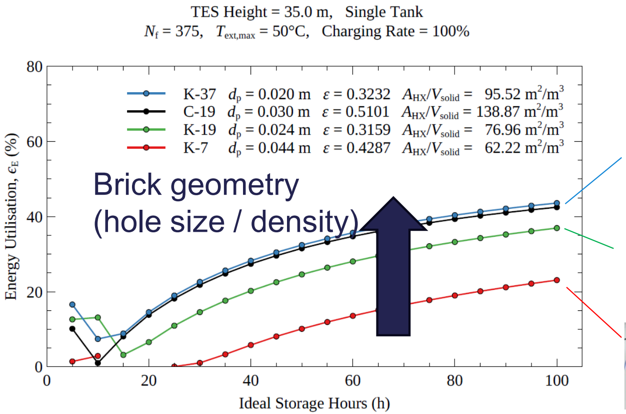
Design improvements

Energy utilisation is the ratio of energy discharged in one cycle relative to a theoretical maximum storage capacity. Ways to improve utilisation:

- Improved thermal insulation
- Multi tank blending of outlet air
- Modified brick geometries



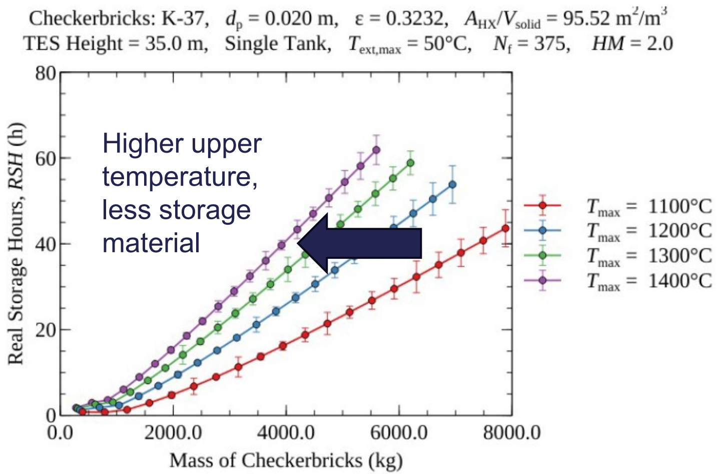


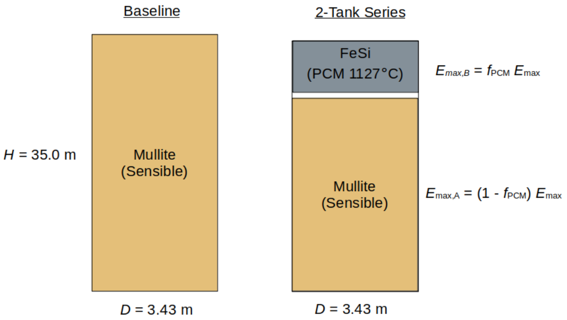


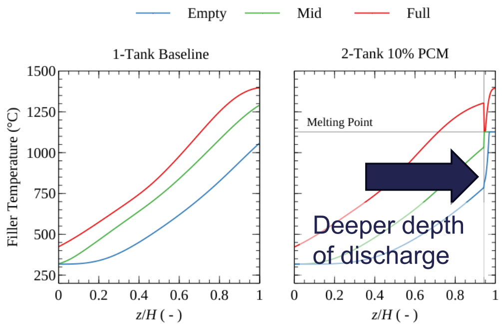
Design improvements

Energy utilisation is the ratio of energy discharged in one cycle relative to a theoretical maximum storage capacity. Ways to improve utilisation:

- Improved thermal insulation
- Multi tank blending of outlet air
- Modified brick geometries
- Increase the charging temperature
- Incorporating phase change materials

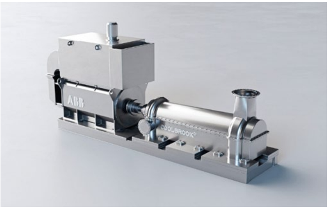






Case	Reference	10% PCM
Energy utilisation	29.7%	38.2%

Coolbrook RotoDynamic Heater



Siemens Turbo Heater

High temperature turbomachinery-type heaters capable of 1400-1700°C hot air are being developed (prototype scale)

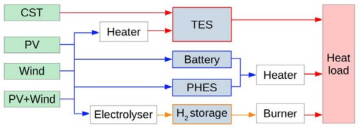
CST vs. PV/wind or grid electricity for TES

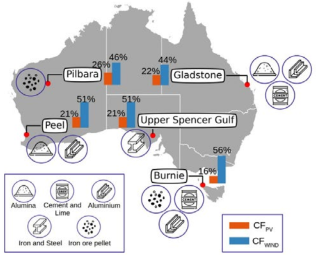
The bad news

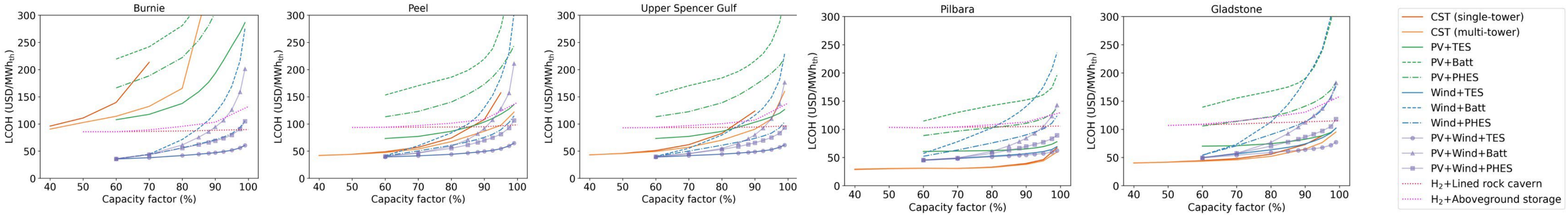
- PV + Wind beats CST when integrated with TES in most locations near existing industrial process in Australia, according to our HILT CRC Green Heat study
- At the moment, grid connected TES appears more favourable than either behind-the-meter PV or CST. This may change as more storage comes into the grid.
- Electrically charged TES has an advantage for very high temperature applications (due to heat losses from CST receivers and cost/feasibility of transporting heat)

The good news

- CST has a clear advantage with regards to land use compared to PV/wind, which is important and often overlooked.
- CST came out ahead in the sunniest location (the Pilbara) in our HILT CRC Green Heat study. This is a location without much heat need right now, but a potential hub for green iron production.
- Molten salt storage still leads the pack as the most technical mature TES technology and integrates very well with CST. Track record is important to industry.







Acknowledgement

This presentation was supported by research funded by the Heavy Industry Low-Carbon Transition Cooperative Research Centre.

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