ELECTRO-THERMAL ENERGY STORAGE - TRANSFORMING INDUSTRIAL ENERGY

BY PROF. ERICH KISI

Understand the drivers for ETES adoption, the stakeholders who stand to benefit, the technology developed by MGA Thermal, and the investment and policy conditions required to scale ETES to meet the challenge.

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1. Abstract

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Approximately 50% of global energy is consumed as heat, with nearly half of that derived from the direct combustion of fossil fuels in industrial processes. Despite significant progress in decarbonising electricity supply, industrial heat has proven far more resistant to transition, largely due to the absence of pre-existing economically viable alternatives at the required scale and temperature range.

Electro-Thermal Energy Storage (ETES) addresses this gap directly. By converting grid electricity - purchased preferentially during periods of oversupply and low price - into stored thermal energy that can be dispatched on demand as industrial steam or other hot working fluids, ETES enables a cost-effective, high-return-efficiency replacement for fossil fuel boilers across a broad range of industries.

Beyond decarbonising industrial heat, ETES offers compounding benefits: stabilising electricity grids with high renewable penetration, improving the bankability of new solar and wind assets, and enabling companies to materially reduce Scope 1 emissions. Universal adoption of ETES across mid-to-high temperature industrial applications has the potential to abate 10–12% of global carbon emissions by 2050.

This article outlines the drivers for ETES adoption, the stakeholders who stand to benefit, the technology developed by MGA Thermal, and the investment and policy conditions required to scale ETES to meet the challenge.

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CONTENTS:

2.Introduction

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Societies globally are decarbonising their energy use in order to stabilise the earth's climate. Major progress has been made in the area of decarbonised electricity supply. However, the attainment of fully renewable electricity grids faces a growing challenge - the declining ROI of developing new renewable energy projects in an already highly renewable market.

In contrast to the encouraging progress in renewable electricity supply, an equally large sector of the global energy economy has made little progress on decarbonisation. There is an urgent need to decarbonise that large sector of the economy that burns fossil fuels directly to generate heat. Approximately 50% of global energy is consumed as heat and almost half of that is industrial heat from direct fossil fuel consumption. The economical decarbonisation of industrial heat is therefore a large and essential part of the energy transition, one which is lagging significantly behind the decarbonisation of electricity markets.

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Electro-Thermal Energy Storage (ETES) is a long duration energy storage technology that enables the transition of up to 20% of global energy use from fossil fuels to renewable electricity. It does this by soaking up renewably generated electricity in times of abundance, converting it into heat, storing and supplying that heat to the industrial process heat user. ETES enables the 24h on demand dispatch of economically priced industrial heat from an intermittent and price volatile electricity supply.

ETES is uniquely placed to address a great many of the challenges facing the transition to a net zero economy. Seldom in recent human history has one technology held the key to so many individual, company, government and, global energy and climate goals. It has the potential to revolutionise industrial heat supply while stabilising electricity grid supply. Recent geopolitical events - including the Russian invasion of Ukraine, global LNG market volatility, Red Sea shipping disruptions, and broader energy supply chain tensions have highlighted the vulnerability of economies and industrial sectors that rely heavily on internationally traded fuels such as natural gas, coal, and oil.

Electrifying industrial heat using ETES can materially strengthen energy security by reducing dependence on imported fossil fuels and enabling more efficient use of domestic renewable energy resources. By allowing the efficient use of renewable resources, the technology improves the ROI of existing renewable solar and wind power assets and the bankability of new asset developments. It can catalyse whole new industries and overall greatly accelerate the achievement of global emissions targets.

3.Heat Reliant Industries

Food & Beverage

Mineral Processing

Chemicals

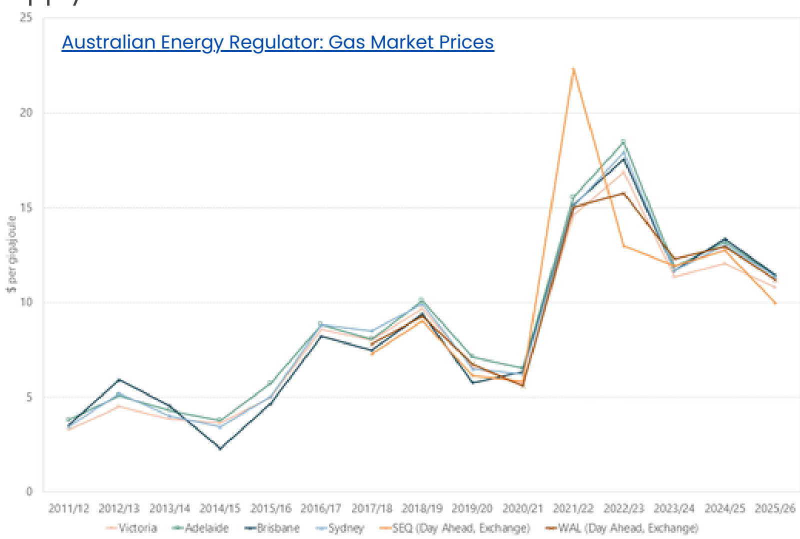
Materials & Manufacturing

Oil & Gas

The initial beneficiaries of ETES will be heat-reliant industries in the food and beverage, mineral processing, materials and manufacturing, chemicals, and oil and gas industries. These industries use heat to cook, break down, reform, react and shape raw materials as well as essential high temperature cleaning and sterilisation of equipment. Scarcely a product that we purchase in daily life has been produced without some form of industrial heat. Currently a large portion of industrial heat is generated by burning fossil fuels such as natural gas, oil or coal, to heat a working fluid such as steam. The required temperatures may be low (0-150°C), medium (150-250°C), high (250-500°C) or very high (>500°C) depending on the industry.

3.1 Challenges facing heat-reliant industries

In Australia, the primary working fluid for the medium and high temperature industrial heat is steam. Emissions from these industries is often almost unaffected by the increasing market penetration of renewable electricity as their primary energy use is directly burning natural gas in large boilers to make steam, often 24h per day, seven days per week. This raises a number of challenges. The natural gas price has undergone several large increases globally over the past few years and in Australia domestic prices have escalated in the face of competition from gas exports. This has been accompanied by increasing price volatility and concerns about long term supply.



The safeguards mechanism for large emitters and the introduction of mandatory emissions reporting in many organisations also present challenges. Heat-reliant industries are in desperate need of a decarbonised thermal energy solution.

3.2 Solutions available

Solutions fall into two categories, those that involve renewable fuels and those that rely upon electrification. Neither of the two predominant renewable fuels, biofuel and hydrogen, are economically viable alternatives for most heat users. Biogfuel supply is quite low and variable which restricts its applicability primarily to industries where the organic waste stream for gas production is generated on the same site e.g. at sugar refineries. Economical green hydrogen production is not yet available at large scale having eluded humanity through more than 50 years of research.

That leaves the replacement of the fossil fuel source with electricity which is increasingly generated from renewable sources and prima facie a simple solution. The one for one replacement of gas-powered boilers with electric boilers may indeed work for some industries that have modest heat requirements and flexible use patterns that are able to track fluctuating renewable supply and pricing. Other, low temperature industries, may be able to use electrically powered heat pumps on the same basis of modest heat requirements and flexible use patterns. However, due to the nature of electricity pricing in most market economies, simple electrification does not capture the main advantage of existing gas boilers which is constant or on-demand supply of affordable industrial heat.

In most large economies, the price of electricity is determined by availability. For example, on the East Coast of Australia, large solar photovoltaic capacity means that the price is very low or negative in times of strong daylight, i.e. between 8am and 4pm[1]. However, in the evening peak and particularly at times of low supply, the price can spike to exceptionally high levels for short periods. Therefore, industries that require a continuous energy supply at a predictable price, will require energy storage in addition to electrification.

That leaves ETES as a frontrunning solution that can economically scale to large capacity, provide long duration storage at return efficiency approaching 94% and fit onto existing industrial sites.

Battery electricity storage is uneconomical for this purpose due to the long duration required and is often not feasible due to the large footprint of sufficient batteries to keep a continuous supply to large industrial users of heat.

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[1] Based on an annualised average, this period lengthens by 1-2h in summer and shortens by approx.. 1h in winter.

4.ETES and Who Benefits?

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4.1 Heat Reliant Industries: A typical ETES unit accepts energy in the form of electricity, sometimes from on-site renewable electricity generation but most often via the electricity grid. That electrical energy is converted very efficiently into heat. The heat is stored by raising the temperature of, and/or inducing a phase change in, a storage medium housed in an insulated environment. The system is typically engineered to have very low thermal losses. Heat is dispatched to the industrial process in the same way as fossil fuel generated heat, often by heating a working fluid such as steam. This means that an ETES can be seamlessly integrated into most mid to high temperature heat reliant industries. Because the incoming electricity can be purchased in times of oversupply e.g. between 8am and 4pm on the East Coast of Australia, the fuel (electricity) cost can be substantially less than for the existing fossil fuel supply and potentially negative. The end user of the energy can also exercise control over the charging period and associated electricity cost.

ETES is the ideal form of energy storage for a cost effective electrified industrial heat system. A properly designed ETES system can accept electrical energy at any time, store it at high return efficiency and discharge the energy in the exact form required by the heat user e.g. as industrial steam or other hot working fluid. This removes the need for a separate electric boiler and superheater as the ETES system functions as a combined energy management system, storage system and steam dispatch system that can interface seamlessly with existing heat reliant industrial plants.

Due to attractive system operating cost, the capital cost of changeover may be quickly recovered. ETES systems are scalable from a few MWh which would cover the thermal energy use of a small dairy, right up to several GWh capacity for example in large scale mineral processing plants. As the majority of ETES installations in the coming decade will be to operating plants on brown field sites, the small footprint achievable compared with other storage technologies is paramount.

In addition to the operational benefits of ETES, there are evolving mechanisms for ETES operators to access revenue for grid services as discussed below.

4.2. The Electricity Grid and Electricity Transmission Companies: As solar PV and wind energy sources achieve higher levels of energy market penetration, electricity grids (or networks) face increasing difficulties across a number of operational metrics.

The intermittent nature of renewable electricity sources can cause grid instability as supply fluctuates. Fossil fuel power stations generally struggle to track rapid changes in either supply or demand as they have long ramp times and can therefore not fully stabilise these fluctuations. ETES can assist with grid stabilisation as a grid connected ETES is a large switchable load that can absorb positive supply fluctuations by taking energy off the grid into storage and can dampen negative fluctuations by ceasing to take power for a period.

Electricity transmission companies can also benefit from ETES for similar reasons. ETES located at or near an edge of the electricity grid can improve electricity supply to a whole area by supporting and stabilising the grid with a large load.

4.3 Investors, Developers and Operators of Solar PV and Wind Energy Assets: The payback time and return on investment for a renewable generation asset is tied heavily to the wholesale electricity price and the capacity of the grid to accept power when generation from a given asset is favourable. As the level of renewable generation capacity across the grid increases, the wholesale price at times of peak generation is very low and often negative in some markets. Investment in and further expansion of renewable generation capacity is destined to become increasingly difficult as returns on new assets become increasingly uncertain. This is particularly the case for solar PV because all assets in this class located in the same geographic region, generate electricity at the same time into the same market. This factor will ultimately be a major barrier to achieving the net zero energy targets of most jurisdictions.

The installation of a substantial energy storage capacity via ETES is able to largely remove this barrier because a properly constructed ETES can accept electricity at any time of day. The large and flexible electrical load of a suite of ETES at heat reliant industries will provide guaranteed off-takers for electricity in times of abundant supply. As such, the widespread installation of ETES can act as a catalyst for increased investment in renewable generation assets.

This synergy between renewable generation assets and ETES also opens opportunities for co-investment in generation and ETES with pre-agreed terms for electricity offtake.

4.4 Governments and the Global Community: The effects of human induced climate change are being increasingly felt and the imperative to decarbonise human economies is growing. The burning of fossil fuels to provide industrial heat is responsible for approximately 20-24% of carbon emissions globally. This sector of the carbon emissions spectrum has proven difficult to address due to a lack of simple pre-existing solutions. ETES is able to address the medium to high temperature range which is dominated by industrial steam in the range 120 – 500ºC. This represents approximately half of the industrial heat market meaning that universal adoption of ETES by 2050 could abate up to 10 – 12% of global carbon emissions and enable global climate targets to be met. What is required for this to occur is accelerated investment in and scale up of ETES companies, accelerated roll out of ETES facilities on industrial sites and accelerated coordination between renewable generators, grid operators, heat-reliant industries and governments to rapidly scale ETES to the required level.

4.5 Company Boards: Mandatory greenhouse gas emission reporting (carbon reporting) in various forms is rolling out across the industrialised economies led by Europe, the USA and Australia all of whom commenced in 2025. Initially targeting the largest emitters, carbon reporting will be rolled out to successively smaller companies and increasing numbers of countries globally in the coming years. For many industries, the principal contribution to emissions is the burning of fossil fuels to liberate industrial heat. As a displacer of fossil fuel burning and generator of clean industrial heat, ETES can be a significant contributor to greatly reduced Scope 1 Emissions in the ESG report for many companies. Additionally, carbon savvy shareholders and Boards are beginning to engage with their suppliers to improve their own Scope 3 Emissions by reviewing the practices and Scope 1 Emissions of their entire supply chain.

5.MGA Thermal ETES

In response to the complex needs of this broad range of industrial heat stakeholders, MGA Thermal has developed a highly scalable ETES system based around a proprietary thermal storage material, the MGA Block. In order to match the needs of the industrial heat market, the MGA ETES system has high energy density which ensures a small plant footprint to fit on existing industry sites and reduced balance of system capital cost.

MGA ETES has capacity to be scaled up to >1GWh size which is required for the larger industrial sites. If required, the system can be operated under continuous discharge conditions as it can charge with electrical energy and discharge high temperature steam at the same time. Alternatively, the system has a very short ramp-up time and therefore can discharge flexibly to track a fluctuating steam demand as is required in some industries. The timing of charging is completely flexible allowing the operator to take advantage of low electricity prices at times of high availability and/or low demand.

Switching time for the charging system is on the order of 100 milliseconds in both directions and therefore the MGA ETES is able to perform a grid services role for demand regulation and related grid enhancing services. The system is also designed for in-service maintenance of some key components with the intention of increasing up time.

6.What Does The Future Hold For ETES?

ETES and the decarbonisation of industrial heat present a rich field of opportunity for technology investors, governments, statutory authorities and renewable energy developers to grow value in the sector whilst simultaneously accelerating the transition to net zero.

There is no doubt that ETES will make a significant contribution to the problem of decarbonising industrial heat. However, there are some significant challenges to be overcome. The first of these is matching the scale of ETES production to the scale of the problem. Annual Industrial heat use globally is approximately 36,000 billion kWh. Burning fossil fuels to generate this heat is expected to release approximately 86 billion tonnes of CO_2 into the atmosphere over the 5 year period 2023 – 2028 alone. The largest ETES globally to date has storage capacity of 56 MWh and will provide up to 30 GWh of thermal energy annually, requiring 1.2 million such units to completely decarbonise the industrial heat market. The largest mineral refineries globally use up to 600 MW of thermal energy continuously, an annualised energy use of approximately 5 billion kWh (5,000 GWh) requiring 600 such modest ETES units to decarbonise a single site. There is therefore an urgent need for scale up of individual ETES designs and more urgently, scale up of the associated manufacturing capacity.

Beyond the mutually beneficial pairing of a heat reliant industry with an ETES provider, are opportunities within the broader energy market. In addition to the curtailment experienced by solar PV electricity generation assets in times of oversupply, there is a significant proportion of their theoretical output that cannot be dispatched irrespective of curtailment. On most solar farms, the energy distribution infrastructure (inverter, switching, controls etc.) is sized on economic grounds to be up to 30% smaller than the maximum output of the solar panels. This clipped amount of energy, although theoretically available from the panels, is never dispatched. Co-location of new heat reliant industries with new solar generation assets in renewable energy hubs would allow DC charging of the ETES to capture the entire solar PV capacity. Coupled with greatly reduced step-up transformer and transmission losses and a guaranteed offtaker for some of the generation capacity, cross ownership or investment becomes attractive. The scene is set for governments, planners, project developers and energy regulators to accept the challenge and adapt to such a model.

A future exciting use of ETES is for the co-generation of heat and electric power. Some ETES systems are able to produce steam at sufficient temperature and pressure to drive a steam turbine generator to produce electricity. If the steam turbine outlet conditions are well chosen, the steam exiting from the turbine can then be used in a heat reliant manufacturing process. For example, if the heat reliant process requires steam at 200°C, up to 20 - 30% of the energy can be dispatched in the form of electricity to meet the electrical needs of the company and the rest used to meet the heat needs of the industrial process.

An extension of co-generation is to maximise the electrical component by using a modern high efficiency steam turbine generator. In this case, surplus (curtailed or clipped) energy from a solar or wind farm is sent to the ETES, stored as heat, and used to produce high pressure, high temperature steam to drive the turbine at a later time. The electricity generated is then dispatched to the grid at times of shortfall. This electricity to electricity use case has round trip efficiency of only around 40% however as the electric input can be at near zero cost and the turbine operation timed for peak electricity prices, this model may prove economical in time, given the right investment decisions and co-location of ETES, turbine generator and solar (or wind) farms.

ETES presents a wide range of opportunities for technology investors; EPC contractors; asset investors; financiers interested in steam as a service models; solar PV and wind energy developers; grid operators and governments to participate and benefit from this rapidly growing market. Given the very large size of the market on the demand side and the small number and current modest scale of ETES providers, the greatest benefits will go to those who act first and fast. Demand will likely outstrip ETES supply in the coming 5 years without substantial investment in the sector by venture firms, financiers, developers, EPCs, governments and others.

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Disclaimer: Professor Kisi is a co-founder of MGA Thermal Pty Ltd and the MGA ETES described herein is the company's principal offering.