Caldera Heat Batteries Ltd

Heat Batteries for Industrial Fuel Switching: End of Feasibility Study Report

September 2022

NZIP Industrial Fuel Switching Competition Phase 1

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Preamble: the challenge of sustainable industrial heat

Data from BloombergNEF shows that around the world excellent progress is being made towards deploying renewables, with solar and wind making up the vast majority of new power generation capacity (Figure 1).

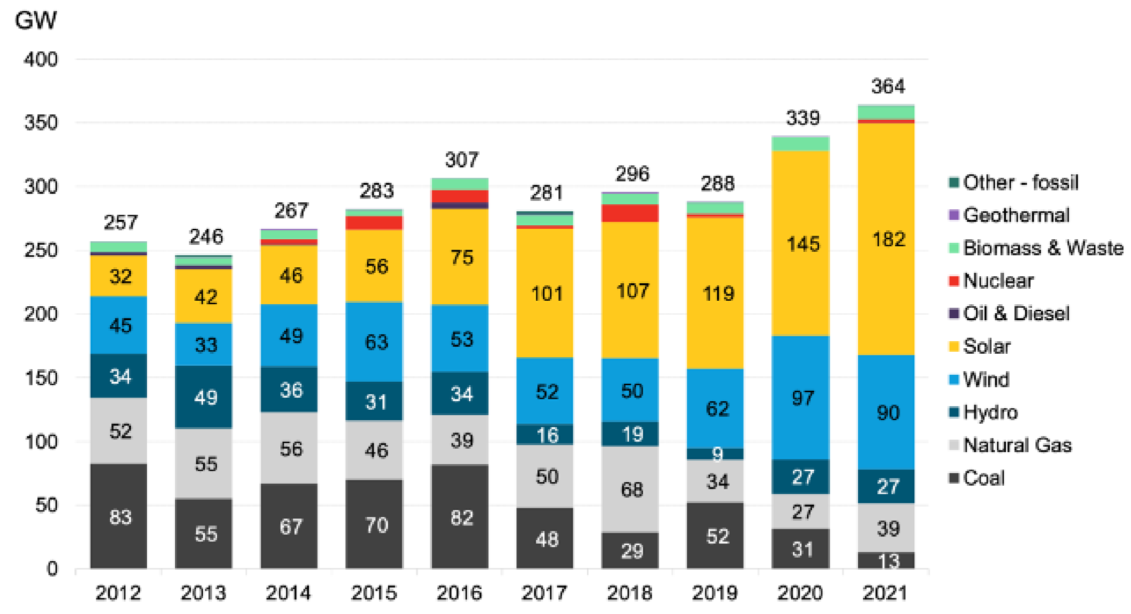

Figure 1: Annual new power-generating capacity additions, global. (Source: Energy Transition Factbook, BloombergNEF, 2022, https://assets.bbhub.io/professional/sites/24/BloombergNEF-CEM-2022-Factbook.pdf)

Within industry low temperature process heat is the largest demand for energy, closely followed by high temperature heat. Decarbonising process heat is therefore the key to decarbonising industry (figure 2).

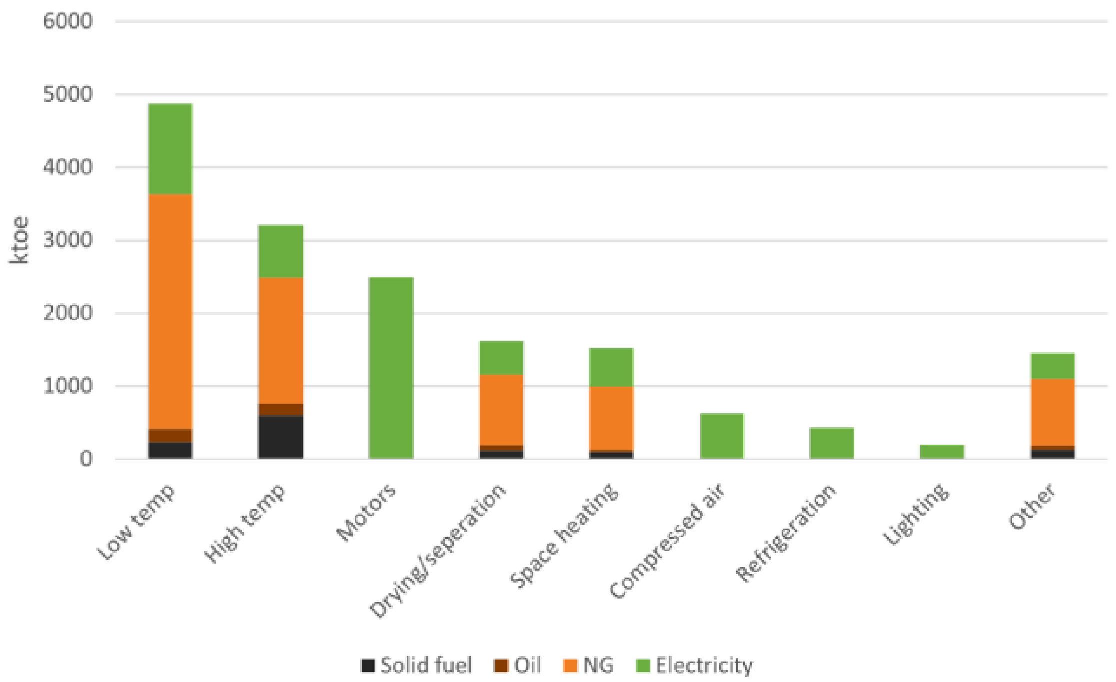

Figure 2: 2020 UK industrial energy use by process and source, in kilotonnes oil equivalent (Source: based on BEIS data)

As process heat is needed regardless of whether renewables are generating, energy storage is a crucial enabler of this transition. Energy storage needs to be affordable to businesses, and available in sufficient quantities. Around the world we are seeing supply chain shortages in everything from microchips to heat pumps and this puts a brake on the energy transition. To avoid a similar shortage of energy storage Caldera plan to create a ‘Gigafactory’, ensuring that we can supply industry with heat batteries when they are needed and at the right price.

Introduction to this report

This feasibility study shares the result of Caldera’s engineering, research and design work on the manufacturing processes required to produce a low cost and high-volume heat battery. These will generate steam on demand for industrial applications from stored renewable electricity.

This report hopes to inform:

- Businesses who are looking to transition away from fossil fuels. From our dissemination work during this project, we know that many companies have made net zero commitments but are struggling to find affordable and practical solution to meet these goals. This report highlights heat batteries as a potential solution where no other technology is commercially viable.
- Education and training institutions, as we know that skilled workers are crucial to enabling Caldera and many others in the sector who are creating green British jobs.
- Suppliers to energy storage manufacturers such as Caldera, who themselves may need to make investment decisions to grow their capacity.
- Investors, who are considering investing in Caldera or others in the sector and are looking to inform their due diligence processes.
- As a mission-driven company Caldera also want to boost the whole sector and are therefore keen to share as much as possible with other companies in the space while delivering the commercial success needed to secure investment, create jobs, and deliver an impact for net zero.

Summary of the Industrial Fuel Switching Competition Phase 1 feasibility study project

Caldera has developed a proprietary heat storage material. The material has a high energy density and conductivity. It requires only readily available, non-toxic and affordable inputs. This means that Caldera is able to provide best-in-class performance. The material is shaped into solid cores which are in the centre of each cylindrical heat store.

Electric elements are used to heat each core to 500°C, at which point the heat battery is ‘full’. A patent-pending vacuum insulation system is used to store this high temperature heat with very low losses, given the overall system high round-trip efficiency. A heat extraction system, which is also patent-pending, is used to withdraw energy from the core without compromising the integrity of the vacuum. In use the cores can drop down to 200°C at which point they are considered empty.

These technologies have already been brought together in Caldera's initial showcase product - the Warmstone Heat Battery, an alternative to fossil fuel boilers that can be retrofitted to heat larger homes. The Warmstone is currently being trialled in UK homes. It was created as a modular system in which multiple units can be combined to provide as much energy storage as is needed, with a view to being able to scale up to larger applications. There is clearly a major opportunity to develop the technology to electrify steam production in industrial processes, and this grant has allowed the company to develop this application.

Production of each unit is currently labour intensive and restricted to small batches. This project tackles the key barrier to success, which is the ability to manufacture the product at scale and for a viable cost. The project focused on the design and feasibility of the manufacturing process and machinery needed to produce Caldera's modular energy storage system (figure 3) at a high volume, high quality and low cost. Designing the most effective manufacturing processes and industrialising the product has taken place hand-in-hand with further design for manufacture (DFM) of the product.

Figure 3:Illustration of Caldera system inside a factory

<u>What did the feasibility study achieve?</u>

The primary aim of the feasibility study was to pave the way for a successful demonstration as part of a potential Phase 2 project, and this has been achieved. We created a fully costed Front End Engineering Design (FEED) for the production process that covers individual processes and a complete factory layout required to achieve an economic piece part price of heat battery cells. To achieve an economic piece part price, we undertook a significant design review exercise to reduce the material content of the heat battery cell while preserving its structural integrity and optimising for manufacturing.

We identified manufacturing techniques and equipment, undertook a robust request for quotation (RFQ) process and obtained quotes from a range of suppliers for the capital equipment needed to support these manufacturing processes. While this was undertaken, we also demonstrated that the product we plan to produce can perform in industrial applications, as well as the domestic setting for which it was originally designed. The rest of this section describes the challenges we overcame in the course of the study.

Technical feasibility of the manufacturing process

Designing a cost-effective manufacturing process for Caldera's system is challenging because each heat battery core is heavy and needs to be handled and manipulated throughout the manufacturing process. There is also the requirement to adapt manufacturing techniques that exist in other industries to a larger scale. Inspiration was drawn from areas such as the automotive industry, food processing, hot water cylinder manufacturing, spiral welding of pipe, compressed gas cylinder manufacturing and manufacture of cement mixer barrels.

Other challenges include the reuse of energy during manufacturing; handling emissions; exclusive use of electrical heat and the heating of rock. We also needed to understand the scaling and automation of all key processes such as steel cutting and forming, pressing, rolling, welding and checking of weld integrity, and insertion of the proprietary heat storage material.

To overcome these production challenges, we have explored the production techniques and equipment that are used across different industries, attended tradeshows and consulted with experts. At this stage in the process, we were in a position to test or model changes to understand which techniques and equipment types were feasible and their effect on the production cost of each heat battery core.

As a result, we have designed a robust serial production system that we believe will be efficient, reliable and scalable. We have a fully costed design for the production that covers each process, factory construction and layout and site modifications/consents. Having conducted a scored procurement process we now have quotes from suppliers for the necessary capital equipment.

We understand the lead-times for machinery, factory automation and site upgrades (including the additional power required to run plant and remove fossil fuels from the production process) some of which are long and have planned a Phase 2 project that can accommodate these times.

Lifetime cost reduction

As we had forecast, we have been able to reduce the projected cost per heat battery core by a factor of 5. Key to achieving this was optimising both the material content of the core and including the elements of design for manufacture identified and tested during the definition of the manufacturing process. In the course of design refinements, we have made the standard size of energy storage 'core' taller, increasing the capacity from 100kWh to 140kWh without significant increases in cost.

Finite element analysis (FEA) was instrumental in reducing the quantity of material needed to produce the heat battery core. This has resulted in improved sustainability, reduced exposure to rising commodity prices and reduced material cost within the individual cores.

Modern manufacturing techniques including automation, robotics and waste heat recovery / re-use, are necessary to achieve the 5 times cost reduction and have been included in the new factory design. As well as reducing health and safety risk, they support the development of a highly skilled work force in the local area.

Technical feasibility of the product

Another objective in Phase 1 was to demonstrate a unit producing 10bar steam at 180C in a representative environment, showing it can replace a fossil fuel boiler with the same performance and steam quality.

To demonstrate this, we built a heat battery core specifically to discharge 10 bar steam and supplied it with a heat exchanger to a global steam solutions supplier for testing on their site. The feedback about the performance of the product was extremely positive.

As deployment of heat battery cores in a modular manner is a key for both scaling system size to customer requirement and the ability to manufacture the heat battery cells in a cost-efficient manner, demonstrating multiple units working together was the final key to the product technical feasibility. We proved this by producing high quality steam from two heat battery cores connected together in series.

Practical ability to create a demonstrator

In Phase 2 we would need a location to practically demonstrate factory processes, as well as an industrial system of a significant size. We now have an agreement in principle on this, with a route to a signed agreement by the Phase 2 application. We also have an agreement from SSE, the distribution network operator (DNO), to provide an upgraded electricity supply. We went through the standard SSE process for an upgraded grid connection, paying a fee of £1,600 for the quote, and this went smoothly. All other consents and permissions needed are in place, so we are ready to go. We have not found any regulatory barriers to success.

The proposed Phase 2 'Megafactory' factory is smaller than originally planned, as we have found a way to reach TRL7 by demonstrating a selection of the key manufacturing processes. This Megafactory will be capable of producing 1,000 cores per annum, with a total capacity of 140 MWh (i.e. well over the 1 MWh size needed to be a 'megafactory'). These key manufacturing processes are the novels ones needed for Caldera. In the course of the feasibility study, we have seen that it is possible to reduce or eliminate the need to include in a Phase 2 project production processes that are already proven and used elsewhere. The Phase 2 demonstration factory will produce a complete product while outsourcing any well proven processes such as laser cutting of steel sheet.

Caldera plan a staged approach to scaling up production, increasing in manageable stages to reach Gigafactory capacity (i.e. capable of producing over 1 GWh of storage per year). This will inform our Phase 2 competition submission.

Carbon emissions savings and potential contributions to net zero

This analysis focuses on the UK, and on the dominant method of process heat production which is based on the generation of steam using natural gas. Switching an industrial process to Caldera's thermal storage solution (charged from off-peak grid electricity) represents a 35% carbon saving based on 2021 data. As the electricity grid decarbonises in line with HM Government's plan, this carbon saving will increase to 80% in 2030 and 97% in 2050 (see Table 1). This level of carbon saving can be reached today by generating electricity from on-site renewables rather than the grid.

Caldera's systems would use off-peak grid electricity or on-site renewables. For this analysis we focused only on off-peak grid electricity. HM Government's Green Book[1] gives the emission for all electricity (peak and off-peak). For 2021 we have estimated that the emissions factor for off-peak electricity is 50% of the emissions for all electricity, which is 136gCO2e/kWh. We ran an analysis of a sample of granular carbon intensity data from CarbonIntensity.org, which suggests this is a conservative estimate (i.e. off-peak electricity is likely to be less than 50% of the carbon intensity of all electricity).

For 2030 we estimate off-peak electricity at 30% of the carbon intensity of all electricity, which is 42gCO2e/kWh. This is in line with the Committee on Climate Change 6th Carbon Budget (Balanced Pathways) who estimate grid carbon intensity at 40gCO2e/kWh in 2030. Carbon intensity drops to 7gCO2e/kWh in 2050, assuming a fully renewables grid mix. Emission factors for natural gas (184gCO2e/kWh) are taken directly from the Green Book. We assume the thermal efficiency of steam generation is 95% for Caldera's system and 84% for natural gas[2].

Table 1: Carbon Savings	*CO2e Emission Factor [gCO2e/kWh]*			*Efficiency [-]*	*Carbon saving versus Natural Gas [-]*		
	2021	*2030*	*2050*		*2021*	*2030*	*2050*
Scenario A: Caldera system charged with off-peak electricity	136	42	7	95%	35%	80%	97%
Scenario B: Natural Gas	184	184	184	84%	0%	0%	0%

In our proposed Industrial Fuel Switching Phase 2 project, Caldera would increase the proportion of recycled materials used in each unit by designing out some parts of each product which requires virgin material. This in turn reduces the energy intensity of

[1] Long-run marginal consumption-based industrial emissions value from Table 2a Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal, https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[2] Chowdhury, J.I. et al., Renewable and Sustainable Energy Review 2018 Vol 94, Pgs 1153-1178, https://www.sciencedirect.com/science/article/pii/S1364032118304775

production. We would also move to fully electrify the production process, replacing a manufacturing step that currently uses fossil fuels with an electrified version, and install renewable generation on site. This means that the carbon emissions from production would be negligible compared to the carbon savings in use.

For a full list of feasibility study objectives and achievements against these see Appendix A.

How did we get input and share what we found?

To enable dissemination, we planned a mixture of mass communication and focused dialogue with key stakeholders. For mass communication we used a press release which was picked up in the niche online journal Process Industry Match[3]. Somewhat to our surprise Energy Live News[4] decided to emphasise that our technology could 'brew new green adventures for the UK's beers'. This led to coverage in Beer Today[5] and Brewers Journal[6], both of which are well read in the brewing industry and created a lot of enquiries from both large and small brewers who are keen to decarbonise. We are now planning another wave of PR, this time aimed at companies that install on-site renewables for industry, as particularly given current fuel prices, Caldera's energy storage is an excellent complement to behind-the-meter solar and wind. This PR push will be supported by new illustrations of the product produced during this feasibility study.

This mass communication has helped enable us to have a wide range of direct conversations, which is the best forum for us to share the role our technology can play in decarbonisation and receive insight to ensure we are meeting a real customer need. We had meetings or site visits with prospective industrial customers including manufacturers of beer, spirits, soft drinks, pet food, chemical precursors to the cosmetics industry, recycling equipment, medicines, and cement pipes. These companies range in size from small microbreweries to dominant global PLCs.

A major part of the feasibility study work was contacting supply chain partners, such as factory equipment manufacturers, which we did both individually and at trade shows. We were pleased to find interest from companies who would like to distribute or manufacture our technology under licence. There is a cross-over between distributors/licensees and potential suppliers as one company will both manufacture their own equipment and specify 3rd party products to create a complete industrial solution. Engaging with these engineers specialised in industrial heat has meant we could both generate awareness and receive insight from experts who work on hundreds of industrial projects each year.

[3] https://www.processindustrymatch.com/technology-news/item/6330-caldera-secures-295k-to-decarbonise-industrial-steam

[4] https://www.energylivenews.com/2022/06/01/heat-batteries-are-brewing-new-green-adventure-for-uks-beers/

[5] https://beertoday.co.uk/2022/06/15/caldera-storage-boiler/

[6] https://www.brewersjournal.info/british-brewers-encouraged-to-tap-into-electric-storage-boilers-to-decarbonise-operations/

Caldera has nearly 1,300 investors thanks to our fundraising with Crowdcube[7], and we have updated them on progress. In the course of the study, we engaged extensively with BEIS, other policy makers, and think tanks through our new trade association Thermal Storage UK[8]. Many of the Caldera team have also volunteered to be STEM ambassadors for local young people.

What did we do for jobs and other social value?

While the feasibility study was underway, but as a separate activity, Caldera had planned to scale up our existing manufacturing processes making Warmstone heat batteries for homes. This would have created 10 new jobs (FTEs) in 2022. Turmoil in the energy market meant this did not go ahead, and this reinforces the importance of the Industrial Fuel Switching project work to move our initial focus to industrial applications. While rising electricity prices has made the electrification of home heating less attractive, for the moment at least, it has redoubled the urgency amongst industry to install the on-site renewables that pair so well with Caldera's energy storage system.

During the feasibility study Caldera have begun an internship programme, taking on our first intern who has contributed to the CAD design work used in the study. 5 people in Caldera's small team has also volunteered as STEM ambassador, promoting the importance of relevant careers to local people.

Most of the further job creation and other social value would come with a potential Phase 2 project. This would create skilled, high value jobs initially in Caldera's own factory and then in a planned global network of facilities which will all be supported from Hampshire and bring revenue back to the UK economy.

Next steps to accelerate development and deployment

The next step is to apply for Industrial Fuel Switching Phase 2 (IFS Phase 2) funding to pursue two interlinked workstreams. We will prove novel manufacturing processes, to demonstrate that the product can be produced in high volumes and at the target price. The factory required to prove these processes will then be used to make a first of a kind demonstration energy storage system.

Workstream 1: Demonstrate the key manufacturing processes needed for large-scale, low-cost, high-quality production. During the project this will mean opening a 'Megafactory' that is able to produce Caldera systems at medium volume (i.e. 1,000 energy storage cores manufactured per year, with each complete system having as many cores as required for the desired amount of energy storage). Crucially the Megafactory would do this while demonstrating all the novel manufacturing processes necessary to create energy stores in a heat battery Gigafactory. Looking at the Gigafactory plan, a potential investor or partner who is familiar with manufacturing will be able to either (a) recognise a widely used process they are comfortable will work or (b) for novel processes be able to see them working live in the Caldera's factory.

[7] https://www.crowdcube.com/companies/caldera
[8] https://www.thermalstorage.org.uk/

Workstream 2: Build a demonstration energy storage system which can generate up to 1 tonne of steam per hour at its peak output. This is the scale necessary for the system to be a credible industrial product, suitable for a wide range of applications. This demonstrator will be based on Caldera's existing product, but at a significantly larger scale to be appropriate for industrial energy switching. It will also have new power electronics, digital controls and secondary heat exchange systems – these are technically straight-forward as they are common industrial components but nevertheless have not been combined before to make a complete Caldera industrial system. Being able to see this first live demonstration will give partners, suppliers, investors and prospective customers the confidence needed to ally with Caldera and support adoption of the technology and scaling of production.

This dual demonstration will enable industrial fuel switching by unlocking equity investment in Caldera to scale up production. It will also enable spending from major purchasers – we have seen that it is often easy to find an ally inside the company who is keen to support Caldera, and they need evidence for a business case that their Chief Financial Officer will accept. A key challenge we face is securing supplies of equipment and materials, with demand often outstripping supply. The IFS Phase 2 would give suppliers the confidence to work with Caldera initially, and the demonstration once complete would secure ongoing confidence in the long term.

Caldera's core technology is already patented or patent-pending, which reduces risks of copying. The team have the expertise needed to build the large-scale energy store, which simply scales up a product that has already been built. We also have deep expertise in manufacturing, with team members having run factories much larger than the demonstrator planned.

<u>What would happen if this didn't go ahead?</u>

Without public funding Caldera would scale up production much more slowly. In line with the competition objectives Caldera are looking to scale up production ahead of demand, which is of course impossible on a purely commercial basis. We would face considerable barriers, for example many landlords would be unlikely to accept Caldera as a tenant until revenue is higher and the company has been running for longer – a catch-22 where we need to be bigger before we can grow, but we cannot grow until we are bigger. This is because institutional landlords are looking for low risk returns for their investors, typically pension funds, and these favour large established companies.

The impact for industrial fuel switching would therefore be delayed at best, and not be possible at all at worse. Caldera would need to scale production behind demand, implying exactly the kind of shortages and multi-year lead times we see in other products today. This implies companies transitioning to low carbon solutions more slowly. Without access to Caldera low-cost technology industry might opt for higher cost solutions such as lithium-ion batteries. Note that this implies higher costs for consumers for the goods produced by industry, as well as higher prices for lithium-ion batteries in everything from electric vehicles to phones (given extra competition for finite minerals such as lithium increases the price).

What is the route to market?

A proven production process would position Caldera with the option of:

i. Licence the technology and production process to third party manufacturers around the world, or
ii. financing and building a first full-sized factory.

After discussions with potential partners/customers, factoring in the capital cost of a full-sized factory and the 5 x cost reductions available at scale it makes strong commercial sense for Caldera to build and prove the first Gigafactory in the UK. This will also show the UK at the forefront of a new technology sector.

In many cases partners will act as licensees or distributors, providing a key route to market, and based on interest to date break down as follows:

- Steam specialists – engineering firms that consult, install, and maintain industrial steam systems. They provide a link into most large companies that have a steam network.
- Renewables installers – companies that specialise in providing, and often financing, solar and wind generation 'behind the meter' for large companies. They are increasingly looking for ways to provide energy storage as a package with this generation.
- Sector specialists – we have spoken to engineering consultancies focused on brewing, and on distilling. In each case they have a wide and deep range of industry contacts and are keen to offer decarbonisation solutions.

As a result of the dissemination work undertaken as part of the project, we have had confidential conversations with prospective buyers across a range of sectors, scales and geographies. This includes enquiries from microbreweries that would only need 3 cores, and a major food manufacturer installing wind turbines and a large solar array who might need 300 cores. We have also spoken to prospective partner such as engineering companies who are receiving enquiries from customers who want to decarbonise and are unable to find an existing technology solution that is both technical feasible and economically viable.

As a result of all these conversations, we are confident that the product under development will meet a real need if it can be delivered in the volume and price that we project. That said, a vital precursor to economic viability is the availability of low cost and low carbon electricity. For a few sites today these companies have installed, or are installing, their own solar PV or wind turbines at a scale large enough to have excess electricity. This is the niche Caldera can serve today. We see these sites as the vanguard, going ahead of a much larger market that will emerge as more renewables come on to the grid.

Note: Related confidential information
Due to this report being publicly available, additional information including technical and commercially sensitive information was provided separately to BEIS in confidence.

Appendix A:
Detailed Feasibility Study Objectives

Note that in our Phase 1 submission we referred to ‘units, while in this document we also use the term ‘cores’ as this more accurately reflects the ability to combine as many cores as required into a single energy storage system.

Feasibility Study Objective	**Status**
To be able demonstrate how to advance the manufacturing to TRL8 (a first full factory) from TRL5 (current production).	Achieved
To produce a fully costed design for the production process that covers each process, internal factory layout and site modifications/consents	Achieved
To obtain quotes for the different elements, which will involve producing an RFQ for each part of the process for orders placed in early 2022 for the Phase 2 project.	Achieved
To demonstrate Warmstone units producing 10bar steam at 180C in a representative environment.	Achieved
To demonstrate a Warmstone unit producing 10bar steam at 180C on a third-party industrial site.	Achieved
Securing an option on suitable premises for a Phase 2 demonstration project along with all necessary consents and permissions	Agreed in principle – will be signed prior to Phase 2 application
A Phase 2 demonstration expected to cost in the region of [confidential] residual value	Achieved Phase 2 demonstration plan with lower cost than anticipated
A Phase 2 project that will demonstrate that each novel/adapted process can produce 10 units per hour	Achieved
That Phase 2 can achieve a unit cost of [confidential], with a pathway demonstrating how to reach a cost of [confidential] per unit at scale.	Achieved when scaled for 40% increase in size
That a Phase 2 factory will show the UK at the forefront of a new technology sector and create 56 new jobs.	Achieved with reduced job creation in line with smaller Phase 2 factory
A route to reduce the cost of production of a Warmstone heat battery by a factor of 4-6 greatly increases the market size for the product.	Achieved
That a Phase 2 factory will provide a route to a proven production process that can lead to a first full UK factory that can be licensed to other continents.	Achieved
That these technical manufacturing challenges are met: • handling a [heavy] unit; • reuse of energy during manufacturing; • handling emissions; • exclusive use of electrical heat and • heating of the rock.	Achieved