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Australian Renewable Energy Agency

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ARENA INSIGHTS
KNOWLEDGE FOR INDUSTRY

Insights Forum 26 March 2024 | Sydney

Australian Government
Australian Renewable
Energy Agency

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ARENA INSIGHTS

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Opening Plenary

Welcome

Presented by Kate O’Callaghan (ARENA)

Australian Government
Australian Renewable Energy Agency

ARENA

Opening Plenary

Welcome to Country

Presented by Uncle Allan Murray

ARENA INSIGHTS

ARENA acknowledges the Traditional Custodians of Country across Australia and their continuing connection to land, sea and community. We pay our respects to Elders past and present.

Australian Government
Australian Renewable Energy Agency

Opening remarks

Presented by Darren Miller (ARENA)

Australian Government
Australian Renewable Energy Agency

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Keynote Presentation

Presented by Alex Campbell (LDES)

ARENA INSIGHTS

LONG DURATION ENERGY STORAGE: Powering the future

Alex Campbell
Director of Policy & Partnerships, Long Duration Energy Storage Council
ARENA INSIGHTS 26 March 2024

Agenda

- About the LDES Council
- The global need for long duration energy storage
- LDES technologies
- Example use cases
- Policy & regulatory reform
- Policy examples worldwide

The LDES Council is formed by ~ 60 companies, from start-ups to large corporates, in over 20 countries

TECHNOLOGY PROVIDERS

- 1414°
- Electrified Thermal Solutions
- e-zinc
- MAGALDI
- RONDO
- hyme
- ENERGYDOME Our world can't wait.
- Form energy
- MALTA
- Rye Development
- ANTORA
- ENERGYNEST
- Fusion Energy Group
- MGA THERMAL
- SAGE GEOSYSTEMS
- TES THULE ENERGY STORAGE
- ENERGY VAULT
- HYDROSTOR
- noon ENERGY
- SaltX Technology
- BUILD TO ZERO
- ENERVENUE
- INVINITY ENERGY SYSTEMS
- VOLTSTORAGE
- SENS
- Breeze
- ENLIGHTEN
- KRAFTBLOCK
- Quidnet Energy
- STORWORKS
- cellcube Energy Storage Systems Inc
- eos
- KYOTO
- redflow
- STRYTEN ENERGY
- ceres
- ESS INC
- LARGO
- RheEnergise
- Sumitomo SHI FW
- ECHOGEN power systems

ANCHOR MEMBERS

Industry & services customers

Equipment manufacturers

Low-carbon energy system integrators & developers

- COMPASS datacenters
- RioTinto
- ALFA LAVAL
- Ørsted
- MN8
- EGA
- SOUTH32
- Baker Hughes
- NEOM نيوم
- Microsoft
- Google
- Diamond Generating Corporation
- SIEMENS energy
- OXY
- slb
- Sumitomo SHI FW
- TotalEnergies

Capital providers

- Breakthrough Energy
- quinbrook infrastructure PARTNERS

SERVICE PROVIDERS

- ESB

Membership overview as of January 2024

Key principles of the LDES Council

- Executive-led
- Global
- Fact-based
- For societal benefit
- All types of energy storage (Chemical, Thermal Electrochemical, Mechanical)

LDES provides discharge energy continuously for **8+ hours**

- ○ Multi-hour
- ○ Multi-days
- ○ Weeks
- ○ Months, seasonal

Global Renewables Alliance

IRENA
International Renewable Energy Agency

DOUBLE DOWN,
TRIPLE UP.
THE WORLD NEEDS #3xRENEWABLES

See the open letter and supporters of the #3xRenewables campaign here

CAN WE COUNT ON YOU?

#3xRenewables

Global Renewables Alliance

INTERNATIONAL GEOTHERMAL ASSOCIATION
IGA

GH2 Green Hydrogen Organisation

LDES
LONG DURATION ENERGY STORAGE COUNCIL

GWEC
GLOBAL WIND ENERGY COUNCIL

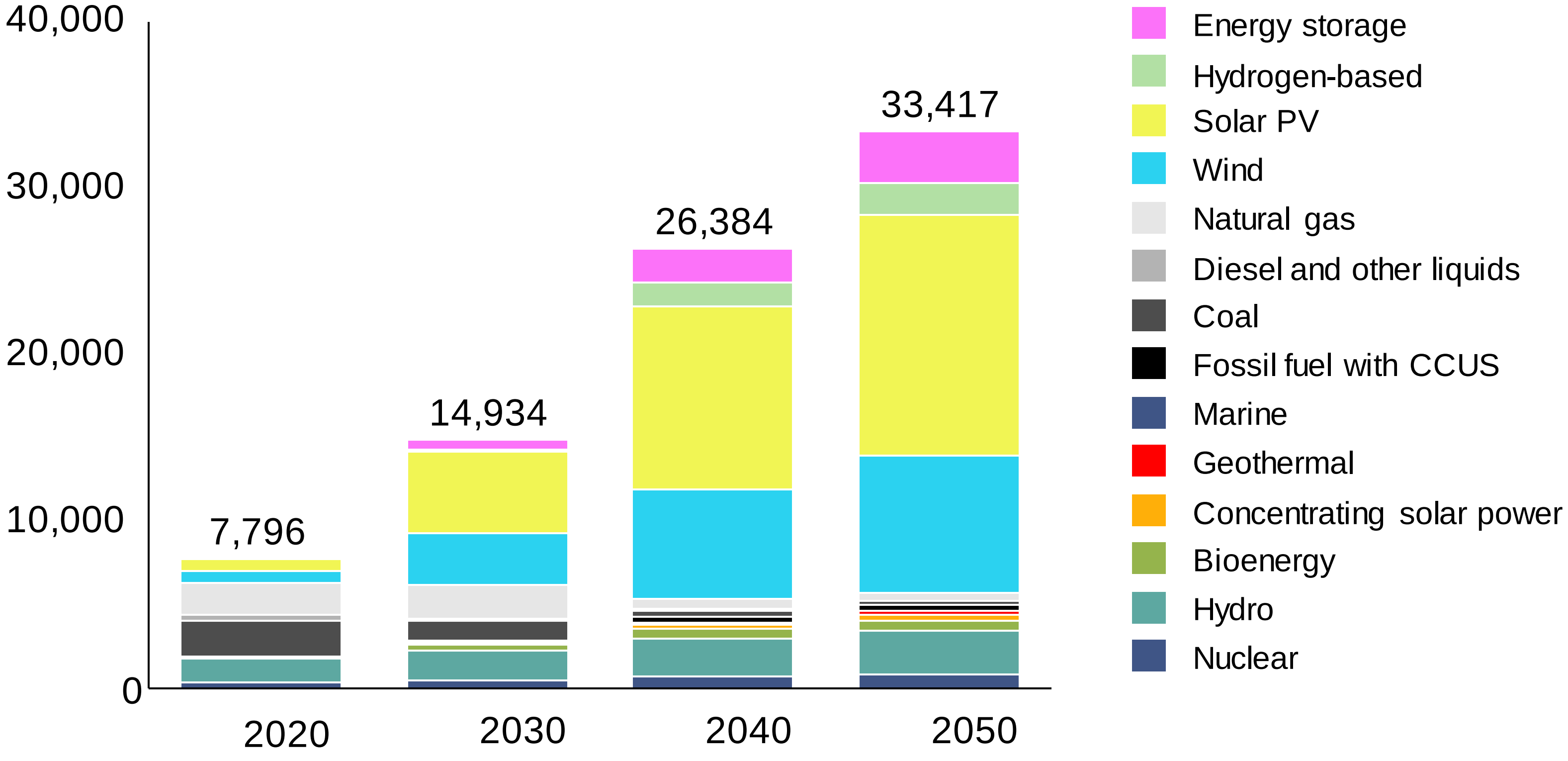
iha
international hydropower association

Global Solar Council

Decarbonization of power will create a “flexibility gap”, requiring new resources to balance the net-zero grid – LDES can de-risk the transition

Power capacity especially of variable renewables – solar PV and wind – expected to increase significantly while conventional flexibility is phased out

Power capacity as modeled by IEA Net Zero by 2050 outlook (GW)



RES integration leads to new system challenges:

Power supply and demand not always in balance

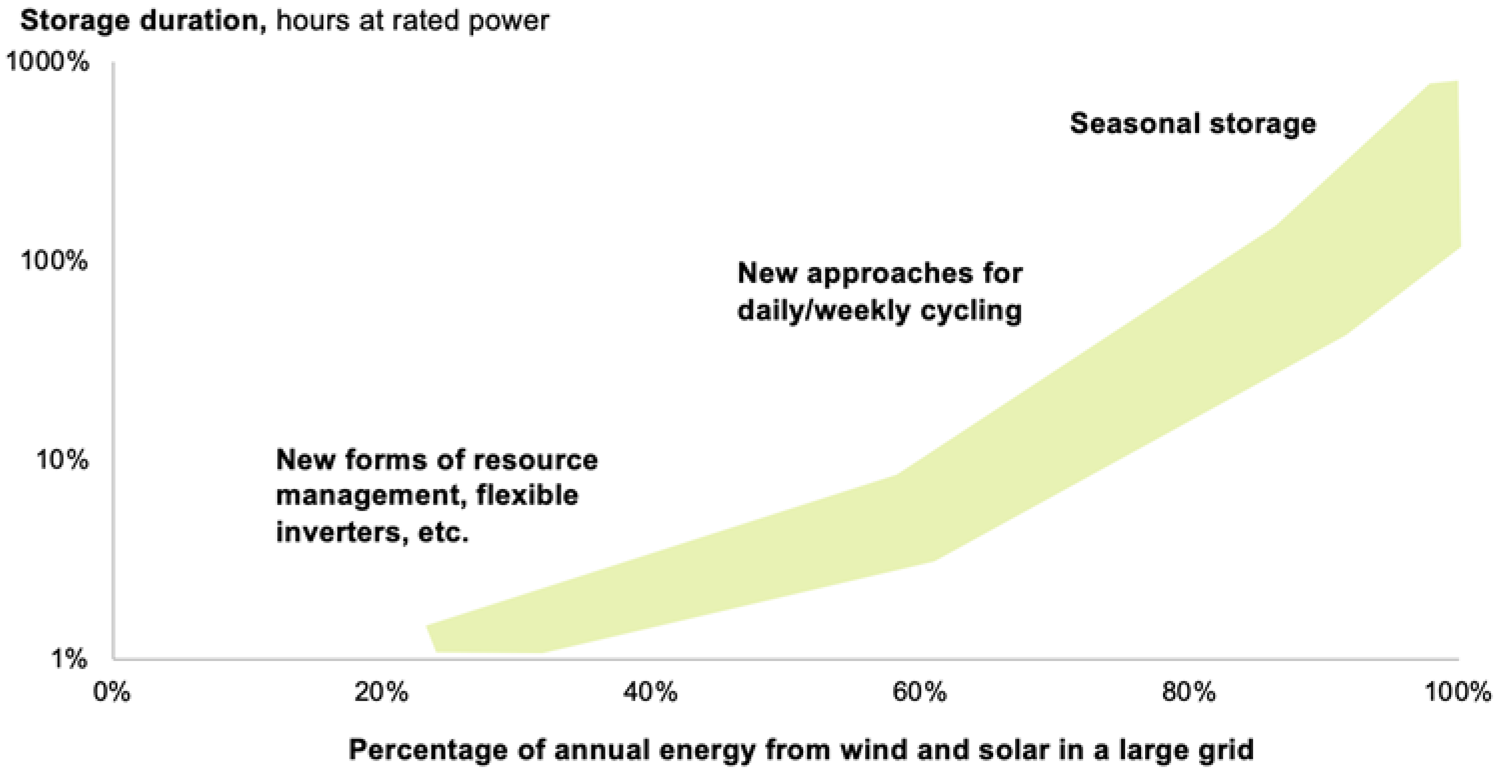
Transmission flow changes potentially require costly and lengthy transmission upgrades

Retirement of conventional, synchronous generators creates need for new sources of grid support services, e.g., reactive power, inertia

Source: IEA

LDES will be required to get to net-zero power systems

Adoption curve of longer flexibility durations accelerates at 60-70% RE penetration

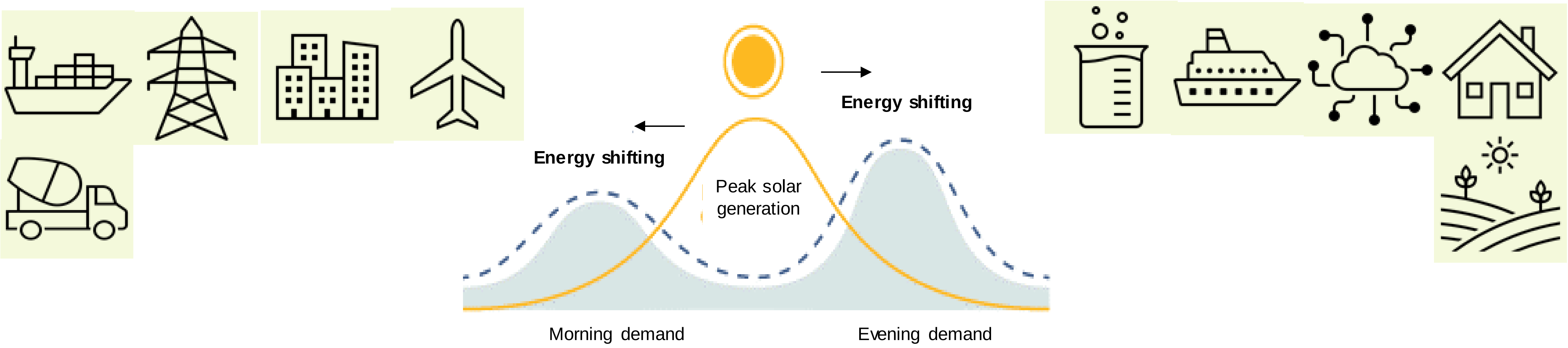


Source: Advanced Research Projects Agency–Energy

As the proportion of variable renewable generation increases on power grids, the depth of storage required to keep the system functioning increases.

With very high levels of variable renewable generation it becomes necessary to store energy across seasonal durations.

LDES overall system benefits



Growing realization by all sectors of the critical role of LDES

8 TW

total potential LDES capacity deployed by 2040

$4 trillion

total capex required to deploy LDES by 2040

$540 billion

system savings in an 8 TW scenario

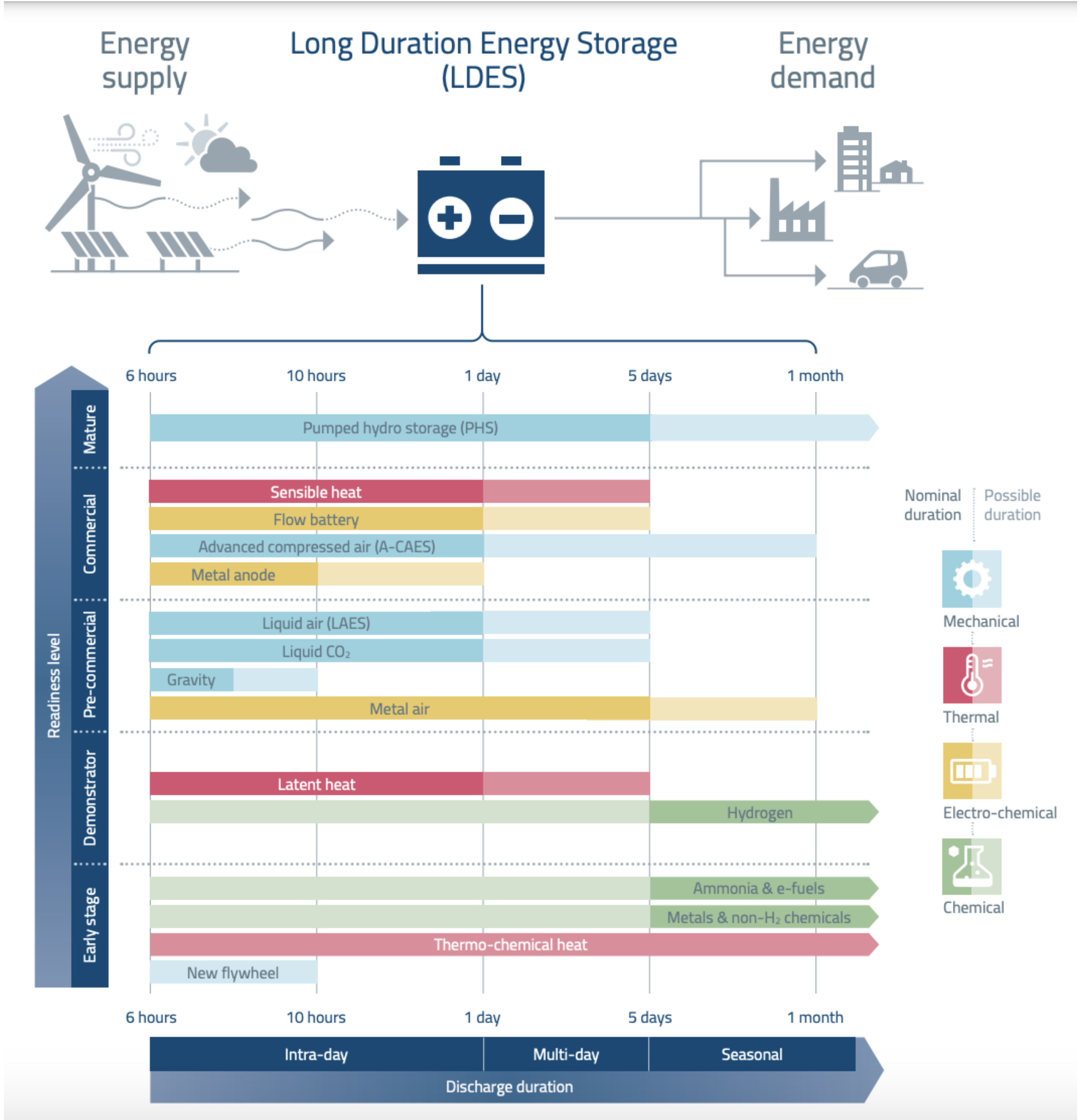
1.5 - 2.3 GT

avoided power sector carbon dioxide equivalent emissions

Various technical approaches for LDES – most at pilot or commercial stage deployment – but all can benefit from additional scale

Type	Description	Technology	Market readiness today
Mechanical	Mechanical LDES store potential or kinetic energy in systems, so that they can release it in the future	Novel pumped hydro (PHS)	Commercial
		Gravity-based	Pilot
		Compressed air (CAES)	Commercial
		Liquid air (LAES)	Pilot (commercial announced)
		Liquid CO_2	Pilot
Thermal	Thermal energy storage systems use thermal energy to store and release electricity and heat	Sensible heat (e.g., molten salts, rock material, concrete)	R&D/pilot
		Latent heat (e.g., aluminum alloy)	Commercial
		Thermochemical heat (e.g., zeolites, silica gel)	R&D
Chemical	Chemical energy storage systems store electricity through the creation of chemical bonds	Power-to-gas-(incl. hydrogen, syngas)-to-power	Pilot (commercial announced)
Electrochemical	Electrochemical LDES refers to batteries of different chemistries that store energy	Aqueous electrolyte flow batteries	Pilot/commercial
		Metal anode batteries	R&D/pilot
		Hybrid flow battery, with liquid electrolyte and metal anode	Commercial
		Hybrid cathode batteries	Commercial

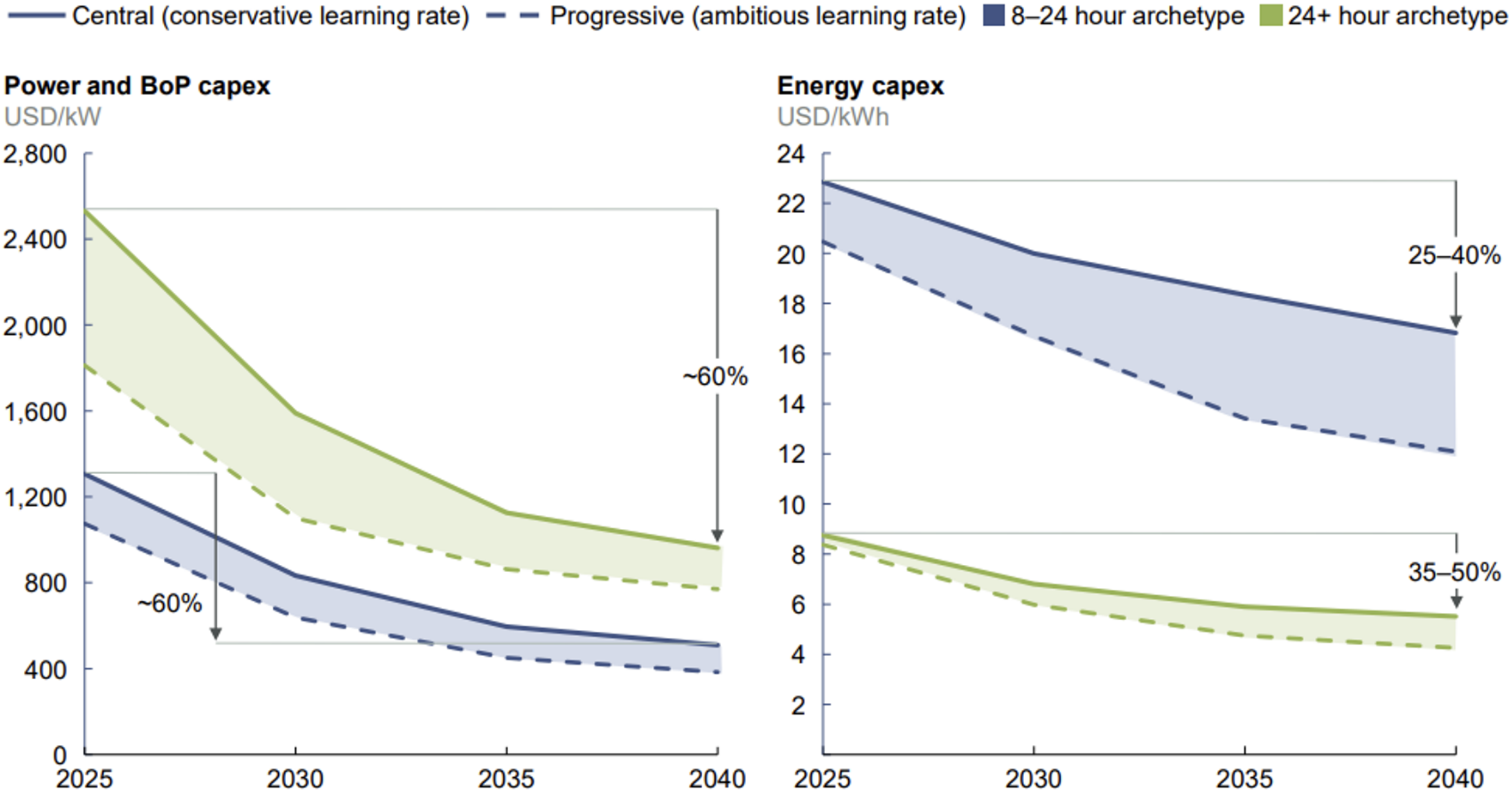
Source: LDES Council The journey to net-zero: An action plan to unlock a secure net-zero power system (June 2022)



Different types of LDES are suitable for different end-use requirements.

The capabilities of LDES technologies are increasing over time with continued investment and innovation.

LDES power and energy capex trajectories


Power and BoP capex USD/kW

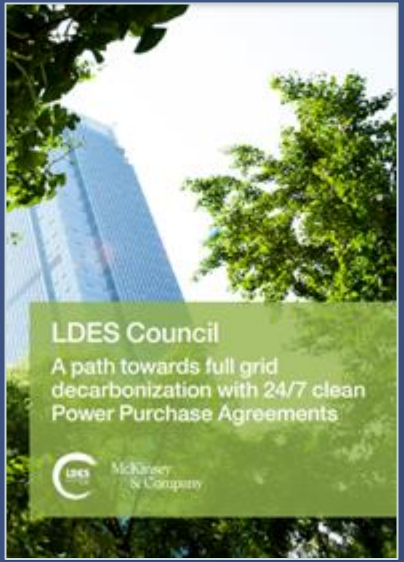
Energy capex USD/kWh

Source: LDES Council member technology benchmarking

Example LDES Use Cases

- 24/ 7 PPAs

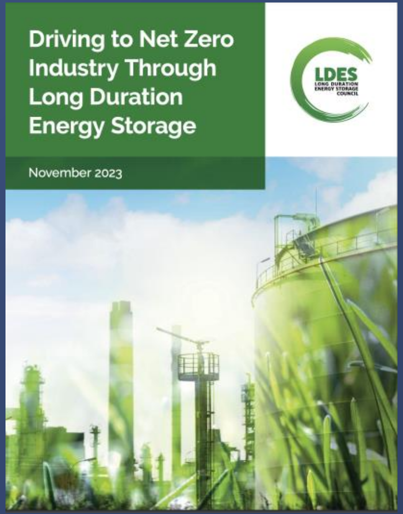
- Industrial decarbonisation



LDES Council

A path towards full grid decarbonization with 24/7 clean Power Purchase Agreements

McKinsey & Company

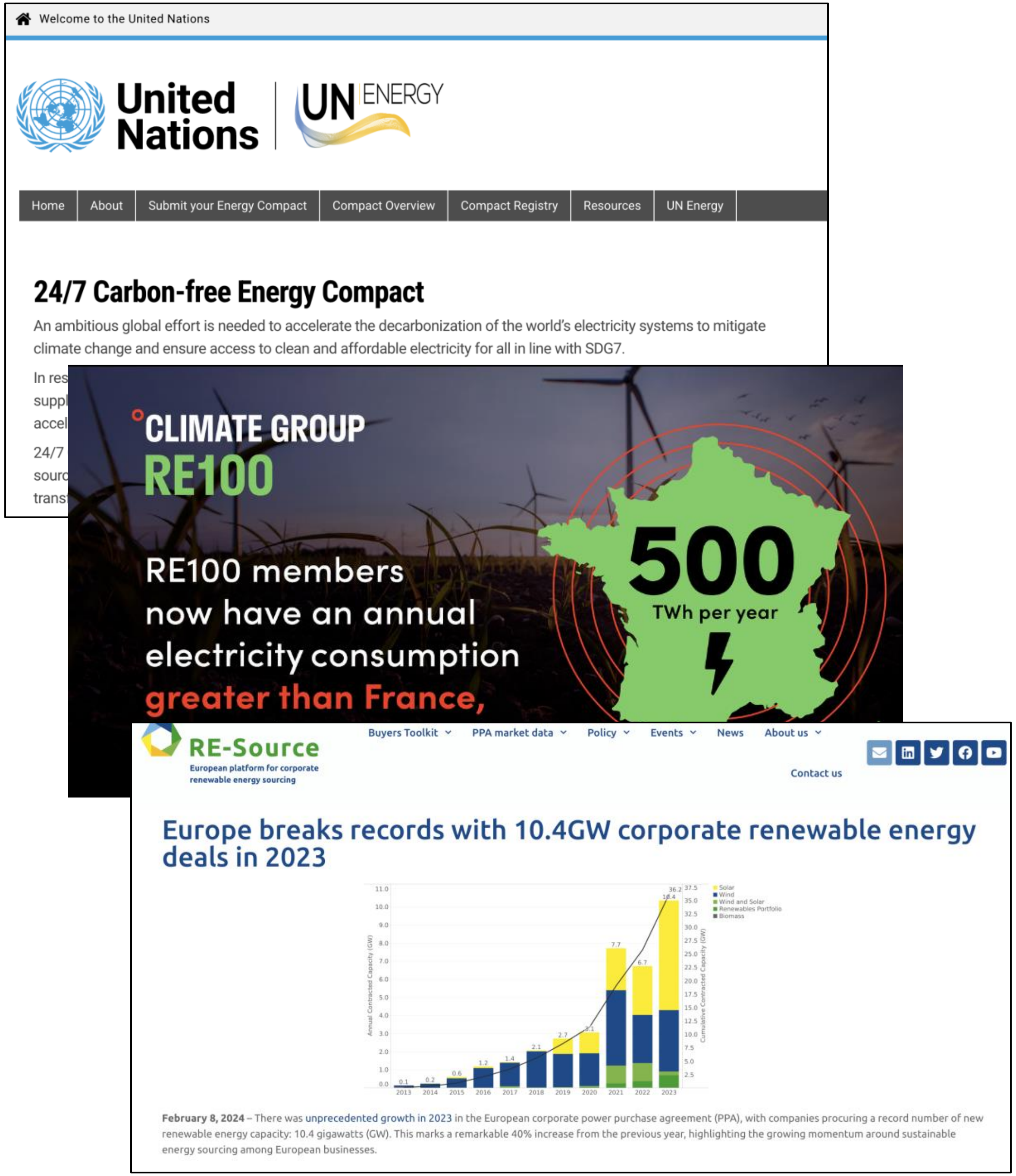


Driving to Net Zero Industry Through Long Duration Energy Storage

November 2023

24/ 7 Power Purchase Agreements

- Power purchase agreements (PPAs) are used to match buyers of electricity with generation.
- ‘Clean’ PPAs enable users of electricity to decarbonise their operations, by demonstrating that they are using low carbon electricity.
- Huge growth in corporate clean PPAs.
- However conventional clean PPAs are not sufficiently granular to fully decarbonize.
- 24/7 clean PPAs with LDES can provide this guarantee.
- Greenhouse Gas Protocol, ISO net zero guidelines expected to move towards greater granularity.



Welcome to the United Nations

United Nations | UN ENERGY

24/7 Carbon-free Energy Compact

An ambitious global effort is needed to accelerate the decarbonization of the world's electricity systems to mitigate climate change and ensure access to clean and affordable electricity for all in line with SDG7.

In res
suppl
accel

24/7
sourc
trans

CLIMATE GROUP
RE100

RE100 members now have an annual electricity consumption greater than France,

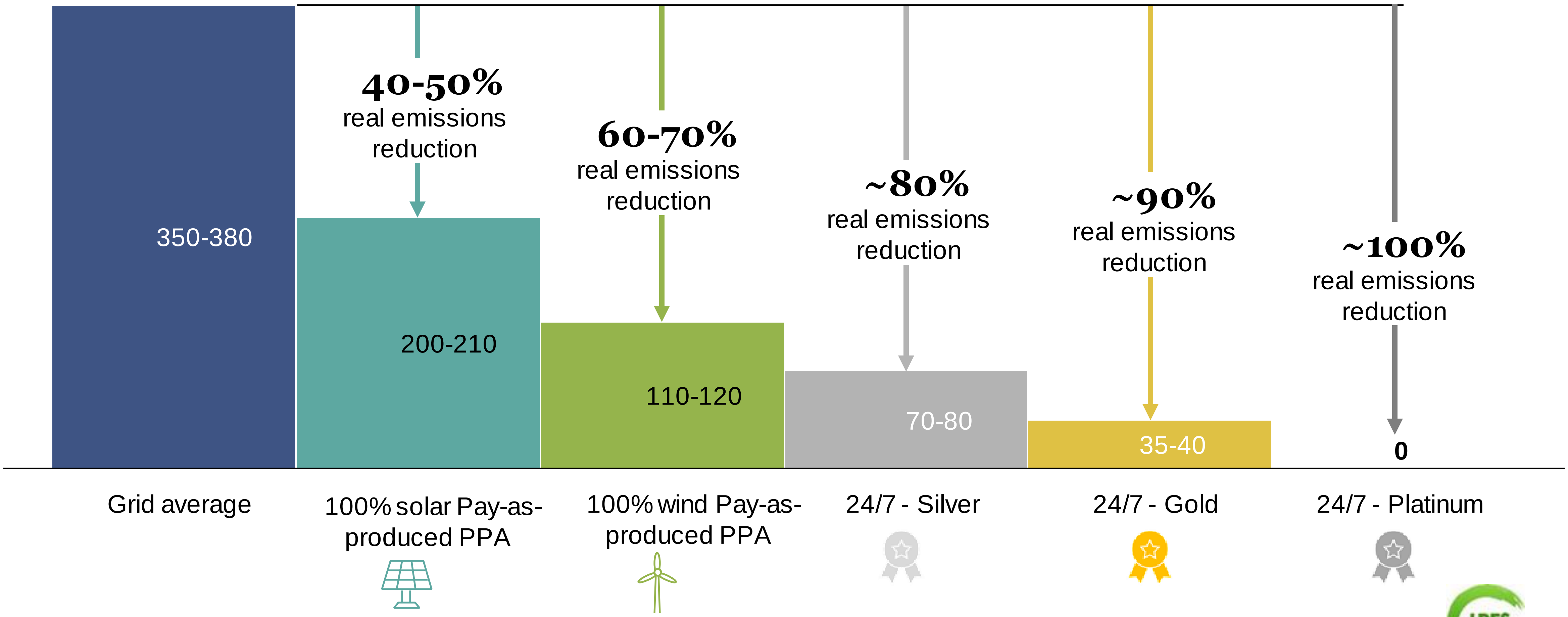
RE-Source
European platform for corporate renewable energy sourcing

Europe breaks records with 10.4GW corporate renewable energy deals in 2023

February 8, 2024 – There was unprecedented growth in 2023 in the European corporate power purchase agreement (PPA), with companies procuring a record number of new renewable energy capacity: 10.4 gigawatts (GW). This marks a remarkable 40% increase from the previous year, highlighting the growing momentum around sustainable energy sourcing among European businesses.

24/7 clean PPAs enable up to 100% reduction of actual emissions intensity from power consumption

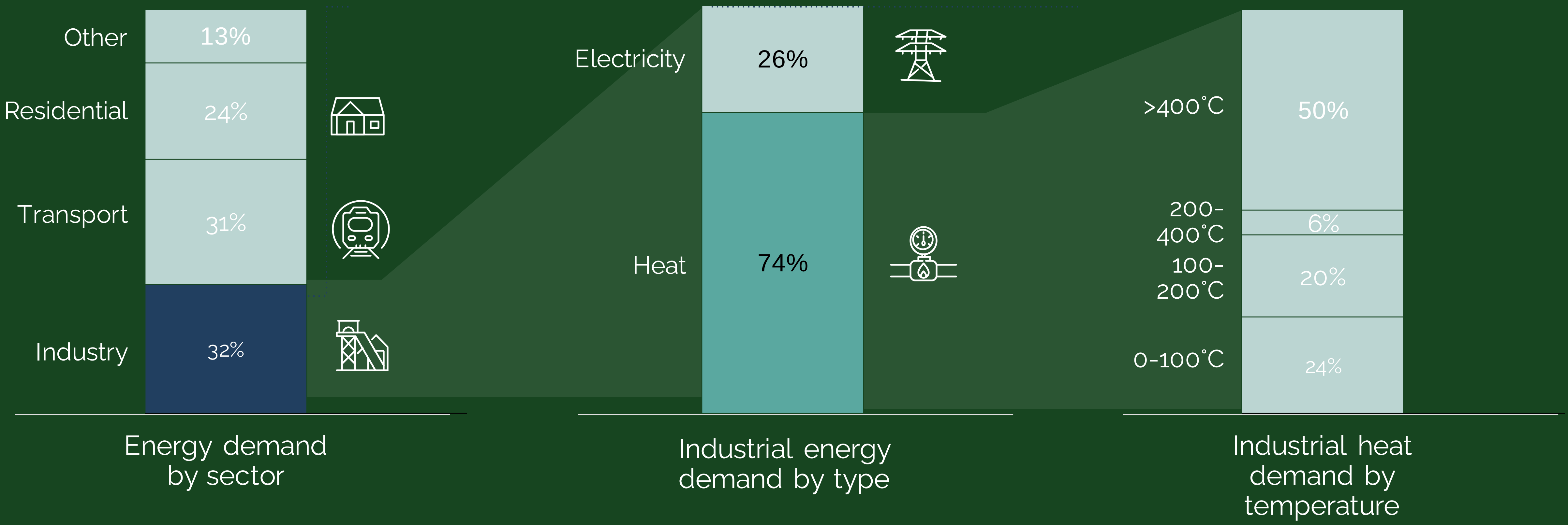
Emissions intensity of different power procurement options when assessing consumption on hourly basis, gCO2eq/kWh



Source: LDES Council 24/7 clean PPA report 2022

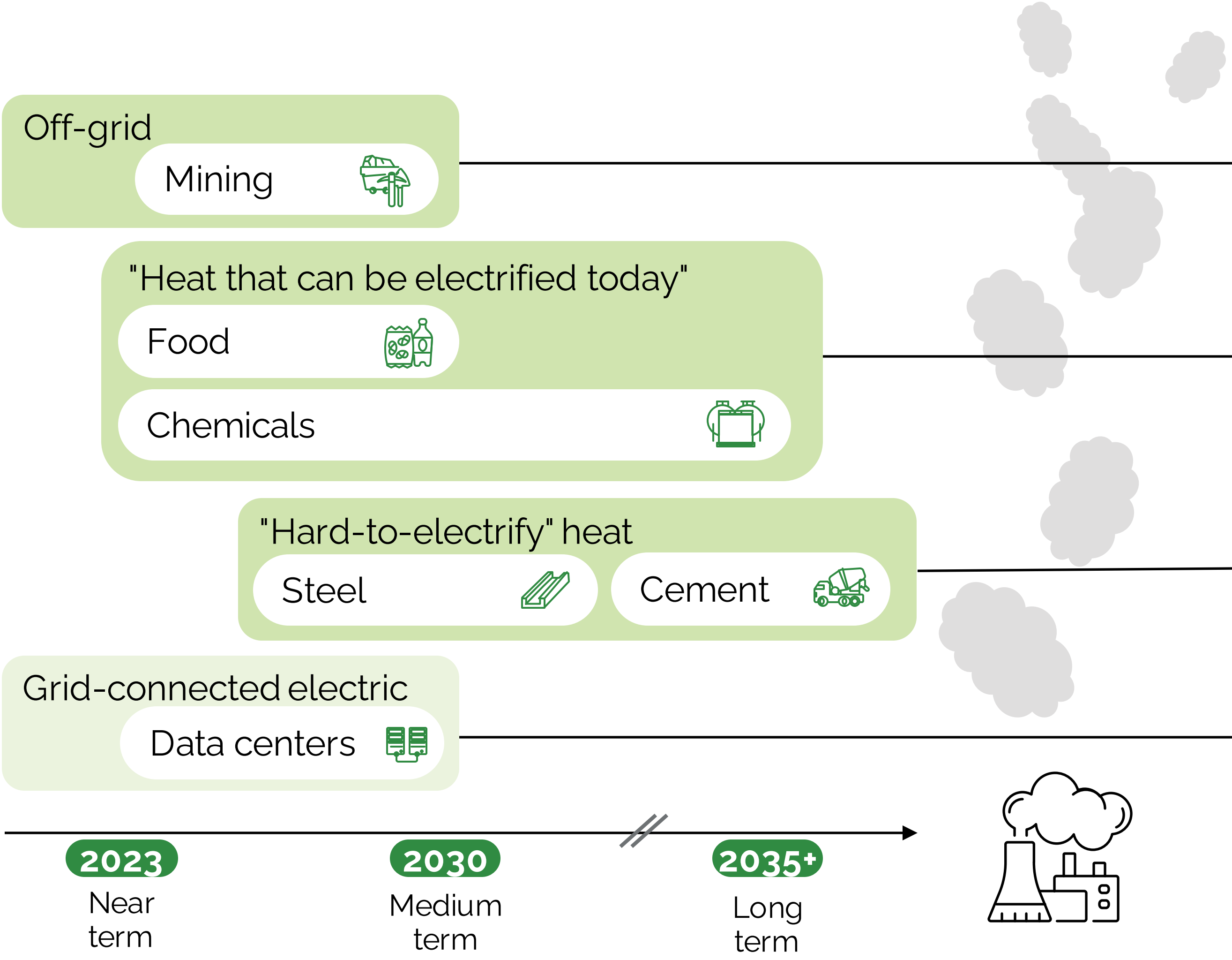
The majority of industrial processes utilise fossil fuels, with heat accounting for three-quarters of energy demand

GLOBAL ENERGY DEMAND DRIVERS



Source: C2ES Center for Climate and Energy Solutions; IEA

LDES technologies are economically attractive options to abate off-grid electric and "Heat that can be electrified today" applications



Off-grid

Mining

"Heat that can be electrified today"

Food

Chemicals

"Hard-to-electrify" heat

Steel

Cement

Grid-connected electric

Data centers

2023
Near term

2030
Medium term

2035+
Long term

Off-grid

Industry that is remote and not grid connected, where LDES can enable transition from fossil fuels to intermittent renewable generation

"Heat that can be electrified today"

Sectors with heat requirements that can already be electrified with existing technologies and/or electric loads that require high uptime. Up to 8% of current global gas use could be electrified by 2030.

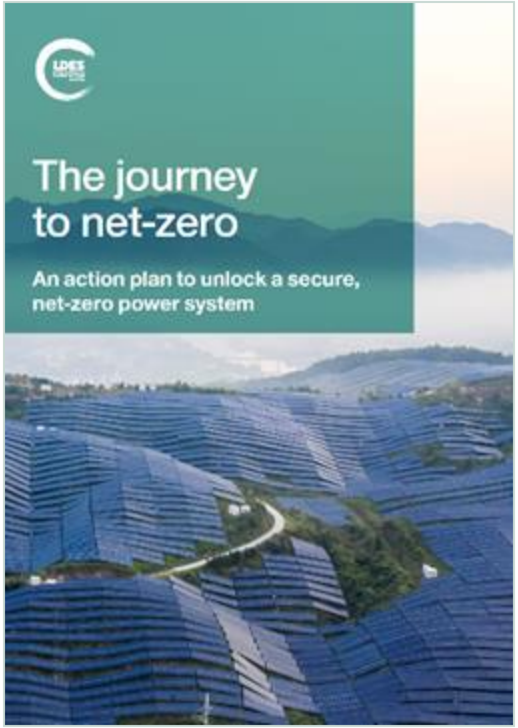
"Hard-to-electrify"

Sectors where electrification is limited by process requirements, need for high temperatures (>1,000°C) or radiative heat

Grid-connected electric

Industry that is grid connected, where LDES can enable transition from fossil fuels to intermittent renewable generation

Policy & regulatory reform needed to unlock LDES



The journey to net-zero

An action plan to unlock a secure, net-zero power system

Despite clear decarbonisation, economic and energy security benefits LDES is not being deployed at the pace needed to secure the energy transition.

Electricity markets are not currently structured in such a way to incentivise LDES deployment – limited long term revenue visibility, flexibility rarely rewarded etc.

Reference technologies may not reflect the full range of LDES.

First of a kind/ early deployment projects may have higher CAPEX, risk weighting.

Enabling actions by government and regulators can unlock investment to secure benefits for consumers.

There are a range of different policy options to help accelerate deployment

Long-term market signals

Inform the trajectory of the energy system

- Carbon pricing and greenhouse gas reduction targets
- Procurement targets
- Grid planning
- Renewable energy targets
- Phase-out of fossil fuel subsidies
- Storage capacity targets

Revenue mechanisms

Enhance the viability of projects

- Cap and floor
- Long term bilateral contract for balancing / ancillary services
- Capacity market
- Nodal & locational pricing
- Contract for Difference
- Regulated asset base
- Hourly energy attribute certificates
- 24/7 clean PPA

Direct technology support and enabling measures

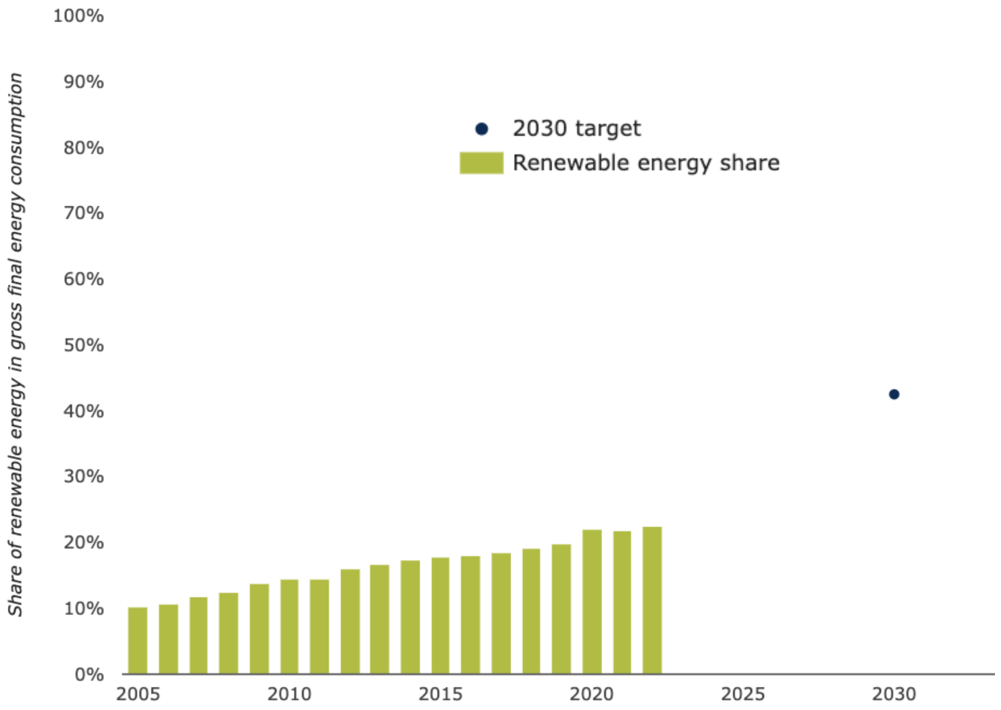
Create pathways for access and uptake

- Grants and incentives
- Investment de-risk mechanisms
- Sandboxes
- Market rules
- Targeted tenders
- Technology standards

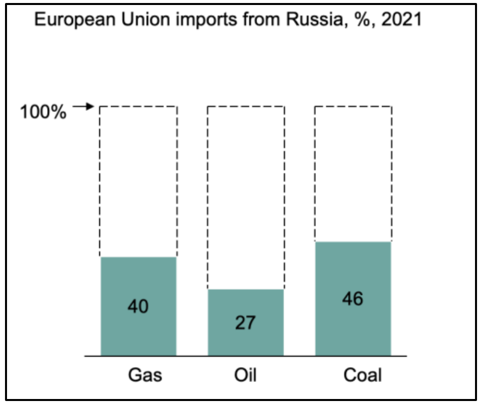
Source: LDES Council The journey to net-zero: An action plan to unlock a secure net-zero power system (June 2022)

Policy development: EU

- Russia’s invasion of Ukraine has accelerated the EU’s already ambitious decarbonisation plans
- The REPowerEU plan increased the EU’s 2030 target for the share of renewables to 42.5%. The previous target was 32% (2022 share was 23%).
- In Dec ’23 political agreement reached on new EU Electricity Market Design (EMD).
- All EU Member States will be required to undertake a flexibility assessment for at least a 5-10 year period.
- And establish an indicative target for non-fossil flexibility ‘with a focus on the contributions by demand response and energy storage’.
- EMD gives further permission to design support schemes.



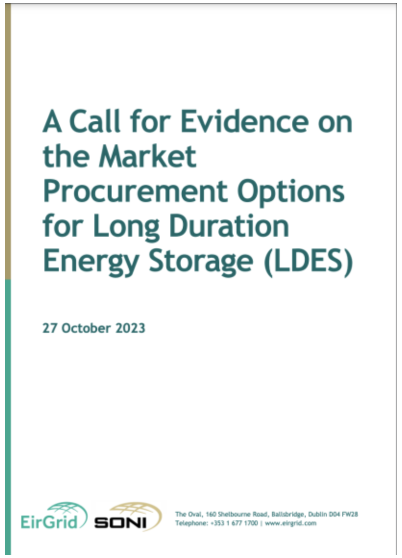
Invasion of Ukraine ‘has fuelled funding boom for clean energy’



Policy case study: Ireland & Italy, island & peninsula

In Ireland the Transmission System Operators are considering procurement options for LDES.

- Up to 2.75 GW needed for an 80% renewable grid by 2030.
- Options considered include stand-alone storage auction and a fixed term system services contract with central control (the preferred option).



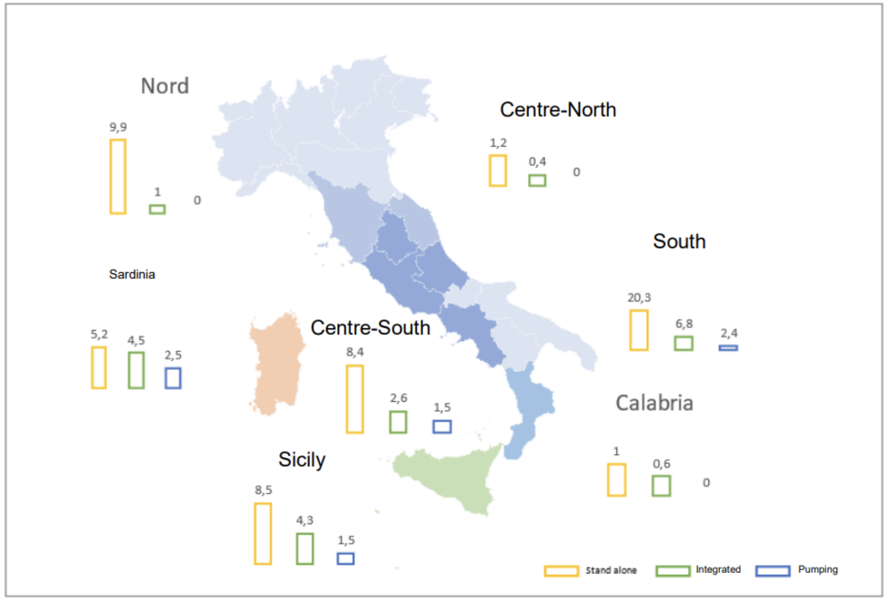
A Call for Evidence on the Market Procurement Options for Long Duration Energy Storage (LDES)

27 October 2023

The Oval, 160 Shelbourne Road, Ballsbridge, Dublin D04 FW28
Telephone: +353 1 677 1700 | www.eirgrid.com

In Italy auctions expected in 2024 with delivery in 2026+

- System operator TERNA will directly tender fixed price, long term contracts (12-14 years BESS, up to 30 for PSH)
- 4-8 hour durations, up to 71GWh
- Can be split into contracted (managed by TERNA) and merchant tranche
- Initially only lithium-ion and pumped storage could participate. Broadened to include up to 10% of capacity going to other technologies – but need to have same RTE as Li-ion.



Zonal distribution of storage and pumped hydro grid connection requests (GW)

Policy example: UK 'cap and floor'

- 'Cap and floor' mechanism to incentivise investment (similar to that deployed for interconnectors between GB and continental Europe & Ireland).

- Two proposed 'streams'
  - Stream 1: TRL 9 and projects >100 MW
  - Stream 2: TRL 8 and projects > 50 MW

- Duration 6 hours+

- Contracts 'administratively allocated' (i.e. not auction), proposed assessment criteria include reducing system costs

- Electricity only

- Excludes technology that can be 'funded under existing market arrangements' (i.e. Li-ion) or have other support mechanisms (e.g. hydrogen)

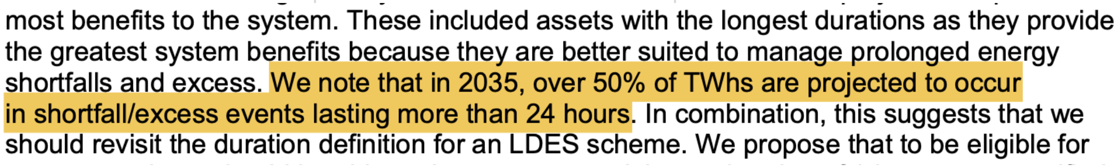
- Plan to award contracts in 2025…

Department for
Energy Security
& Net Zero

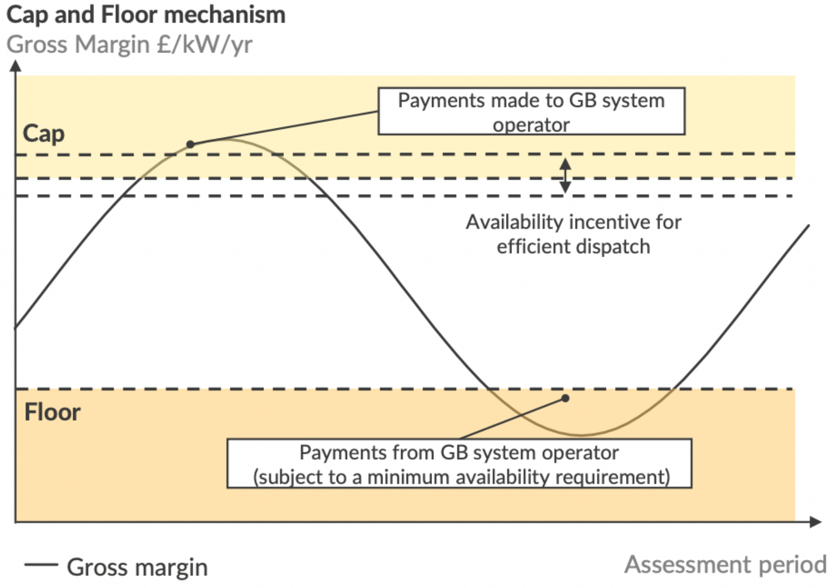
Long duration electricity storage consultation

Designing a policy framework to enable investment in long duration electricity storage.

Closing date: 5th March 2024



most benefits to the system. These included assets with the longest durations as they provide the greatest system benefits because they are better suited to manage prolonged energy shortfalls and excess. We note that in 2035, over 50% of TWhs are projected to occur in shortfall/excess events lasting more than 24 hours. In combination, this suggests that we should revisit the duration definition for an LDES scheme. We propose that to be eligible for



Source: Aurora, 'Long Duration Energy Storage' (17 February 2022): https://auroraer.com/media/long-duration-electricity-storage-in-gb/

Policy: United States – federal & state level

- Biden Administration targeting net zero power grid by 2035
- Inflation Reduction Act – significant (30%) tax credit benefits

- California Energy Commission found LDES need ranging from 5 GW (if gas stays on the grid) to 37 GW (gas retired) by 2045
- Has set a specific mandate of 1 GW of 8+ hour LDES for 2028. Apportioned between utilities on a load share basis.

THE NATIONAL CONSORTIUM FOR THE
ADVANCEMENT OF LONG DURATION
ENERGY STORAGE TECHNOLOGIES

- Led by Sandia National Laboratories and 5 other national labs, with strong industry participation.
- Focus on developing commercialization strategies for a full range of diverse LDES technologies.
- Funded 2023-2026

- New York has a 6 GW / 2030 storage target
- Includes USD 15m direct funding for 4 LDES projects
- Analysis suggests 35 GW of ‘multi-day’ storage needed by 2040

China & India

- Huge growth in renewables. Between 2023-2028, China to deploy almost 5x more than the EU and 6x more than the USA.
- Chinese rules require renewable plants to integrate storage equivalent to 20% of their generation capacity, with at least a 2–4 hour duration.
- Targeting 120 GW of pumped storage by 2030 (up from ~45 GW).

- 500GW of Renewables by 2030 (up from 122 GW in 2022)
- Power demand growing over 8% year on year
- Storage capacity required in 2030 expected to be ~60 GW / 336 GWh
- And by 2047 ~320 GW / 2,380 GWh
- The ’Energy Storage Obligation’ places requirements on distribution utilities to procure a minimum amount of their power consumption from energy storage.

Support for LDES

$2 Billion in Chile for energy storage, including LDES

$220 Million in Canada for energy storage

€1.1 Billion state aid in Hungary for energy storage, including LDES

£30 Million in United Kingdom for LDES

$505 Million in the United States for LDES

$1 Billion from World Bank for BESS

$350 Million in Spain for LDES

€341 million in Greece for energy storage, including LDES

Over $4 billion invested in LDES technologies in 2023, 2022 was $1.8 billion

IEA Feb 2024 Ministerial Outcome – encourages global targets on storage

IRENA – long duration storage report Q3

SUPERCHARGING BATTERY STORAGE
AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

Thank you

e: acampbell@ldescouncil.com

linkedin.com/in/alexcampbella1/

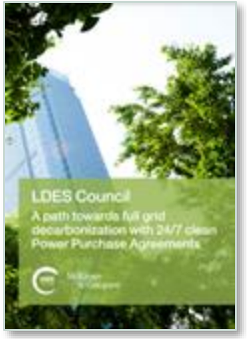
Our reports are at: ldescouncil.com/insights/

Coming up in 2024:

- Updated costs benchmarking
- Project tracker

Net-zero power

Long duration energy storage for a renewable grid



LDES Council

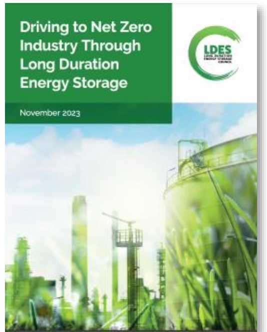
A path towards full grid decarbonization with 24/7 clean Power Purchase Agreements

The journey to net-zero

An action plan to unlock a secure, net-zero power system

Net-zero heat

Long Duration Energy Storage to accelerate energy system decarbonization



Driving to Net Zero Industry Through Long Duration Energy Storage

November 2023

10:30 – 11:00

Morning Tea

Upcoming Session: Technologies for Electricity Storage

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Session 1

Technologies for electricity storage

Presented by Elicia Cantelo (ARENA)

ARENA INSIGHTS

NEOEN

Hornsdale Power Reserve Inertia and Grid Services

March 2024

Key Project Stakeholders and Supporters

ARENA

Australian Government

Australian Renewable Energy Agency

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.

An Initiative of Government of South Australia

TESLA

ElectraNet

AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Contents

Figure 1 – Image of Hornsdale Power Reserve (Source: Neoen)

Project Overview

- Following the September 2016 state-wide blackout, Neoen and Tesla were selected by the South Australian Government to supply Australia's first grid scale battery named the Hornsdale Power Reserve (HPR).
- The HPR expansion project (HPRX) commenced construction in November 2019 with the installation of an additional 50MW, bringing the total installed capacity to 150MW.

The project received funding from:

  - South Australian Government's Department of Energy and Mining (DEM), through its Grid Scale Storage Fund - $15M
  - ARENA, through its Advancing Renewables Program - $8M

- The project contained several parallel work streams:
  - Demonstrate that BESS projects can provide inertia services, thereby replacing the inertia traditionally provided by synchronous generation
  - Expansion of the System Integrity Protection Scheme (SIPS)

Figure 2 – Map of region around the Hornsdale Pow er Reserve (Source: Neoen)

Virtual Machine Mode

Virtual Machine Mode

- ***VMM (Virtual Machine Mode)*** is a mode of operation which can be implemented on Tesla Powerpack inverters that mimics the behaviour and inertial response of a synchronous machine to grid disturbances.
- The virtual machine component runs in parallel with the conventional current source component.
- Like more traditional inverters, under stable system conditions the inverter's behaviour is driven by the ***current source component***. The inverter charges and discharges in accordance with the real and reactive power commands received from the operator.
- If there is a grid disturbance, the ***rotating component*** responds by:
    - Producing an active power response proportional to the rate of change of frequency
    - Producing a reactive current in response to changes in voltage.
- With VMM, there are two sources of inertia:
    - Rotor inertia (H)
    - Damping inertia (D)

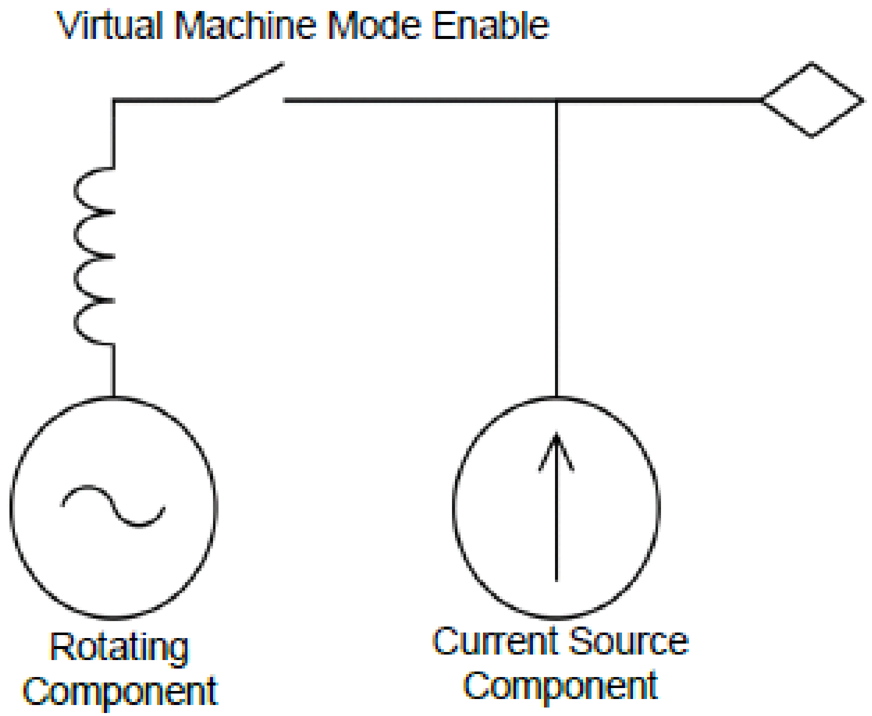


Figure 3 – Representation of VMM (Source: Tesla)

Traditional Inertia vs Synthetic Inertia

Figure 4 – Synchronous Condenser (Source: Electranet)

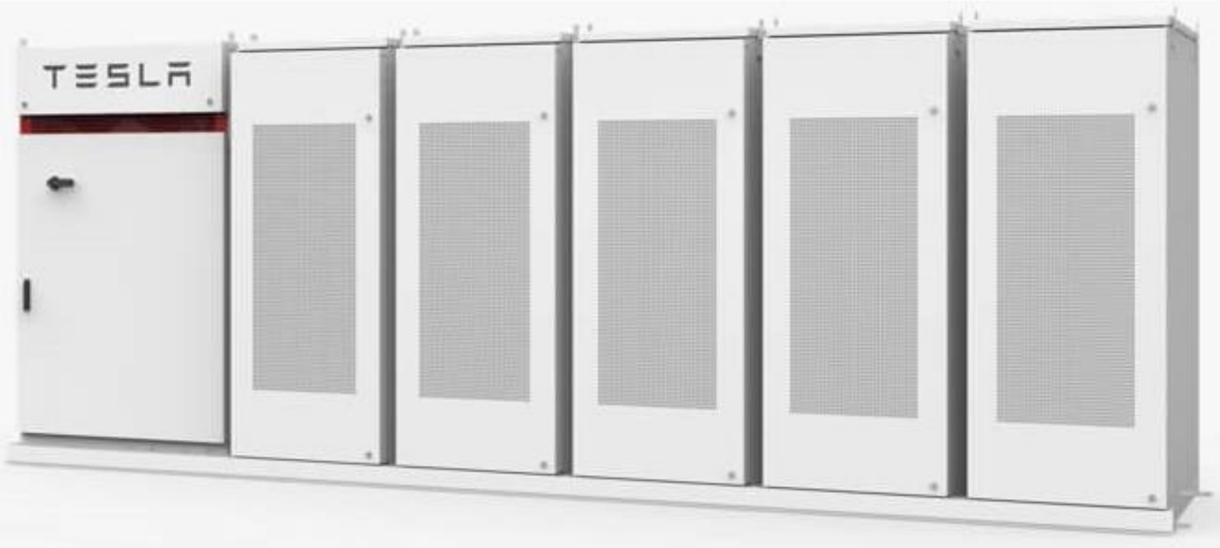


Figure 5 – Tesla Powerpack and Inverter Units (Source: Tesla)

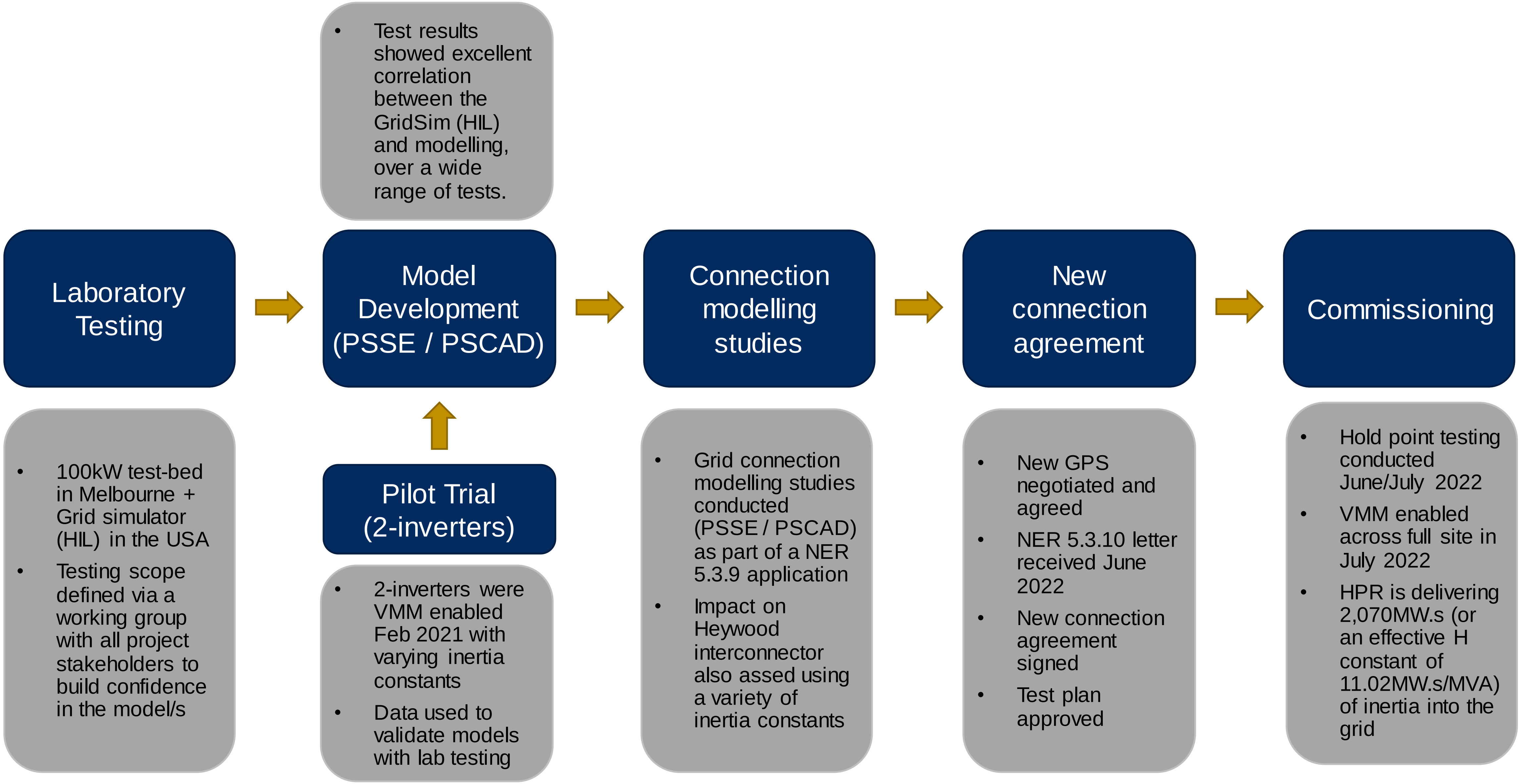
Traditional Inertia

- Power response is proportional to the Rate of Change of Frequency (RoCoF)
- Synchronous rotation provides a “metronome” to keep time through events (coupled in phase with grid)
- Inertia constant “H” is fixed, and dependent on rotational mass and radial velocity
- Typical overload ratings of 5-10 times nominal rating

Synthetic Inertia

- Inverter technology mimics the behavior of synchronous machines (with ***virtual*** rotating element) through advanced control systems.
- Inertia constant “H” is configurable to regional conditions
- Typical inverter overload ratings of 1.2-1.3 times nominal rating
- Tesla calls this feature “Virtual Machine Mode” (VMM)

Modelling, Testing, and Commissioning



Laboratory Testing

- 100kW test-bed in Melbourne + Grid simulator (HIL) in the USA
- Testing scope defined via a working group with all project stakeholders to build confidence in the model/s

Model Development (PSSE / PSCAD)

- Test results showed excellent correlation between the GridSim (HIL) and modelling, over a wide range of tests.

Pilot Trial (2-inverters)

- 2-inverters were VMM enabled Feb 2021 with varying inertia constants
- Data used to validate models with lab testing

Connection modelling studies

- Grid connection modelling studies conducted (PSSE / PSCAD) as part of a NER 5.3.9 application
- Impact on Heywood interconnector also assed using a variety of inertia constants

New connection agreement

- New GPS negotiated and agreed
- NER 5.3.10 letter received June 2022
- New connection agreement signed
- Test plan approved

Commissioning

- Hold point testing conducted June/July 2022
- VMM enabled across full site in July 2022
- HPR is delivering 2,070MW.s (or an effective H constant of 11.02MW.s/MVA) of inertia into the grid

Dual Inverter Trial Results

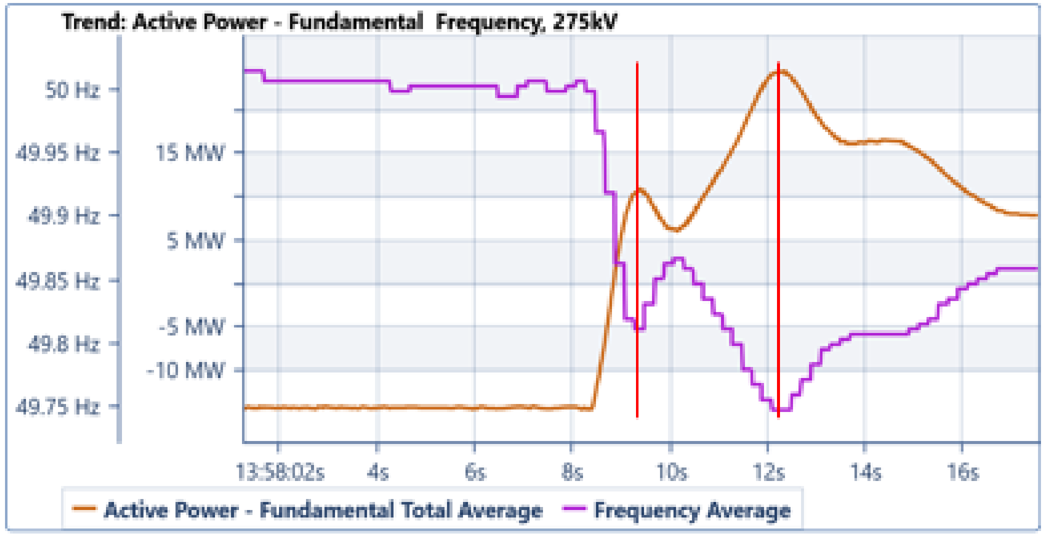


Figure 6 – HPR grid following response (Source: Neoen)

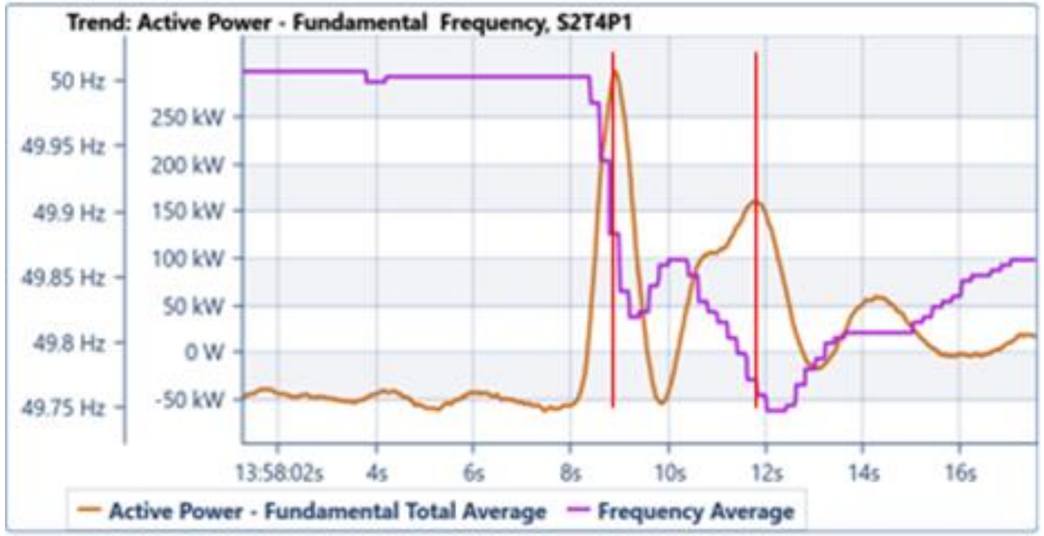


Figure 7 – HPR VMM enabled inverter (Source: Neoen)

Droop response (without inertia)

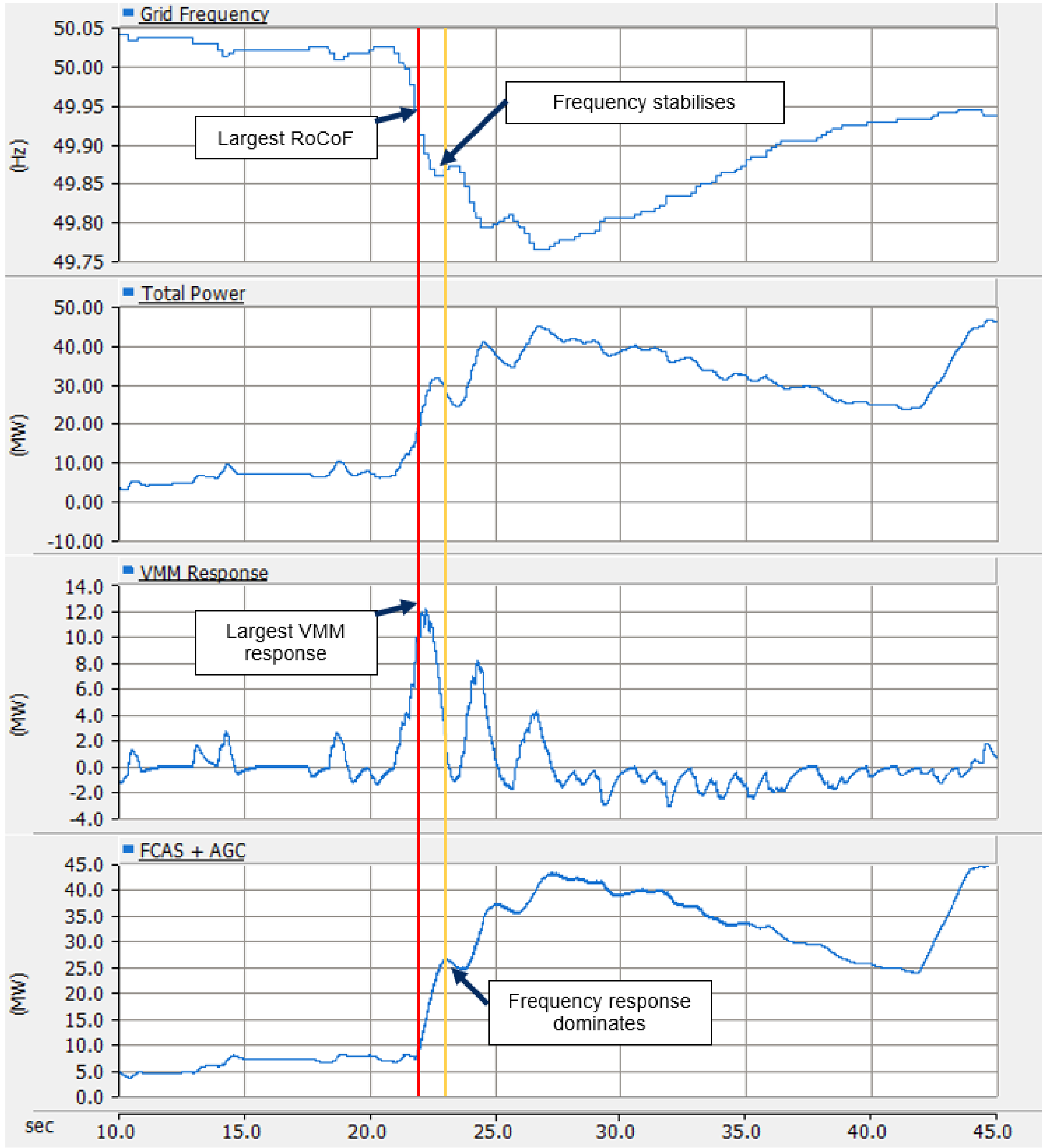
- This example was measured at a site level (>99% of inverters were not enabled for inertia)
- Active power response proportional to frequency
- Response commences when frequency departs the “dead-band”
- Maximum response at minimum frequency (nadir)

Virtual inertia (aggressive settings for dramatic effect)

- This example was measured at a single inverter (1 of 294) enabled as part of a pilot trial
- “H” constant was set to 50 (extremely large turbine)
- Maximum response at maximum RoCoF
- Response is faster and peaks prior to nadir
- Smaller response at minimum frequency

Full-Scale Deployment

- The final output (Total Power) is an aggregation of the 3 types of response:
  - Inertia (VMM Response)
    - The total inertia is the summation of rotor and damping inertia, with the final settings chosen yielding ~2,070 MW.s of inertia, and the overall equivalent H constant is 11.02MW.s/MVA.
  - Droop response + Secondary frequency control
    - AGC is received every 4-seconds as a “reference point”
    - Control system follows the AGC, and the droop response is provided as a delta to the AGC
- In the event analysed, it can be seen that VMM responds proportional to RoCoF, while FCAS is responding proportionally to the frequency deviation from a nominal 50Hz.
- A transition can be seen from the initially large RoCoF, where VMM dominates the response, to a reduced RoCoF, when standard droop response takes over.
- The transition occurs at the nadir of the first frequency drop.



Largest RoCoF

Frequency stabilises

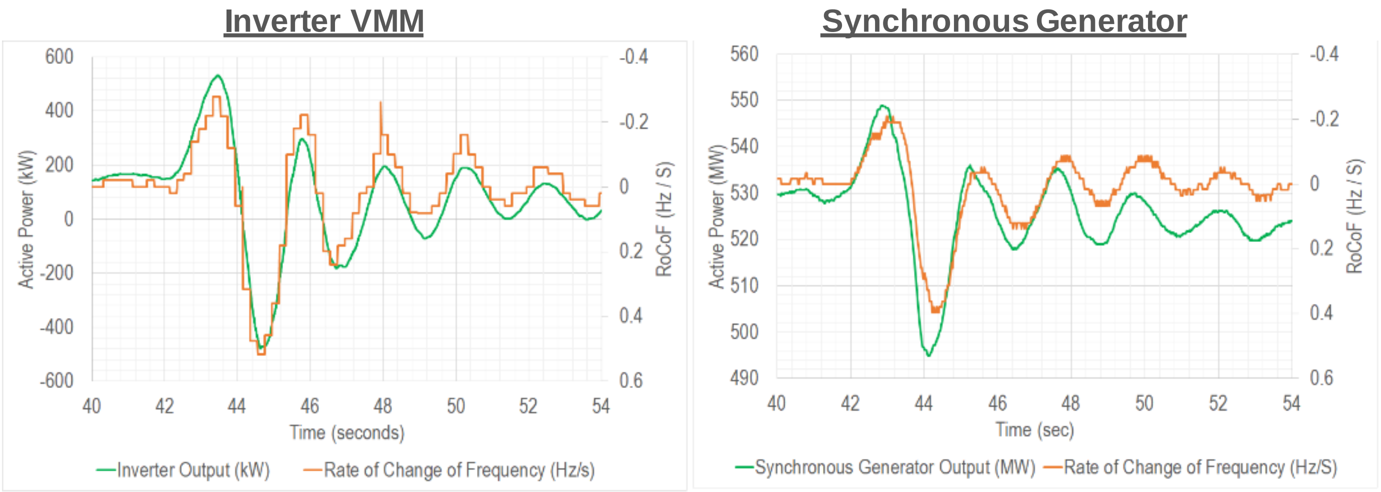
Largest VMM response

Frequency response dominates

Figure 8 – HPR aggregated and individual VMM and FCAS responses (Source: Tesla)

Results vs traditional generators

- In discussions with AEMO, an important consideration has arisen when quantifying the inertia contribution from inverter-based technology, and the amount of ***headroom*** that is available.
- The amount of inertia available from:
  - ***Traditional synchronous generators:*** inherently linked to the mass and velocity of the rotating elements (short-term overload ratings of up to 10 times nominal rating)
  - ***Inverters:*** limited to the maximum output limit and the active power setpoint at that point in time (~1.3 times nominal overload rating).
- As the active power setpoint increases, the inertia contribution from an inverter starts to reduce due to lower available headroom before the plant hits its maximum operating limit. For a BESS, this can be viewed in a similar way to FCAS trapeziums.



Figure/s 9 and 10 – comparison between HPR VMM response and example Synchronous Generator (Source: AEMO)

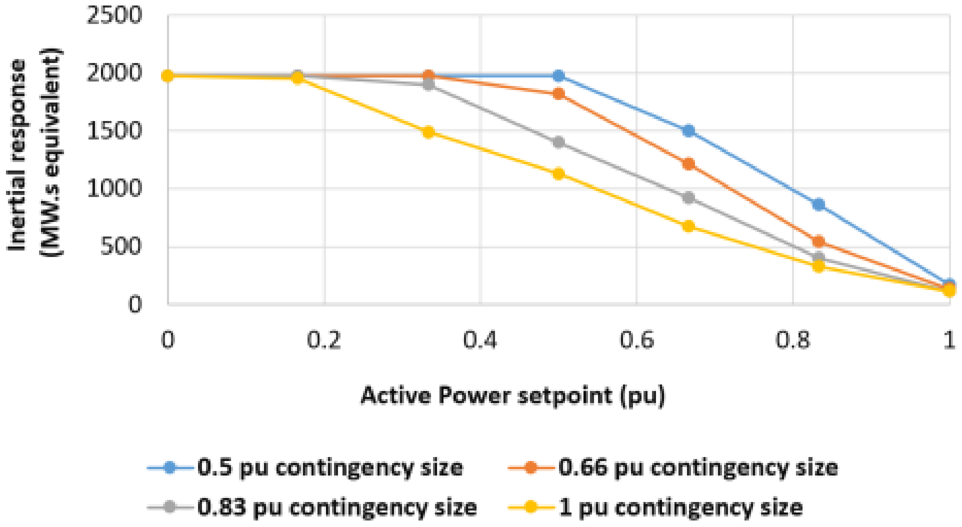


Figure 11 – Synthetic inertial contribution for an example GFM BESS, under various operating conditions and when exposed to different sizes of contingency (Source: AEMO)

System Integrity Protection Scheme (SIPS)
&
Wide Area Protection Scheme (WAPS)

Network Support – SIPS

- The System Integrity Protection Scheme (SIPS) was commissioned in December 2017 to detect and respond to conditions that occur in the lead up to loss of synchronism between South Australia and Victoria.
- The control actions include:
  - *Stage 1* – Rapidly injecting power from Battery Energy Storage Systems (BESS)
  - *Stage 2* – Shedding load at designated locations.
  - Upon receiving the SIPS “On” signal, the BESS active power rapidly increases its active power by 70MW
- ElectraNet, in consultation with AEMO, worked to improve the performance of the scheme using a time synchronised phasor-based scheme. The new scheme is called Wide Area Protection Scheme (WAPS)

Source: AEMO

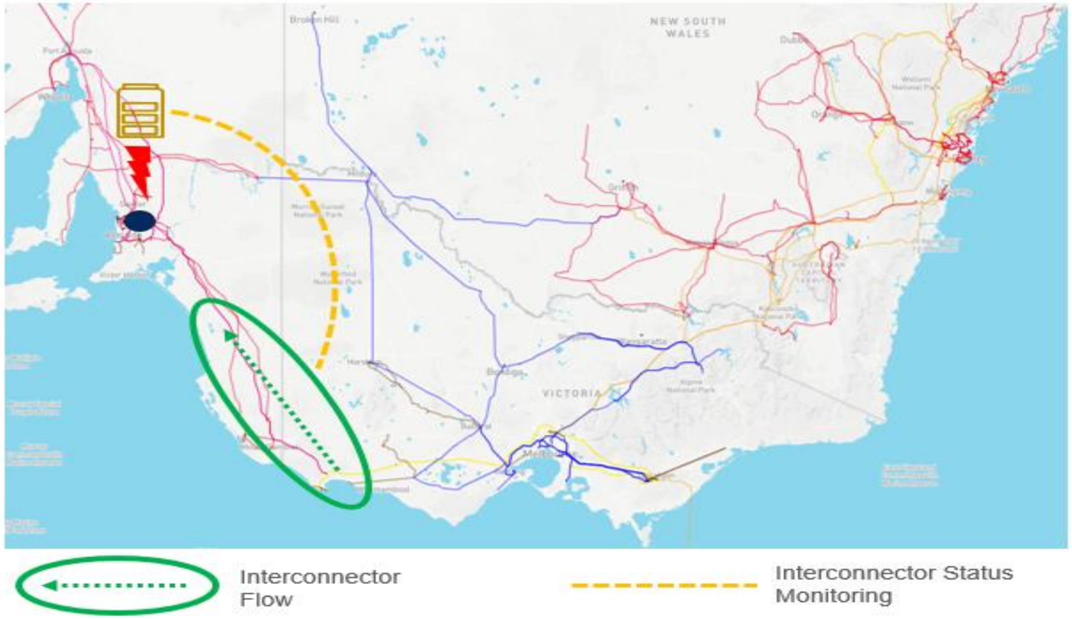
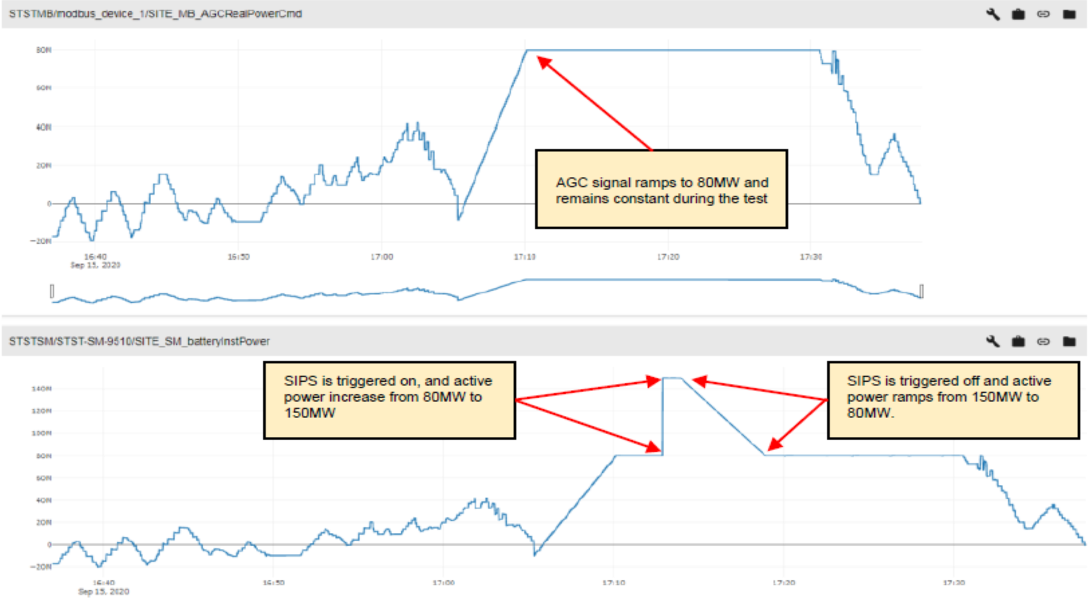


Figure 12 – representation of HPR SIPS flow and monitoring (Source: AEMO and Neoen)


STSTMB/modbus_device_1/SITE_MB_AGCRealPowerCmd

AGC signal ramps to 80MW and remains constant during the test

STSTSM/STST-SM-9510/SITE_SM_batteryInstPower

SIPS is triggered on, and active power increase from 80MW to 150MW

SIPS is triggered off and active power ramps from 150MW to 80MW.

Figure 13 – data from a SIPS test at HPR (Source: Neoen)

HPR Integration into WAPS

- Additional capacity and charging functionality from HPR in the WAPS will significantly improve the effectiveness of the WAPS, hence, the security and resilience of the SA power system to low probability, high impact non-credible contingencies.
- HPR now receives signals each corresponding to a required injection (discharge) or absorption (charge) of 30MW blocks, to create a response profile that is proportionate to the required change of flow on the interconnector.
- Enhanced data exchange from HPR provides ElectraNet with real-time site capability and support capacity

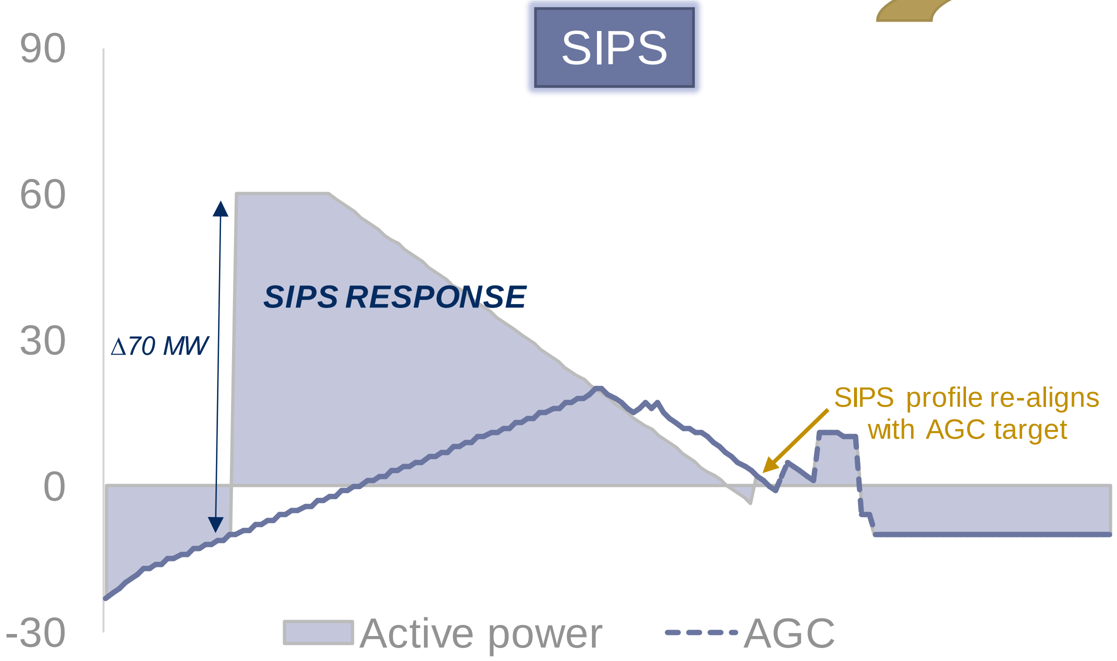


Figure 14 – representation of HPR SIPS response (Source: Neoen)

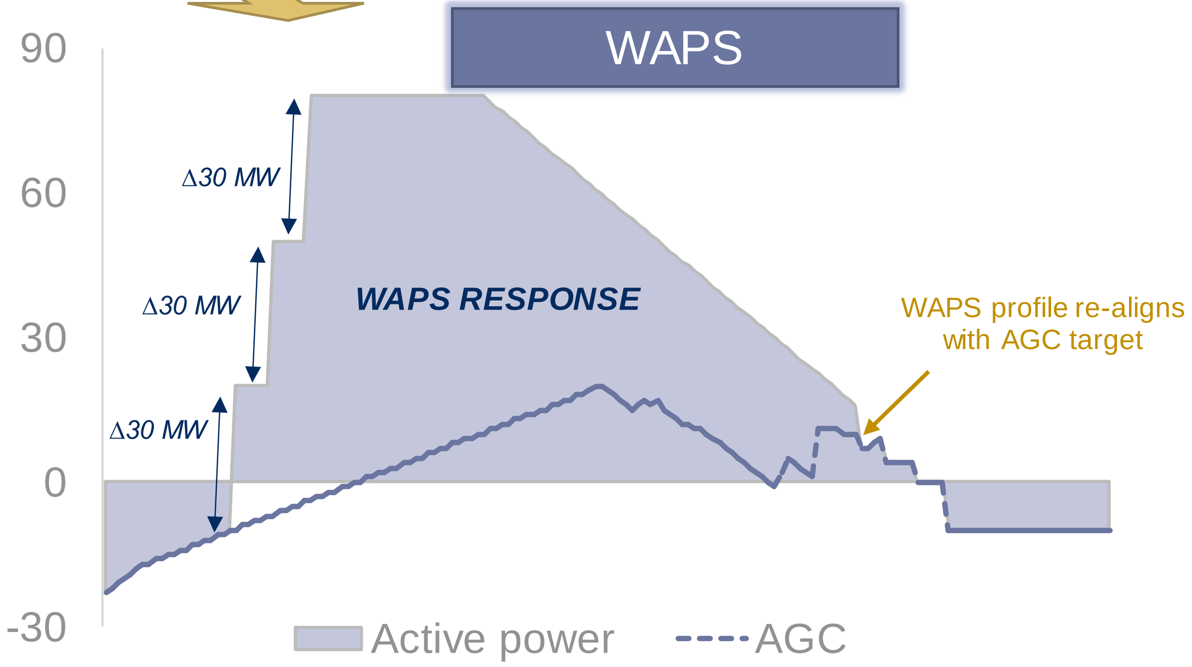


Figure 15 – representation of HPR WAPS response (Source: Neoen)

Thank you for listening

Edify™

ARENA INSIGHTS

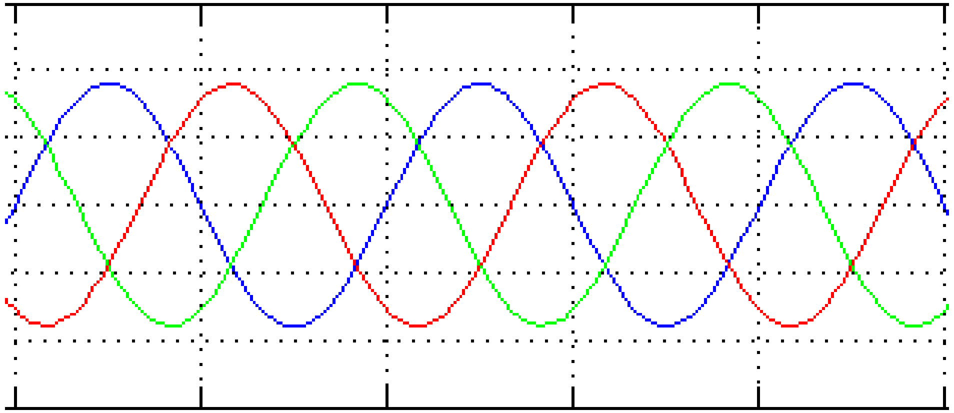
Storage for the Energy Transition

Grid Forming Batteries for System Strength

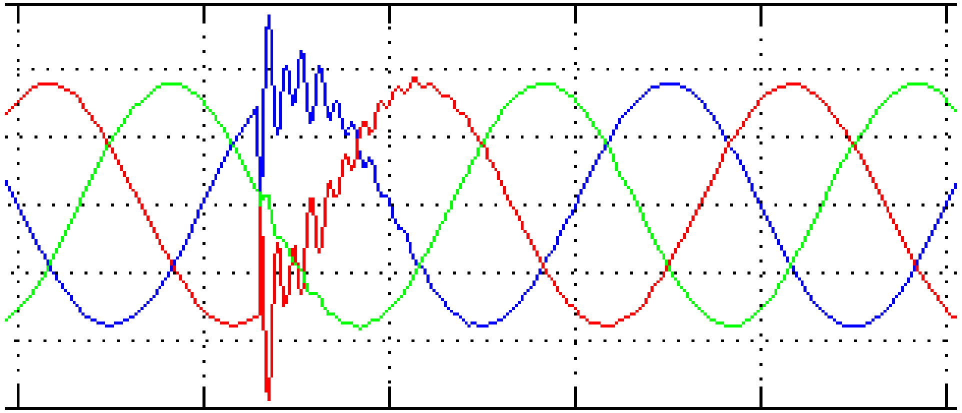
System Strength

What is System Strength?

> *"AEMO sees system strength as the ability of the power system to maintain and control the voltage waveform at any given location in the power system, both during steady state operation and following a disturbance"*
>
> **System Strength Impact Assessment Guidelines**



Voltage Waveform – Normal Conditions



Voltage Waveform – Disturbance

System Strength

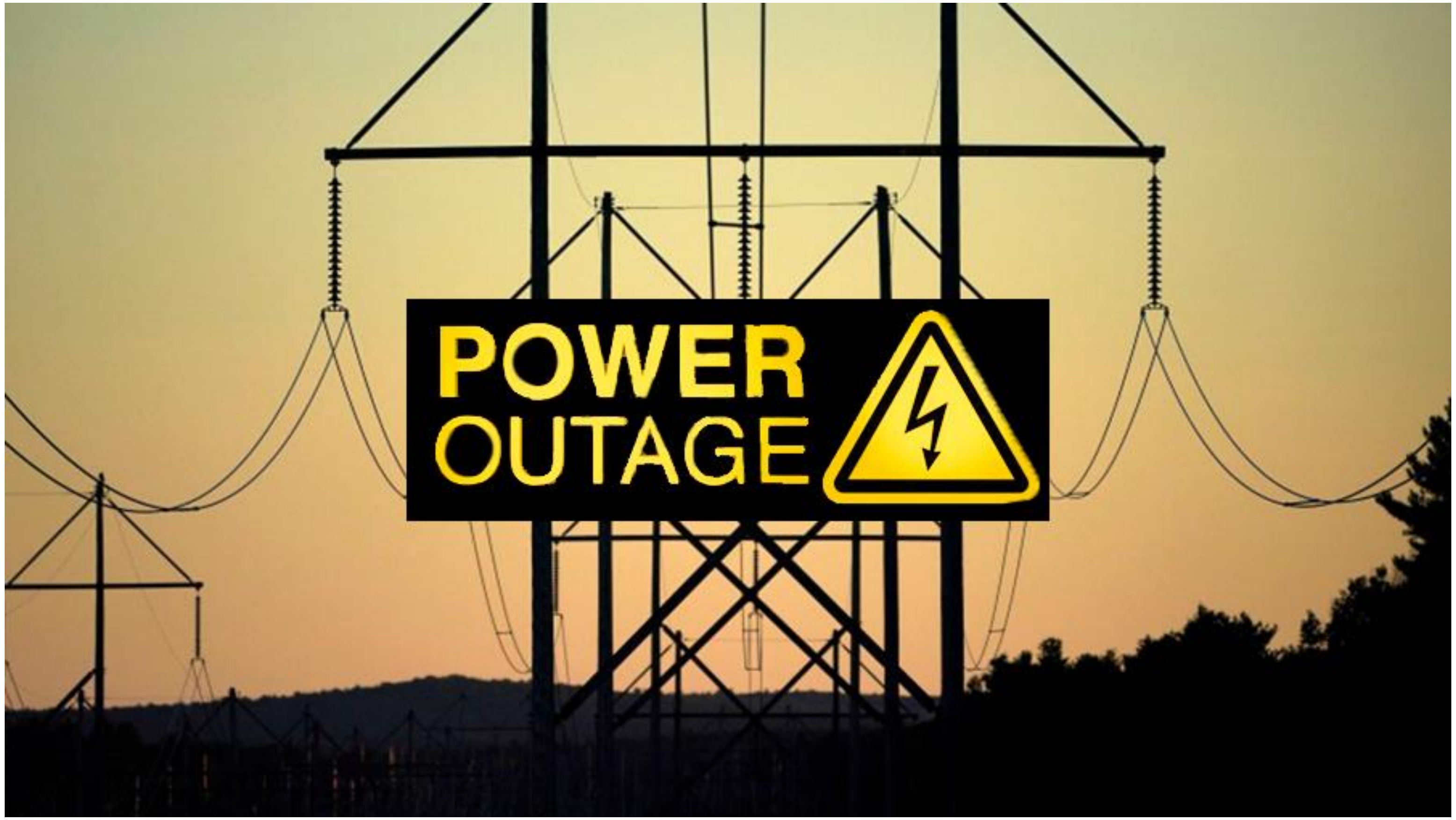
What is System Strength?

- Not easily quantifiable or measurable
- Required in certain amounts to operate a reliable network
- Inherently provided by synchronous generators
- Not provided by the majority of inverter-based generators (solar and wind)
- Location specific

System Strength

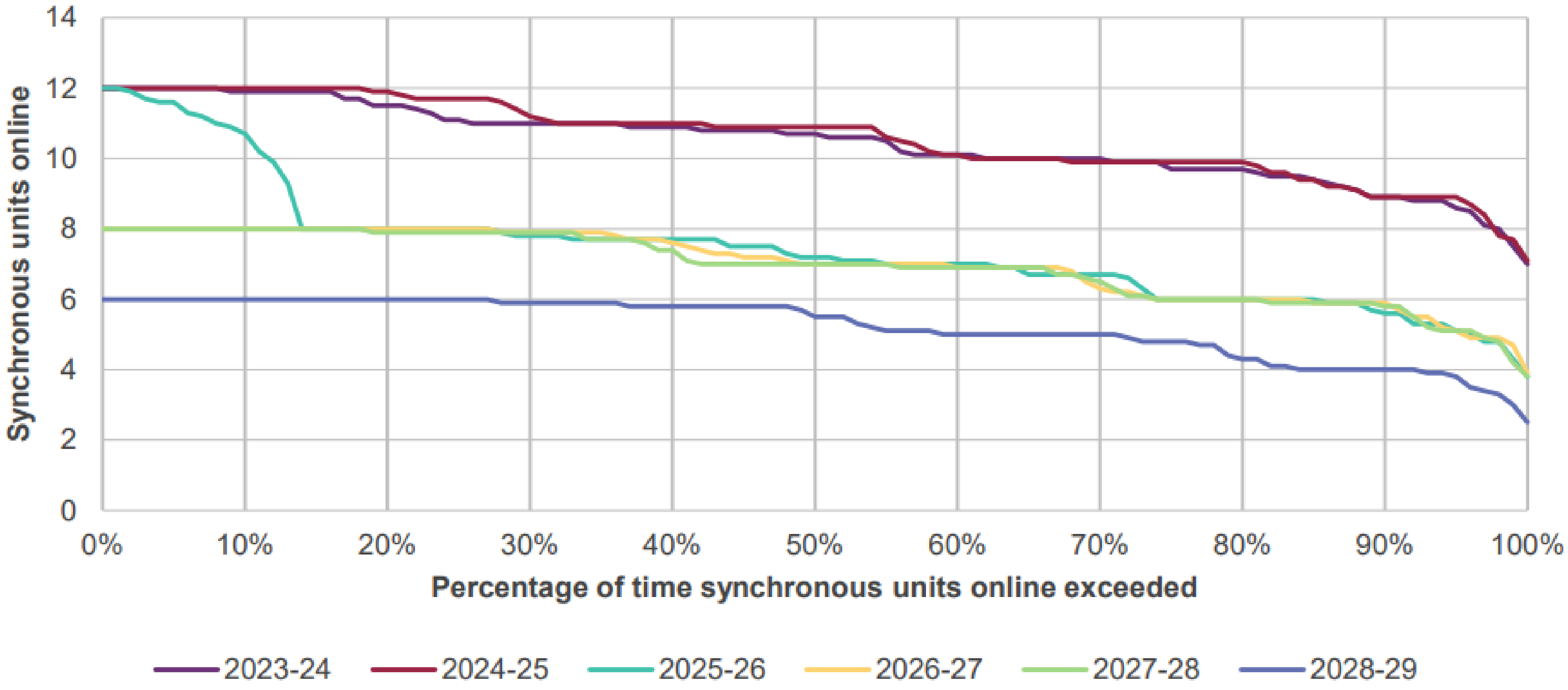
Why do we need it?

- Maintain a functioning grid
- Avoid System Strength Constraints



Energy Transition

Declining provision of system strength by Synchronous Generation

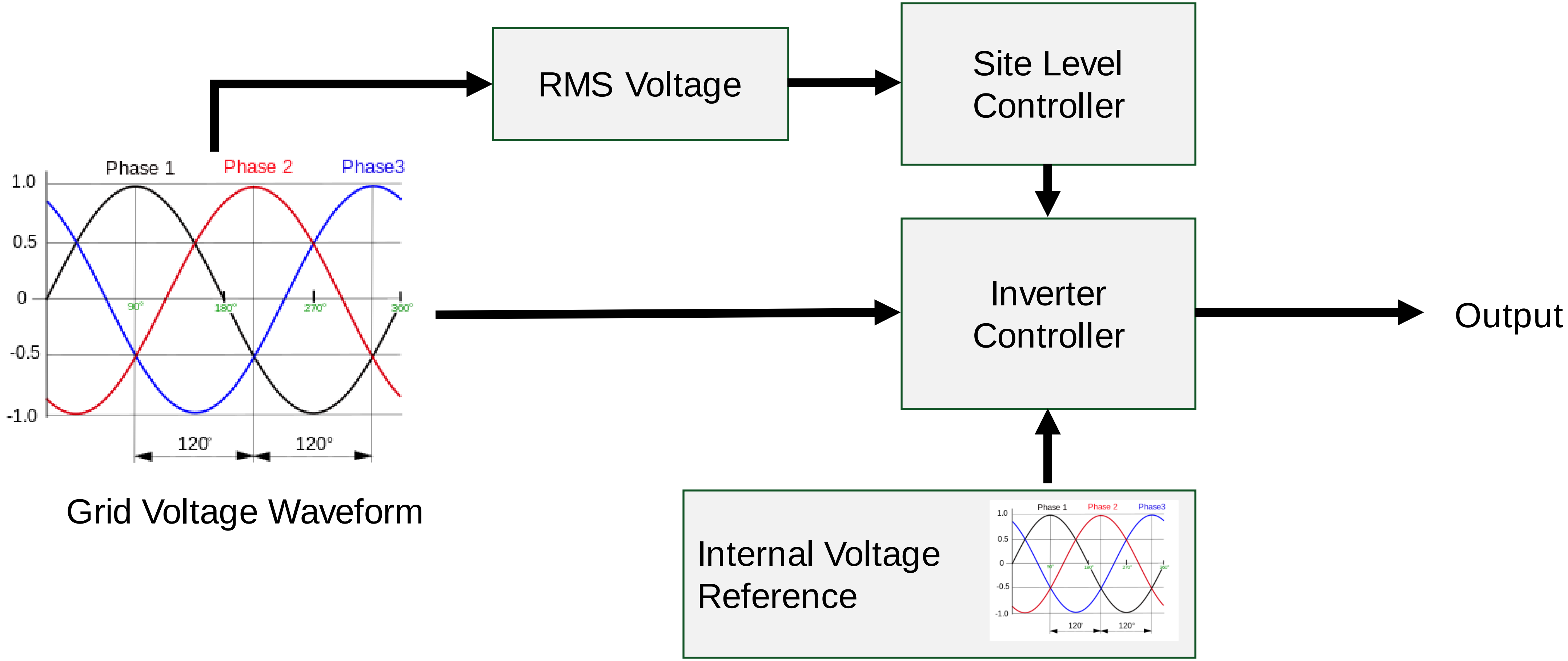


Source: AEMO 2023 System Strength Report – Synchronous units projected online under Step Change scenario, New South Wales

Batteries with Grid Forming Inverter

Can Grid Forming Inverter Based BESS Provide System Strength?

Grid forming inverters can provide system strength by mimicking how rotating machines operate.



RMS Voltage

Site Level Controller

Inverter Controller

Output

Grid Voltage Waveform

Internal Voltage Reference

Darlington Point Energy Storage System

150MW Grid Forming Battery

- 150MW/300MWh
- Grid Forming BESS
- Tesla Megapack 2
- Intent to demonstrate that the grid forming inverters can provide system strength
- Delivered with equity partner Federation Asset Management

Achievements

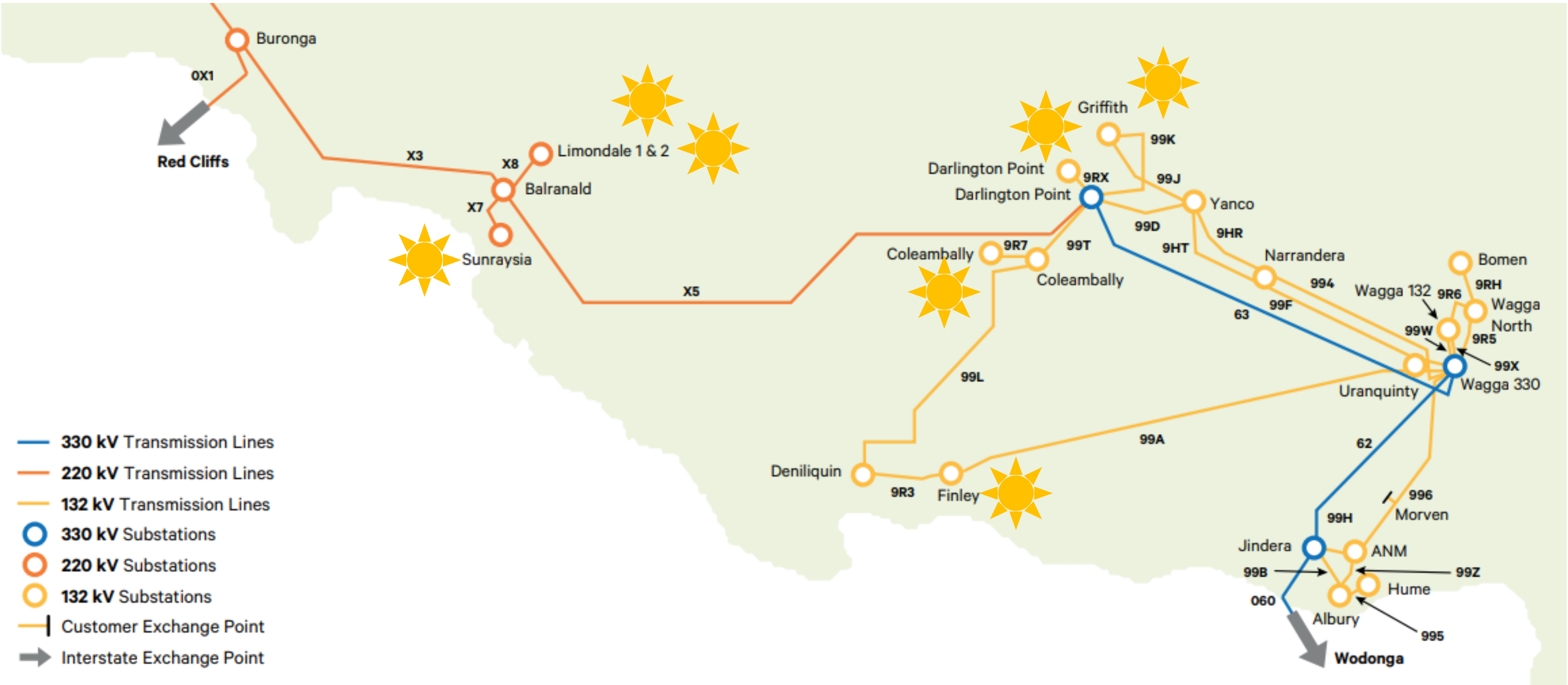
Key Achievements to Date

- ✓ One of the first projects to agree a GPS suitable for grid forming inverters
- ✓ Registered and Commissioned in 2023
- ✓ Operating as grid forming from first energisation
- ✓ Achieved full operation in September 2023
- ✓ The project is contributing to the growing acceptance that grid forming BESS can contribute to System Strength as evidenced through two network processes

Improving Stability in Southwest NSW

Improving Existing Network Constraints

- 1 GW + Existing Solar
- Constraints due to voltage stability
- RIT-T identified 150MW BESS as being able to alleviate the constraints
- Preferred to other network options

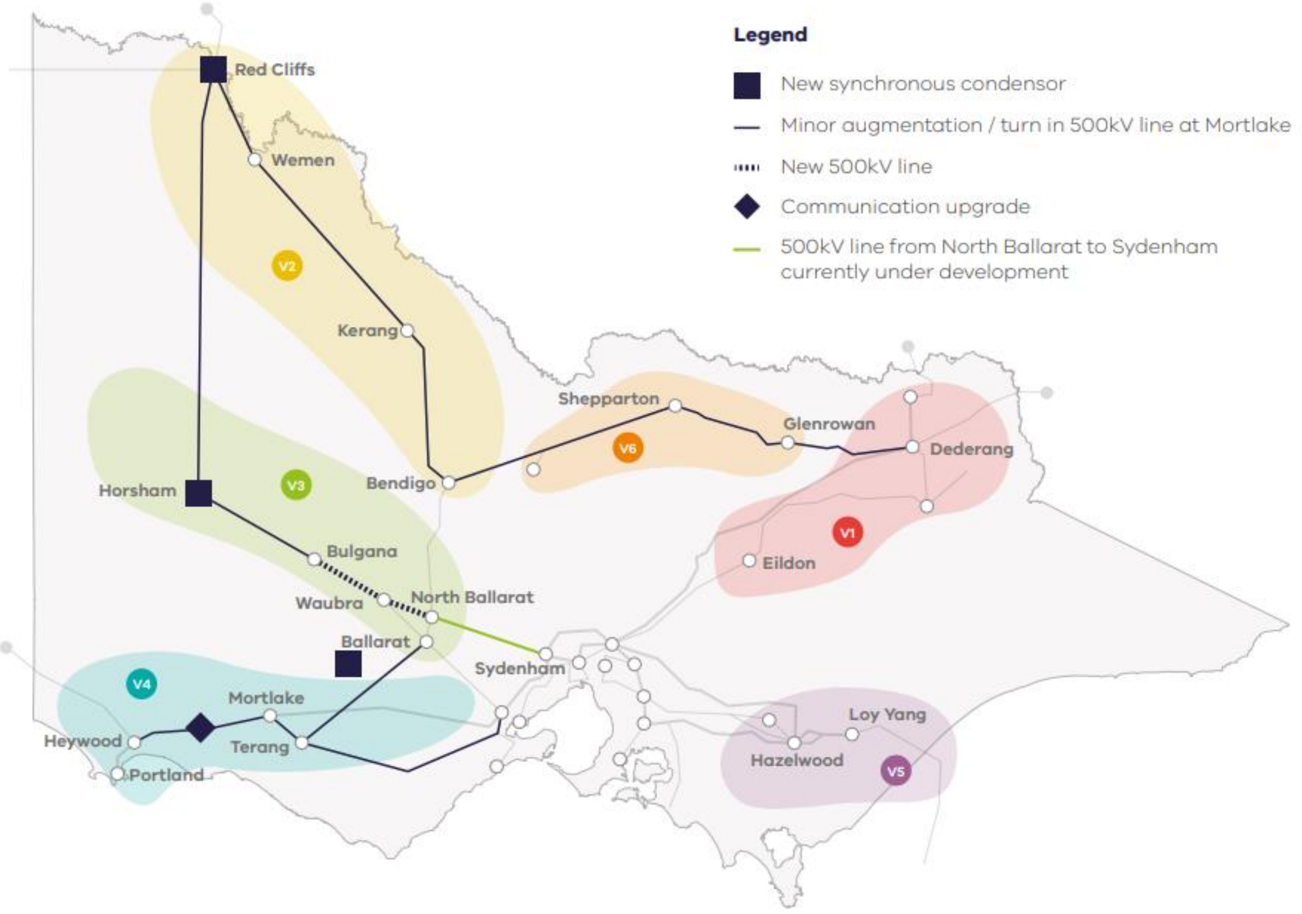


Source: Transgrid TAPR 2023

Increasing Generation in Murray River

Koorangie Energy Storage System

- System Support Agreement AEMO to provide services to strengthen the power system and increase the potential for generation in the Murray River region.
- Increase the renewable hosting capacity of the Murray River REZ by up to 300MW
- Displaced Synchronous Condensers
- Being delivered in partnership with owners Sosteneo Infrastructure Partners



Source: Victorian Renewable Energy Zones Development Plan

Impact of Providing System Strength

Provision of System Strength

- Can be provided without impacting on the market operation of the BESS
  - Full Export
  - Full Import
  - Idle

- Does not require additional hardware or oversizing of key equipment

- Overall low impact to change from grid following to grid following:
  - Little if any difference in hardware
  - OEM control systems and model readiness are critical
  - Grid connection process can accommodate.

ARENA

Insights Forum

26 Mar 2024

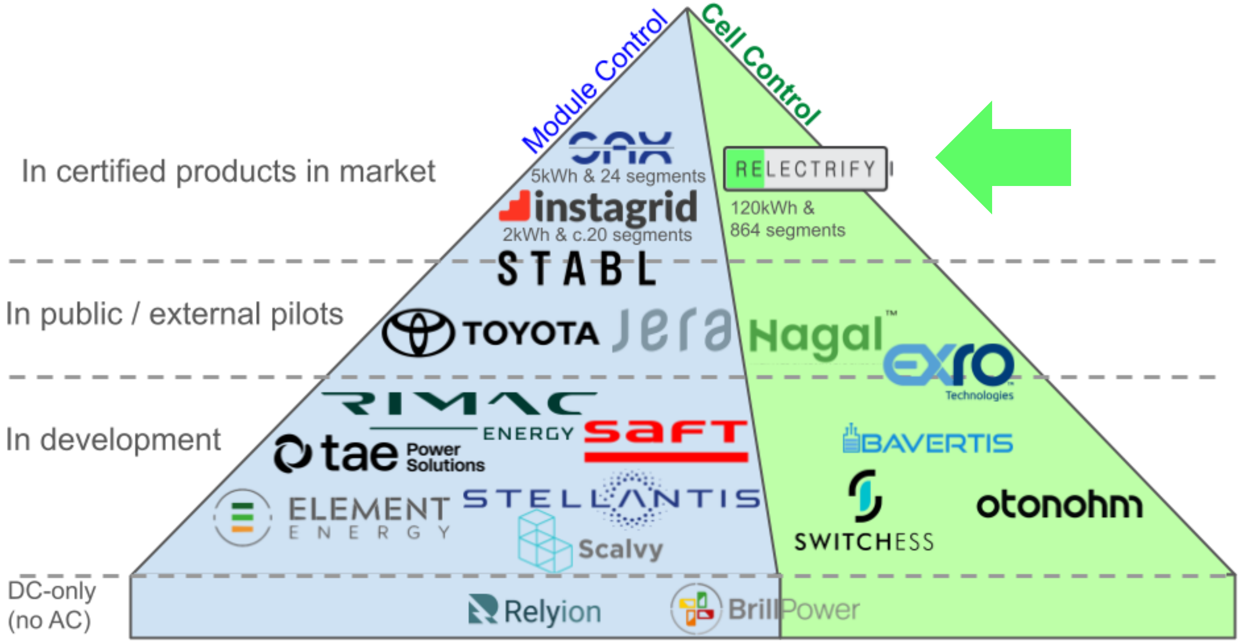
Relectrify is a global leader in cell-level control

RELECTRIFY

Based in Melbourne,
backed by global investors

cefc · TOYOTA VENTURES · gsfutures · edp · Energy Innovation Capital · Energy Environment Investment

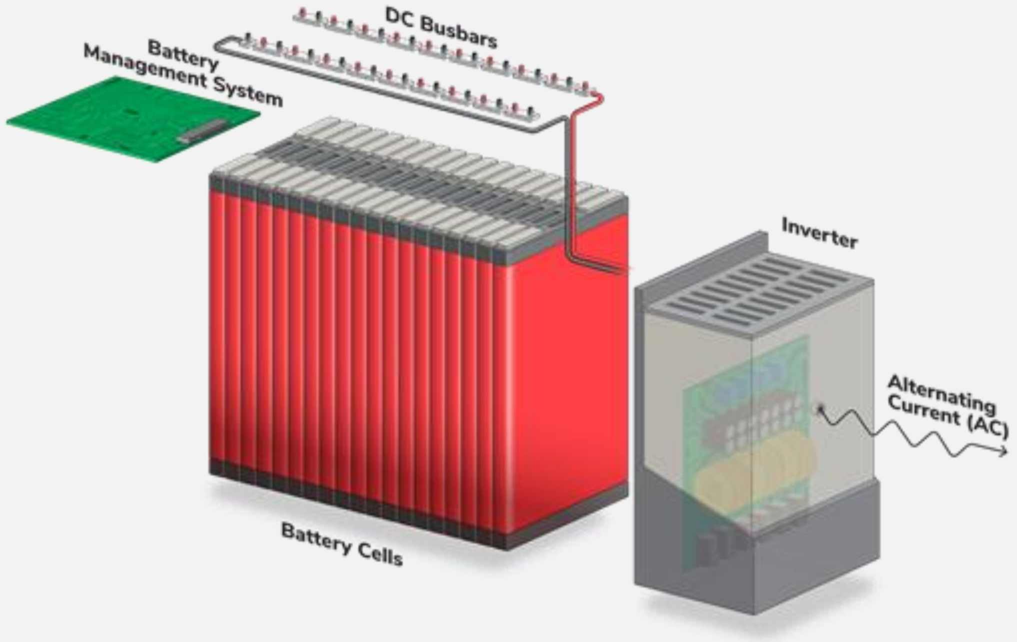
The world's first certified BESS using full cell-level control



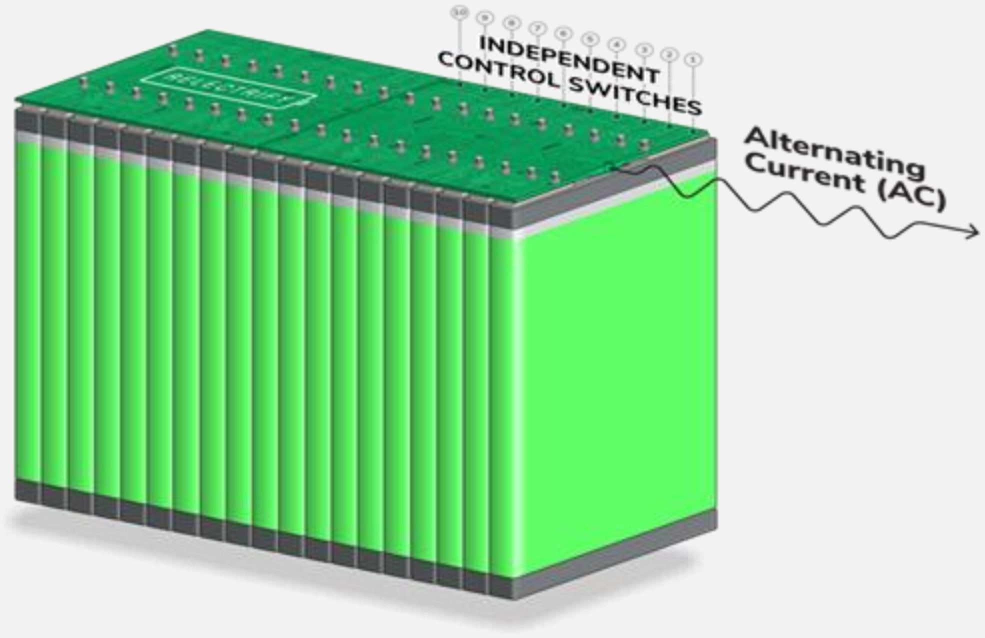
Distributed Battery Management Inverters: The New Frontier For Life-Extended, Cost-Reduced Batteries *[Cleantechnica, DEC 2023]*

Cell-level control is fundamentally different

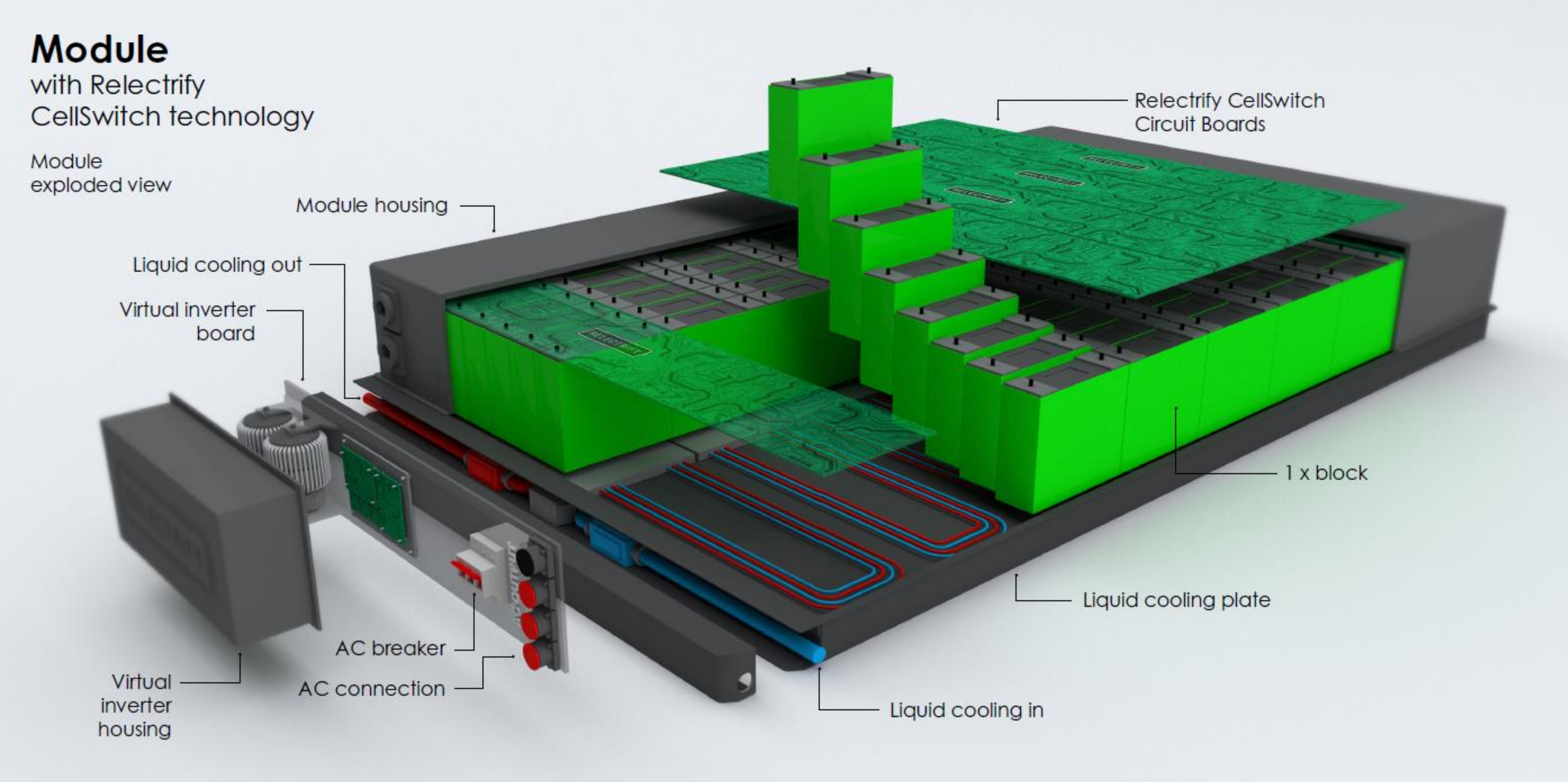
Conventional system architecture



Relectrify CellSwitch^{TM} architecture

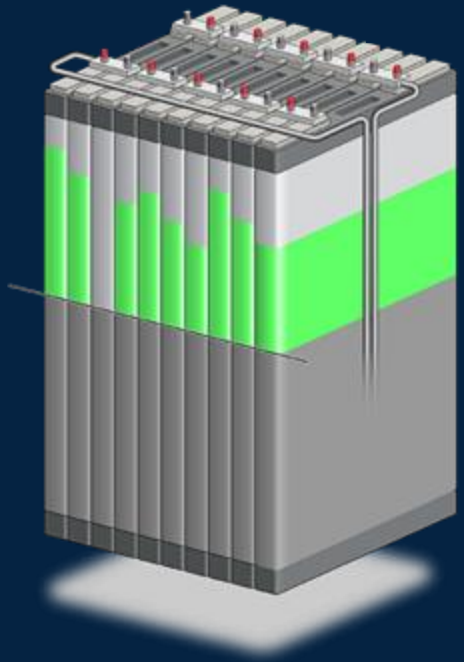


The AC battery module

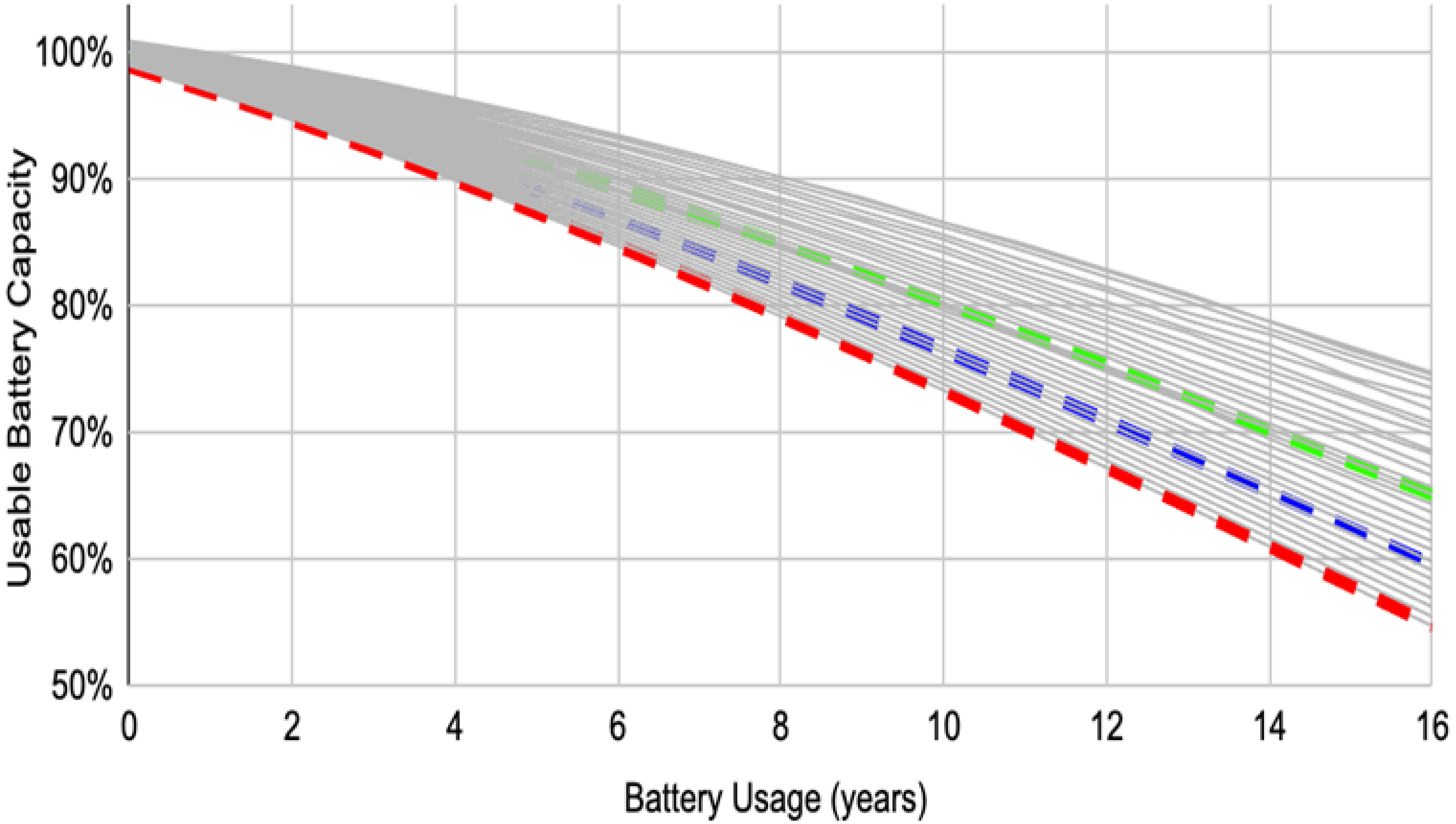


Architecture to deliver longevity

Maximising BESS performance by managing each cell individually



Indicative BESS capacity curve over time(Source: Cleantechnica December 2023)



RELECTRIFY

Engineered to unlock better project returns

Improved system energy density

Extended system longevity

Lower project costs

Advanced safety protections

Accurate real-time system status

Cell + chemistry agnostic

Automatic balancing

Engineering the future of battery energy storage

Jeff Renaud

CEO

Jeff.renaud@relectrify.com

info@relectrify.com

www.relectrify.com

RELECTRIFY

Panel Discussion

Diana Tulip

Asset manager
Neoen

Sam Hill

Asset Manager, Edify

Jeff Renaud

CEO, Relectrify

Jesse Steinfeld

Energy Transition manager, Transgrid

Chris Mock

Principal engineer,
AEMO

12:30 – 1:30

Lunch

Upcoming Session: Long Duration Storage Technologies

Australian Government
Australian Renewable Energy Agency

ARENA

ARENA INSIGHTS
KNOWLEDGE FOR INDUSTRY

Insights Forum 2024 | Sydney

Australian Government
Australian Renewable Energy Agency

ARENA

Session 2

Long Duration Storage Technologies

Presented by Dr. Tania Benedetti (ARENA)

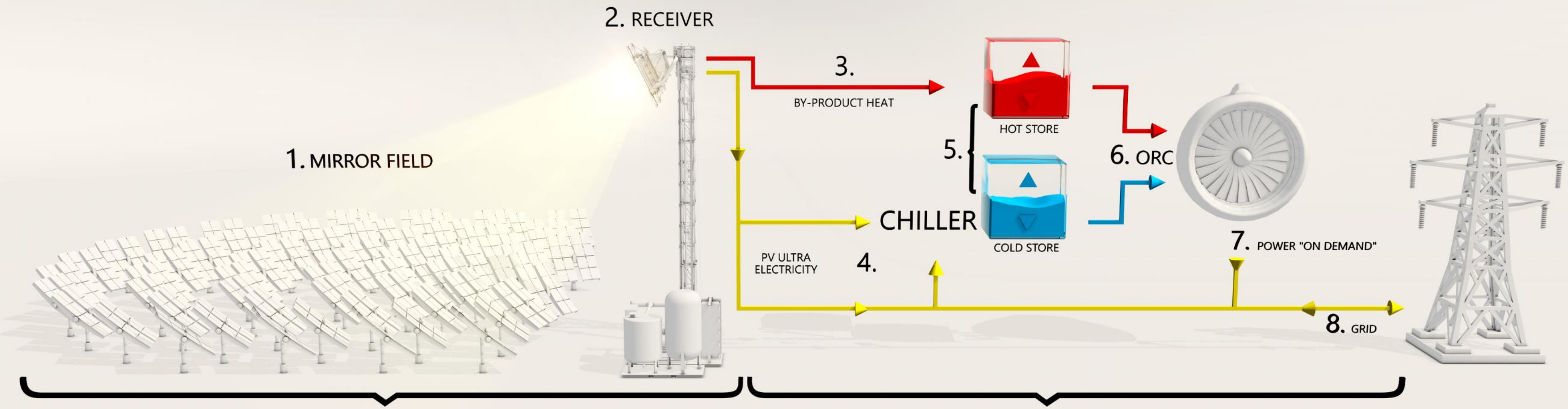
ARENA INSIGHTS

RAYGEN


Broken Hill
Menindee
NEW SOUTH WALES
Dubbo
Newcastle
Wollemi National Park
Orange
Bathurst
Whyalla
Port Pirie
Sydney
Clare
Wallaroo
Renmark
Raygen PV Ultra Thermal Hydro
Griffith
Leeton
Wollongong
Goulburn
Port Lincoln
Adelaide
Nowra
Mount Barker
Wagga Wagga
Canberra
Kangaroo Island
Ngarkat
Echuca
Albury
Shepparton
Kosciuszko National Park
VICTORIA
Robe
Mount Gambier
Melbourne
Geelong
Traralgon
Warrnambool


High Lift Branch Channel
High Lift Branch Channel
Raygen PV Ultra Thermal Hydro
S W Angle Rd
S W Angle Rd
S W Angle Rd

Storage duration can be flexibly and independently configured by increasing/ decreasing pit size; **typical durations range from 8-24 hours**



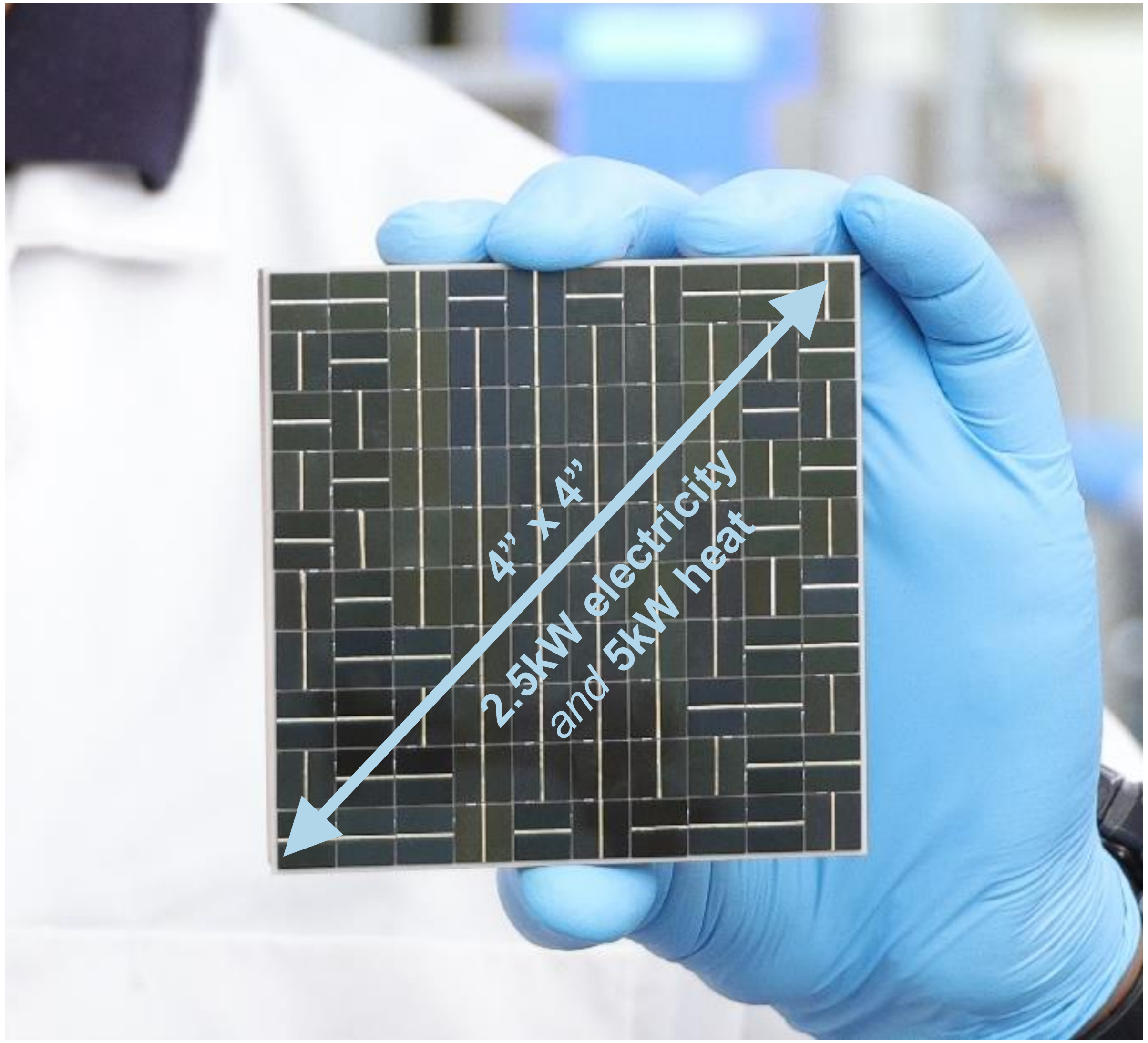
Solar

Not 'CSP' – Mirrors focus sunlight onto RayGen's photovoltaic modules, which convert light directly to electricity (water-cooling captures additional heat).

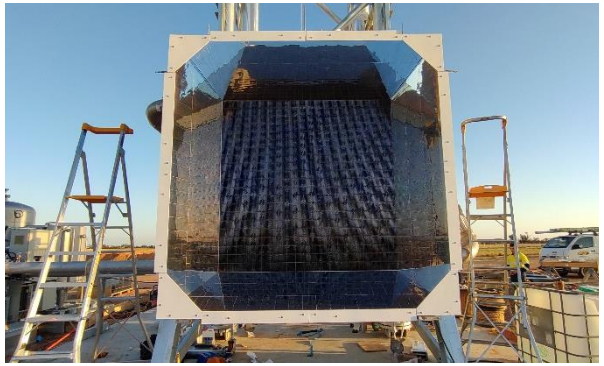
Storage

By-product heat from RayGen's solar boosts efficiency of RayGen's storage. Storage can be charged by on-site solar, or by the grid. Solar can export to the grid, or charge storage.

Exceptional, high performance RayGen solar modules



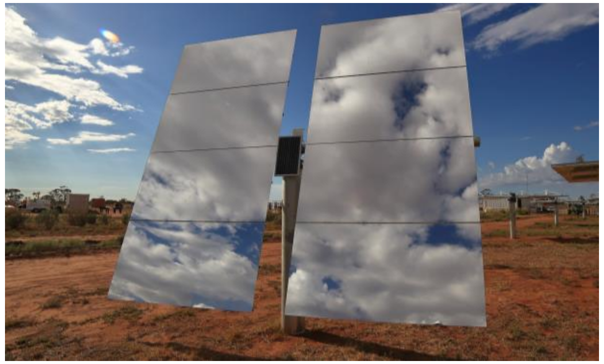
RayGen-made solar modules fabricated in Melbourne, AU
No polysilicon used



Over 400 modules in receiver for 1 MW of electricity, 2 MW of heat

RayGen converts 1/3rd sunlight to electricity and 2/3rd heat

Low cost, low complexity, self-powered mirrors



Self-powered, wireless mirror tracking

Pile-driven posts
No field wiring
No concrete foundations

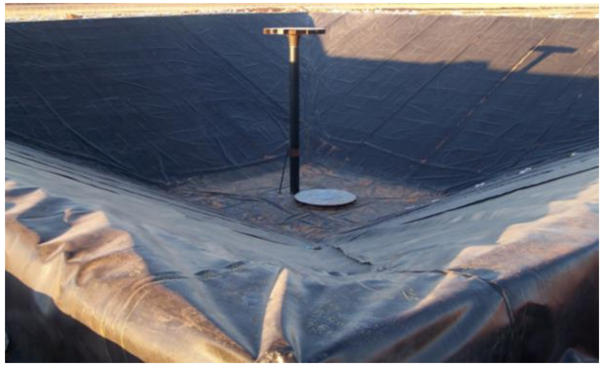
Co-located with grazing agriculture since 2014

Pit thermal energy storage (PTES)

Structurally lowest cost storage medium (hot & cold water)

PTES, an established technology, has capability for *seasonal storage,* with **<10% energy loss over 6 months**

Simple, low risk pit construction;
Max depth of 15-20 m



Simple, high efficiency, low-cost rubber insulation

Lowest cost storage medium (water);
Filtered and treated from any water source (river, well, sea)

Storage power block

Standard industrial chillers, heat pumps, turbines and generators

For every 1 MWh into the chiller, RayGen can recover 0.7-0.8 MWh out of the ORC, for **net round-trip efficiency of 70-80%**

Hot PTES charged with ‘free’ by-product heat from solar

Cold PTES charged with high efficiency industrial chiller

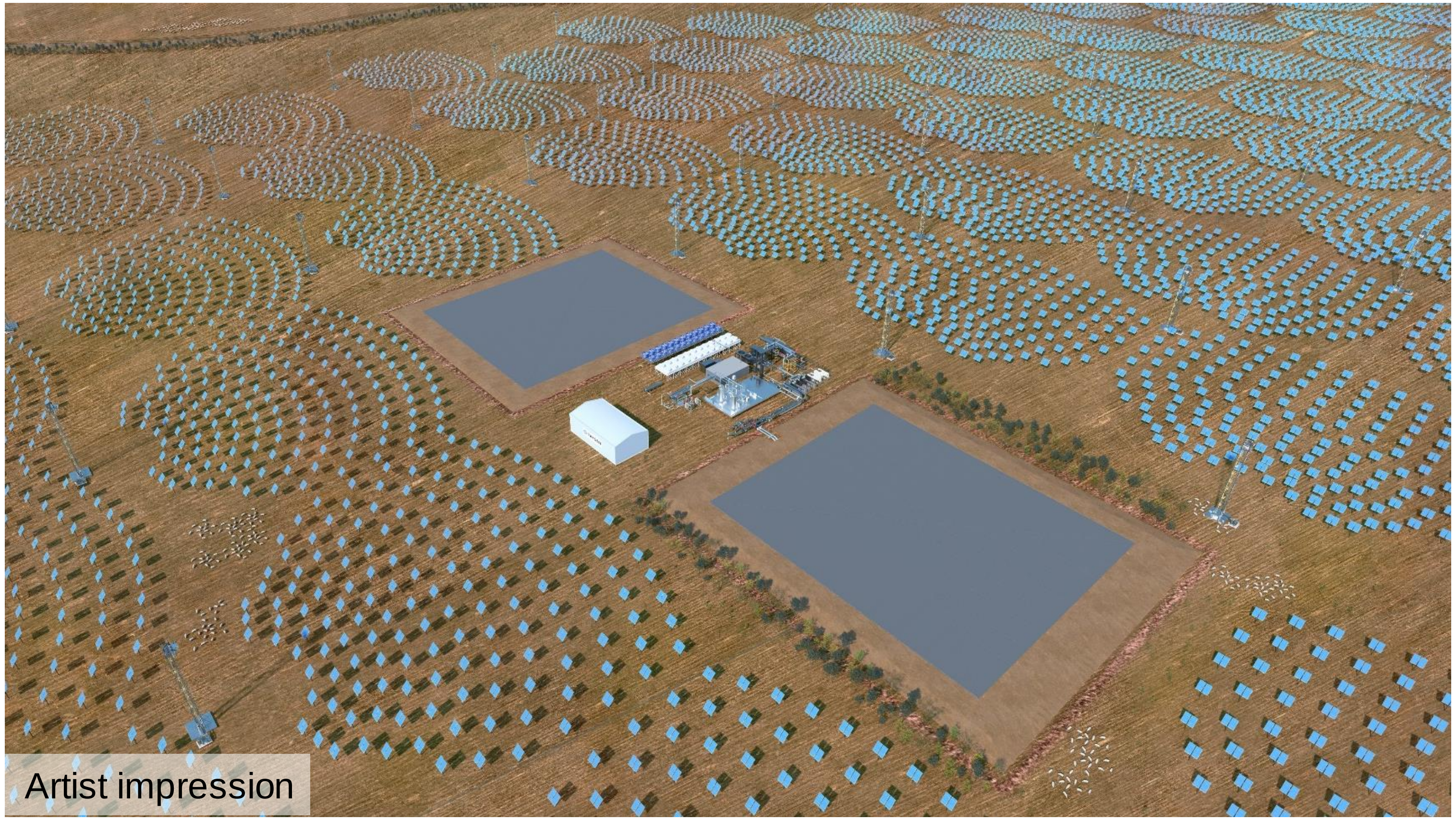
Uses conventional geothermal turbine

Future projects

Subsequent projects will scale-*out* RayGen's modular technology


Photo

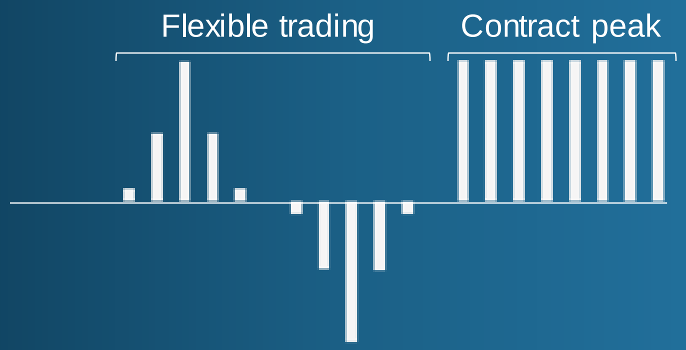

Artist impression


Artist impression

50 MWh Solar Power Plant One, Carwarp
4 MW Solar – 4x 1MW PV Ultra towers
3 MW Storage – 1x 3MW ORC w/
50 MWh (**17 hours**) – 2x 17,000m^3 pits

1.4 GWh Solar Power Plant Two
50 MW Solar – 50x 1MW PV Ultra towers
29 MW Storage – 1x 29MW ORC w/
350 MWh (**12 hours**) – 2x 165-200,000m^3 pits
x4

Customers are seeking flexible generation to maximise on-grid revenues and reliable generation to minimise energy costs



	GREEN PEAKER & TRADING	GREEN BASELOAD
Objective	Maximum profit (IRR) across energy products	Lowest cost (PPA) of supplied electricity
Requirements	100% reliable dispatch (capacity and contract peak); high/low trading; ancillary services & inertia; green subsidies	100% reliable supply of electricity; contingent capacity in event of fault; system strength
Integrations	On-site RayGen solar to charge storage; option to charge storage from grid, wind, other solar PV; behind-the-meter loads	On-site RayGen solar to charge storage; integration with wind, diesel gen-sets, open-cycle gas turbines; local loads; H2 and NH3
Markets	On-grid only	On-grid, hydrogen and remote

RAYGEN

RayGen.com

Suitability of zinc-bromine flow batteries for LDES

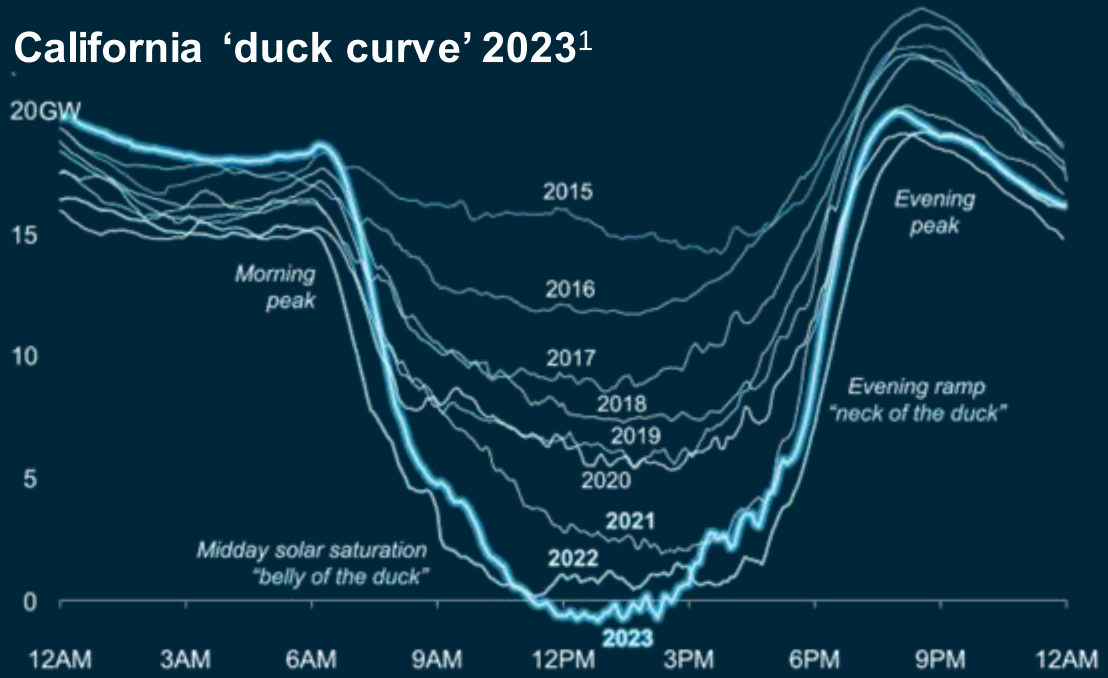
and their role in reliable energy delivery.

Presented by: Conan Jones, Product Manager

LDES increasingly seen as crucial to the energy transition

Renewables acceleration generates new challenges that LDES is best equipped to solve

California 'duck curve' 2023[1]



Source: CAISO | @BPBartholomew
Note: Net load shown is demand minus utility-scale wind and solar

> *"Long-duration energy storage is not a luxury, but a necessity. This is not an economic paradigm, it's a reliability paradigm."*[2]

Key LDES applications

- Bulk energy shifting
- Renewables integration
- Energy arbitrage
- Back up source

Redflow aligned to core LDES requirements

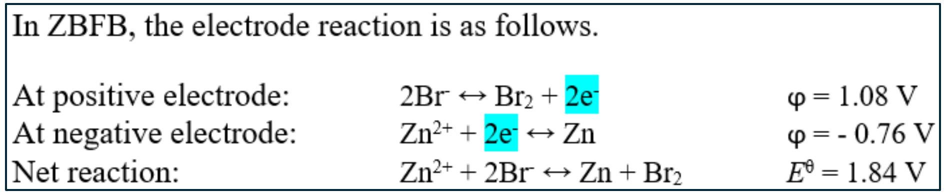
- Use 100% energy
- Flexible duration
- Frequent cycling & long life
- High temperature tolerance
- Fully recyclable and no fire risk

---

1. CAISO
2. PNNL.gov, *Long-Duration Energy Storage: The Time Is Now*, May 2023, Citing PNNL study in Journal of Energy Storage, *Defining long duration energy storage*, April 2023

Zinc-bromine flow battery chemistry

- Using the Zn-Br redox reaction for energy storage was patented over 100 years ago and has been investigated by the likes of Exxon and Gould (for EPRI) in the 70's and several others since then.[1]
- A major benefit is that it yields 2 electrons per half-reaction.
- The electrolyte component materials are also abundantly available: zinc the 4th most abundant metal on earth and bromine occurring naturally with salt deposits and desalination activities.
- An organic complexing agent (BCA) is added to a high-purity form of a standard industrial oil/gas-well finishing fluid.
- This BCA captures the bromine (Br_2) as it develops at the positive electrode (during charging), while metallic zinc is plated onto the negative electrode.



In ZBFB, the electrode reaction is as follows.

At positive electrode:	$2Br^- \leftrightarrow Br_2 + 2e^-$	$\varphi = 1.08$ V
At negative electrode:	$Zn^{2+} + 2e^- \leftrightarrow Zn$	$\varphi = - 0.76$ V
Net reaction:	$Zn^{2+} + 2Br^- \leftrightarrow Zn + Br_2$	$E^\theta = 1.84$ V

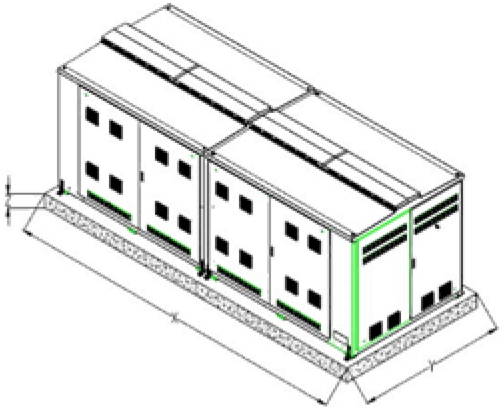
Zinc-bromine redox reaction and resulting half-cell potentials.[2]

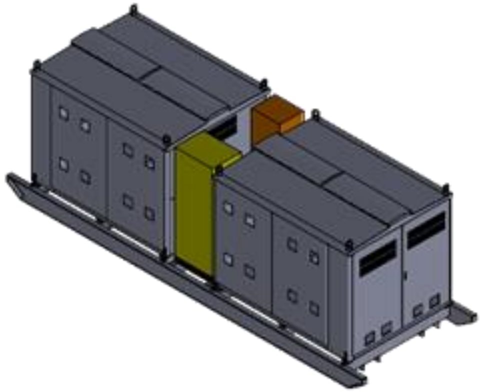
---

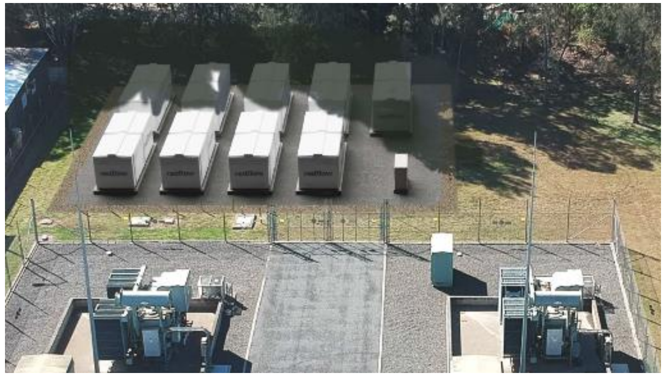
1. EPRI Research Project 635-1, *Assessment of Technical and Economic Feasibility of Zinc/Bromine Batteries for Utility Load-Leveling, May 1979.*
2. Chemical Engineering Journal, volume 380, *Low-dimensional nitrogen-based carbon for Br_2/Br^- redox reaction in zinc-bromine flow battery*, January 2020

Zinc-bromine flow battery solution

Proven building block for scale up to multi-MWh systems





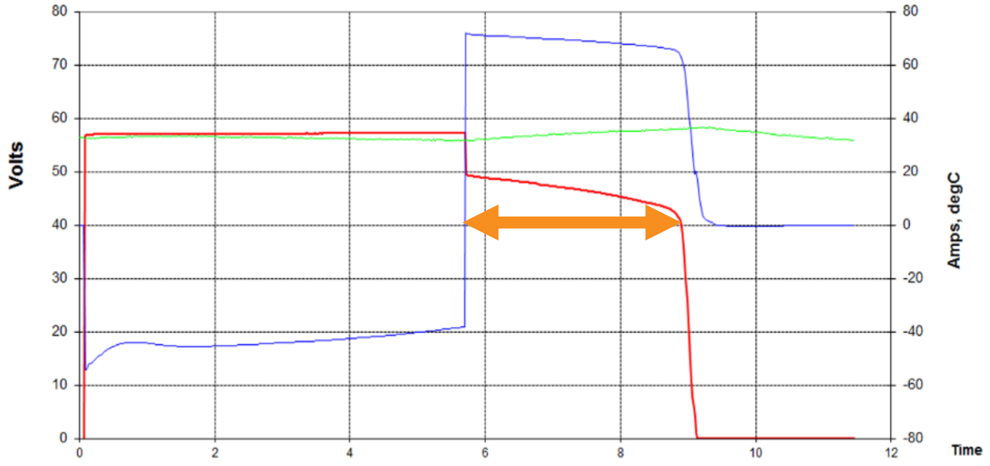


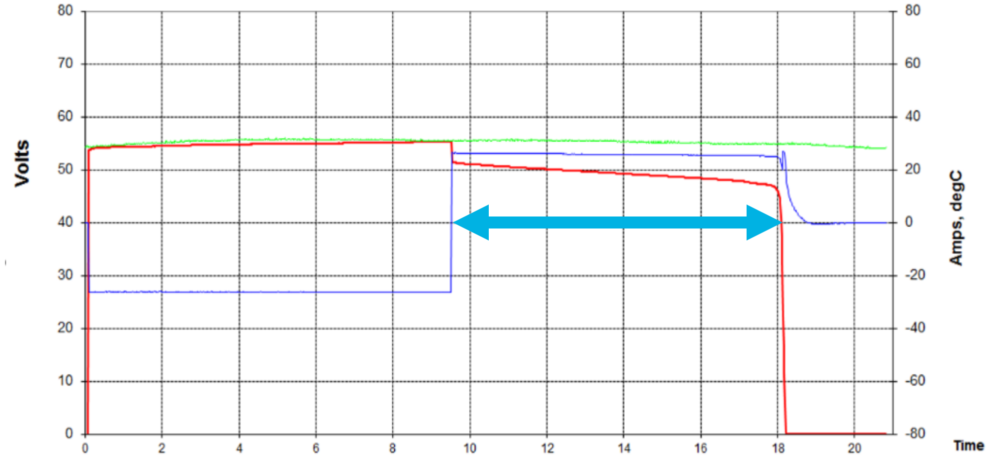
+ Proven globally deployed solutions since 2008
+ Fire safe aqueous & fire-retardant electrolyte
+ Chemistry lends itself to LDES
+ Zero self-discharge in hibernation mode

+ The 200 kWh Energy Pod concept (using the core ZBM3 batteries) designed as a stand-alone enclosure for C&I needs.
+ Delivered as 2 per 20 ft container and mounted back-to-back as a ‘Pod-Pair’, they become an ideal building block to meet the needs of many MWh-scale projects.
    + Large C&I (“Anaergia” 2 MWh)
    + Community Batteries (“Paskenta” 15 MWh, “Barona” 6.6 MWh)
    + Remote & semi-utility (“VCH” ~35 MWh)
    + Within distribution networks (“EQ” 4 MWh)

+ Can be delivered from Thailand as complete system (FAT) or with dry batteries for US electrolyte filling.
+ Ease of site install with robust parallel connection architecture and 850 Vdc output enable MWh deployments with larger industrial central storage inverters from 1 MW.

Zinc-bromine flow battery charge/discharge characteristics

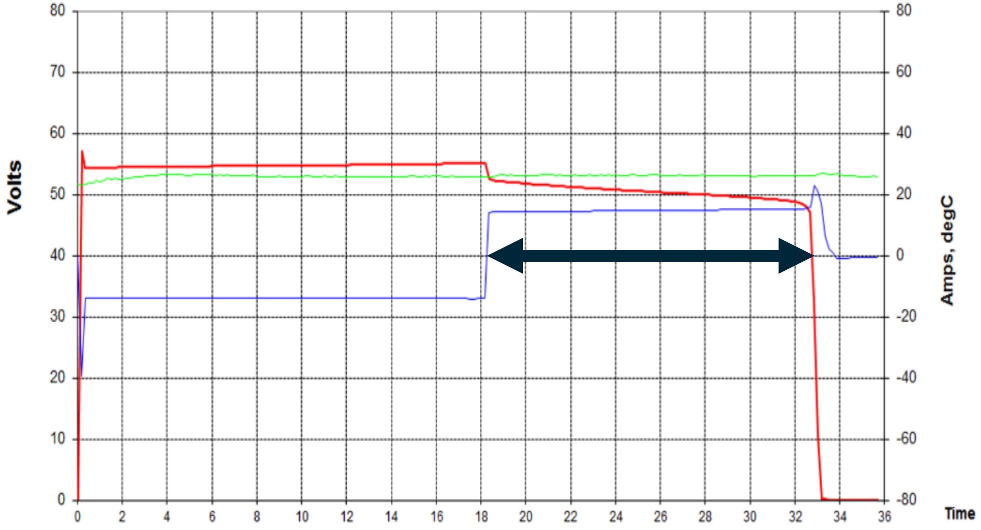


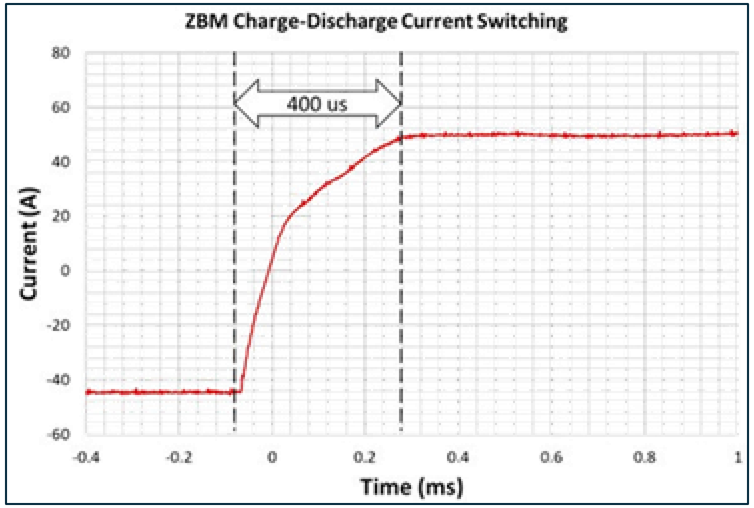


3.1 kW for 3:18 hrs (45.5 Vdc & 68 A)

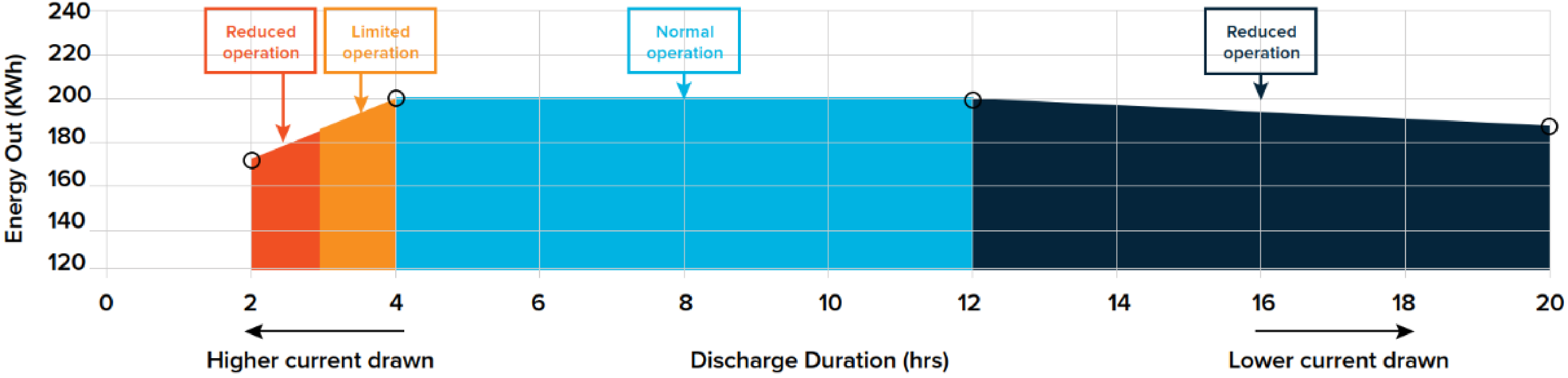
750 W for 14:48 hrs (49.8 Vdc & 15 A)

1.25 kW for 8:42 hrs (49 Vdc & 25.8 A)

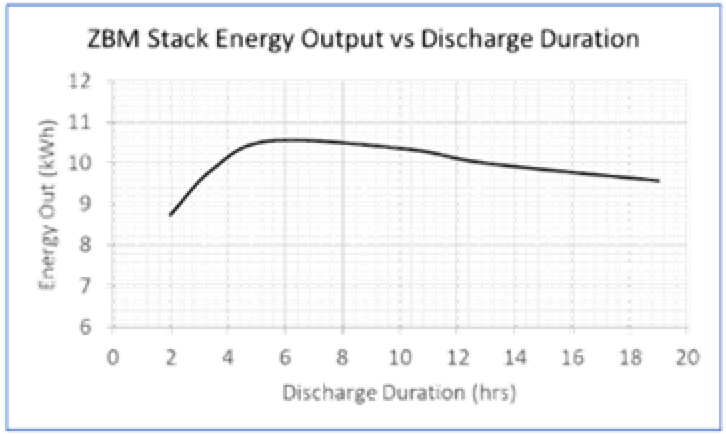


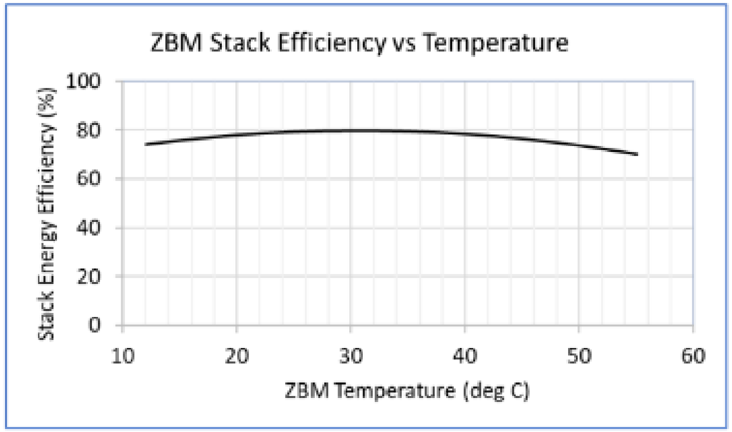


Redflow's short and long-duration capabilities



High power incurs IsquareR losses.
Long duration has more time for self-discharge loss.

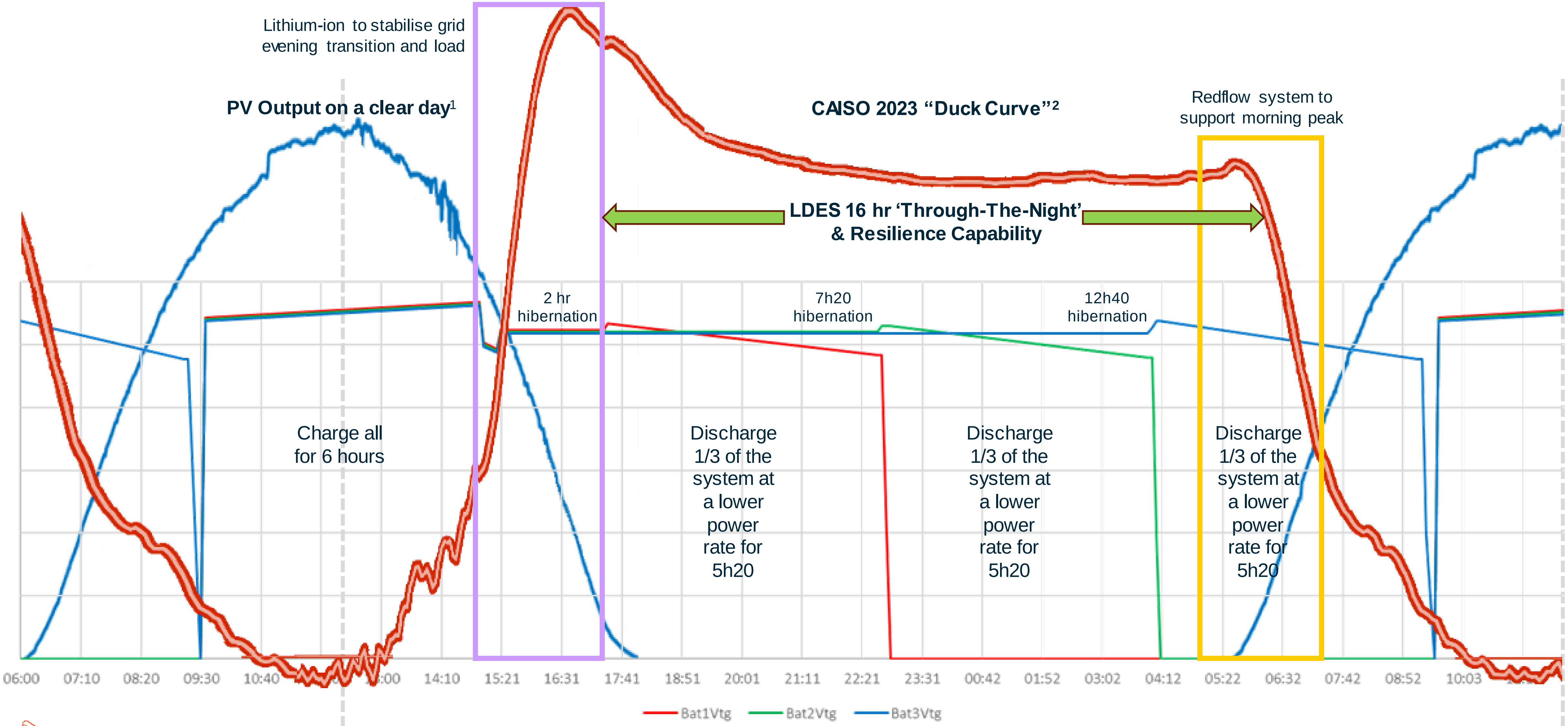




Optimum temperature is ~ 30 deg C. Efficiency falls at temperature extremes.

redflow

Redflow's unique hibernation feature – ideal for LDES



Lithium-ion to stabilise grid evening transition and load

PV Output on a clear day[1]

CAISO 2023 "Duck Curve"[2]

Redflow system to support morning peak

LDES 16 hr 'Through-The-Night' & Resilience Capability

2 hr hibernation

7h20 hibernation

12h40 hibernation

Charge all for 6 hours

Discharge 1/3 of the system at a lower power rate for 5h20

Discharge 1/3 of the system at a lower power rate for 5h20

Discharge 1/3 of the system at a lower power rate for 5h20

1. Source: Modified from ResearchGate: *On recent advances in PV output power forecast*, 07/2016
2. Source: Modified from CAISO / @BPBartholomew
3. NOT TO SCALE

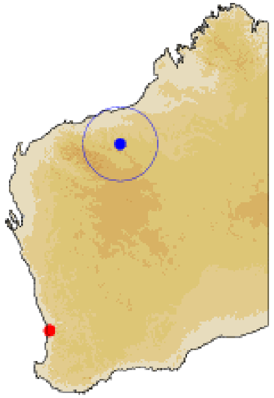
Horizon Power – Project overview

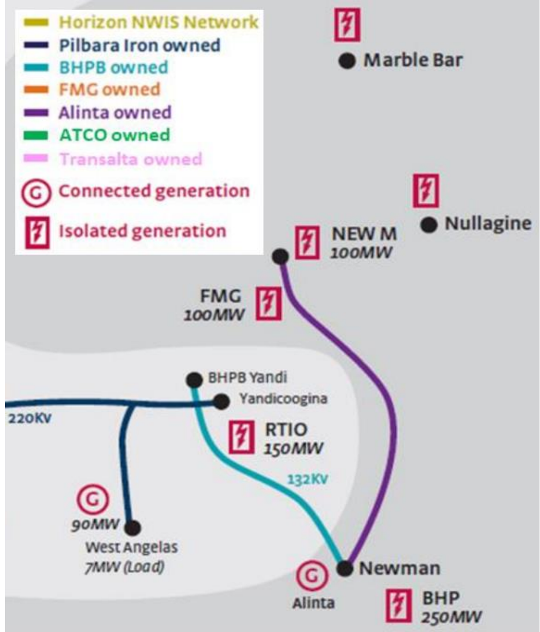
- Horizon Power wishes to investigate
    - the performance of zinc-bromine flow batteries in a high ambient temperature environment.
    - this specific hybrid flow battery technology.
    - integration into the DERMS.
    - LDES-supporting capabilities such as ‘hibernation’.
    - functionality alongside other traditional and renewable generation resources.
- It will be incorporated into the network, but treated as a testing site, working closely with Redflow to advise and support improvement opportunities.
- Integration with high-end, full capability inverter (ABB PCS100) will enable testing of FCAS, grid-following to grid-forming and other grid stabilisation aspects.

Nullagine Solar Power Station

Horizon Power – Project challenges

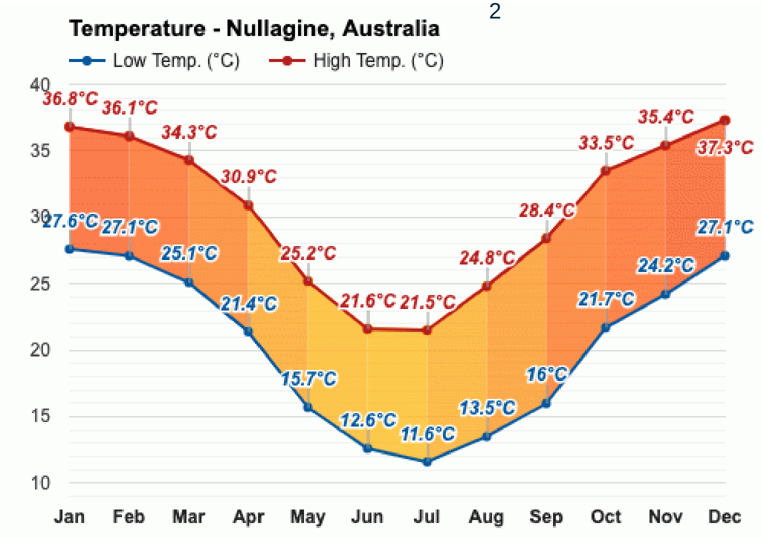
- Originally specified for another site but discussions with Horizon Power indicated that there was a preference for Nullagine to specifically focus on the high temperature capabilities.
- Near Marble Bar, Australia's record holder for the longest heatwave,[1] with current average daily temperatures in December of 41.6 °C. (49 °C on Saturday 31st December 2023).
- Dust ingress into forced air-cooling filters.
- The site is effectively an isolated microgrid without any larger network connection.
- Integrating and providing the optimal benefit between the local solar generation and existing diesel gensets.





2

3



1. 160 days over 37.7 °C in 1923-24
2. Source: Horizon Power Pilbara Network – System Description, December 2021
3. Source: https://www.weather-atlas.com/en/australia/nullagine-climate

redflow

Long Duration Energy Storage (LDES)

Next Steps in Storage Technology

David Edwards – Future Technology & Innovation Manager

March/April 2024

Horizon Power at a glance

2.3m square km
of regional and remote WA is serviced by Horizon Power

510
employees

>53,300
customer connection points to network

>1,000 GWh
electricity delivered a year

8,404 km
of overhead and underground transmission and distribution lines

>70 stand alone power systems
(SPS) installed

3 energy types
gas, diesel, and renewable energy (wind, solar, and hydro) + hydrogen storage

17.8 GWh renewable energy
purchased from our customers a year

0.54 kg CO2-e/kWh
carbon emissions

Long Duration Energy Storage

- Decarbonisation requires shifting large volumes of solar PV energy to ‘dark’ peaks, or periods outside of solar
- We will require storage systems with more kWh than kW
- Large capacities to absorb excess renewables will reduce customer PV curtailment
- We will inevitably build much larger storage systems than we have installed to date
- Lithium-Ion batteries have thrived in the services market but can become too costly when delivering energy for more than 4 or 5 hours
- Zero Hydrocarbons operation will require storage capable of delivering 10 hours +

<u>Prework:</u>

- Engaged with industry for advice on removing the bias towards Lithium-Ion in our BESS standard
- Re-crafted the standard to become a technology agnostic Energy Storage Standard (ESS)
- Engage with the ‘Battery Panel’ of suppliers to remove barriers to Long Duration Energy Storage

Market Scan & Techno-Economic Study

The study used 28 dimensions of assessment

The following top tier requirements were used to filter immature or unsuitable technologies.

- Technology Readiness Level TRL of 6/7 or above
- The company has an agent in Australia
- Western Australian Support is available
- The company has system integration experience
- The company has a relationship with an Australian deployment partner
- MWh deployed to date (can be international as well as Australian)
- Delivery timeframes to Fremantle/Perth

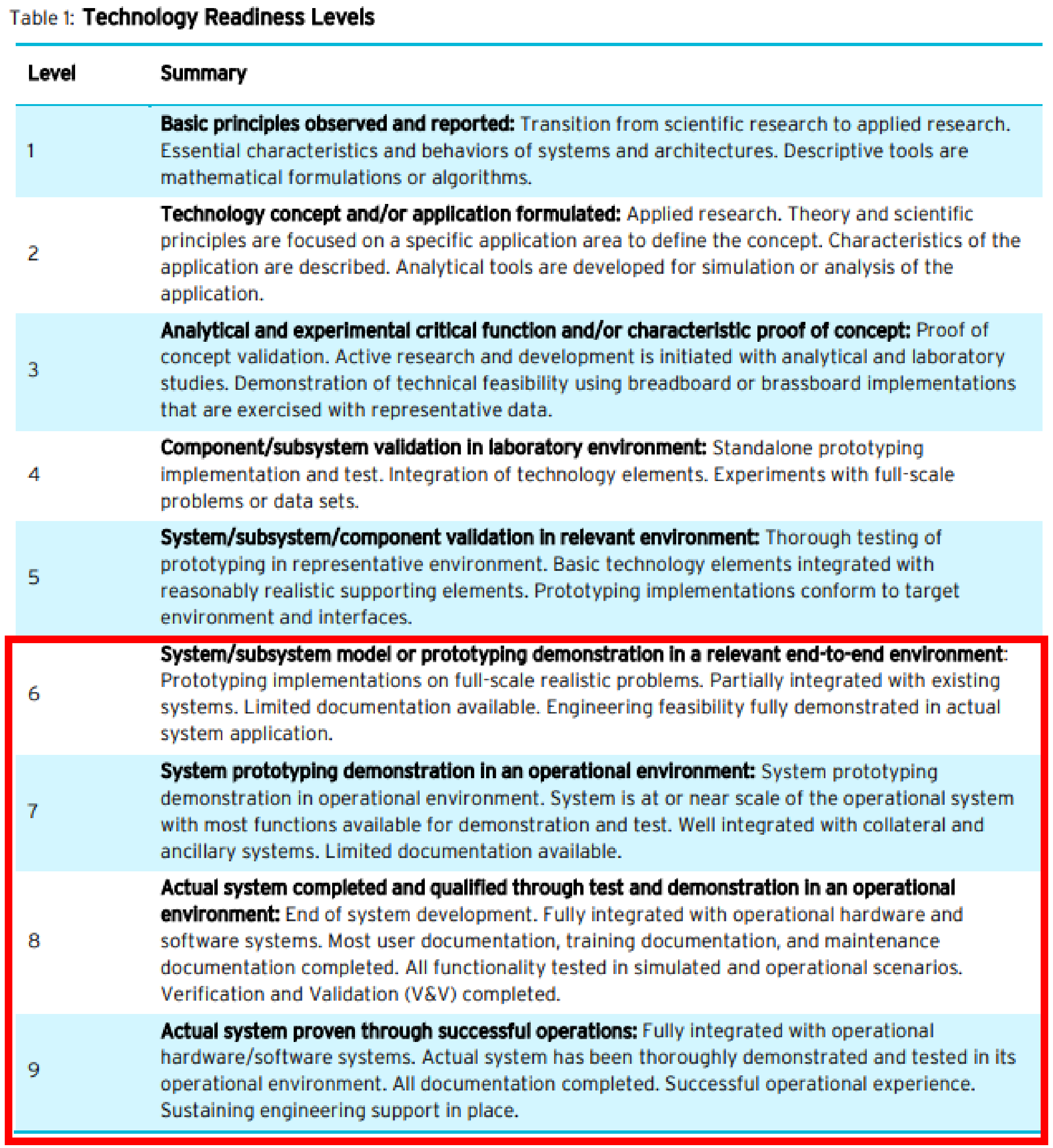


Table 1: **Technology Readiness Levels**

Level	Summary
1	**Basic principles observed and reported:** Transition from scientific research to applied research. Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.
2	**Technology concept and/or application formulated:** Applied research. Theory and scientific principles are focused on a specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.
3	**Analytical and experimental critical function and/or characteristic proof of concept:** Proof of concept validation. Active research and development is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.
4	**Component/subsystem validation in laboratory environment:** Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.
5	**System/subsystem/component validation in relevant environment:** Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.
6	**System/subsystem model or prototyping demonstration in a relevant end-to-end environment:** Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.
7	**System prototyping demonstration in an operational environment:** System prototyping demonstration in operational environment. System is at or near scale of the operational system with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.
8	**Actual system completed and qualified through test and demonstration in an operational environment:** End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation (V&V) completed.
9	**Actual system proven through successful operations:** Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

Techno-Economic Study

Technologies included in the assessment	Technologies excluded from the assessment
Vanadium Redox Flow Batteries	Lithium-Ion
Zinc Bromine Flow Batteries	Lead Acid
Static Zinc Bromine Gel Batteries	Kinetic Flywheels
Thermal Energy + Heat Engine	Compressed Air Technologies
Hydrogen & Metal Hydride Storage	Potential Energy Storage – Concrete Block
Sodium/Sulphur Battery	Pumped Hydro

Financial, Operational & Environmental dimensions of Assessment		
CAPEX	AS 4777 inverter compatibility	Cyclonic durability
O&M - OPEX	Ability to support F P Q	Safety considerations
$/MWh – Long Run Marginal cost	Control interface IEEE 2030.5 compatibility	Land requirements / footprint
Asset lifespan	Cycles per unit/cell lifespan	Noise emissions
Critical components	Depth of discharge	Visual Impact
Single points of failure	Round trip efficiency & Parasitic load(s)	Lifecycle assessment
Internal redundancy	Maintenance cycles	Circular economy considerations

Merits & Disadvantages

It's not a level playing field across the different technologies

Merits and	Disadvantages
100% depth of discharge	Can require another energy source to re-energise
Can discharged over long periods of time	Low round trip efficiencies
Can hold a charge indefinitely	Parasitic losses and high self-discharge
Standby mode to cut parasitic losses	Slow to respond coming out of standby mode
fast response = ability to provide network support	Slow to respond in milli seconds making network support hard
Ability to absorb fluctuating renewables directly	Constrained run-times and operational requirements
Ability to operate in high temperatures (50°C+)	Require cooling to remain efficient

Trial Decision Criteria

- ✓ Technology Readiness Level of 6/7 or above
- ✓ Supplier has an agent in Australia, relationship with an Australian deployment partner & support in WA
- ✓ Deployment Partner has system integration experience
- ✓ Amount of MWh deployed (globally)
- ✓ Delivery time

Based on the results of a techno-economic study, Vanadium Redox Flow battery, Zinc Bromine Flow battery and Sodium Sulphur battery storage technologies have been selected as suitable for remote microgrid trials

	Prototype	Vendor	Presence in AUS	TRL	MWh deployed globally	Delivery time	Lifespan	Degradation	RTE[1]	Temperature resilience	Depth of discharge	Thermal Runaway
Vanadium Redox Flow Battery **Kununurra**		Invinity/ VSun	Yes	9	>33MWh	9 months	25	1%	75-80%	Up to 50°C	100%	No
Zinc Bromine Flow Battery **Nullagine**		Redflow	Yes	9	7.5MWh	4 months	25	1%	73%	Up to 50°C	100%	No
Sodium Sulphur Battery **Carnarvon**		NGK/ BASF	Yes	9	4,900MWh	9 months	20	20%	86%	Maintains 300°C internally	100%	No

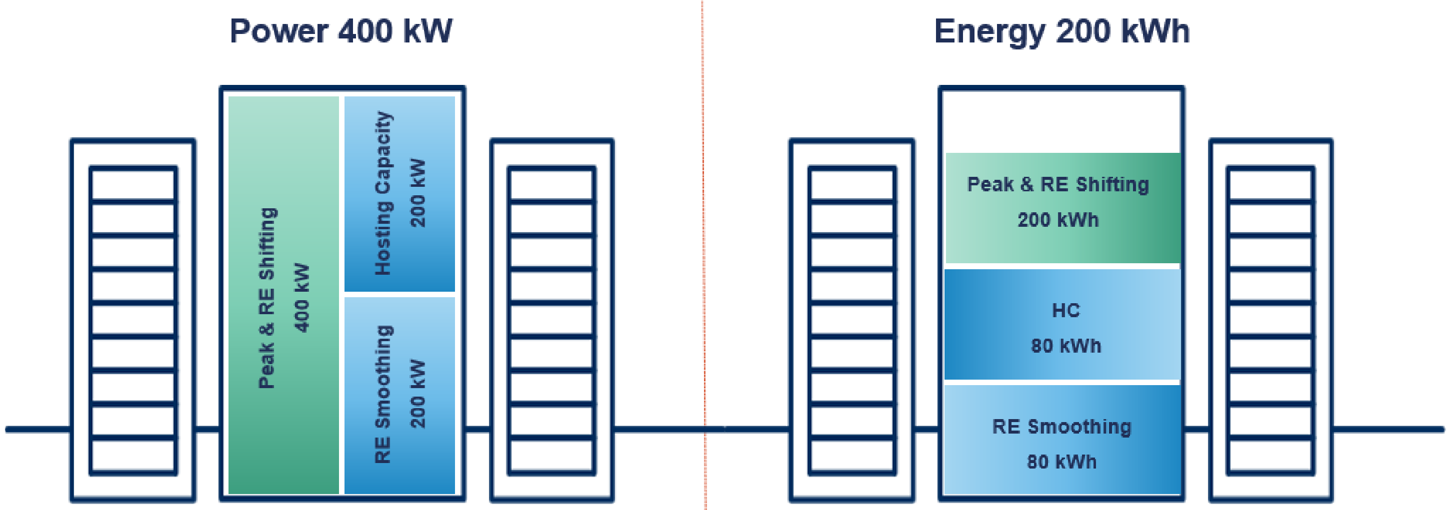
Orchestration of storage assets

- Shift the Power System Control Philosophy into the DERMS Platform
- DERMS assigns different jobs to different ESS assets during the day to achieve:

  a) The operating constraints or requirements prescribed in the control philosophy, while

  b) Maximising ESS return on investment and preserving cycles in the case of Li-ion.

- Orchestrate the ESS technologies to meet the needs of the system
- Decouple the Jobs from the assets to find flexibility
- Now the emerging ESS value proposition is Network Location.
- Strategically locate assets to avoid or delay network augmentation to meet the decarbonisation targets
- Evolve the ESS strategies to marginalise spinning generation while preserving system strength.



Hosting Capacity = BESS kW / RE Fluctuation Factor
= 400 kW / 0.561[1] = **714 kW PV**

Smoothing Capacity = BESS kW / RE Fluctuation Factor
= 400 kW / 0.561[1] = **714 kW PV**

Usable BESS kWh =
Hosting Capacity * RE Fluctuation Factor * (12/60)
= 714 kW * 0.561[1] * (12/60) = **80 kWh**

Usable BESS kWh =
Smoothing Capacity * RE Fluctuation Factor * (12/60)
= 714 kW * 0.561[1] * (12/60) = **80 kWh**

Thank You

Panel Discussion

Dr. Kira Rundel

Head of strategic projects,
RayGen

Conan Jones

Product Manager,
Redflow

David Edwards

Future technologies and
Innovation Manager,
Horizon Power

Naureen Alam

Group Manager, AGL

Alex Campbell

Director of Policy and
Partnerships,
LDES Council

3:00 – 3:30

Afternoon Tea

Upcoming Sessions:

- Participation of Storage in Electricity Markets (Blaxland B)
- Thermal Storage for Process Heat (Blaxland A)

Australian Government
Australian Renewable Energy Agency

ARENA

ARENA INSIGHTS
KNOWLEDGE FOR INDUSTRY

Insights Forum 2024 | Sydney

Australian Government
Australian Renewable Energy Agency

ARENA

Session 3A

Participation of Storage in Electricity Markets

Presented by Greg Williams(ARENA)

ARENA INSIGHTS

Transgrid Group

ARENA insights forum: Lumea

March 2024

Introducing the Transgrid Group

Transgrid
Group

Transgrid

Transgrid operates and manages the high voltage electricity transmission network in NSW and the ACT.

Lumea
Transgrid Group

Lumea is Australia's leading infrastructure and energy services provider operating in the contestable energy market

Transgrid Group Investors

spark infrastructure

UTA

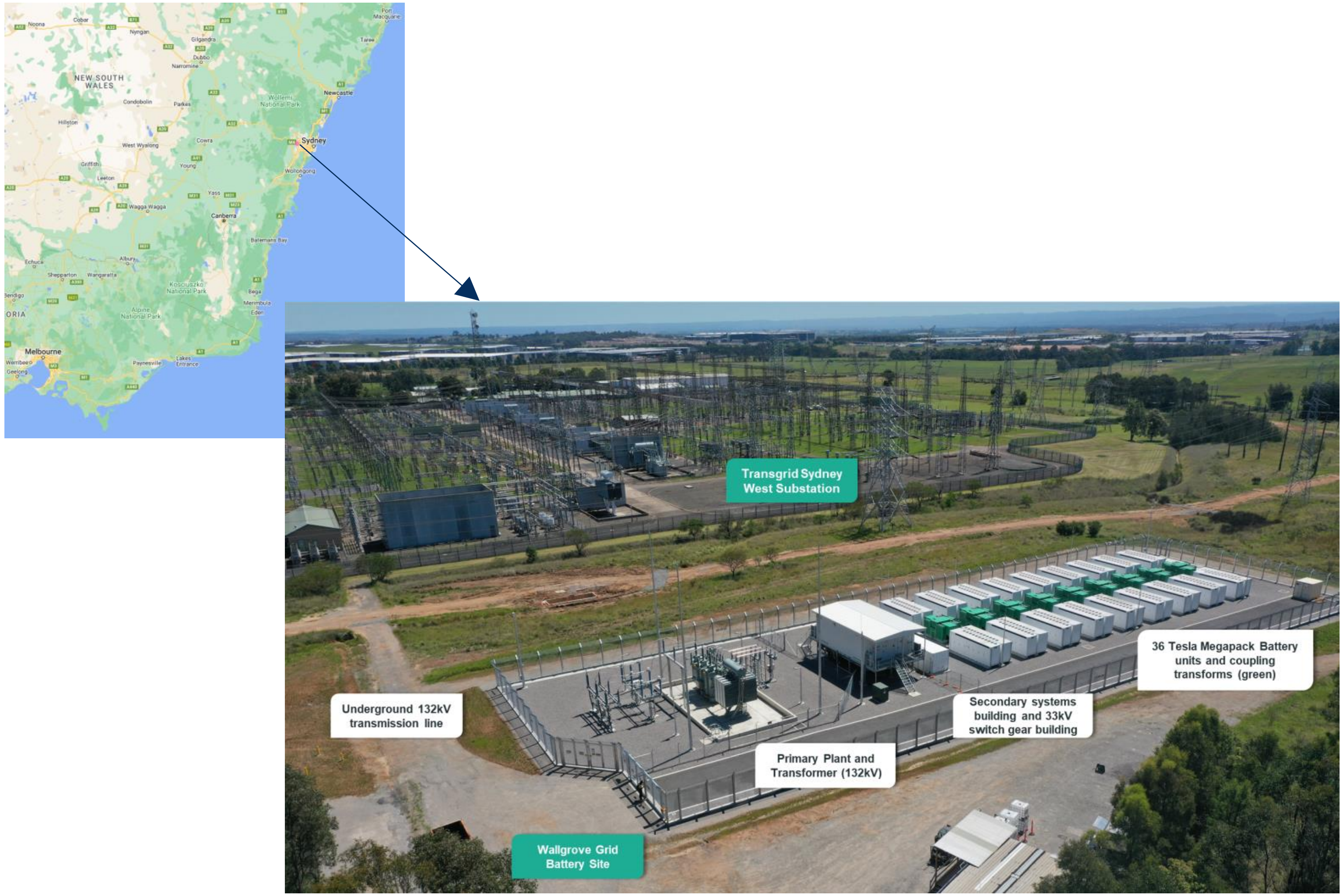
Caisse de dépôt et placement du Québec

ADIA

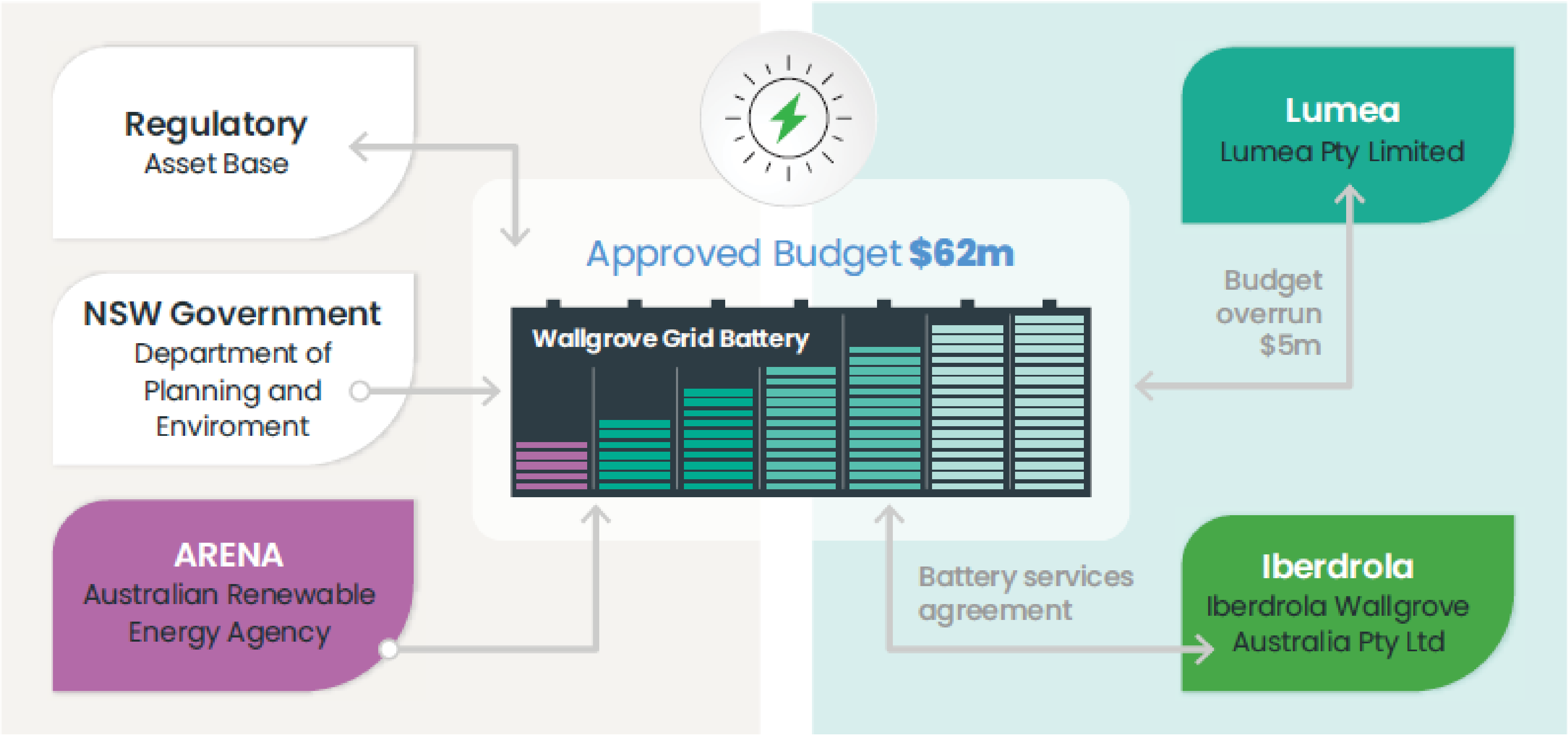
OMERS

The Wallgrove Grid Battery

Technical Parameters	
Nominal discharge power	50 MW
Nominal charge power	47 MW
Registered storage capacity	75 MWh
Network connection	132 kV
Point of connection	Sydney West 330/132 kV substation



Funding model



Regulated funding for network services

Unregulated funding for market services

Regulatory
Asset Base

NSW Government
Department of Planning and Enviroment

ARENA
Australian Renewable Energy Agency

Approved Budget **$62m**

Wallgrove Grid Battery

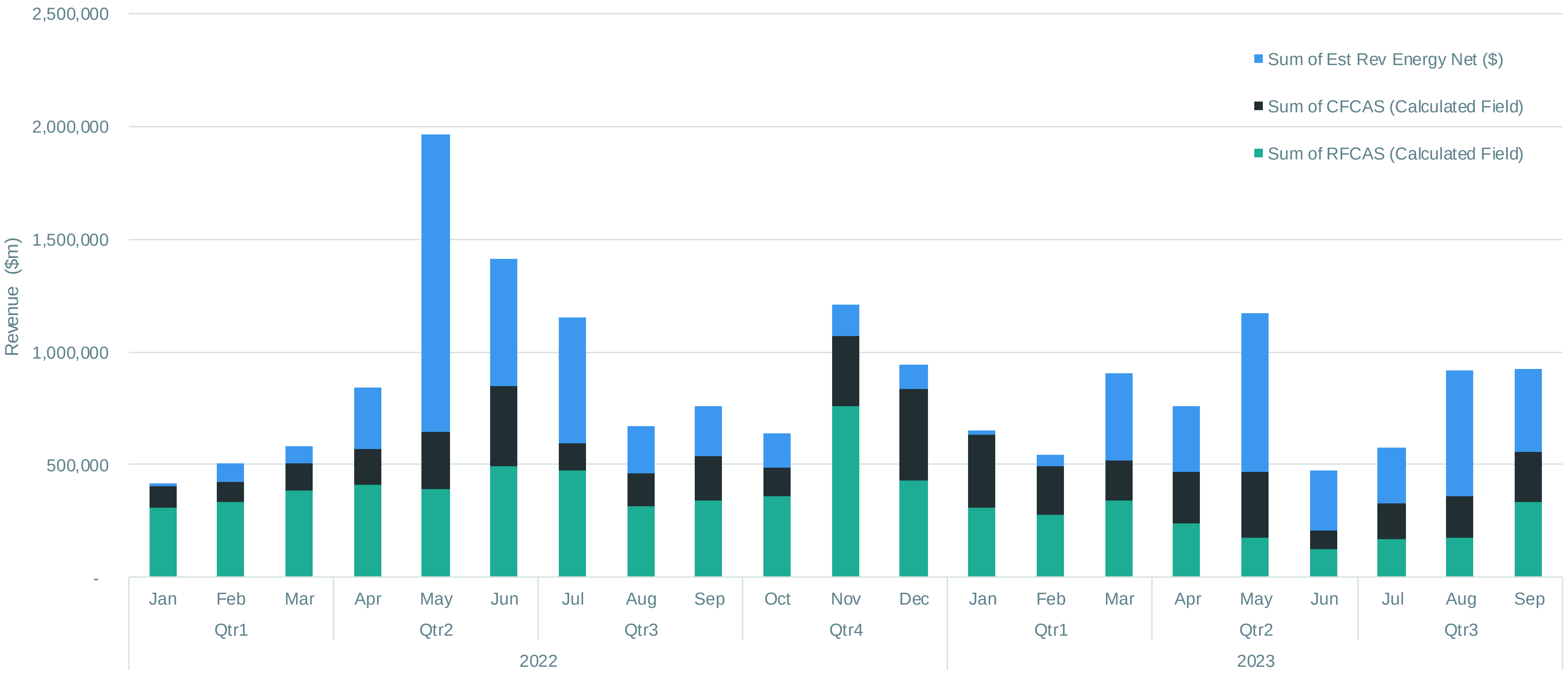
Lumea
Lumea Pty Limited

Budget overrun $5m

Battery services agreement

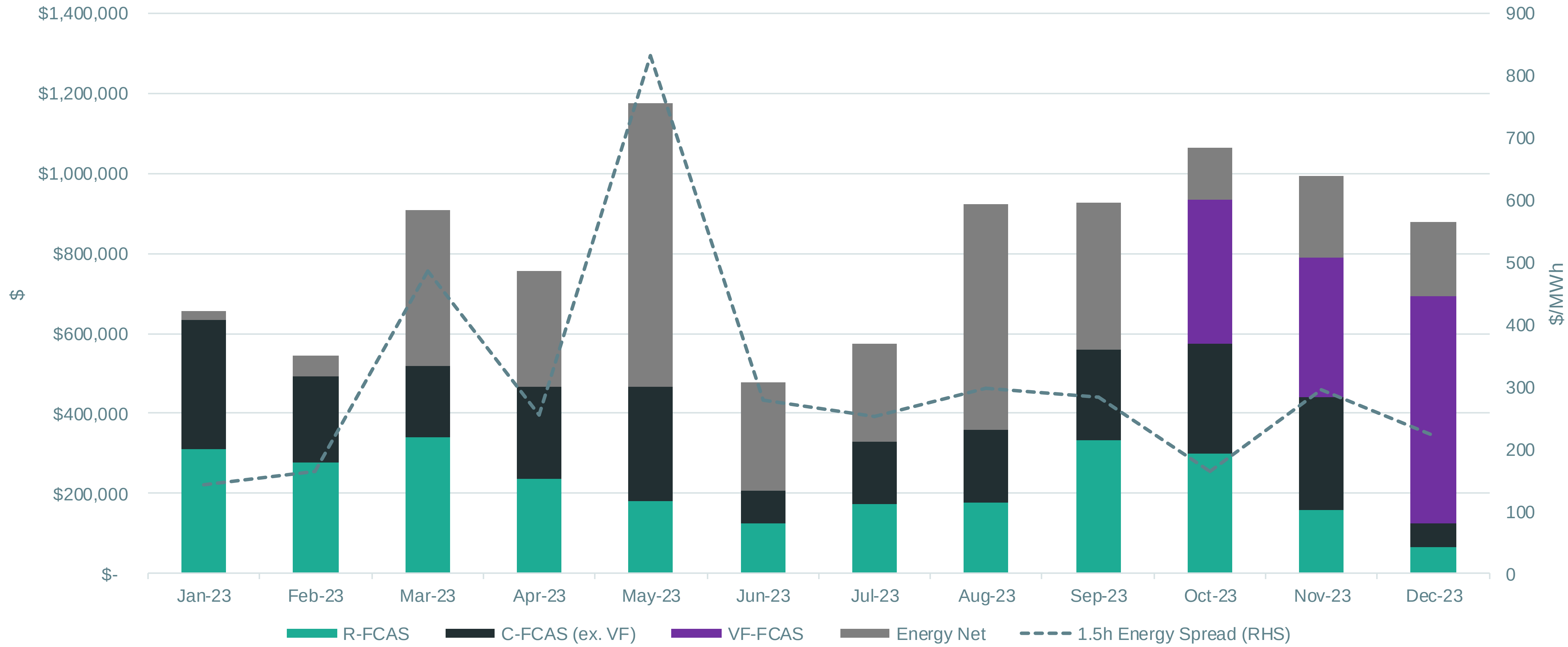
Iberdrola
Iberdrola Wallgrove Australia Pty Ltd

Market revenue by month

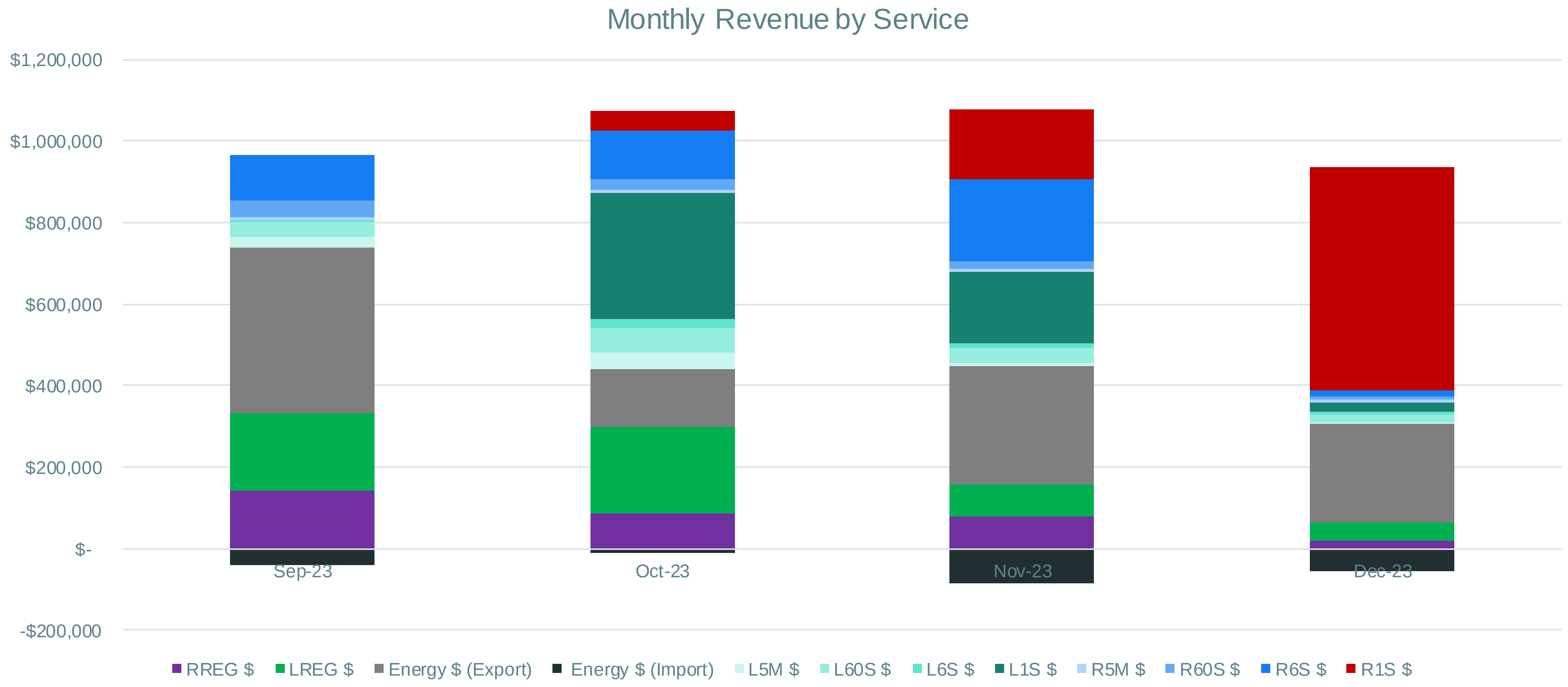


2023 revenue by month including spreads

Lumea
Transgrid Group

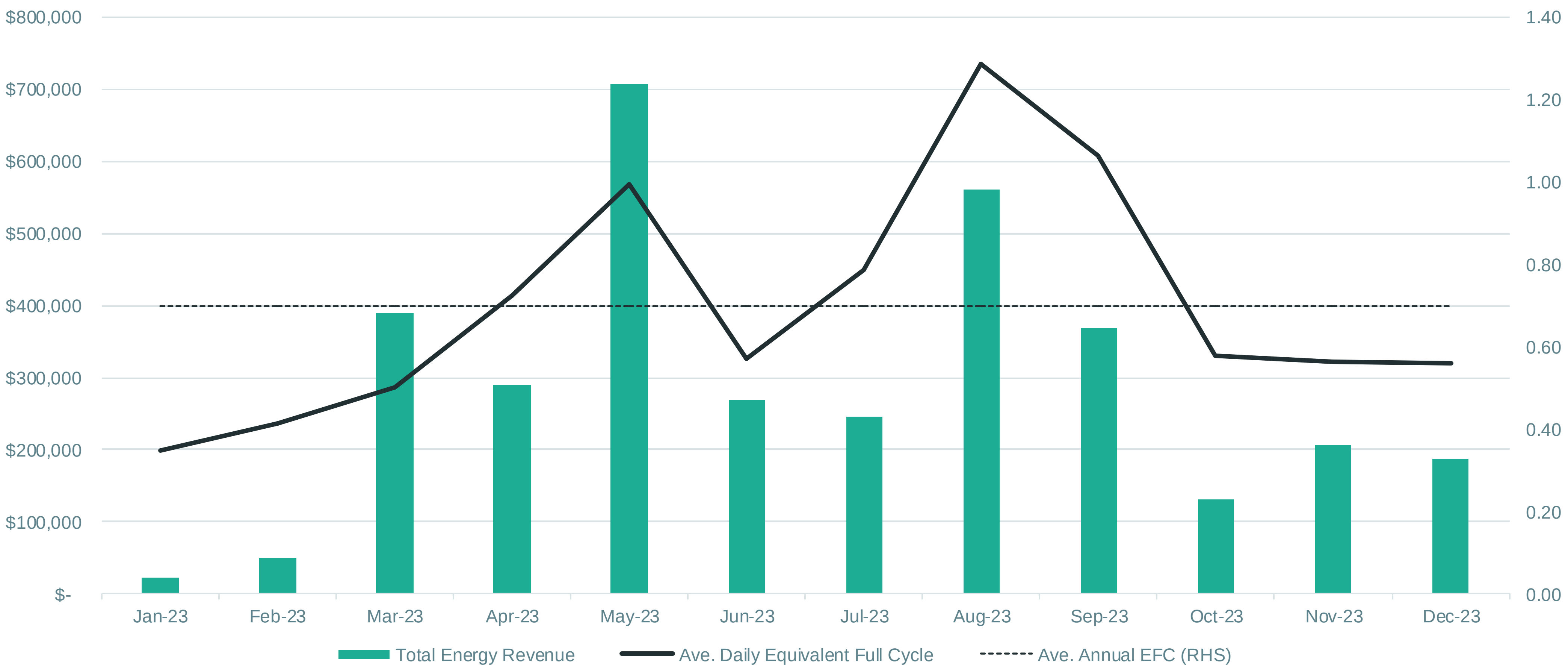


The commencement of 1 second FCAS markets

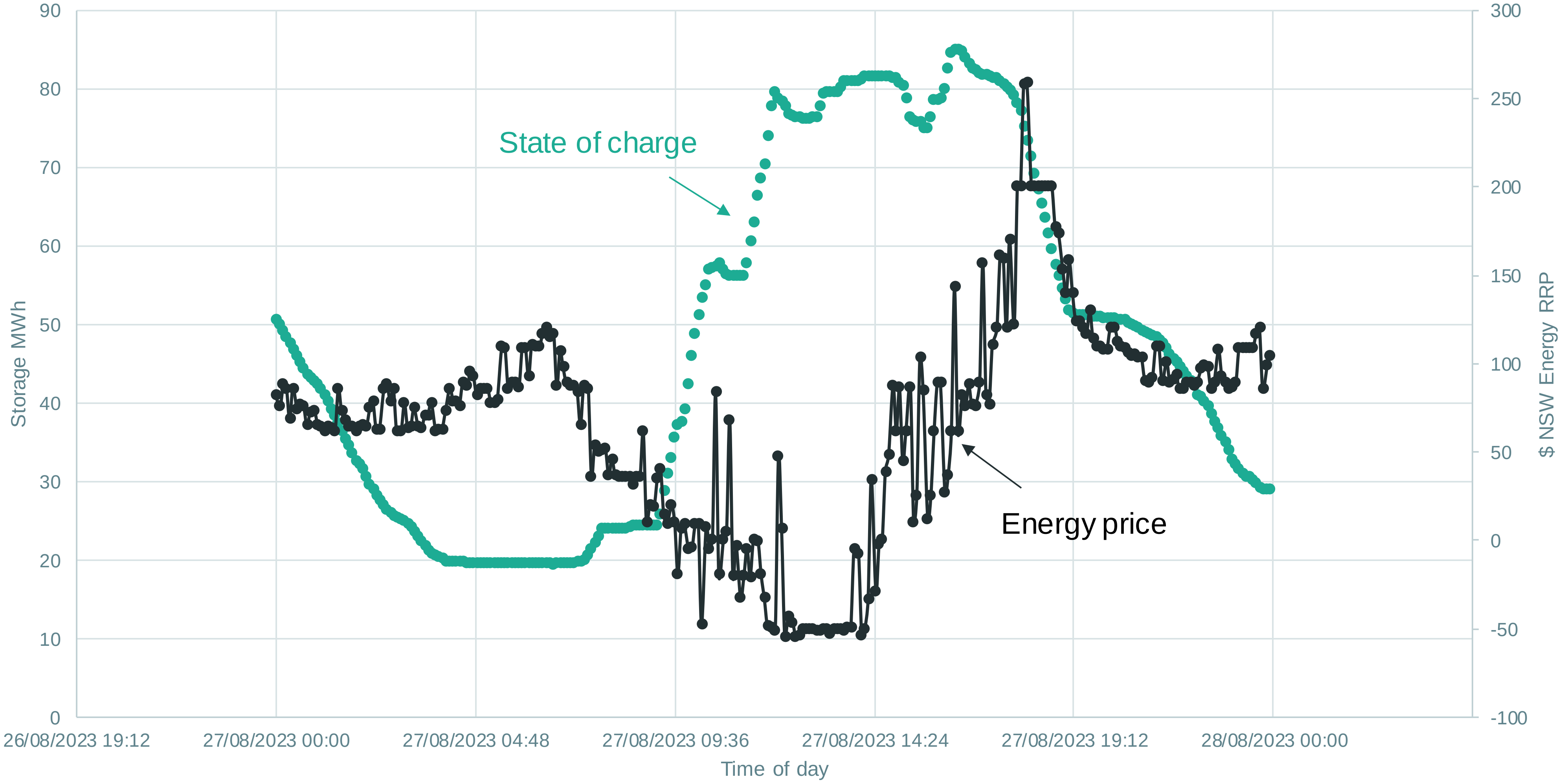


Total net energy revenue vs equivalent full cycles

Lumea
Transgrid Group

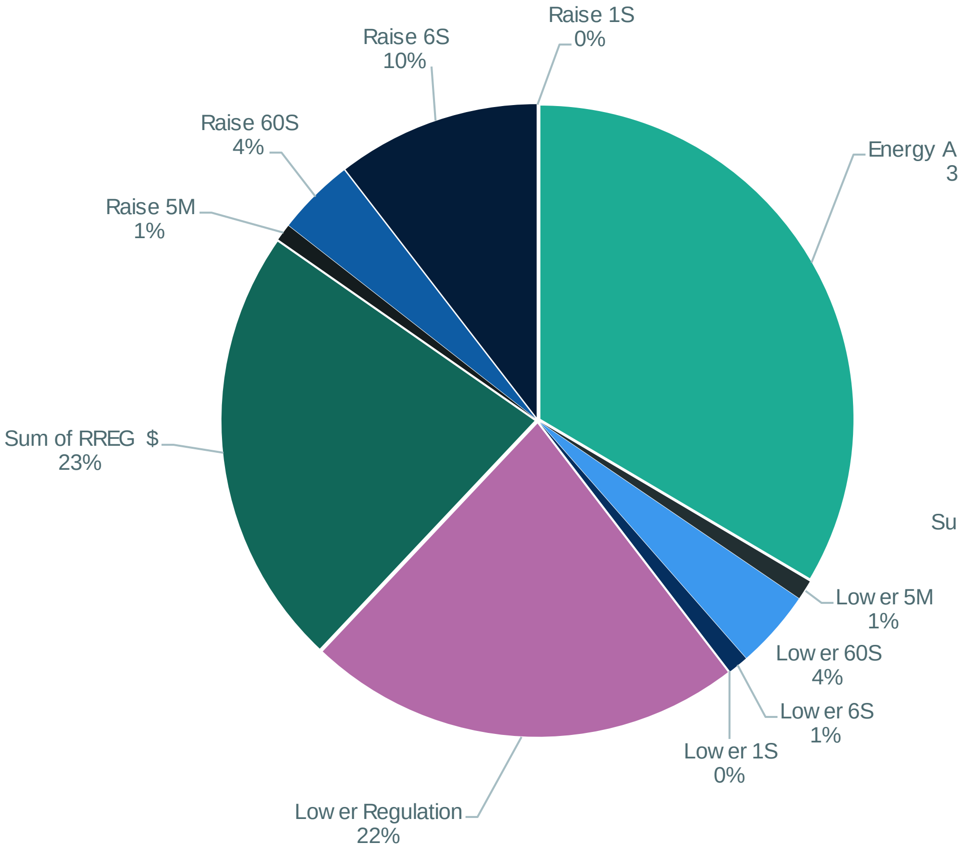


Alignment of energy prices and state of charge

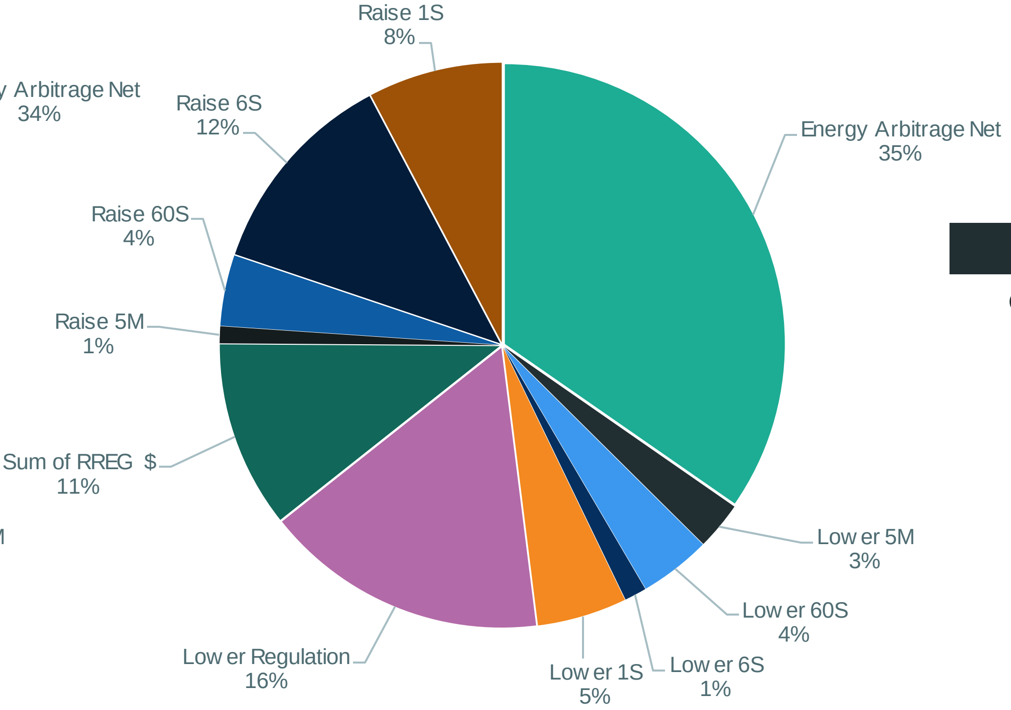


Breakdown of revenue sources

2022 - $11.1m



2023 - $9.9m



Service	2022	2023
Contingency FCAS	$2.4m	$3.8m ($1.3m 1sec)
Regulation FCAS	$5m	$2.6m
Energy	$3.7m	$3.5m

Thank you!

MONASH University

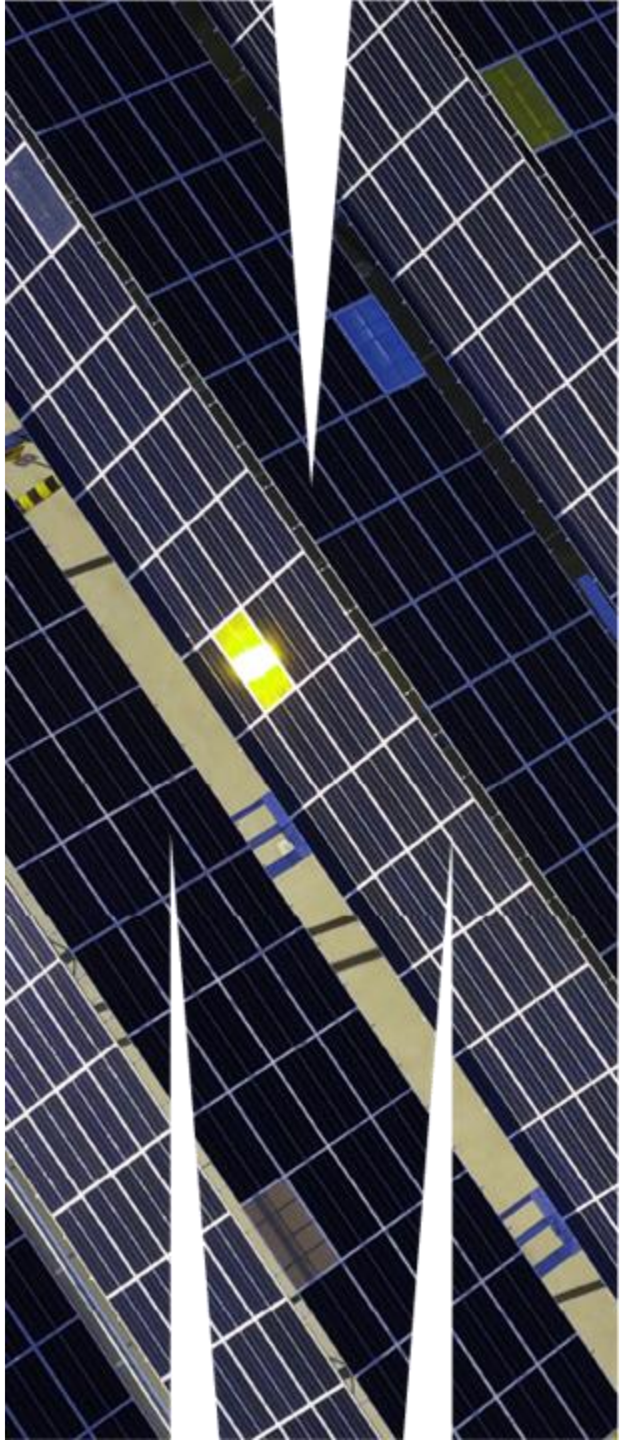
MONASH
ENERGY
INSTITUTE

SOME ECONOMICS OF GRID-SCALE STORAGE

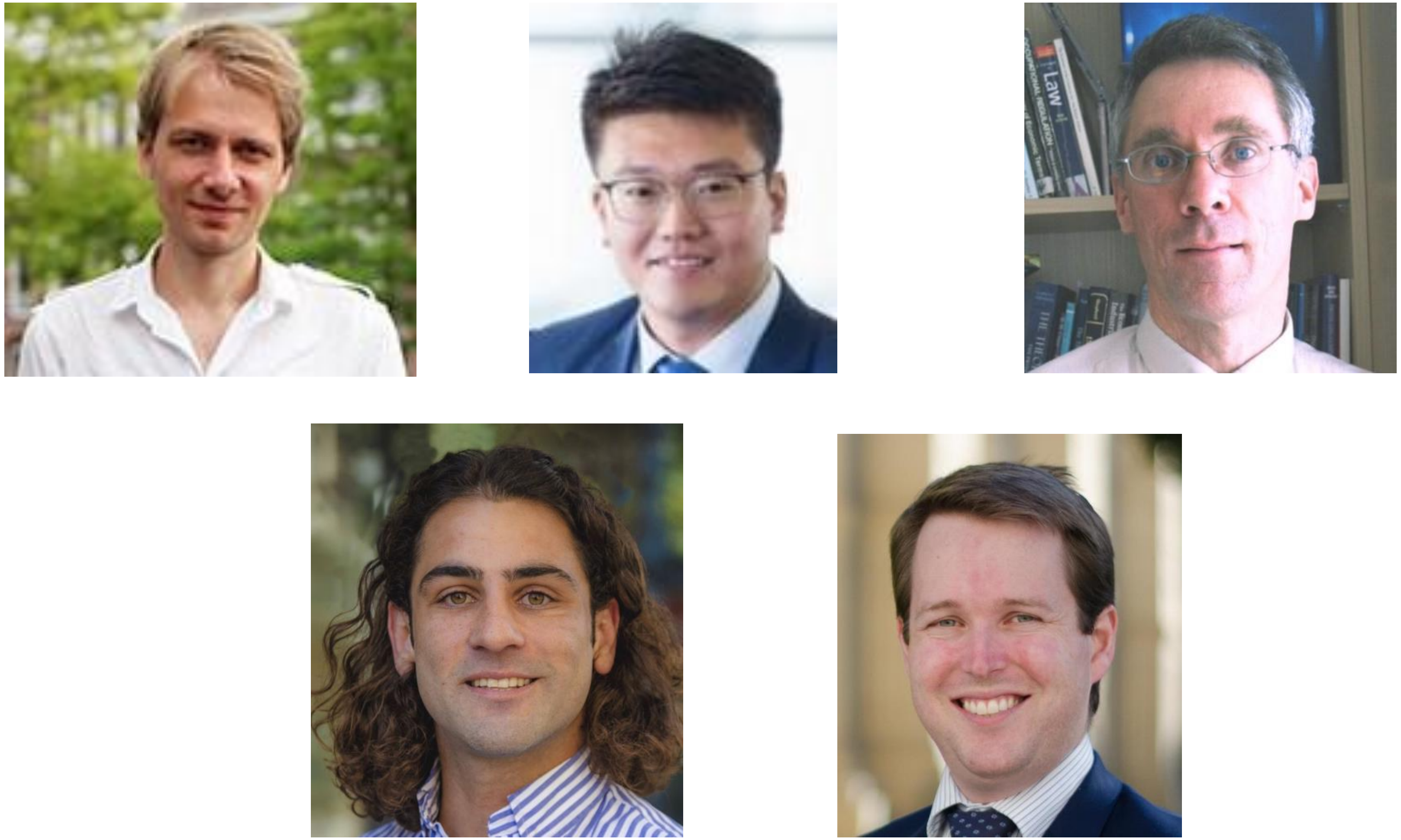
Partial results of an ARENA-supported project

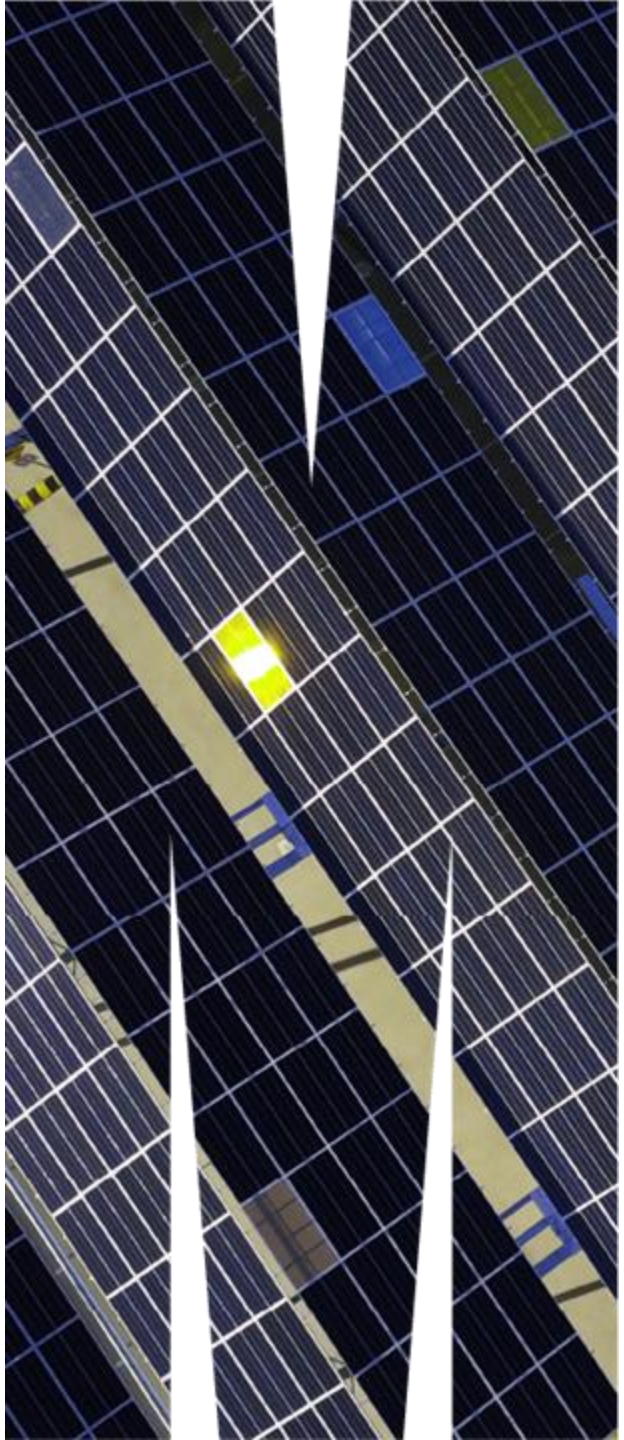
26 March 2024

Guillaume Roger, Monash University



Research team at Monash





Why is storage so different?

Aspect 1: dynamics

1. Storage delivers intertemporal substitution
2. Dynamics:
  - first buy *only* to then sell
  - cannot sell more than stored: sum of past decision
  - decisions today affect tomorrow’s

Aspect 2: market power

Move prices when
- selling and
- when *buying*

KEY QUESTION: implications for market rules?

The toolkit

Goal: craft appropriate market rules (bidding, clearing, dispatch)

First: understand how storage behaves

- Model a *stochastic* game
  - Demand uncertainty
  - Market power
  - Varying capacity

- Three distinct sets of results
  - Single storage unit—approximate equilibria
  - Competing storage units—subgame perfect Nash equilibria
  - Intraday trading: cycles—optimal control

- Implications
  - Understanding bidding incentives
  - Competition policy
  - Market rules

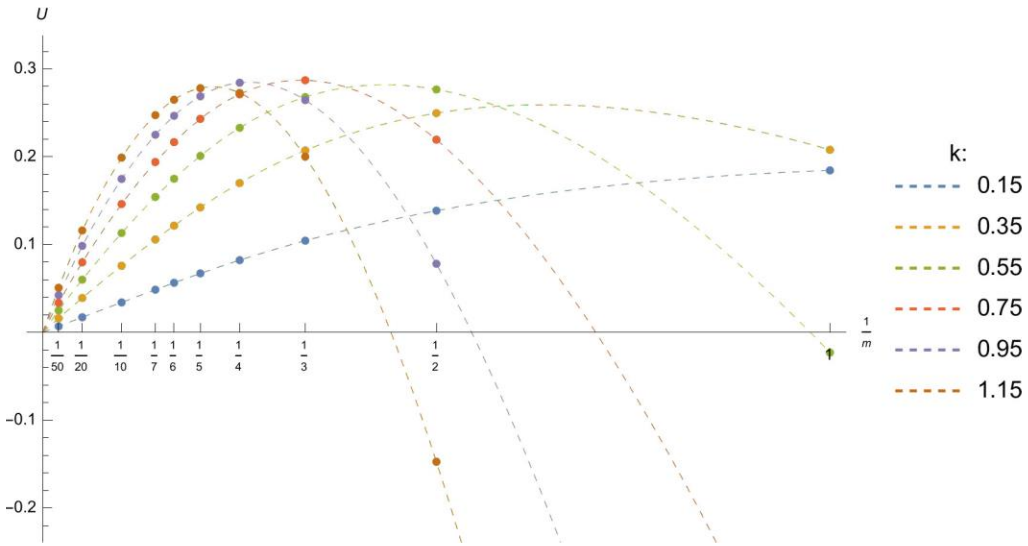
Some results - 1

Market power matters…a lot!

- When selling
- When *buying*
- Arbitrage spread dissipates
- Hence, severe quantity restrictions
- Relevant consideration on a network with local transmission constraints

Uncertainty is costly…not in the usual sense.

- *Continuation* risk
- Corollary to market power
- More capacity, less utilization
- Quantity restrictions



Sponge?

Some results - 2

Competing units have strong incentives to collude

- Market power effect
- Cooperation restrains quantities traded—taking turns
- New equilibrium (Partial Cooperation)
- More capacity, more collusion

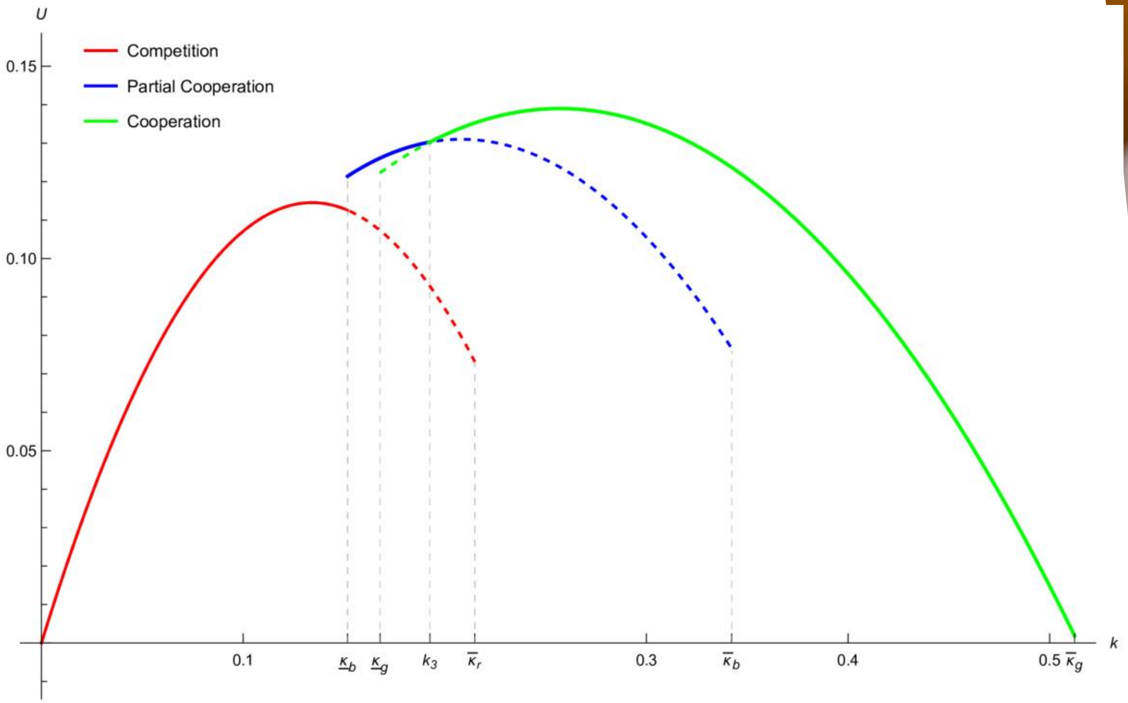
Again, sponge?

But it may not always be bad!

- Nuanced result
- Cooperation:

1. lower utilization, but
2. Larger capacity—dominant effect

ACCC response?



Some results – 3: Intraday trading

Model of cyclical storage under uncertainty

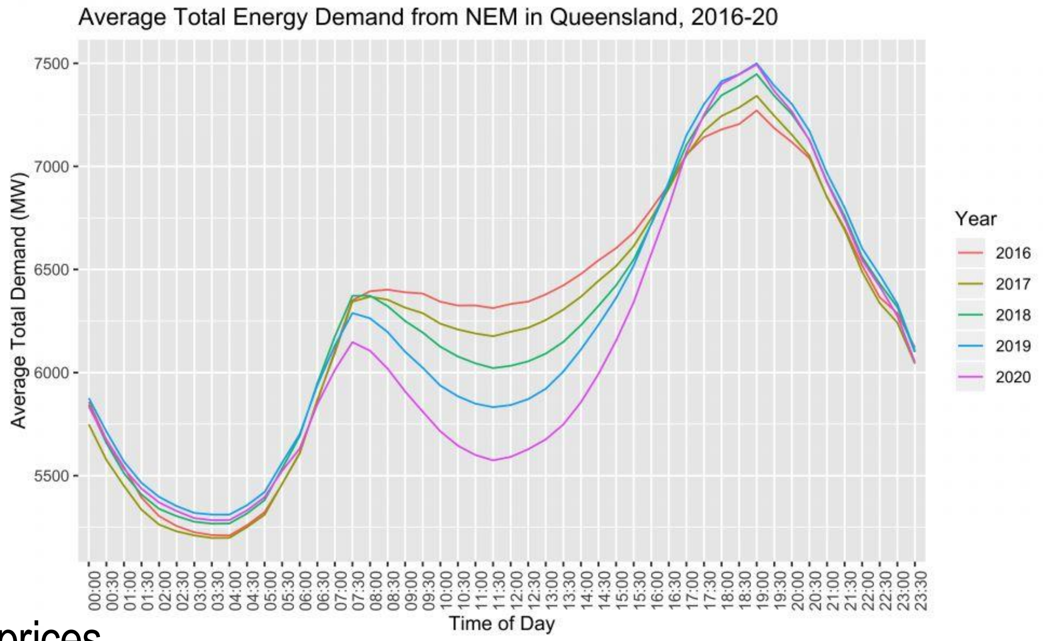
- Resolution of uncertainty over time
- *When* to optimally charge and discharge?

- Buying too little:

1. Lost revenue opportunity
2. High equilibrium prices

- Buying too much:

1. Overpaid for energy
2. Ripple effects on future quantities and prices



Sell:

- at rate “proportional” to demand
- at most stored energy
- stop: replacement cost exceeds revenue

Compute expected quantity

Buy: expected quantity

Intertemporal spillovers

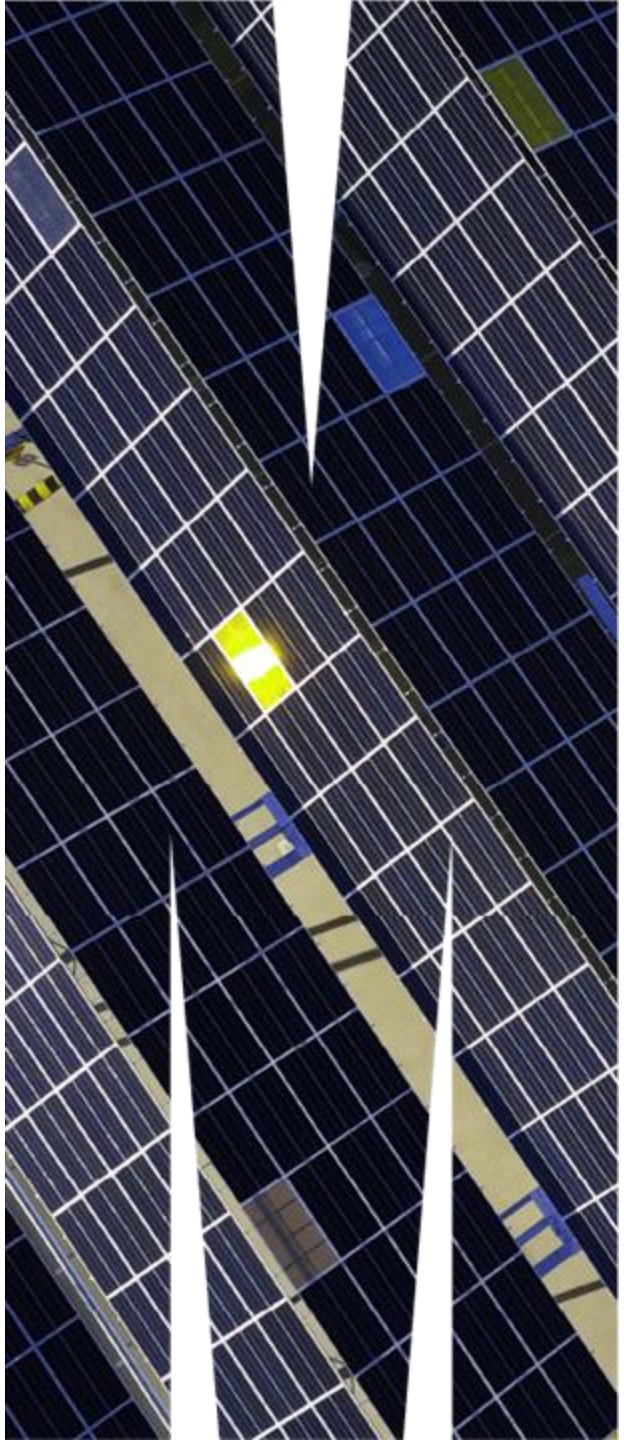
Some implications and further work

- Salient market power—arbitrage spread
- Corollary: social vs private incentives
- Local monopolies on meshed network
- Competition policy
- Intraday trading: intertemporal spillovers

- VRE and storage without thermal—equilibrium strategies
- Implications for price caps and price floors

Thank you!

Guillaume.Roger@monash.edu



Assessing the impact of battery storage on Australian Electricity Markets

Sean Foley[1], Arvind Rangarajan[1], Stefan Trück[1]

[1]Macquarie Business School & Transforming Energy Markets Research Centre

Macquarie University

ARENA Insights – Storage for the Energy Transition

March 26, 2024

Motivation

Research objective: Examine the hypothesis that utility-scale lithium-ion battery storage facilities have a significant impact on overall ancillary market costs

- First empirical insights in a stream of literature that is mainly dominated by theoretical studies.
- Detailed analysis of impact of large battery installations on different Frequency Control Ancillary Services markets
- Changes to offered capacity and marginal pricing by different generation technologies pre- and post introduction of battery facilities

Frequency Control Ancillary Markets

FCAS	Regulation	Contingency		
Load-balance timeframes	4s	6s	60s	5min
Lower services	Lower/Raise deviations within ± 0.15Hz	Lower/Raise deviations over ± 0.15Hz		
Raise services				

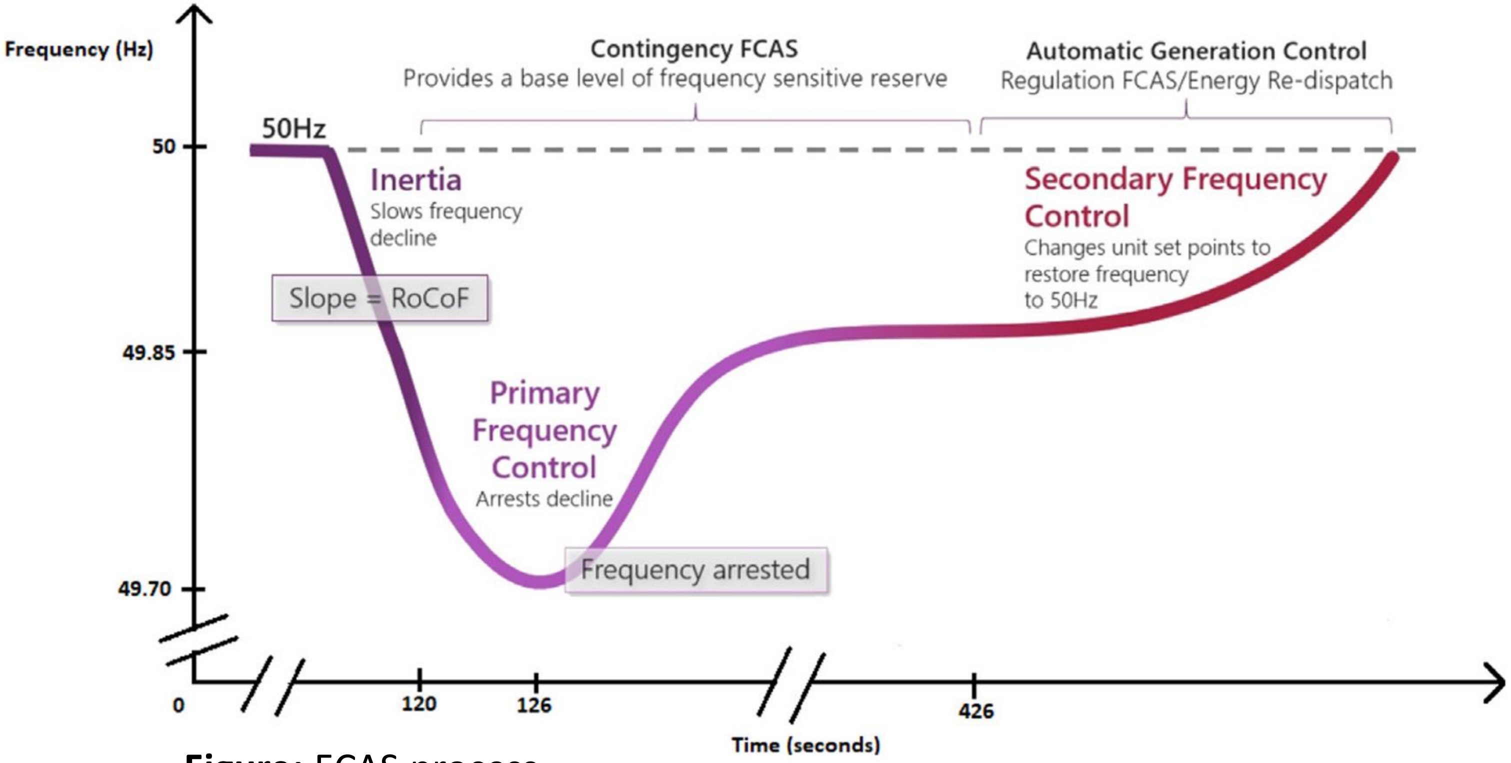


Figure: FCAS process.
Source: AEMO(2020)

Battery facilities examined

BESS	Region	Capacity	Commission date
Hornsdale Power Reserve	SA	150MW/ 194MWh	14-Nov-2017
Dalrymple BESS	SA	30MW/ 8MWh	10-Dec-2018
Ballarat BESS	VIC	30MW/ 30MWh	19-Jan-2019
Lake Bonney BESS	SA	25MW/ 52MWh	31-Oct-2019

Table: Batteries considered in this study.
Commission dates represent the date of first dispatch into the FCAS market, sourced from the data.

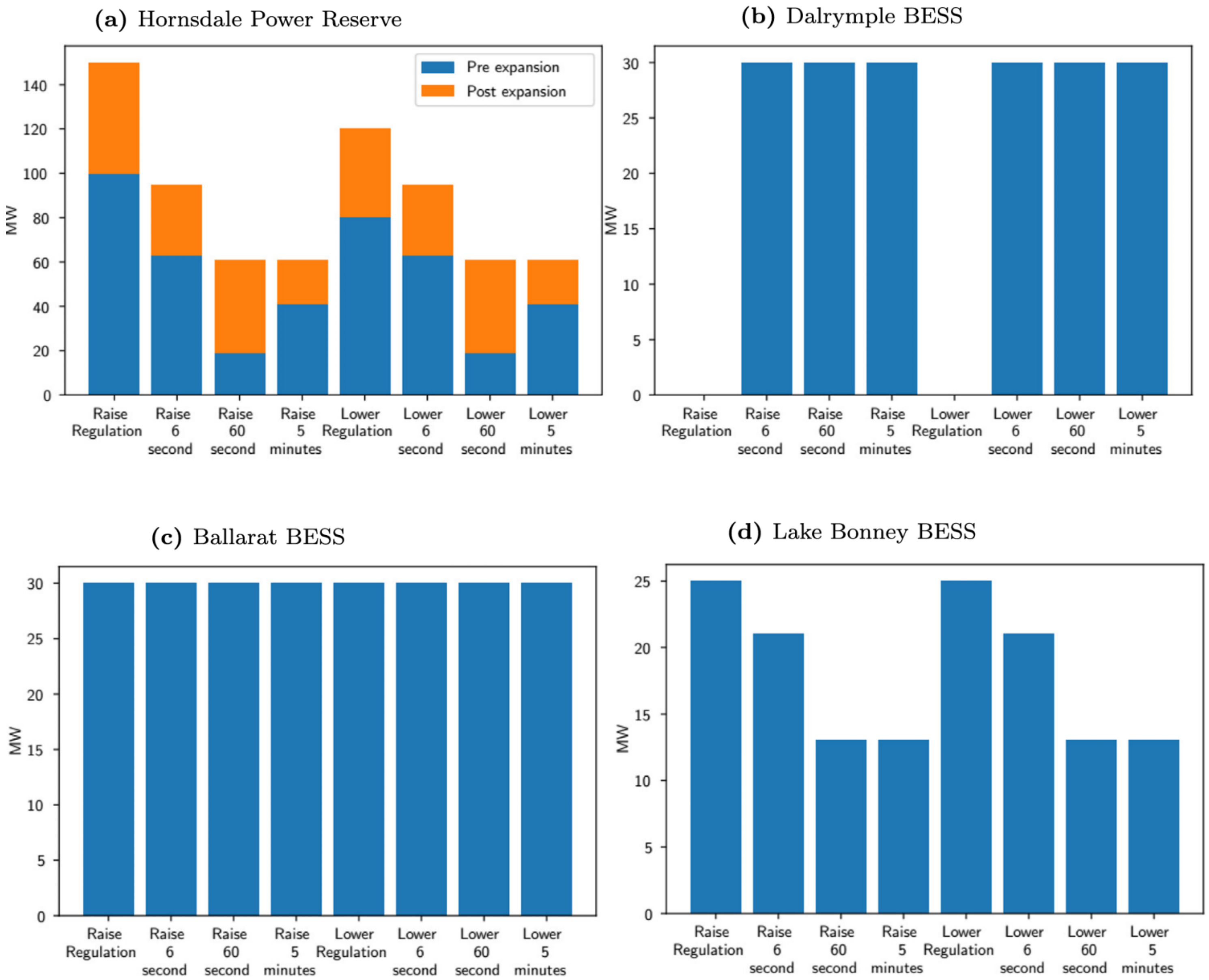


Figure: Registered capacities for batteries in different markets.

Event Study: Impact of battery participation on FCAS prices

We examine the following model:

$$FCAS_t = \beta_0 + \beta_1 Post_t + \beta_2 RRP_t + \beta_3 Dispatch_t + \beta_4 VRE_t + \beta_5 FE + \varepsilon_t$$

- $FCAS_t$ denotes FCAS prices for each trading interval t
- $Post_t$ takes the value 1 after the commission date of a battery facility
- RRP_t represents wholesale market prices to control market correlations
- $Dispatch_t$ and Fixed effects, including indicator variables for each 5-minute interval, days of the week and months, to control for intraday and weekly seasonal effects in electricity consumption

Key Findings for HPR and Ballarat

- Battery facilities had a large impact, statistically significant at the 1% level, on regulation markets.
- For HPR, average prices in each trading interval for raise and lower services decreased by AUD177.05/MWh (RR) and AUD130.50/MWh (LR).
- Impact on HPR 6-second services to a much smaller magnitude, whereby average costs for raise and lower services decreased by AUD1.28/MWh and AUD1.78/MWh.
- Markets where HPR registered lower amounts of capacity (60-second and 5-minute), either faced higher average costs or did not experience significant price changes.
- Ballarat BESS also significantly lowered overall ancillary costs (for R6, R60, R5M), however, at a smaller magnitude (overall AUD4/MWh).
- Larger size of HPR might have been reason for stronger impact on prices.

Overall Impact of HPR on FCAS cost

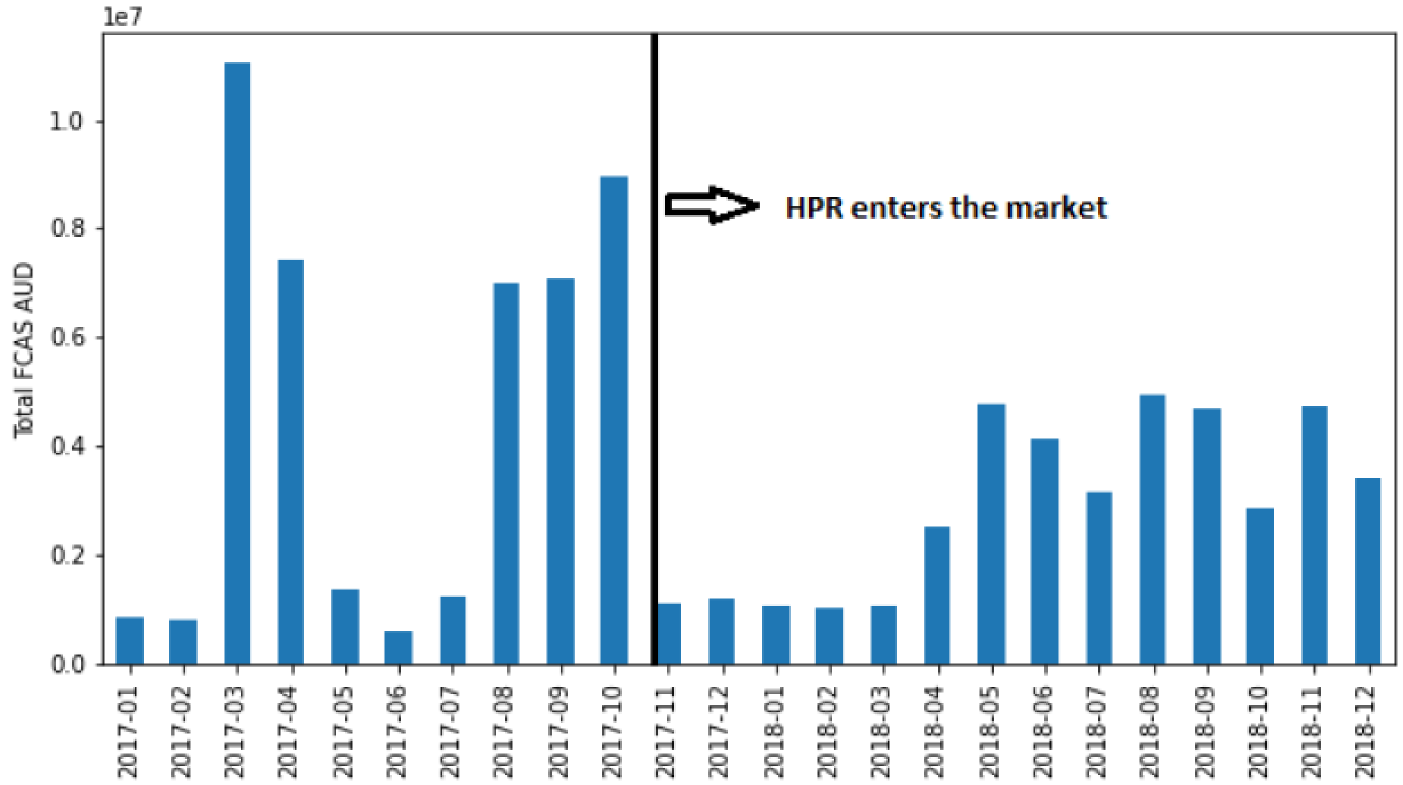


Figure: Monthly total FCAS cost for SA January 2017 to December 2018.

→ After participation of HPR, average total monthly FCAS cost in SA was AUD25 million, i.e. 45% lower than the previous 10 months (AUD46.3 million).

Difference-in-Difference Analysis

We run the following DiD regression on FCAS prices to estimate battery impact in 3 different formats:

$$FCAS_t = \beta_0 + \beta_1 Post_t + \beta_2 Battery_i + \beta_3 (Post_t x\ Battery_i) + \beta_4 RRP_{it} + \beta_5 Dispatch_{it} + \beta_6 VRE_{it} + \beta_7 FE + \varepsilon_{it}$$

- $Battery_i$ is an indicator variable that takes the value 1 after the commission date of a battery facility in the first format.
- All other variables are the same as before.

Impact of Batteries (DiD Results)

	HPR	Ballarat BESS	HPR (Extended sample)	Capacity (MW)	Capacity/Demand (%)
R6	−18.951***	−1.748	−25.122***	−0.171***	−2.130***
	(1.210)	(1.175)	(1.257)	(0.010)	(0.121)
R60	0.816**	0.564	4.476***	0.045***	0.583***
	(0.326)	(0.425)	(0.452)	(0.005)	(0.058)
R5M	1.893***	−5.524***	1.737***	0.011***	0.149***
	(0.380)	(0.448)	(0.323)	(0.003)	(0.035)
RR	−115.067***	10.632***	−90.699***	−0.571***	−7.141***
	(4.378)	(0.799)	(3.605)	(0.023)	(0.291)
L6	−1.212***	−0.078	−1.745***	−0.040***	−0.527***
	(0.233)	(0.260)	(0.399)	(0.006)	(0.074)
L60	0.355	0.021***	7.210***	0.054***	0.675***
	(0.237)	(0.004)	(0.372)	(0.003)	(0.037)
L5M	0.219	0.098***	1.698***	0.023***	0.300***
	(0.168)	(0.004)	(0.142)	(0.001)	(0.017)
LR	−100.519***	0.246	−95.114***	−0.691***	−8.655***
	(3.785)	(0.580)	(3.610)	(0.026)	(0.332)
N	420,480	420,480	841,534	841,534	841,534
Control state	TAS	TAS	TAS	TAS	TAS

Table: Difference in difference analysis.

Fuel Pricing and Participation

We also examine how introduction of batteries impacts on participation, bidding and price-setting of other generators (coal, gas, hydro, etc.) in FCAS markets.

Key results:

- Evidence of strong participation of BESS in different FCAS markets, putting competitive pressure on other technologies.
- In L6 market, HPR provided price-setting bids over 29% of the time and supplied more than 29% of the contracted volume.
- The introduction of major BESS facilities resulted in natural gas generators lowering their average bid prices by over AUD1000/MWh.
- Competitive pressures from HPR also resulted in black coal and hydro generators lowering their average bid prices across the lower and raise services.
- Impact on FCAS markets directly related to participation of BESS participation (e.g. significantly smaller effect on R60 and R5 markets)

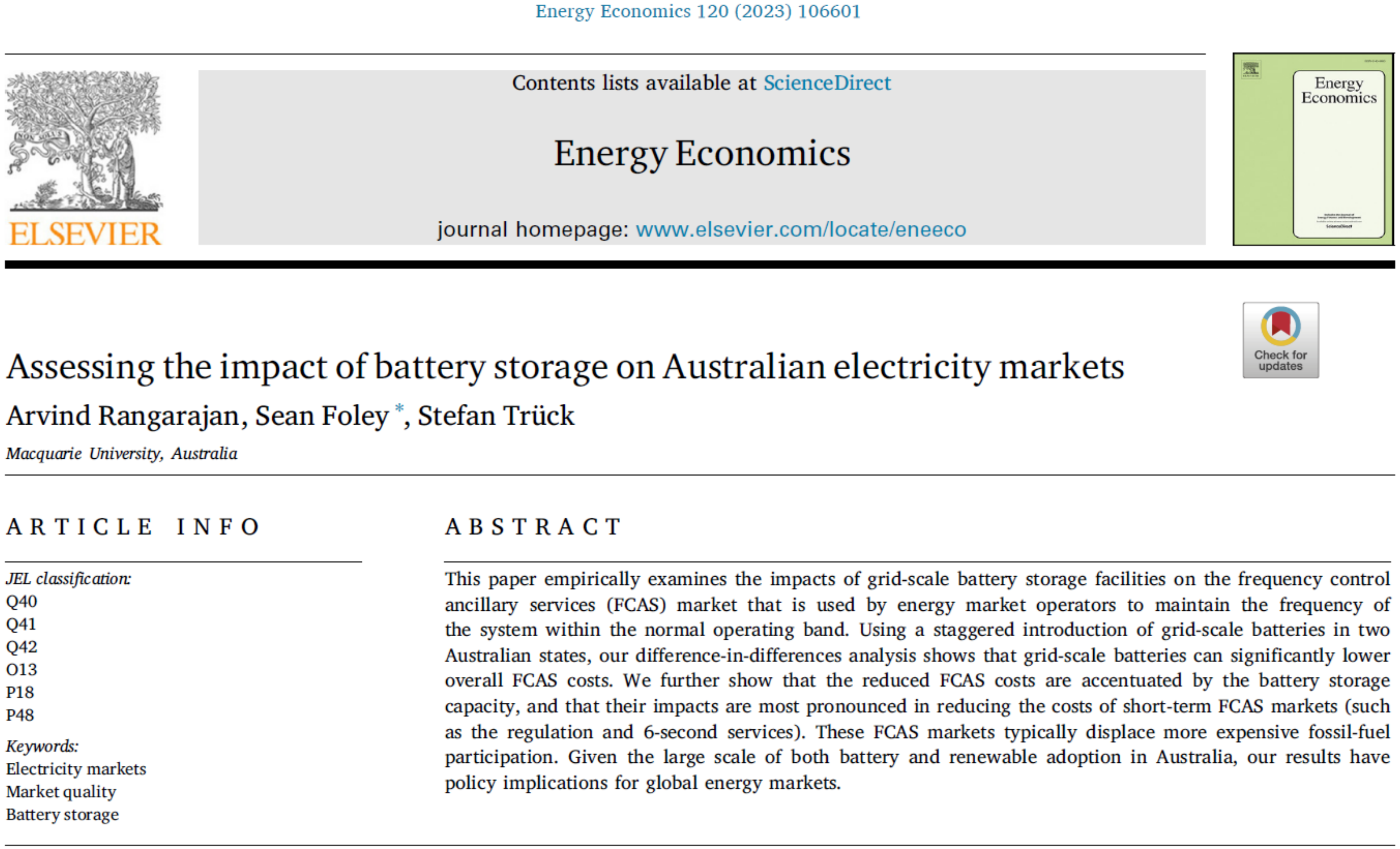
Conclusions

- Overall, our study suggests that the introduction of BESS have significantly lowered overall ancillary costs.
- Results of reduced cost are robust against different applied methodologies (event study, difference-in-difference),
- BESS had significant impact on participation and bidding behaviour of other generation technologies.
- Introduction of BESS brought sizeable cost reductions in regulation markets, since its competitive pressures forced natural gas generators (but also other generators) to lower their bid prices significantly.

Conclusions

- HPR brought sizeable cost-reductions in regulation markets (magnitude of over AUD100/MWh).
    - Driven by competitive pressures forcing natural gas generators to lower their bid prices significantly.
- Markets with infrequent BESS participation (60-second and 5-minute contingency markets) saw prices unchanged or even increase.
    - Resulting from increased bid prices by natural gas generators, potentially reflecting cost-recovery behavior.
- The impact of the Ballarat BESS was not as pronounced as for HPR.
    - Likely driven by smaller capacity and more limited participation as a result.

More details on results.....



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ELSEVIER

Assessing the impact of battery storage on Australian electricity markets

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ABSTRACT

This paper empirically examines the impacts of grid-scale battery storage facilities on the frequency control ancillary services (FCAS) market that is used by energy market operators to maintain the frequency of the system within the normal operating band. Using a staggered introduction of grid-scale batteries in two Australian states, our difference-in-differences analysis shows that grid-scale batteries can significantly lower overall FCAS costs. We further show that the reduced FCAS costs are accentuated by the battery storage capacity, and that their impacts are most pronounced in reducing the costs of short-term FCAS markets (such as the regulation and 6-second services). These FCAS markets typically displace more expensive fossil-fuel participation. Given the large scale of both battery and renewable adoption in Australia, our results have policy implications for global energy markets.

(YOU)^{us}

Designing energy markets for a net zero carbon future.
That's YOU to the power of *us*.

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TRANSFORMING ENERGY MARKETS
RESEARCH CENTRE

Panel Discussion

Chris Barrett

Product development manager, Lumea

Prof. Guillaume Roger

Professor, Monash University

Prof. Stefan Trüeck

Professor, Macquarie University

Dr. Neil Lessem

Head of Economics, AEMC

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Session 3B

Thermal Storage for Process Heat

Presented by Peter Haenke (ARENA)

ARENA INSIGHTS

MGA THERMAL

Techno-economics of MGA storage, and learnings as a LDES technology provider

ARENA Insights Forum

March 2024

Watch MGA video here.

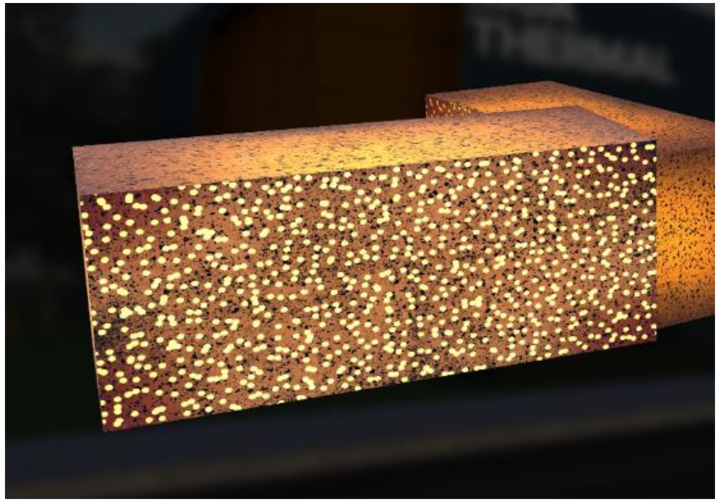
https://www.youtube.com/watch?v=s8YgoXZsPdE

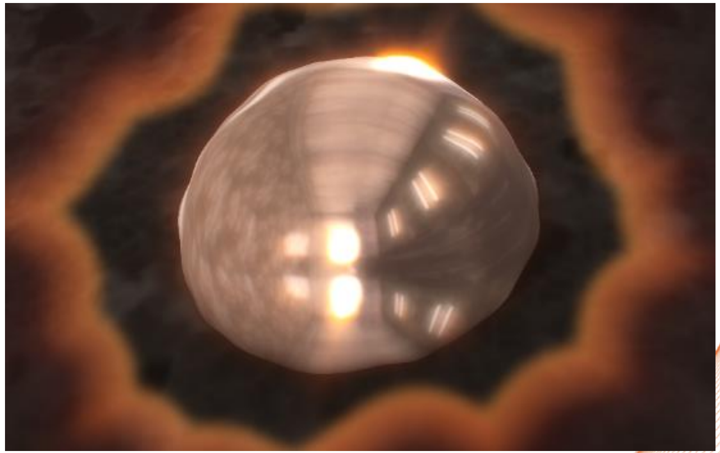
MGA Block: How does it work?

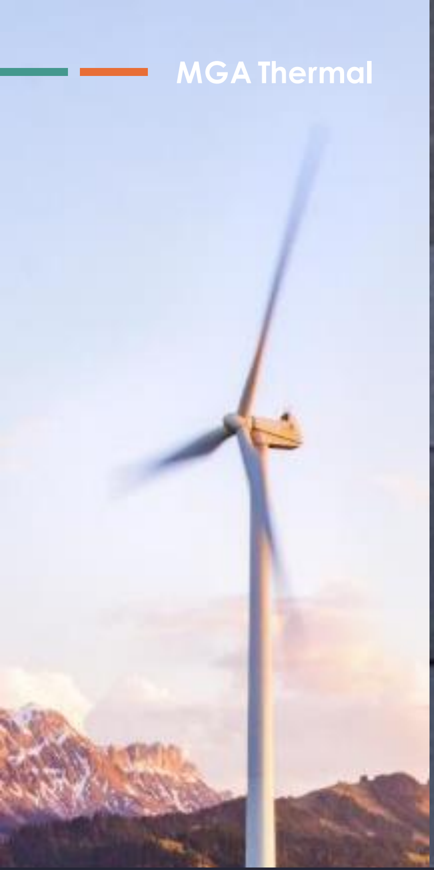
MGA blocks store and deliver thermal energy at a constant temperature while remaining outwardly solid.

MGA is short for Miscibility Gap Alloy

- A matrix material keeps the block solid and a metallic material is dispersed as particles.
- The matrix is highly conductive and rapidly distributes heat, keeping the particles (chocolate chip in a cupcake equivalent) in place as they melt when heat energy is absorbed.
- The blocks store massive thermal energy through the solid-liquid phase change, which is released as they cool and the particles solidify.







Renewable

Renewable friendly system compatible with solar, wind, & other renewables.

Modular

The units are stackable, making them scalable to any size.

High-Capacity

200-300% energy storage capacity of traditional thermal energy storage systems.

Sustainable

Long lifetime can be made using recycled materials. Fully recyclable.

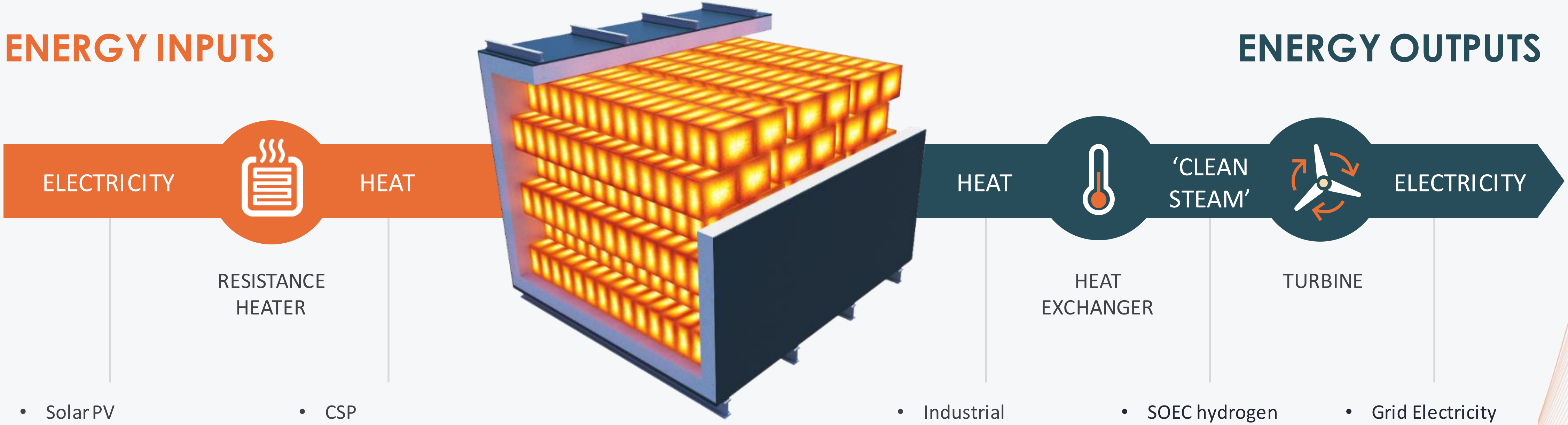
Economic

MGA Blocks are mass-manufactured using common and readily available materials.

Safe

When heated, the molten material is fully encapsulated, safe non-toxic raw materials.

A Thermal Energy Storage Solution



ENERGY INPUTS

ELECTRICITY

RESISTANCE HEATER

HEAT

- Solar PV
- Wind
- Grid Electricity

- CSP
- Waste Heat

ENERGY OUTPUTS

HEAT

HEAT EXCHANGER

‘CLEAN STEAM’

TURBINE

ELECTRICITY

- Industrial process heat
- Commercial and domestic space heating & cooling
- sCO_2 Turbines

- SOEC hydrogen generation
- Thermal power station retrofit

- Grid Electricity
- Distributed power

MGA Demonstration Unit

- Proven ability to heat, store & discharge to design specifications at scale.
- The project will measure steam output in an MGA Thermal system.
- Operational H2 2024

Key Specs

- 5 MWh storage
- 3700 Blocks **10 hours steam discharge at 385^{o}C, up to 40 Bar**

12m L, 3m w, 4m h

Use cases include a range of applications

INDUSTRIAL HEAT

MGA go to market priority

POWER STATION RETROFIT

GREEN FIELD POWER STATION

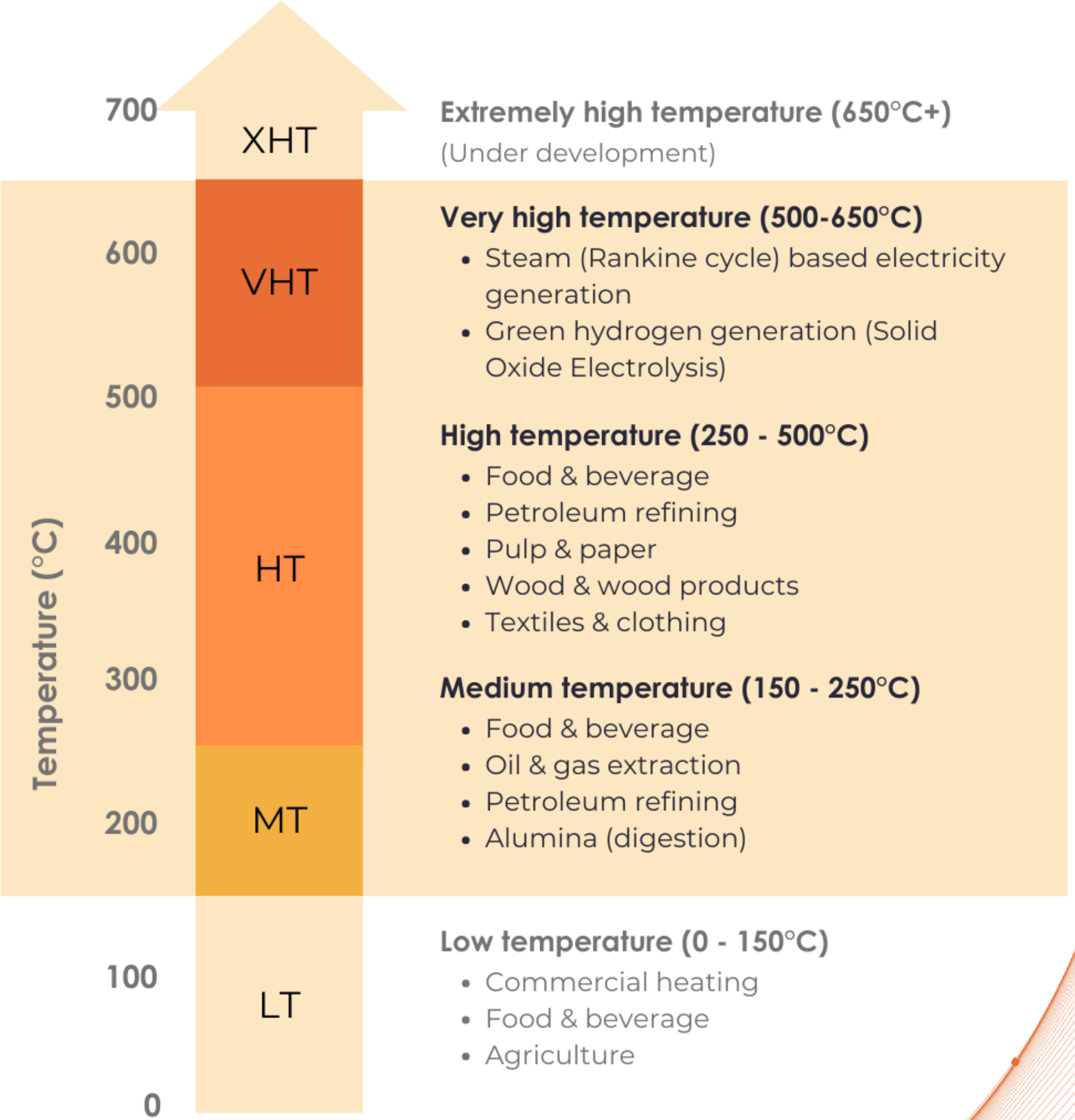
SOLAR & WIND

MGA THERMAL

Key Use Cases

Our core product can provide on-demand dispatch of process heat (steam or other working fluid) from medium to very high temperatures (150-650°C), meeting the requirements of most process heat applications as well as steam turbine-based power generation and cogeneration.

We are additionally developing a solution for >650°C process heat for hard-to-abate extreme temperature applications such as cement, iron & steel, alumina calcination



Extremely high temperature (650°C+)
(Under development)

Very high temperature (500-650°C)
- Steam (Rankine cycle) based electricity generation
- Green hydrogen generation (Solid Oxide Electrolysis)

High temperature (250 - 500°C)
- Food & beverage
- Petroleum refining
- Pulp & paper
- Wood & wood products
- Textiles & clothing

Medium temperature (150 - 250°C)
- Food & beverage
- Oil & gas extraction
- Petroleum refining
- Alumina (digestion)

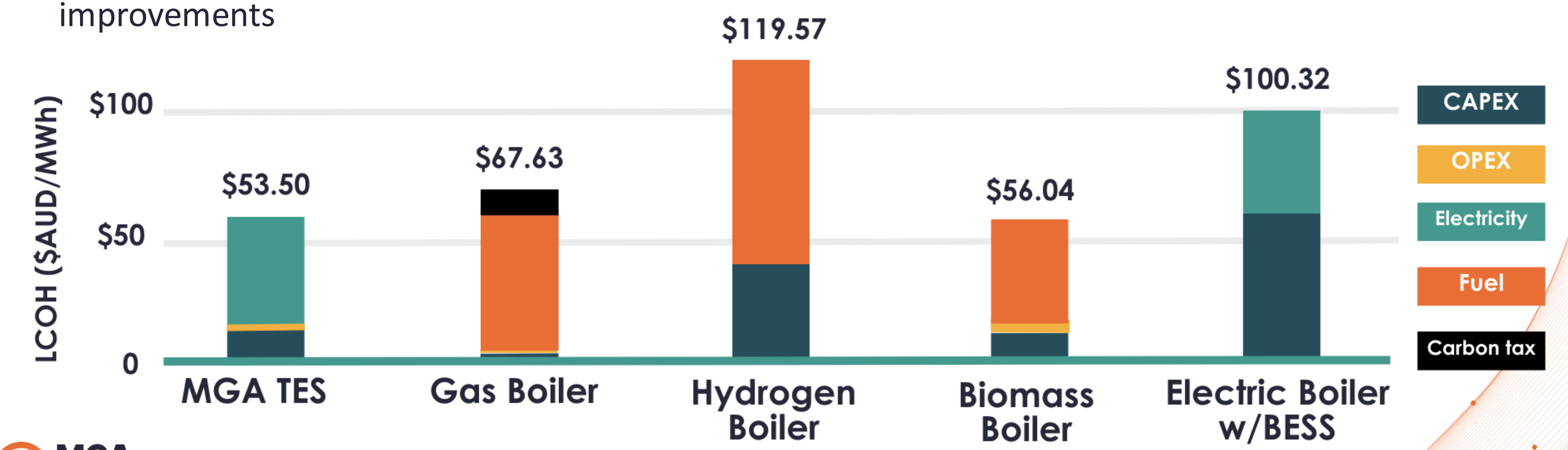
Low temperature (0 - 150°C)
- Commercial heating
- Food & beverage
- Agriculture

MGA THERMAL

Levelised Cost of Heat

The majority of industrial heat is used as steam. If provision of this steam can be achieved by renewable means, then the industry can be decarbonised without changing processes, just substituting the type of boiler.

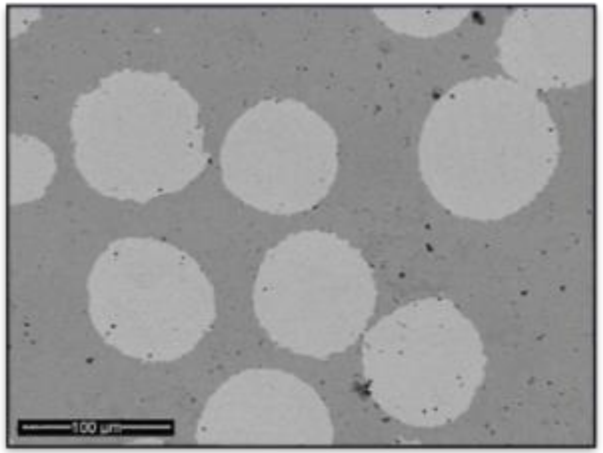
Our Levelised Cost of Heat (LCOH) comparison examines 10 MW (thermal), 24-hour steam supply – corresponding to a large industrial boiler, and are pre any cost out scale up improvements



MGA THERMAL

MGA's unique position in the market

- MGA Thermal originally span out as a material science innovation – *a purpose engineered material with optimised properties for thermal energy storage*
- As the company has grown, the necessary technology has been developed to turn this into a complete thermal energy storage system.
- MGA's business model is centred on being an OEM of the storage media, and providing design guidance for the surrounding TES infrastructure



Left: microstructure of an early MGA formulation

Down: MGA production line (Tomago, NSW)

MGA THERMAL

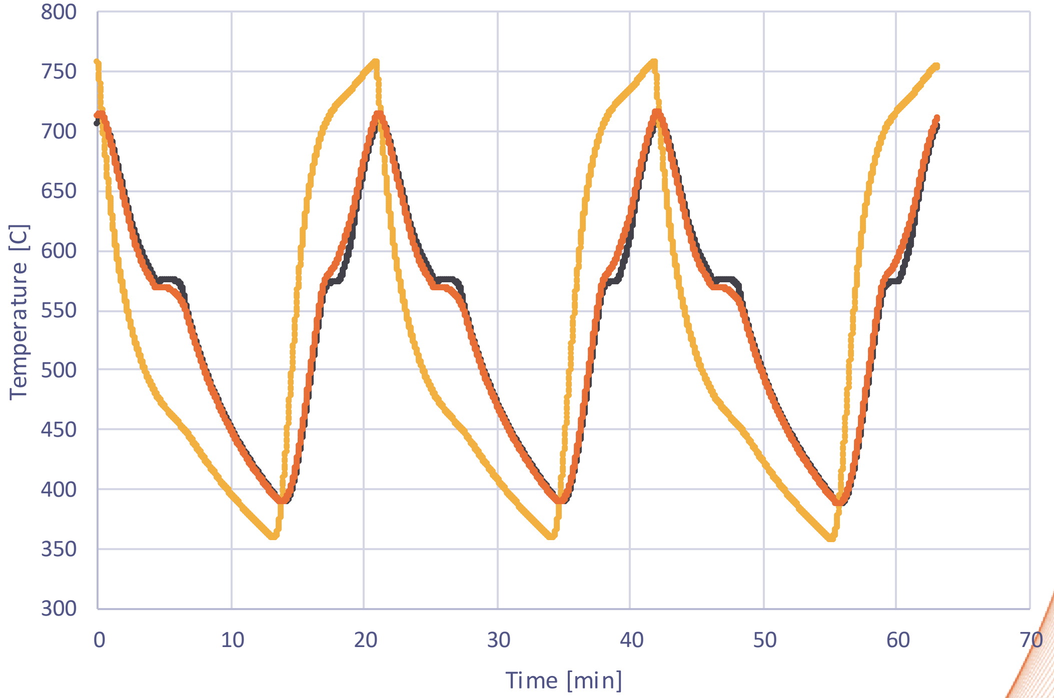
MGA's unique position in the market

Advantages:

- Advanced material properties, and the understanding to adjust them as required (thermal conductivity, energy density, LHOF)
- Whole-of-system optimisation
- System is not core IP – transparency in operating principles
- Can collaborate with other TES companies

Disadvantages:

- Time to market: needed to scale and commercialise the material and it's production, plus the surrounding TES infrastructure in parallel



MGA accelerated ageing time-temperature data (3 cycles – testing is now complete to >3600 cycles / 10 years of operation)

Learnings from the MGA scale up

- Key goal is bringing the technology to market in a de-risked manner ASAP to line with ERT
- Strategic development pathway to increase TRL, unlock capital and scale in achievable steps
- Overheat Lesson (Oct 2023):
  - Importance of inhouse trails at scale before customer deployment
  - Engineering measures & fail safes in the event of an overheat now incorporated into our designs
  - MoC process critical for hardware related deep-tech start ups, along with HAZOP, risk review, SOP, well documented commissioning procedures, delegation of authority, SME consultation etc. These can be seen as a handbrake to agility in early stage, fostering a safety culture is crucial.
  - TES is pushing higher for more energy storage capacity – 1800C+ for some tech. Industry capability and literacy around risks is crucial. Incidents due to rush to develop can set the industry back, but more importantly put people at risk.

Learnings for TES uptake in industry – client side

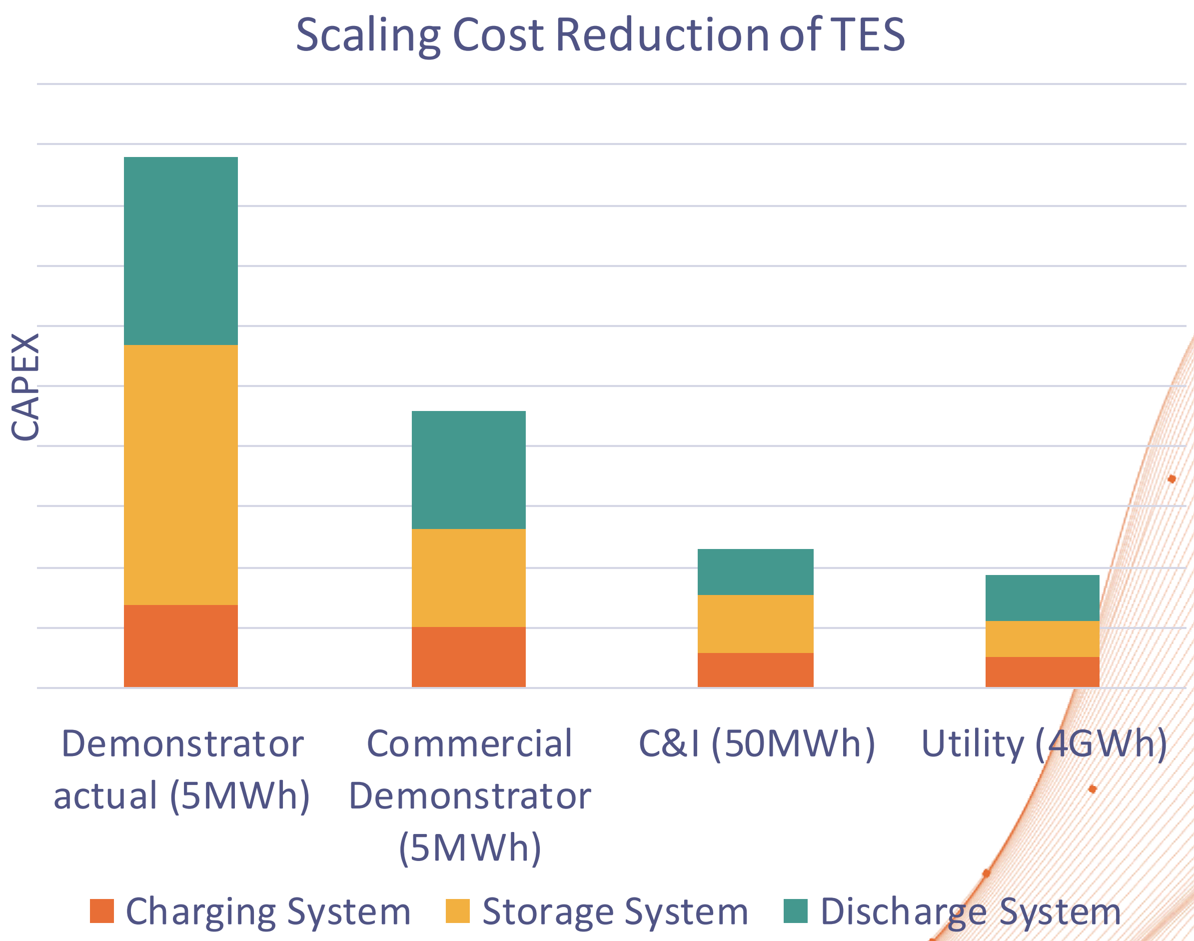
- TES is emerging as a key solution to industrial decarbonisation through low cost firming of intermittent renewables

- BTM simplifies ROI case & reliance on policy

- Process heat go to market: Client use cases are varied – depend on BTM renewables, heat load profile, grid connection… The ability to size charging, storage and discharge infrastructure independently can help with this but has a large engineering overhead.

- The technology + the CAPEX become much more efficient with scale: rough scaling law
    - CAPEX ≈ Capacity^ $^{-0.14}$

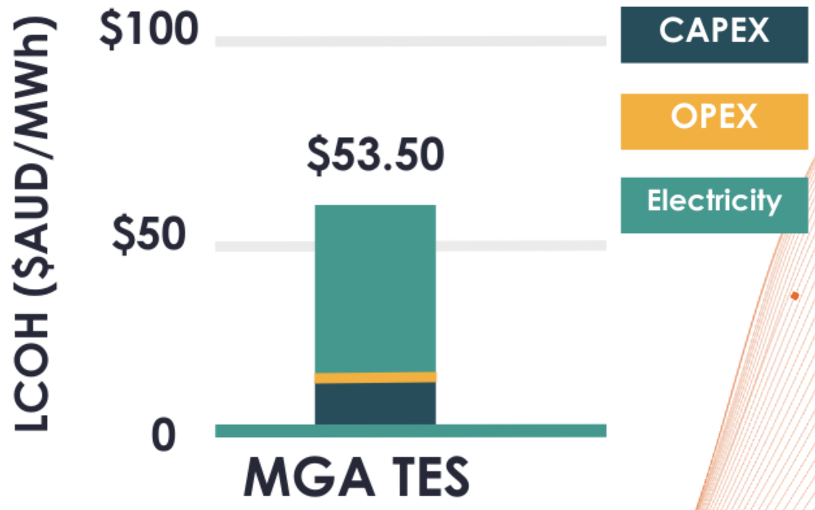
- This means that it lends itself to large scale applications with huge emissions reduction potential, however these are inherently slower moving and harder to de-risk



MGA THERMAL

Learnings for TES uptake in industry – electricity side

- LCOH is dominated by cost of energy to charge - transmission tariff structures vary by geography and can have a large impact on project ROI
- A core issue facing eTES is grid connectivity – typically input electrical power is several X steam output – this can result in 15MW+ connections for a 5MW load (e.g. 8 hr charging, 24 hr discharge regime).



MGA THERMAL

Learnings for TES uptake in industry – Knowledge sharing

- Industrial decarb pathways are being formed presently and have gap in understanding and offerings at scale
- Breadth of technologies hitting the market with varied levels of viability.
  - leaning on organisations like the CSIRO and LDES council to assist deciphering these for industry. Knowledge gap requires education by impartial bodies with deep scientific understanding.
- Missteps due to poor understanding at large scale and ‘white elephants’ can be crippling during early adoption
- Understand compatibility with other emerging technologies – TES of varying operating temps, hydrogen, biofuels, heat pumps, new PPA structures & policies / legislation
- Client process compatibility is still crucial – most decarb technologies are not ‘one size fits all’

Closing remarks

- Huge potential for eTES as a key tool for firming intermittent renewables & enabling path to decarbonisation targets
- Window is closing for new technology to be scaled in time to help reach targets
- Knowledge sharing and transparency can be difficult commercially, but necessary if we want to achieve the fastest and least painful road to decarbonisation

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ARENA Insights – Mars & TES

SUSTAINABILITY IN OUR OPERATIONS
MARS AUSTRALIA, 26 March 2024

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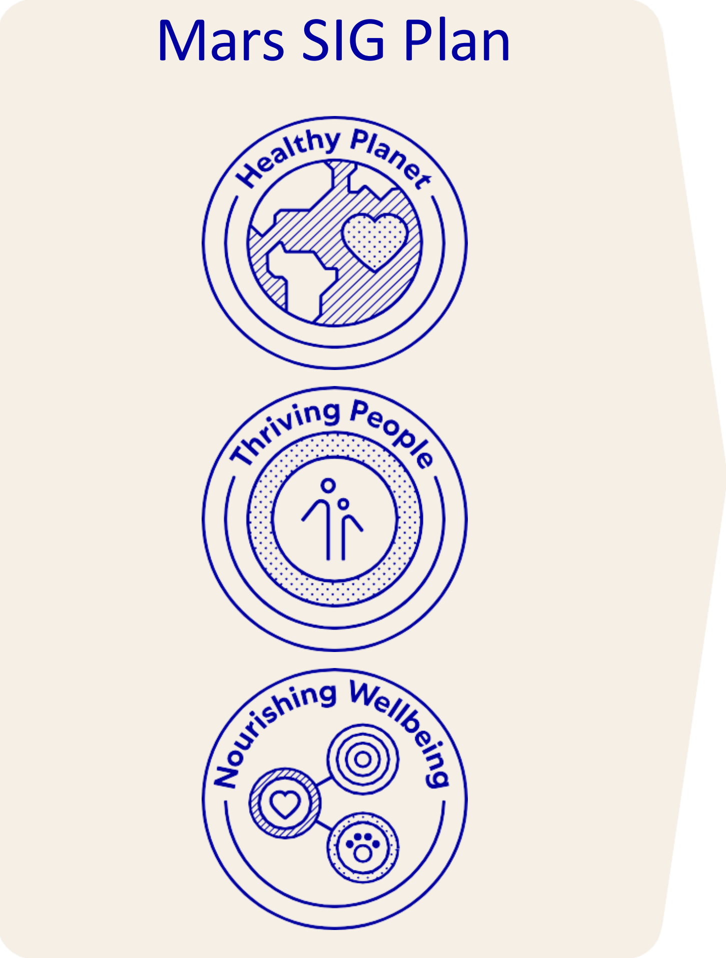
Paul Matuschka +61 407 466 115 / paul.matuschka@effem.com

Sustainable in a Generation Operations Lead

Pet Nutrition Australia

Our Petcare Sustainability Roadmap

Mars SIG Plan



Healthy Planet Improving our environmental pawprint	Circularity	Design our packaging for recyclability and manage our waste - boost circularity
	Climate	Reduce our carbon footprint, helping to tackle climate change
Thriving People Operating and sourcing responsibly	Sourcing	With our suppliers, support their progress on sustainability and take action in key supply chains
	Associates	Continue to be a responsible workplace and advance the Veterinary profession
Pet Wellbeing Expanding access for pets and influencing policy	Access	Increase access to homes, nutrition & care for pets in need, with an emphasis on prevention
	Advocacy	Advocate for policies that boost the sustainability of pet parenthood and enhance pet wellbeing

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Pet Nutrition

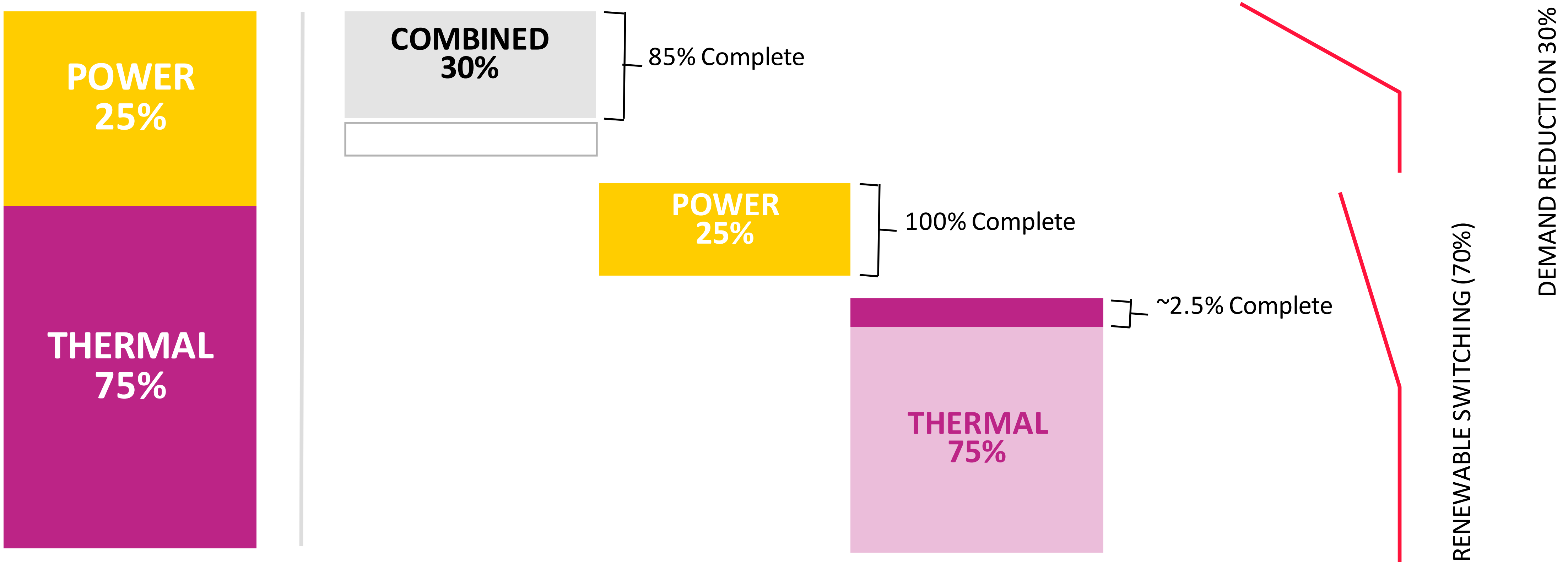
A Better World For Pets

Learn more about our **Sustainable in Generation Plan** and our **Net Zero Roadmap** on Mars.com

Pet Nutrition Australia

100% Renewable, 100% NetZero by 2040 – Direct Operations

TOTAL ENERGY



POWER 25%

THERMAL 75%

COMBINED 30% 85% Complete

POWER 25% 100% Complete

~2.5% Complete

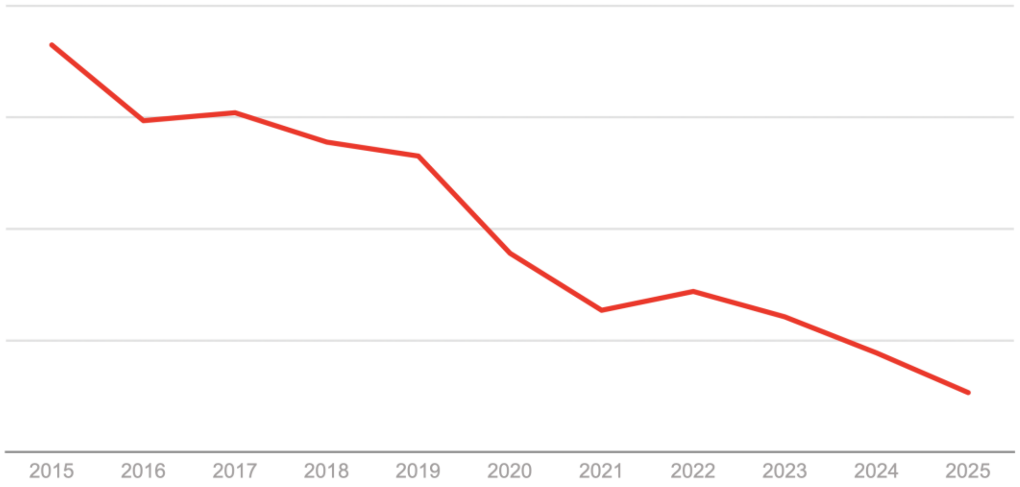
THERMAL 75%

RENEWABLE SWITCHING (70%)

DEMAND REDUCTION 30%

MARS Pet Nutrition | A Better World For Pets

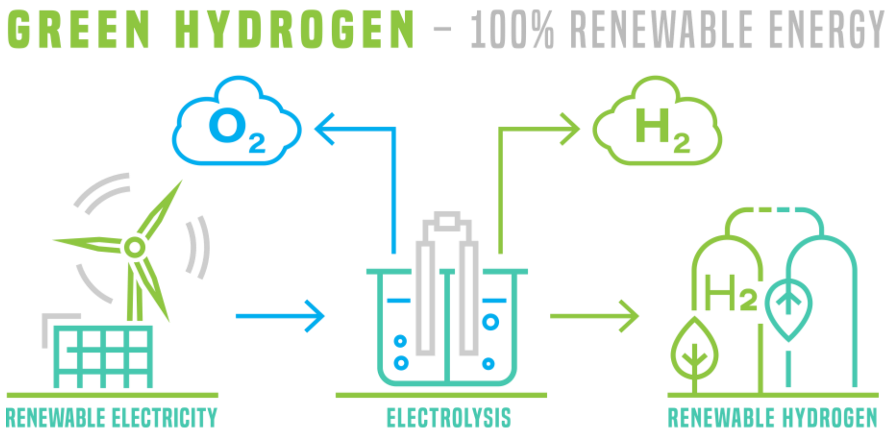
THERMAL ENERGY DEMAND REDUCTION



POWER TO HEAT

HEAT TO HEAT

FUEL TO HEAT



Why Energy Storage is important to us, particularly TES

Power to Heat

Direct Electrification is not Viable

Example ‘*firm*’ GRID (delivered) price of (renewable) electricity $200/MWh (average)

- Commodity 65%
  - **Renewable Value 10%**
  - **Balance 55%**
- Other Charges 35%
  - **Tarif 10%**
    - Peak 8%
    - Off Peak 2%
  - **Capacity 15%**
    - Capacity Charge 10%
    - Critical peak Demand 5%
  - **Other 10%**

In this example the replacement energy value (electrification) is ~3x replacement value of Natural Gas

$200/MWh = $55/GJ (NG) = NOT VIABLE

~$60/GJ (Steam 20 yr.*)*

BTM Solar PV with Storage is Viable

Example BTM Solar PV electricity with TES ($75/MWh equivalent)

Generation 75%

Storage 25%

$75/MWh = $20/GJ (steam) = Viable

Example variants of '*unfirmed*' GRID (delivered) price of (renewable) electricity $50/MWh (average) with TES*

Asset 40% + Delivered Power 60% ≤ $25/GJ (steam) = potentially VIABLE

4 TES

8GWh
2MVA
Std Tariff

Commodity 30%

Other Charges 70%

- Tarif 30%
  - Peak 24%
  - Off Peak 6%
- Capacity Charge 25% assumption excludes CPD
- Other 20%

4 TES

8GWh
2.5MVA
Std Tariff

Commodity 10%

Other Charges 90%

- Tarif 35%
  - Peak 28%
  - Off Peak 7%
- Capacity Charge 35% assumption excludes CPD
- Other 20%

4 TES

8GWh
2.0MVA
Off peak Tariff

Commodity 35%

Other Charges 65%

- Electrification Tarif 20%
- Capacity Charge 25% assumption excludes CPD
- Other 20%

4 TES

15GWh
3MVA
Std Tariff

Commodity 45%

Other Charges 55%

- Tarif 30%
  - Peak 25%
  - Off Peak 5%
- Capacity Charge 14% assumption excludes CPD
- Other 15%

Competitive Power is Possible Today

EBoiler with ‘*firm*’ GRID renewable electricity ~ total $220/MWh

Asset 10%

Firm GRID power 90%

- Power
  - Access to low price power commodity
  - Electrification Tariff (Off Peak Rate)
  - Demand Charge exempt
  - Flexible access to spare external capacity within site specific capability
- Early Adopter Advantage Incentives / Resources
  - Grant Funding for TES Asset deployment; electrical infrastructure (internal or external); BTM Power
  - Technical assistance in detailed modeling & assessments

eTES + ‘special’ Power ~ total $60/MWh (30%)

Asset 50%

Power 50%

Lowest ROI = Faster Uptake

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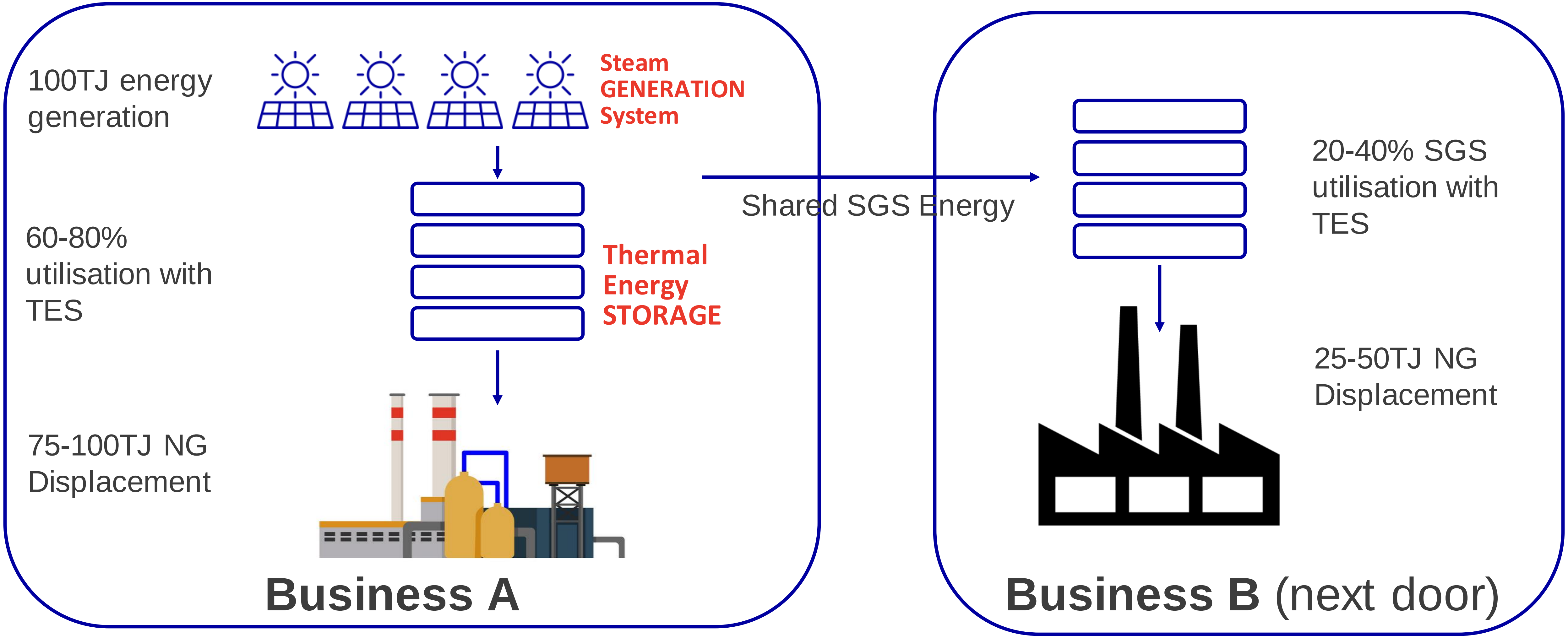
Renewable Energy Fraction	< 50%	50% - 75%	≥ 75%
Difficultly with TES	Easiest	Moderate	Most Difficult
	Levers • Electrification Tariff • Demand Charge changes or removal • Subsidised new capacity infrastructure Opportunity • Cheap electrically commodity	(additional) Levers • Carbon Tax, CBAM Opportunity • Demonstrated technology • Technology cost reduction • Blended BMT + Grid Challenges • Existing assets	Opportunity • Early Mover perks • eBattery Challenges • Critical Peak Demand Charges • Utilisation of storage diminishes the higher the R.E.F. • Availability of renewable energy 24/7, 365
	START NOW	**PLAN NOW**	**HOLD**

Heat to Heat

Generation ≠ Utilisation



100TJ energy generation

Steam GENERATION System

60-80% utilisation with TES

Thermal Energy STORAGE

75-100TJ NG Displacement

Business A

Shared SGS Energy

20-40% SGS utilisation with TES

25-50TJ NG Displacement

Business B (next door)

Steam Generation Value = $25/GJ (*example*)

Short Term Incentive: $5/GJ Steam

Unfirmed Incentive: $17/GJ Steam

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Key Take Outs

Early Mover Advantages

Reduce the ROI Window

Grant / Incentives Support

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A Better World For Pets

MARS Australia: WHAT STARTS HERE, CHANGES THE WORLD

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Sustainable in a Generation Operations Lead

HILT CRC

HEAVY INDUSTRY
LOW-CARBON
TRANSITION
COOPERATIVE
RESEARCH
CENTRE

DE-RISKING DECARBONISATION FOR HEAVY INDUSTRY

Jenny Selway – CEO, HILT CRC

ARENA Insights
26th March 2024

WHO WE ARE – HILT CRC

De-risking decarbonisation for heavy industry.

A collaborative research centre established in 2021 with Industry and Government funding of $200M.

We link world-leading minds from industry, research, and government to create a low-carbon heavy industry sector.

>50 PARTNERS

Together with our partners, we are seeking to develop and demonstrate low-carbon technologies that will help transition the steel, iron, alumina, and cement industries to decarbonise heavy industry and grow Australia’s economy.

CORE PARTNERS

Alcoa
Australian National University
CSIRO
Curtin University
Fortescue
GRANGE RESOURCES
Hydro
LIBERTY
ROY HILL
SOUTH32
THE UNIVERSITY of ADELAIDE

KEY PARTNERS

ADBRI
calix
EGA
الإمارات العالمية للألمنيوم
EMIRATES GLOBAL ALUMINIUM
FCT COMBUSTION
MITSUBISHI HEAVY INDUSTRIES
PRIMETALS TECHNOLOGIES
GOVERNMENT OF WESTERN AUSTRALIA
mriwa
SOUTH AUSTRALIA
Government of South Australia
Department for Energy and Mining
SWIN BUR NE
SWINBURNE UNIVERSITY OF TECHNOLOGY
THE UNIVERSITY OF NEWCASTLE AUSTRALIA
Worley
energy | chemicals | resources

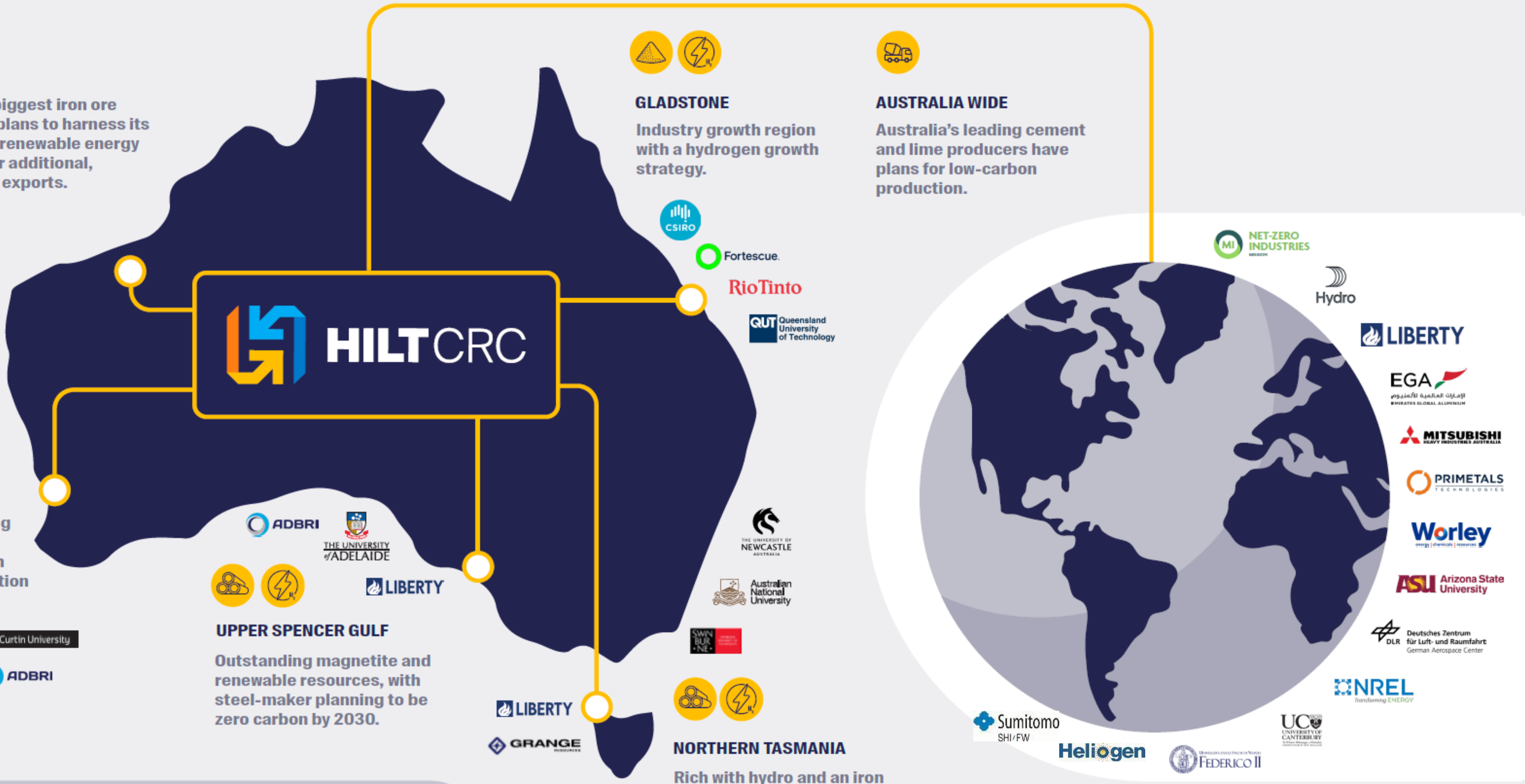
AFFILIATE PARTNERS

CIS
DIMER
GLENCORE TECHNOLOGY
A GLENCORE Company
GPA
HATCH
Heliogen
MAGNETITE MINES
Queensland Government
QUT
RESOURCECO
RioTinto
TEK7
UNO TECHNOLOGY
UNEARTH WHYALLA
ZEN ENERGY

ASSOCIATE PARTNERS

AUSTRALIAN ALUMINIUM COUNCIL LTD
Australian Renewable Energy Hub
AUSTRALIAN STEEL INSTITUTE
ASU Arizona State University
UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II
CEMENT INDUSTRY FEDERATION
CORE
Energy Exemplar
DLR
Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center
fpc Forest Products Commission
PREDICT
Anticipate & Save.
STANDARDS Australia
Sumitomo SHI FW
SynBio
UC UNIVERSITY OF CANTERBURY
wsp

LINKING INDUSTRY, RESEARCH AND GOVERNMENTS



PILBARA

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

Rio Tinto
Fortescue
Roy Hill

KWINANA & SOUTH WEST

World-leading alumina exporter with decarbonisation strategies.

Alcoa
Curtin University
South32
ADBRI

UPPER SPENCER GULF

Outstanding magnetite and renewable resources, with steel-maker planning to be zero carbon by 2030.

ADBRI
The University of Adelaide
LIBERTY

GLADSTONE

Industry growth region with a hydrogen growth strategy.

CSIRO
Fortescue
Rio Tinto
QUT Queensland University of Technology

AUSTRALIA WIDE

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

The University of Newcastle Australia
Australian National University
Swinburne University of Technology

NORTHERN TASMANIA

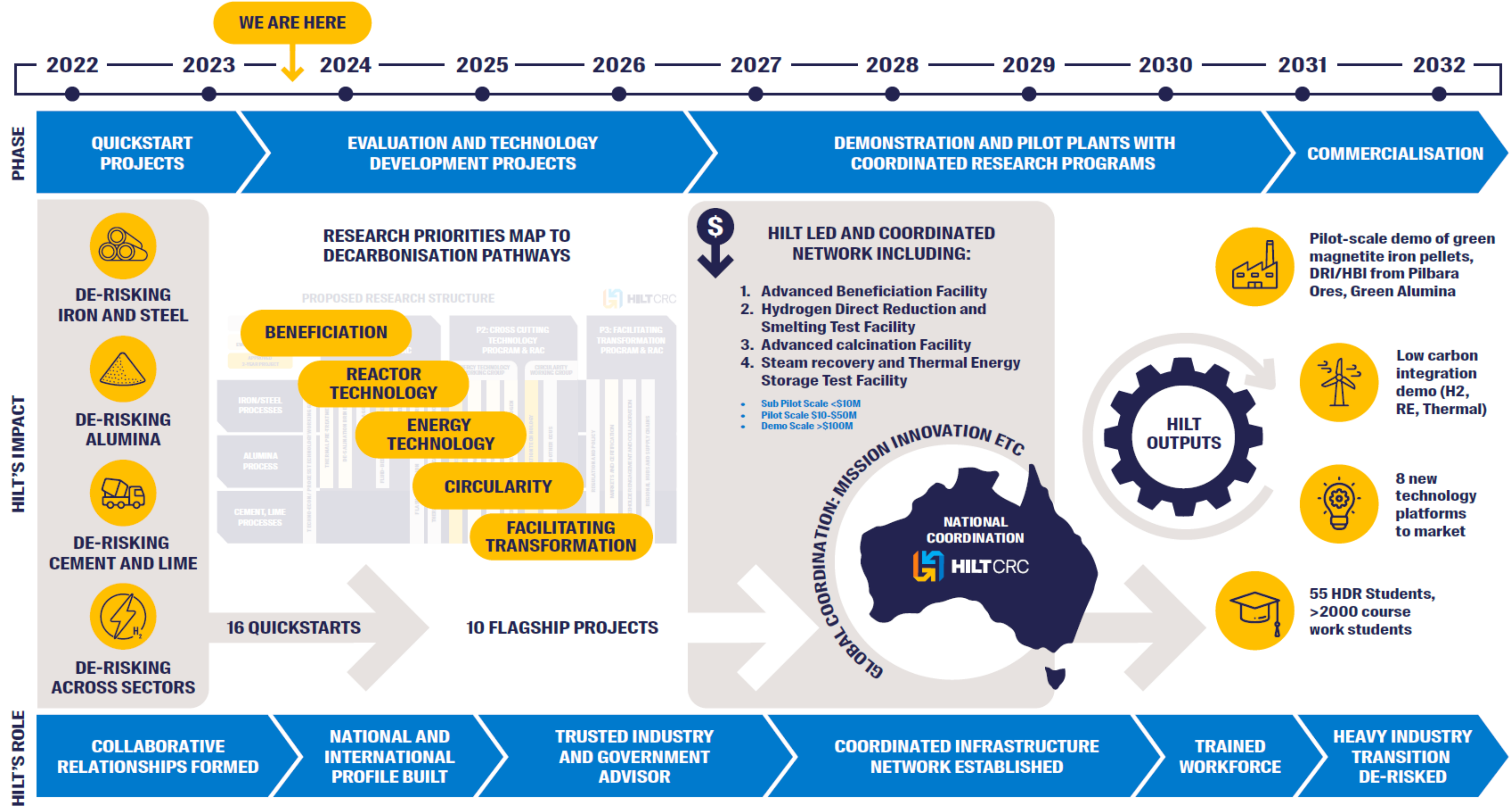
Rich with hydro and an iron pellet exporter, the region has plans for hydrogen.

LIBERTY
GRANGE Resources

Net-Zero Industries
Hydro
LIBERTY
EGA Emirates Global Aluminium
MITSUBISHI Heavy Industries Australia
PRIMETALS Technologies
Worley
ASU Arizona State University
DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center
NREL Transforming ENERGY
UC University of Canterbury
Federico II
Heliogen
Sumitomo SHI FW

Iron & Steel
Alumina
Hydrogen & Ammonia
Cement & Lime

HILT'S 2030 PLAN



WE ARE HERE

2022 — 2023 — 2024 — 2025 — 2026 — 2027 — 2028 — 2029 — 2030 — 2031 — 2032

PHASE

- QUICKSTART PROJECTS
- EVALUATION AND TECHNOLOGY DEVELOPMENT PROJECTS
- DEMONSTRATION AND PILOT PLANTS WITH COORDINATED RESEARCH PROGRAMS
- COMMERCIALISATION

HILT'S IMPACT

DE-RISKING IRON AND STEEL

DE-RISKING ALUMINA

DE-RISKING CEMENT AND LIME

DE-RISKING ACROSS SECTORS

RESEARCH PRIORITIES MAP TO DECARBONISATION PATHWAYS

BENEFICIATION

REACTOR TECHNOLOGY

ENERGY TECHNOLOGY

CIRCULARITY

FACILITATING TRANSFORMATION

16 QUICKSTARTS

10 FLAGSHIP PROJECTS

HILT LED AND COORDINATED NETWORK INCLUDING:

1. Advanced Beneficiation Facility
2. Hydrogen Direct Reduction and Smelting Test Facility
3. Advanced calcination Facility
4. Steam recovery and Thermal Energy Storage Test Facility

- Sub Pilot Scale <$10M
- Pilot Scale $10-$50M
- Demo Scale >$100M

GLOBAL COORDINATION: MISSION INNOVATION ETC

NATIONAL COORDINATION

HILTCRC

HILT OUTPUTS

Pilot-scale demo of green magnetite iron pellets, DRI/HBI from Pilbara Ores, Green Alumina

Low carbon integration demo (H2, RE, Thermal)

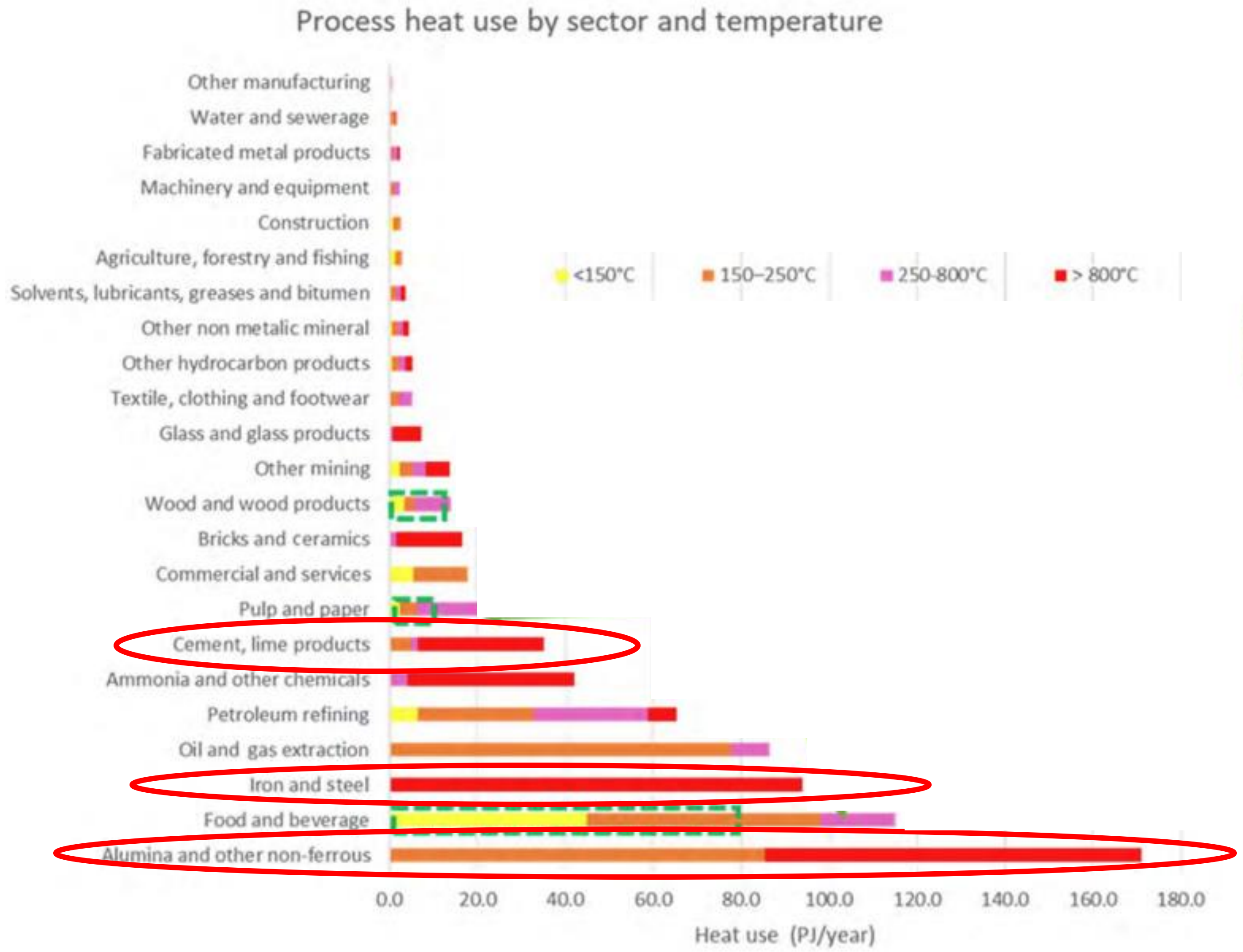
8 new technology platforms to market

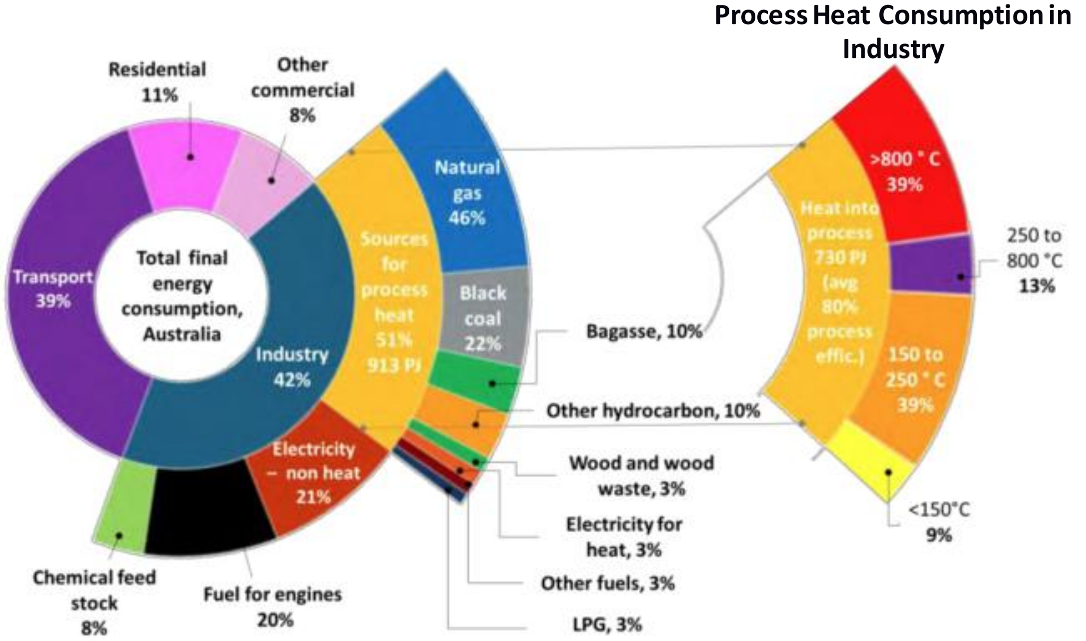
55 HDR Students, >2000 course work students

HILT'S ROLE

- COLLABORATIVE RELATIONSHIPS FORMED
- NATIONAL AND INTERNATIONAL PROFILE BUILT
- TRUSTED INDUSTRY AND GOVERNMENT ADVISOR
- COORDINATED INFRASTRUCTURE NETWORK ESTABLISHED
- TRAINED WORKFORCE
- HEAVY INDUSTRY TRANSITION DE-RISKED

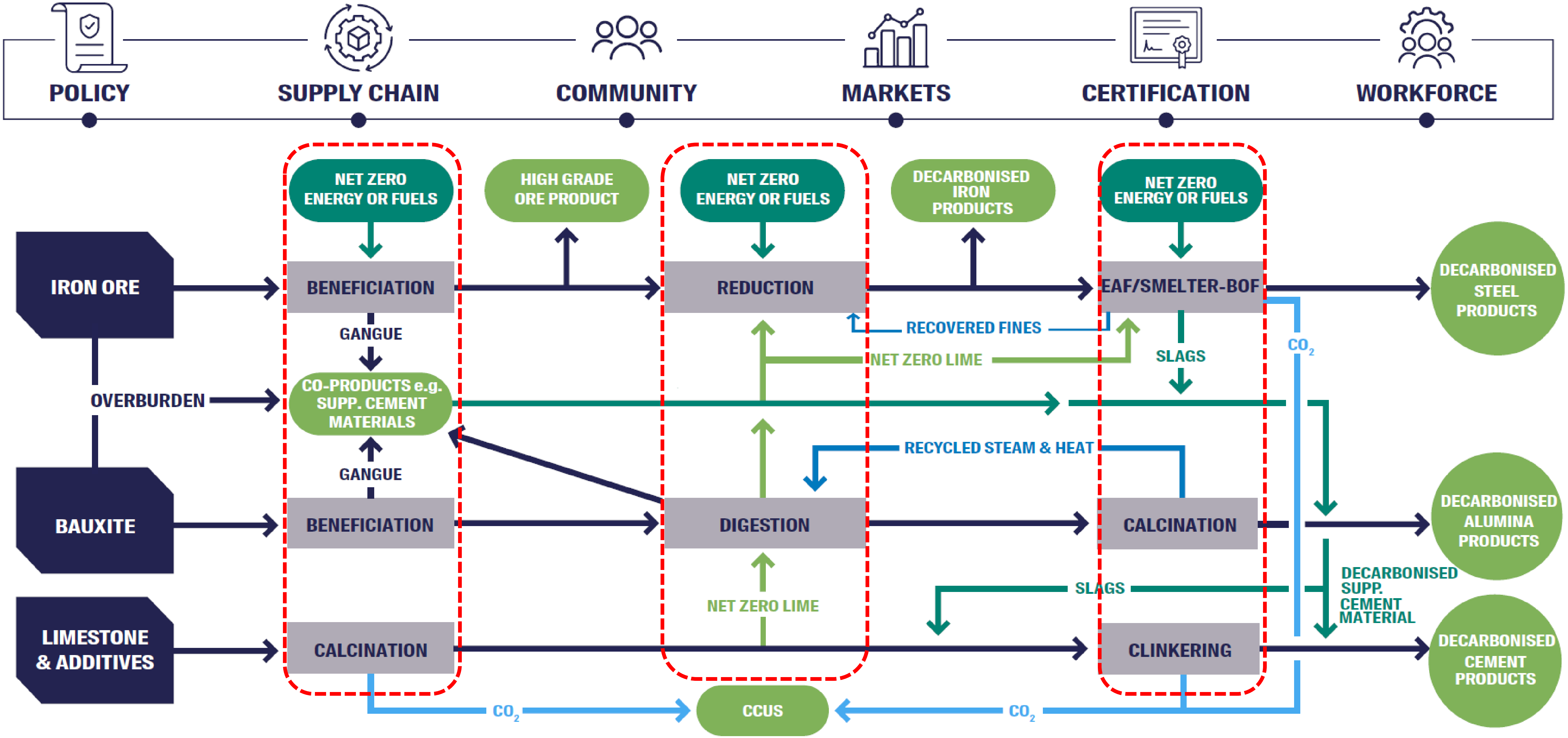
INDUSTRY PROCESS HEAT USE


Process heat use by sector and temperature


Process Heat Consumption in Industry

https://arena.gov.au/assets/2019/11/renewable-energy-options-for-industrial-process-heat.pd

PATHWAYS TO DECARBONISE HEAVY INDUSTRY



POLICY

SUPPLY CHAIN

COMMUNITY

MARKETS

CERTIFICATION

WORKFORCE

IRON ORE

OVERBURDEN

BAUXITE

LIMESTONE & ADDITIVES

NET ZERO ENERGY OR FUELS

BENEFICIATION

GANGUE

CO-PRODUCTS e.g. SUPP. CEMENT MATERIALS

GANGUE

BENEFICIATION

CALCINATION

HIGH GRADE ORE PRODUCT

NET ZERO ENERGY OR FUELS

REDUCTION

DIGESTION

NET ZERO LIME

DECARBONISED IRON PRODUCTS

RECOVERED FINES

NET ZERO LIME

RECYCLED STEAM & HEAT

SLAGS

NET ZERO ENERGY OR FUELS

EAF/SMELTER-BOF

SLAGS

CALCINATION

CLINKERING

CO_2

DECARBONISED SUPP. CEMENT MATERIAL

DECARBONISED STEEL PRODUCTS

DECARBONISED ALUMINA PRODUCTS

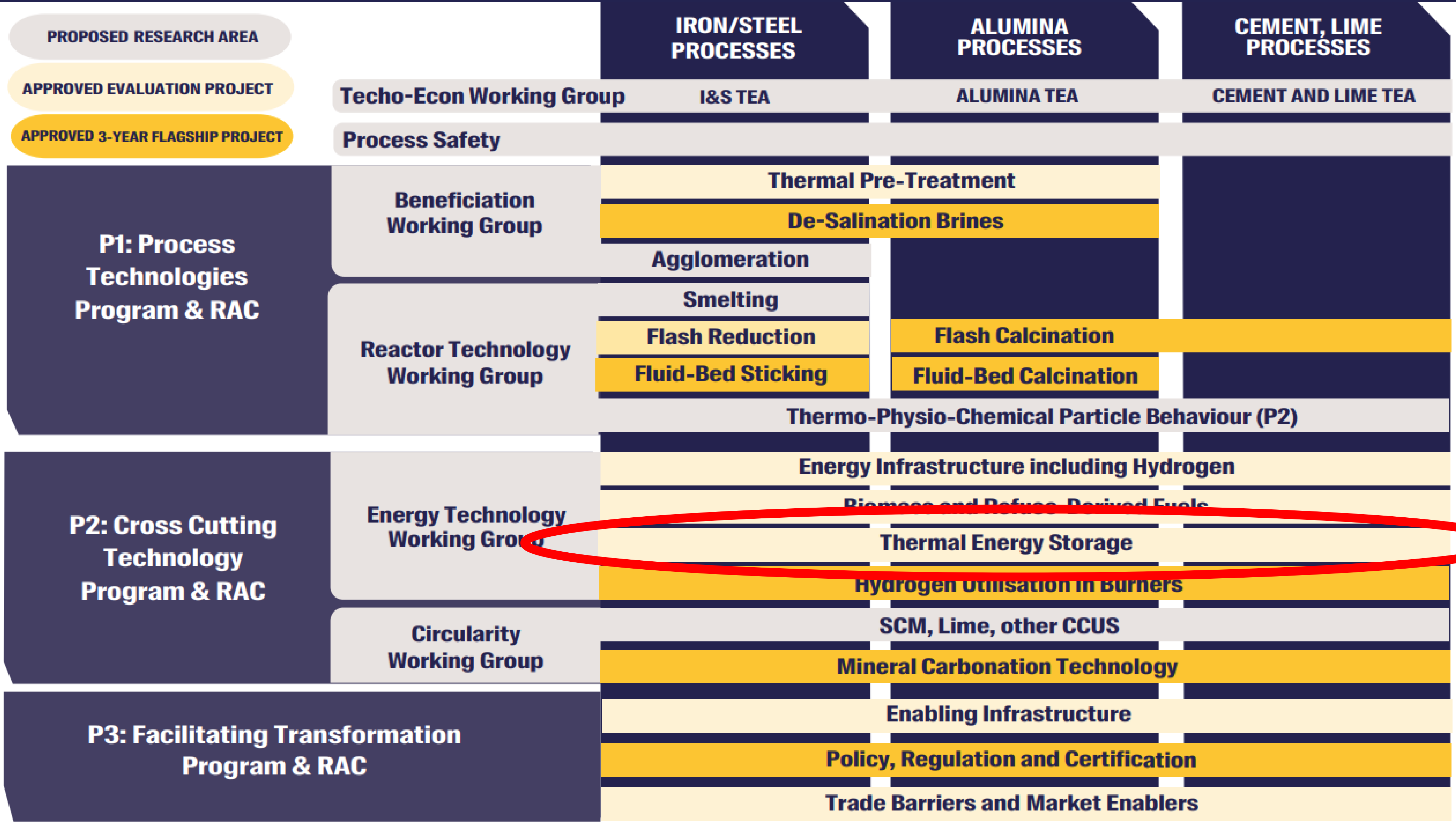
DECARBONISED CEMENT PRODUCTS

CO_2

CCUS

CO_2

RESEARCH FOCUS AREAS



PROPOSED RESEARCH AREA

APPROVED EVALUATION PROJECT

APPROVED 3-YEAR FLAGSHIP PROJECT

IRON/STEEL PROCESSES

ALUMINA PROCESSES

CEMENT, LIME PROCESSES

Techo-Econ Working Group

I&S TEA

ALUMINA TEA

CEMENT AND LIME TEA

Process Safety

P1: Process Technologies Program & RAC

Beneficiation Working Group

Thermal Pre-Treatment

De-Salination Brines

Agglomeration

Reactor Technology Working Group

Smelting

Flash Reduction

Flash Calcination

Fluid-Bed Sticking

Fluid-Bed Calcination

Thermo-Physio-Chemical Particle Behaviour (P2)

P2: Cross Cutting Technology Program & RAC

Energy Technology Working Group

Energy Infrastructure including Hydrogen

Biomass and Refuse-Derived Fuels

Thermal Energy Storage

Hydrogen Utilisation in Burners

Circularity Working Group

SCM, Lime, other CCUS

Mineral Carbonation Technology

P3: Facilitating Transformation Program & RAC

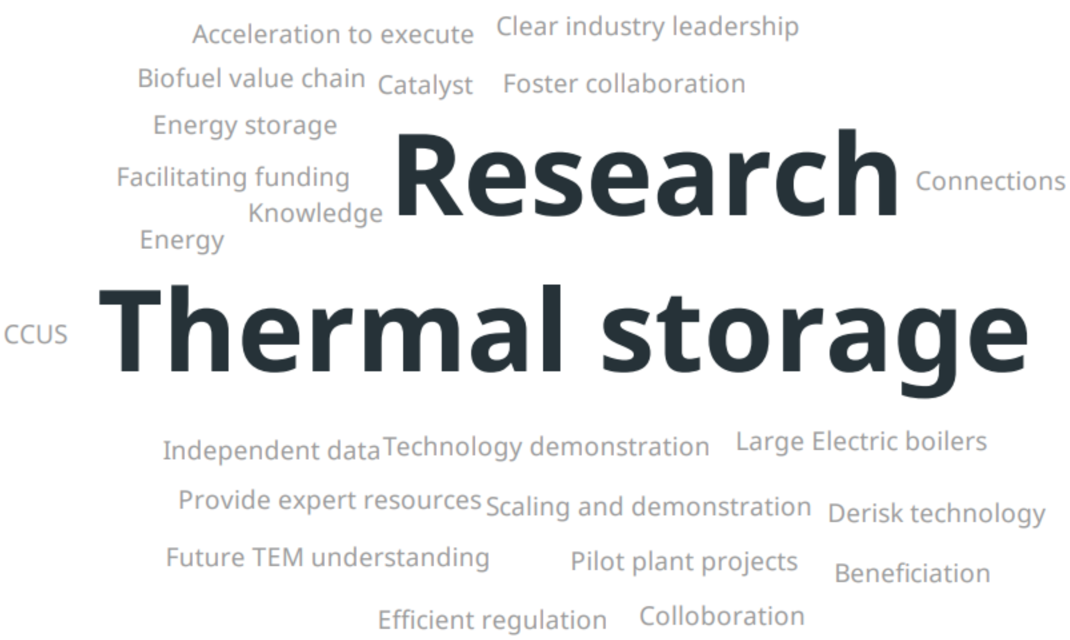
Enabling Infrastructure

Policy, Regulation and Certification

Trade Barriers and Market Enablers

HILT CONFERENCE - INTEREST IN TES

What are your organisation's top three priorities for HILT to support heavy industry's transition to net zero by 2050?



What critical research infrastructure is needed to for universities and research providers to support the low carbon transition?

HILT Conference Survey 2024

INDUSTRY CHALLENGES FOR GREEN HEAT

Iron and Steel

Cement and Lime

Alumina

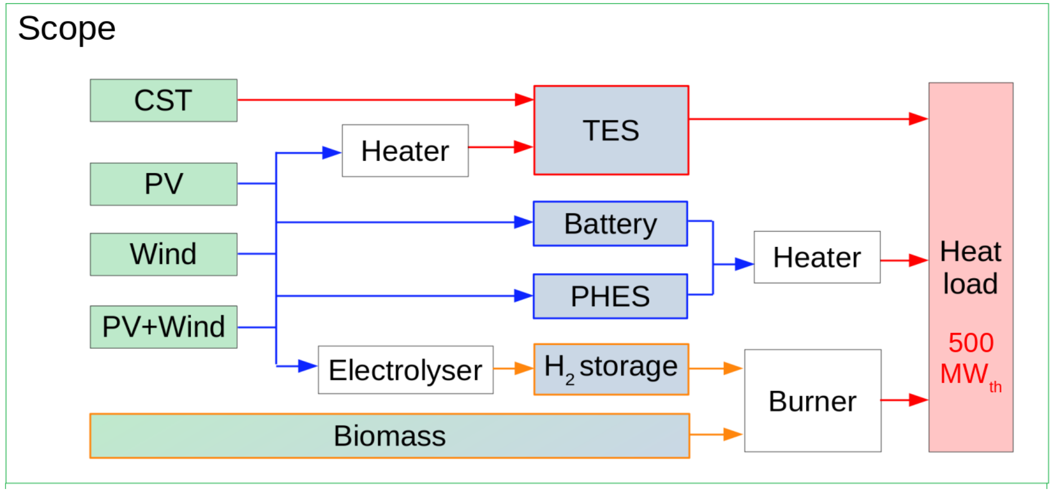
All the options for green heat have different benefits and challenges:

- Temperature
- Cost
- Heat transfer medium (steam, air, other)
- Ease of integration
- Scalability
- Technology readiness

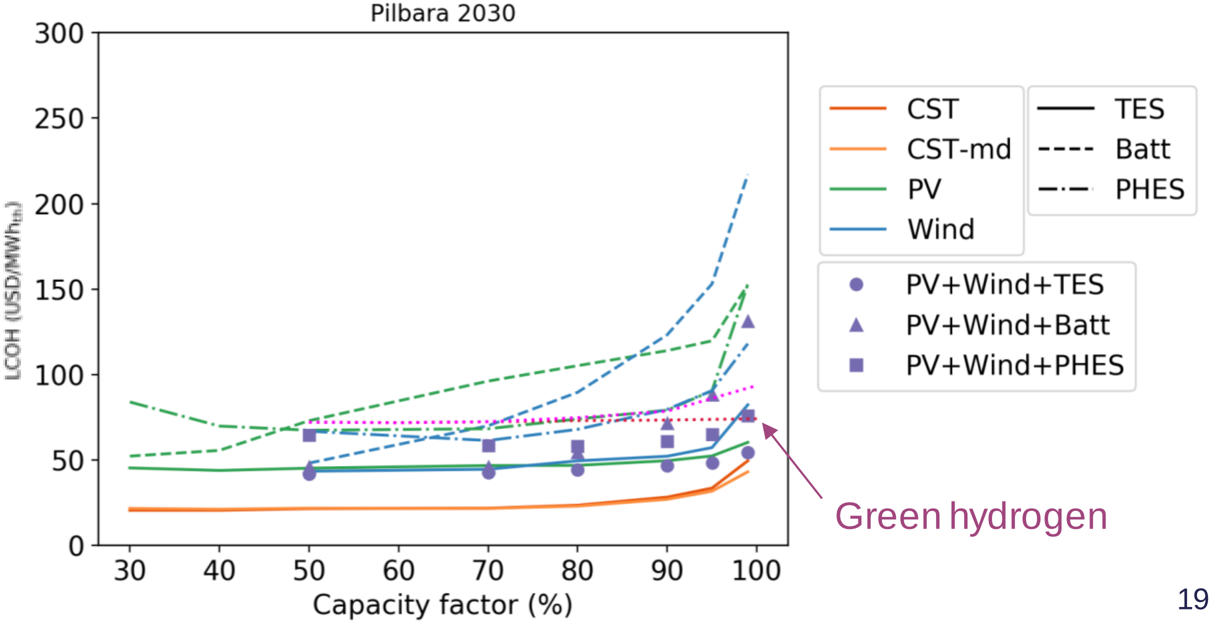
What is the best option for each industry? For each process? For each site / location?

RP2.003 – LEAST COST GREEN HEAT FOR INDUSTRY

- A comparison of various heat supply options with PV/wind/CST plus electrical, heat and hydrogen storage across 5 different locations, based on the costs of conventional molten salt ($NaNO_3$:KNO_3 eutectic) technology at 565°C.
- Continuous supply is always significantly more expensive than at eg 60-80% capacity factor.
- Thermal energy storage (TES) appears cheapest option for continuous heat, charged using varying wind/solar combinations.
- Hydrogen looks cheaper than electrical storage when continuous supply is required.
- Multi-energy and hybrid TES+hydrogen options not yet assessed. High temperatures and thermal transport costs also so far omitted.
- Integration with industrial processes imposes major challenges/costs and cannot be overlooked.


Scope

CST
PV
Wind
PV+Wind
Heater
TES
Battery
PHES
Electrolyser
H_2 storage
Biomass
Heater
Burner
Heat load
500 MW_{th}



HILT RP2.003 Green Heat for Industry, John Pye (ANU)

RP 2.009 – CASE STUDIES OF TES FOR INDUSTRY

Aim: This 1-year project aims to better understand the requirements and needs of users of high-temperature heat within the HILT CRC, and to provide these stakeholders clear, contemporary information about options for high-temperature thermal energy storage integration into their processes.

Approach: The project focusses initially on two use case scenarios:

1) Solar heating combined with thermal energy storage, to provide the heating needs of the fluidised bed H_2DRI process.
2) Integration of thermal energy storage into the Bayer process to provide or supplement heat needs during calcination for Alumina.

Progress: Significant progress in the development of the process flow models, and an annual system simulation of the fluidised bed H_2DRI process, including development of a reactor component in OpenModelica, with verification using FactSage and ThermoCalc.

Developing improved options for integration of TES in alumina refining, working with Partners towards better definition of temperature and heat needs at different stages of the process.

Kick off meeting at the site of TES technology partner 1414 Degrees

HILT RP2.009 Advancing the viability of high temperature TES for industrial applications, Joe Coventry (ANU)

RP1.013: ALUMINEXT

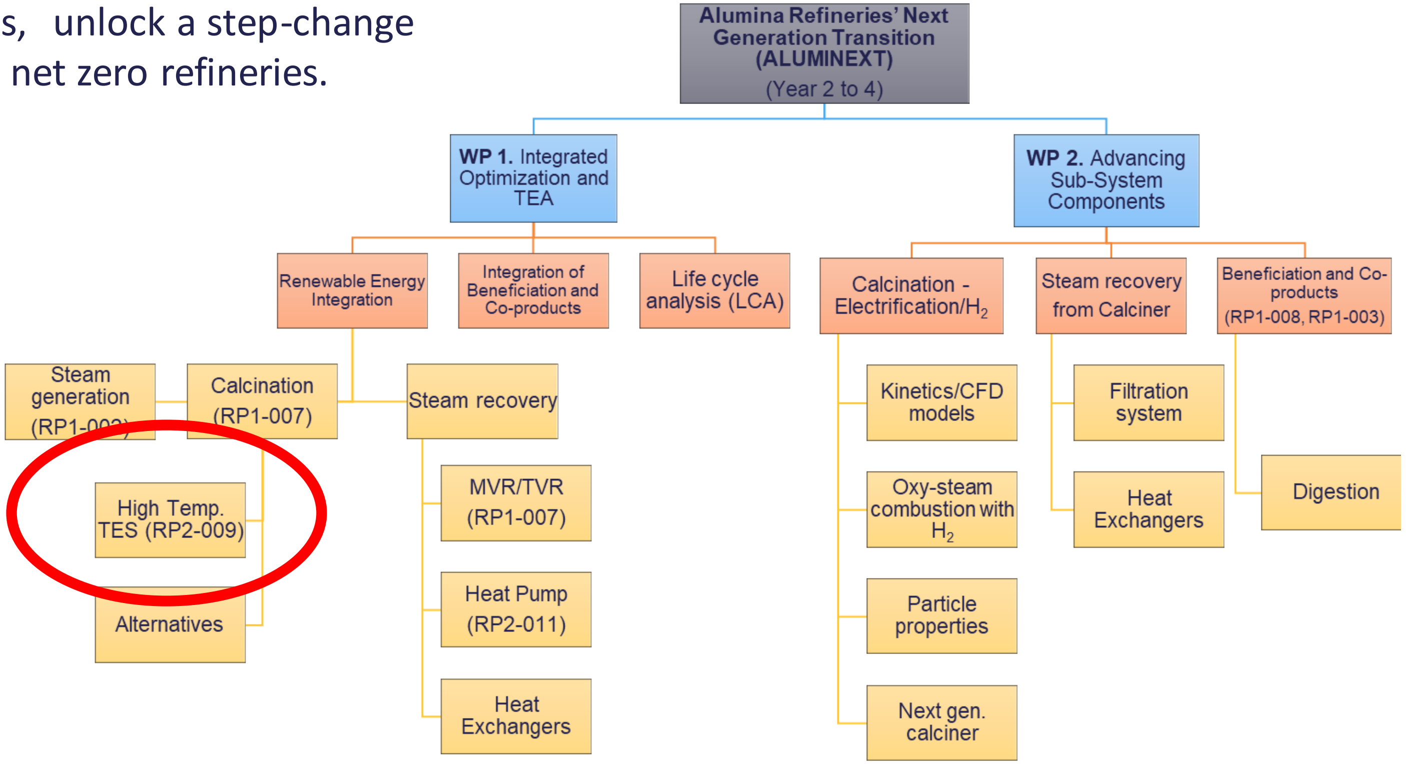
RP1.013 Alumina Refineries' Next Generation Transition, Woei Saw (University of Adelaide) – follow on from RP1.002 and RP1.007

Need and Drivers:

- **Short-term:** to de-risk retro-fitting relatively high TRL emissions reduction technologies to existing alumina refineries
- **Long-term:** to advance development of novel technologies, unlock a step-change in increased efficiency and reduce cost in next generation net zero refineries.

Outcomes:

- Next generation net-zero Bayer process configurations
- Mitigate risk & increase efficiency of the Bayer process
  - Optimise steam generation configurations
  - New steam calciner technology
  - Understand steam calcination reactions
  - Implement novel steam recovery systems
- Collaborate at pilot and demo scales to reduce risks & cost
- Develop workforce of the future in the alumina industry



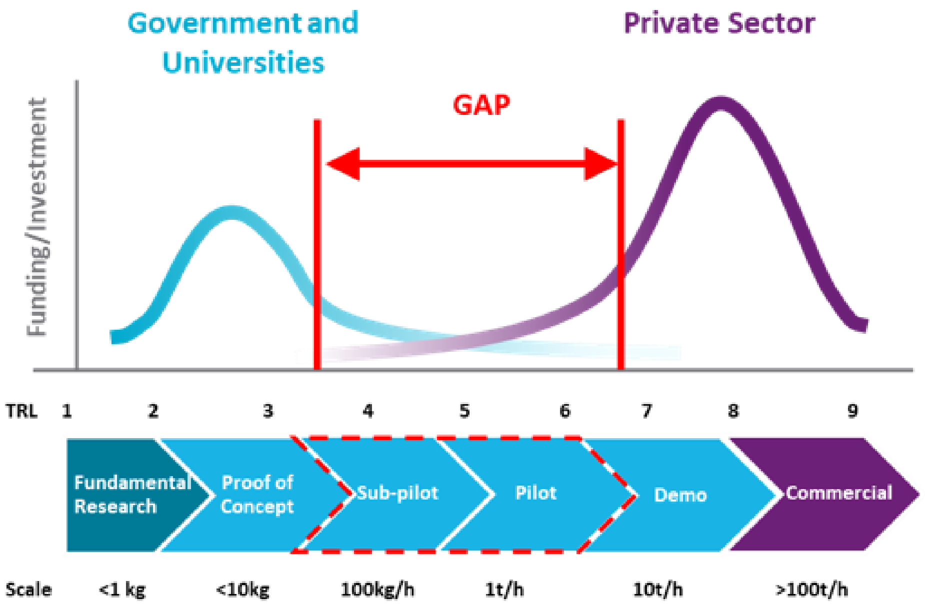
Alumina Refineries' Next Generation Transition (ALUMINEXT)
(Year 2 to 4)

WP 1. Integrated Optimization and TEA
- Renewable Energy Integration
  - Steam generation (RP1-00
  - Calcination (RP1-007)
    - High Temp. TES (RP2-009)
    - Alternatives
  - Steam recovery
    - MVR/TVR (RP1-007)
    - Heat Pump (RP2-011)
    - Heat Exchangers
- Integration of Beneficiation and Co-products
- Life cycle analysis (LCA)

WP 2. Advancing Sub-System Components
- Calcination - Electrification/H_2
  - Kinetics/CFD models
  - Oxy-steam combustion with H_2
  - Particle properties
  - Next gen. calciner
- Steam recovery from Calciner
  - Filtration system
  - Heat Exchangers
- Beneficiation and Co-products (RP1-008, RP1-003)
  - Digestion

POTENTIAL FUTURE RESEARCH AREAS

- Application driven development of TES:
  - Integration into industrial processes is highly process-specific, site specific and challenging.
  - Replacing fossil fuel heat source with TES heat alternative can be very disruptive to process design and operation
  - How do build up confidence in TES for heavy industry?
    - Low, mid or high temperature heat?
    - Scaling up TES?
    - Scaling up electrical infrastructure and/or process variability?
- Technology development:
  - Verifying TES options as a function of temperature range and heat transfer medium.
  - How do we verify long-term performance of TES materials?



Research gap for HILT focus?

HILT CRC

DE-RISKING
DECARBONISATION
FOR HEAVY INDUSTRY

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HILTCRC.COM.AU

Australian Government
Department of Industry, Science and Resources

AusIndustry
Cooperative Research Centres Program

Panel Discussion

Dr. Alexander Post

CTO, MGA Thermal

Paul Mzatuschka

Head of Sustainability, Mars

Jenny Selway

CEO, HILT CRC

Byron Ross

COO, Graphite Energy

Sreeraj Balachandran

Manager Climate Change, Rio Tinto

Tom Geiser

Head of Australia, Rondo Energy

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https://forms.office.com/r/xcegMF09dV

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e-bank