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USING A HIGH TEMPERATURE HEAT STORE TO OVERCOME GRID CONSTRAINTS

BEIS GREEN DISTILLERIES PHASE 1 – GD142

THE UIST DISTILLING COMPANY LTD

The Uist Distilling Company Ltd

Locogen | Flexitricity | LUMENION

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Executive Summary

Locogen Ltd have partnered with Flexitricity Ltd to deliver a BEIS green distilleries Phase 1 study investigating the techno-economic feasibility of creating a new build distillery that uses a Grid Scale High Temperature Energy Store (GSHTES) to import electricity from the grid and dispatch process heat for distillation. The GSHTES is the intellectual property of Lumenion GmbH who also form the project team partnership. The Uist Distilling Company have received planning permission for the development of Benbecula Distillery, North Uist and are committed to finding a low carbon distilling solution from inception. Benbecula Distillery was therefore used as a real world test case with which to conduct the feasibility study.

The technical solution design for the GSHTES at Benbecula Distillery is displayed in the table below. The GSHTES uses steel elements that can be heated to a maximum of 650°C, by means of conventional resistive heating elements within a nitrogen environment, which facilitates heat transfer whilst mitigating corrosion. The system is highly insulated to retain the heat produced, with thermal losses of ~0.5% per day. Conventional heat exchangers are utilised to produce process heat in the form of steam which is then used to drive the distillation process through the conventional steam infrastructure. The heat exchanger efficiencies are >95%.

Parameter	Value
GSHTES storage capacity (MWh)	6
Peak charging power (MW)	1.8
Peak thermal demand discharge (MW)	0.6
Dimensions	15m x 15m x 16m
Heat exchanger efficiency	95%
Thermal energy loss per day	0.5%
Transformer	11kV stepped down to 690V

The GSHTES is capable of providing a balancing load within a one second response, which can generate revenue through grid balancing services. Flexitricity used their experience as an aggregator of energy storage systems to optimise the performance of the GSHTES and to predict cost savings compared to direct electric consumption following an instantaneous demand profile. Overall running costs were found to still be greater than the counterfactual business as usual case of using fuel oil. Government policy is required to offer monetary reward for installation and use of low carbon heating systems and fossil fuel alternatives need to be charged based on carbon emissions for there to be a parity in price.

The project is calculated to save 748 tCO2 per year and over **23,000 tCO2** through a project operation of 25 years. There is a carbon emissions saving of **15.5 kgCO2/£** of BEIS money spent and of **2.1 kgCO2/LOA** produced. These calculations do not account for the high renewables penetration on the local grid and the likelihood that the cheapest electricity prices will coincide with excess renewable generation and can therefore be considered conservative. The GSHTES helps to balance the local grid and will reduce the necessity for installed renewable energy assets to be curtailed, thereby increasing the penetration of renewable power onto the grid. Additionally, strengthening the grid in this way will support an increase in installed capacity of renewables connected to the grid.

Lumenion's business plan is to add value to the local supply chain by manufacturing the GHSTES as close to the place of installation as possible. Manufacturers have been engaged with in detail for this project and delivery and installation can be provided by the same companies. The modular design of the store allows for ease of scalability across sizing and demands. This allows the GSHTES to be directly applicable to other industries that use process heat such as food, rubber and plastic, paper and printing, vehicle production, metal and chemical processing. With industry accounting for 24% of UK heat use, and process heat responsible for 75% of that, the GSHTES has the potential to make a very significant impact on the UK's carbon emissions and in reaching the Net Zero 2050 target

Glossary

ANM	Active Network Management
BEIS	UK government Department for Business, Energy & Industrial Strategy
BM	Balancing Mechanism
Capex	Capital expenditure
CHP	Combined heat and power
DA	Day Ahead
DNO	Distribution Network Operator
DSO	Distribution System Operator
DUoS	Distribution Use of System
GSHTES	Grid Scale High Temperature Energy Store
ID	Intraday
IRR	Internal Rate of Return
KPI	Key Performance Indicators
LOA	Litres of alcohol
LPG	Liquified petroleum gas
NPV	Net Present Value
Opex	Operational expenditure
PV	Photovoltaic
REA	Renewable Energy Association
SSEN	Scottish and Southern Energy Networks
SWA	Scotch Whisky Association
TNUoS	Transmission Network Use of System
TSO	Transmission System Operator
TUDC	The Uist Distilling Company Ltd

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1. Project Overview

The distillation process for most operational distilleries is fuelled by the raising of steam through burning fuel oil or natural gas. Distilleries are often situated in remote areas where the electrical infrastructure is highly constrained, meaning that onsite renewable energy generation is not a feasible option as export to the grid is not possible. This makes it very difficult for distilleries to become zero or low carbon.

This project has analysed the opportunity for distilleries to use an innovative high temperature and flexible heat store to provide a pathway to decarbonisation for distilleries. The Grid Scale High Temperature Energy Store (GSHTES) offers a unique solution to fuel switch from fossil fuels to electricity whilst also acting as an energy storage vessel.

Benbecula Distillery is a new build distillery in Benbecula, North Uist at the pre-construction stage. The local electricity grid is highly constrained, and installation of renewable energy generation is severely limited as a result. This is due to a current excess of renewable generation from existing operational wind sites and lack of matching demand. The GSHTES can operate flexibly to consume power when it is cheap, which coincides with periods of excess renewable generation. Thereby resulting in a low carbon and cost-effective option for providing the distillery with energy. The GSHTES also therefore alleviates strain on the grid by helping to balance supply and demand and also enabling greater penetration of renewable generation onto the grid as well as development of new generation.

The project is a Phase 1 project funded through the UK government Department for Business, Energy & Industrial Strategy (BEIS) green distilleries competition.

1.1. Project team

The Uist Distilling Company Ltd ('TUDC') are a special purpose vehicle set up to develop Benbecula Distillery. The owners of TUDC own the development land proposed for the distillery, which is on the island of Benbecula, North Uist. The owners are local and have operated in other business ventures in the area and within the drinks industry over many years. The distillery has received planning permission and initial architectural design has been completed. TUDC are eager to explore possibilities for supplying the distillery with a renewable energy solution so that the counterfactual usage of fuel oil can be avoided. TUDC are aware that low carbon and renewable options can be cost prohibitive and are therefore actively seeking grant funding opportunities to finance a low carbon option.

Locogen Ltd ('Locogen') are Project Manager for the project and have been responsible for overall delivery as well as technical and financial feasibility. Locogen is an independent renewable energy consultancy and developer with over a decade of experience in development, implementation and monitoring of renewable technologies. Locogen designs and delivers, low carbon heat solutions, district heating, wind, solar, hydro and hydrogen projects and therefore has the understanding of challenges in developing and operating low carbon projects which enables managing the inter-dependency of multiple low carbon technologies that may comprise an optimal energy system.

Flexitricity was the first Demand Side Response aggregator to enter the UK market. Their role is to aggregate flexible assets into a virtual power plant and to monetise this flexibility by making it available to transmission and distribution network operators. Flexitricity communicate, monitor, dispatch, control and report via a robust proprietary platform which has been refined with over 12 years' worth of live market participation, all from a state of the art 24/7 manned control room. The services they offer are the most diverse in the industry with ~700MW of contracted flexibility, including grid scale energy storage, EV charge points, gas CHPs, heat pumps, and hydro. Flexitricity will use their unique market insight and proprietary models to assess the opportunities for the GSHTES to be monetised in the UK market.

Lumenion GmbH own the IP of GSHTES and the majority shareholder are Econnext GmbH, a green business catalyst who support profitable businesses that have a positive social and environmental impact. The series of investors that comprise the Econnext team channel capital into green business projects once it can be evidenced that the project is a positive financial investment. The Green Distilleries funding will be the catalyst to secure further funding from the investors for Phase 2 and future further commercialisation. Without the support of the Green Distilleries funding, it would be difficult for the required funding to be raised to deliver such an innovative and replicable project, and certainly not to the desired timescales. The Lumenion business model seeks local manufacturers to ensure that local value is added throughout the supply chain, thereby ensuring a just transition to a low carbon economy.

1.2. Aims and objectives

The project aims to design a GSHTES energy system that can be applied at a distillery to displace fossil fuels for delivering heat for distillation. To do this, the following objectives were identified:

- Define Benbecula Distillery's expected energy use and distillation infrastructure;
- Create costed engineering design for the project;
- Conduct detailed energy balance modelling;
- Undertake a route to market assessment;
- Conduct financial feasibility assessment;
- Identify risks to the project; and
- Create dissemination strategy.

1.3. Technology options appraisal

Prior to the undertaking of the Phase 1 project, a comparison of different low carbon technologies and energy systems was conducted for Benbecula Distillery. Table 1 provides a high-level comparison of different low carbon technologies that could be applied at Benbecula Distillery. From this analysis it was evident that the Lumenion Grid Scale High Temperature Energy Storage (GSHTES) offered a promising opportunity for a feasible low carbon solution to distillation, compared to the counterfactual of an oil boiler.

	Oil Boiler	**GSHTES**	**Biomass**	**Heat Pumps**	**Hydrogen**
High heat temperature					
Ease to retrofit	■■■	■■□	■■□	■□□	■■■
Supply chain constraints	■■■	■■■	■■□	■■■	
Impact on grid Constraints	■■■	■■■	■■■	■■□	■■□
Energy efficiency	■■□	■■■	■■□	■■■	
Rapid ramp rates	■■■	■■■	■■■	■■□	■■■
Energy density	■■□	■■■	■■□	■■□	
Zero emissions	■□□	■■□	■■□	■■■	■■□
Capex	■■■	■■□	■■□	■■□	
Opex	■■□	■■□	■■□	■■■	■■□

Table 1: Summary of suitability of technologies

1.3.1. GSHTES technology overview

The GSHTES (see Figure 1) uses electricity to heat up steel elements to store energy and provide process heat to industrial processes up to ~550ºC. This electricity can be from either mains electricity, onsite renewable generation, offsite private wire, or a combination. It can import a regular supply of electricity or respond to a supply / demand curve and is therefore able to integrate flexibly with the grid and /or intermittent renewable generation. The steel elements can be heated to a maximum of 650°C, by means of conventional resistive heating elements within a nitrogen environment, which facilitates heat transfer whilst mitigating corrosion. The system is highly insulated to retain the heat produced, with thermal losses of ~0.5% per day. Conventional heat exchangers are utilised to produce process heat in the form of steam which is then used to drive the distillation process through the conventional steam infrastructure. The heat exchanger efficiencies are >95%.

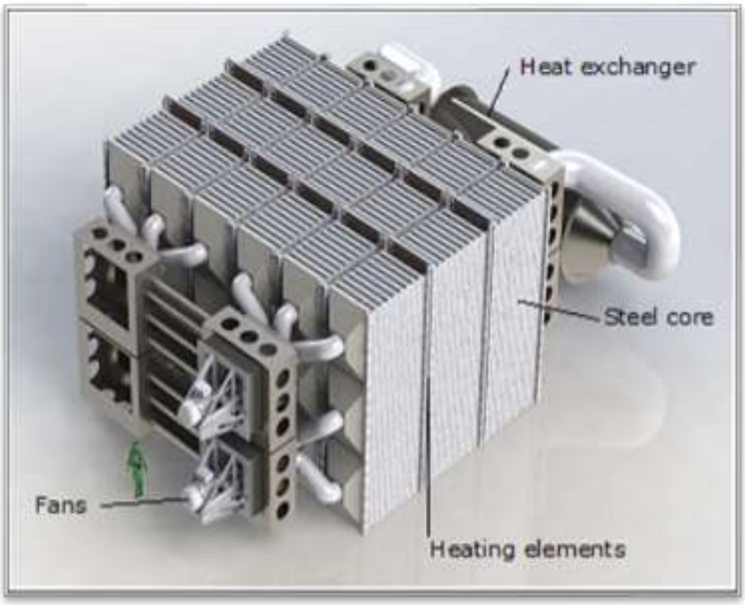

Figure 1: GSHTES technology. GSHTES is the IP of Lumenion GmbH

Charging is initialised by switching on the resistive heating elements, which can be cascaded and installed with bespoke dimensions for the distillery. The GSHTES is capable of providing a balancing load within a one second response, which can generate revenue through the Transmission System Operator (TSO) grid balancing services. Given that the load is at a MW scale, it is eligible for most grid balancing services and can attract an aggregator to optimise the revenue generated for the site.

1.3.2. Alternative technologies

Heat pumps also provide an electrical option for distilleries, and heat pump systems have been developed to be able to raise steam, but at lower pressures than the design of most currently utilised stills, meaning that refurbishment or replacement of the still would be required. Where high temperature systems are available, they are also not able to operate with rapid ramp rates utilised in most current distillery processes, and therefore require either large steam accumulators or modifications to the process methodology.

Hydrogen technologies have been proposed and tested in distillery applications too. However, the consideration of burner change on the steam boiler needs to be carefully undertaken. The production, transportation and storage of hydrogen all pose technical challenges that need to be considered on a case-by-case basis and may limit the dissemination of the technology, especially where distilleries may be remote and far from other hydrogen infrastructure. The round-trip efficiency of electricity to hydrogen production must also be considered.

Biomass and biofuel systems have also been utilised to replace oil-fired steam systems in distilleries, to reduce carbon emissions. Fuel supply and transport are key limiting factors in the feasibility of these schemes, and both still have concerns related to local air quality.

2. Feasibility results and conclusions

2.1. Modelling

2.1.1. Baselining energy use and operation

Benbecula Distillery is a new build distillery and therefore a true demand profile is not available. Instead, an estimate of the energy demands based on proposed sizing of equipment and operating schedule was made.

The distillation process is to be on an eight-hour cycle, which is common within the industry, and is to comprise a single mash. In the first three years of operation, new distilleries often operate at a reduced capacity in order to minimise costs before producing a product that can be sold. One of the requirements for a product to be labelled as scotch whisky is the need for the spirit to be matured for a minimum of three years in oak barrels. It is after this point that distilleries are able to sell a signature single malt scotch whisky and overall production and energy consumption increases.

The energy system must be sized to deliver the required energy for the distillery when it is at peak operation, from the design outset. Benbecula Distillery, with the GSHTES installed, is estimated to have a primary electricity demand of approximately 4,000 MWh/a, with a peak load of 535 kW.

2.1.2. Grid balancing services

Electricity is more expensive than fuel oil but optimising the heat store to import low-cost energy and avoiding peaks will provide cost savings. Flexitricity built a custom in-house model to estimate how the electrical import of the GSHTES from the grid could be optimised to deliver the lowest annual cost of energy. The optimisation strategy modelled is based on using the Day Ahead (DA) and Intraday (ID) market to meet minimum demand and use the Balancing Mechanism (BM) to top up and fill the heat store if a more lucrative opportunity is identified.

Key variables of the model are electricity tariff, skip rate and commodity percentage and these were adjusted in the modelling to present models representing a 'conservative' and 'optimistic' scenario for total expenditure on imported electricity from the grid. It is noted that the savings are greater for the conservative case due to the higher cost electricity tariff.

Item	Conservative		Optimistic	
	Non Optimised Electricity Cost	Optimised Electricity Cost	Non Optimised Electricity Cost	Optimised Electricity Cost
Electricity tariff (p/kWh)	17		13	
Skip rate	0.85		0.70	
Commodity %	40%		45%	
Commodity	£274,836	£101,892	£236,440	£119,229
Non-commodity	£412,254		£288,982	
Total electricity spend	£687,089	**£514,146**	£525,421	**£408,211**
Total savings		**£172,944**		**£117,211**

Table 2: Annual running costs and savings of an optimised GSHTES

2.1.3. Financial modelling

A financial model was created for the project which calculated financial key performance indicators (KPIs). These include internal rate of return (IRR) and net present value (NPV) against the counterfactual business as usual scenario. IRR and NPV were modelled over 10 and 25 year periods and a payback period calculated for invested capital expenditure (capex). Other

KPIs included carbon emissions abated, reduction in operational costs, cost saving per litre of alcohol (LOA) produced and carbon saved for the capital invested.

The model is built on a monthly resolution over the project lifetime. Capex and opex are inputted along with other assumptions, outlined in Appendix B. The results from energy flow modelling and revenue generated through export of excess generation to the grid were also inputted into the model. The heat and power demands satisfied by different sources were defined under the project and business as usual scenarios. The month when capex is spent is defined for each of the capital elements, which also then defines what month opex costs begin to be incurred.

The running costs relative to business as usual, including revenue generated, are calculated on a monthly basis and this is combined with the capex to calculate a monthly nett cashflow profile along with a cumulative cashflow profile. From these profiles, IRR, NPV and payback years can be calculated for the project. The starting month for the IRR, NPV and payback years calculations is defined by the first month of capex spend.

The amount of capital requested from Phase 2 of the BEIS green distilleries competition is included within the financial model to quantify the impact that grant funding would have on the project's financial case. A maximum of £3,000,000 can be requested in grant funding from BEIS for the Phase 2 competition and the impact of this was calculated.

2.2. Technical solution

Lumenion approached multiple local manufacturers to discuss the engineering requirements of the system to satisfy the energy demands of Benbecula Distillery. The final engineering design parameters are presented in Table 3 below.

Parameter	Value
GTHTES storage capacity (MWh)	6
Peak charging power (MW)	1.8
Peak thermal demand discharge (MW)	0.6
Dimensions	15m x 15m x 16m
Heat exchanger efficiency	95%
Thermal energy loss per day	0.5%
Connection	11kV transformed to 690V

Table 3: GTHTES design specification for Benbecula Distillery

Figure 2 below provides an outline schematic of the GSHTES system as applied within a distillery setting using steam as the heat transfer medium. This schematic is the property of Lumenion GmbH and it is noted that pressure and temperature values are illustrative only and are not applicable to the project.

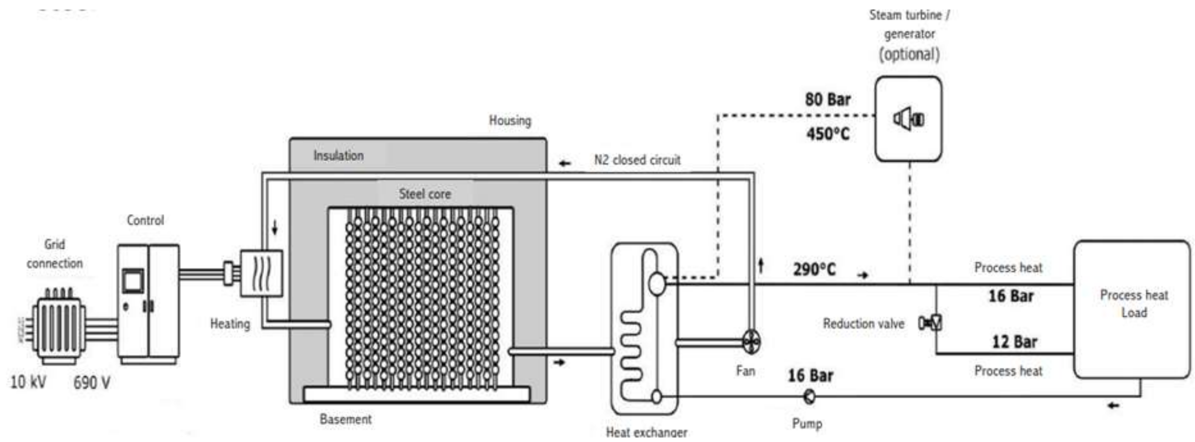

Figure 2: Schematic of GSHTES technology integrated with steam distillation system

2.2.1. Costs

The total estimated capex for the proposed optimal solution is £1,500,000. Opex for all elements other than energy costs is estimated to be between £93,216 and £137,744 with an estimate of approximately £107,000 most likely. Including for energy costs, as calculated in Section 2.1.2, gives a total annual opex of between approximately £530,000 and £695,000.

Using local partners and manufacturers will enable the creation of a local and national supply chain. Establishing a supply chain for manufacturing, installation and operation and maintenance will drive down costs for future installations and this will be an important outcome from the demonstrator project. Based on investigations to date, UK added value of over 80% of the total project capex is achievable, with 70% being a minimum. Further, it is expected that this proportion will rise with growing size and storage capacity of the GSHTES. A conservative estimate is therefore that £945,000 in capex will be added into the UK supply chain.

2.3. Financial & carbon assessment

The counterfactual annual spend on energy is calculated to be £268,711. An optimistic scenario results in the GSHTES leading to an annual spend of £408,211. Even with the capex for the project provided through grant funding, it is apparent that there will be no payback or return on investment. However, an increase in carbon emission taxation would see the GSHTES provide a lower cost solution over the long term than fuel oil as well as greater security. This greater security will enable TUDC, and any other distillery or business owner, to more easily forecast long term expenditure and cashflow. For whisky distilleries especially, having an accurate long term forecast of running costs is extremely important given the time it takes to start selling products from the point of production. Financial analysis (Appendix E) calculated that an equivalent increase in fossil fuel price of 30% (through taxation or other means) would result in running cost parity between the GSHTES and the business as usual case of burning fuel oil.

The project is calculated to save 748 tCO_2 per year and over **23,000 tCO_2** through a project operation of 25 years. There is a carbon emissions saving of **15.5 $kgCO_2$/£** of BEIS money spent and of **2.1 $kgCO_2$/LOA** produced. With the social value attributed to the carbon emissions abatement and the return on investment for BEIS over the project lifetime, this represents a positive investment for the UK government in its carbon emission targets and the green economic recovery. This calculation does not account for the high renewables penetration on the local grid and the likelihood that the cheapest electricity prices will coincide with excess renewable generation. The carbon emissions associated with import from the grid are based off BEIS projected UK grid carbon intensity figures and are therefore conservative when applied to the location and optimisation of this project.

3. Demonstration project description

The demonstrator project will be based at Benbecula Distillery, North Uist in the Western Isles. The demonstrator project will build upon the feasibility study enclosed within this assessment as well as the research and development work that has developed the technology in other settings, such as the pilot project connected to Berlin's district heating network. The BEIS green distilleries Phase 2 demonstrator phase will allow for the GSHTES to be installed in a distillery setting, thereby showcasing its adaptability across different industries.

The demonstrator project will comprise a 6 MWh GSHTES with a maximum delivered thermal output of 600 kW. The GSHTES will have a maximum electrical import of 1.8 MW which will be provided via connection to the local electricity grid. A 2 MVA transformer will be installed at the project site to step down the 11 kV grid connection to the GSHTES operational 690 V. The demonstrator will include concrete foundations for the heat store along with pipework connections to the boiler house and return pipework for the condensate. The demonstration phase will be used to refine the operational design for the GSHTES and test all components as well as its integration with the distillery. Materials for the industrial rollout of the technology will be produced including:

- Detailed designs;
- Documents supporting planning permissions;
- Power connections;
- Assembly manuals;
- Operations manuals;
- Health & safety manuals; and
- Summary of certificate documentation.

In addition, the demonstrator phase will establish a robust supply chain and outline the options for local sourcing, which is currently estimated to be 70% as an absolute minimum and likely to be significantly higher.

A Phase 2 project plan has been devised along with associated costs and this is presented in Section 6. Figure 3 below presents the layout and location of the demonstrator project at Benbecula Distillery.

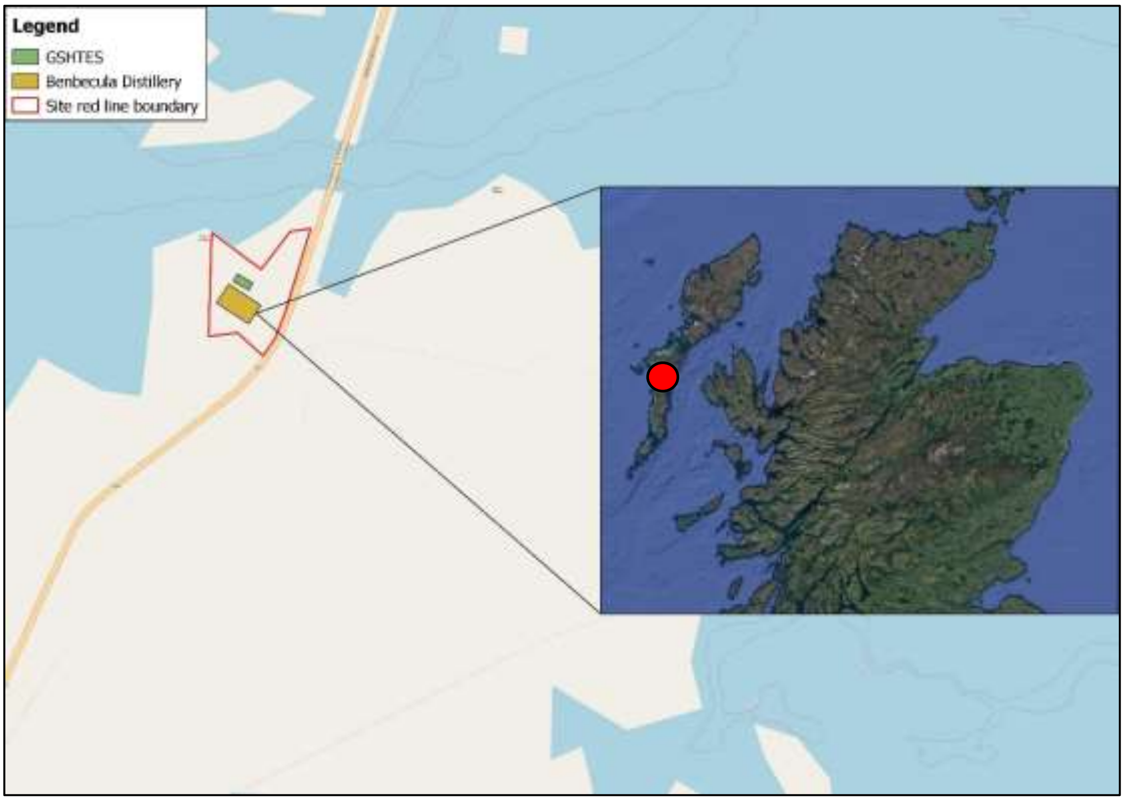

Figure 3: Demonstrator project location

4. Design for demonstration project

A detailed design has been created specific to the project, which follows the outline design displayed in Figure 3. Figure 4 to Figure 11 below displays the finalised design and detail the major group of parts.

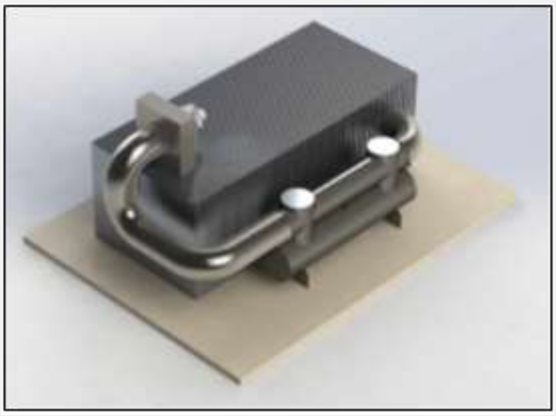

Figure 4: Isometric view

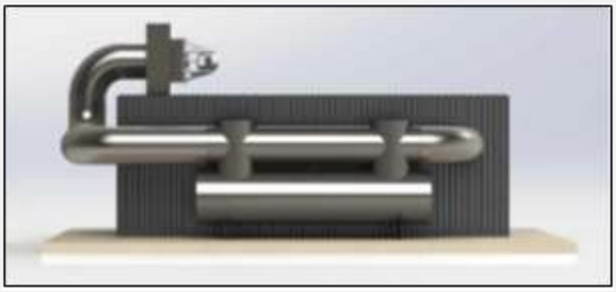

Figure 5: Landscape view

Figure 6: Front view

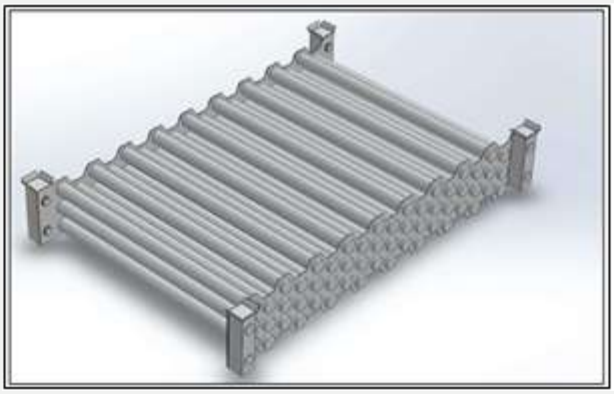

Figure 7: Core module 3.2t

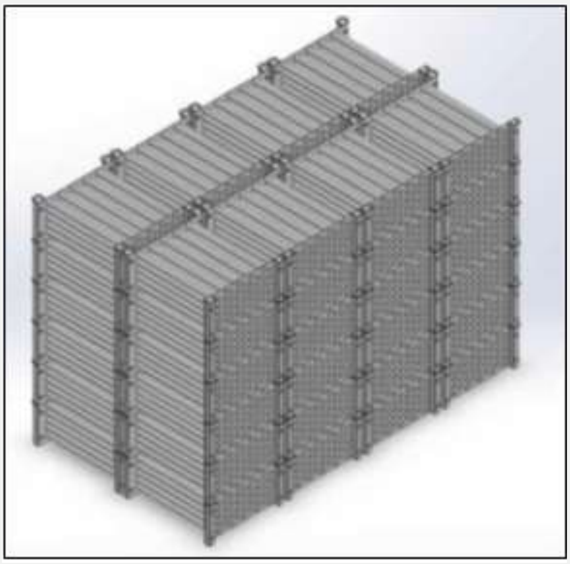

Figure 8: Steel core

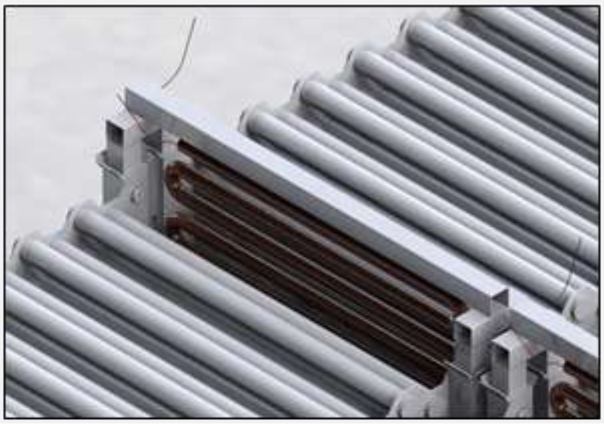

Figure 9: Resistive heating elements

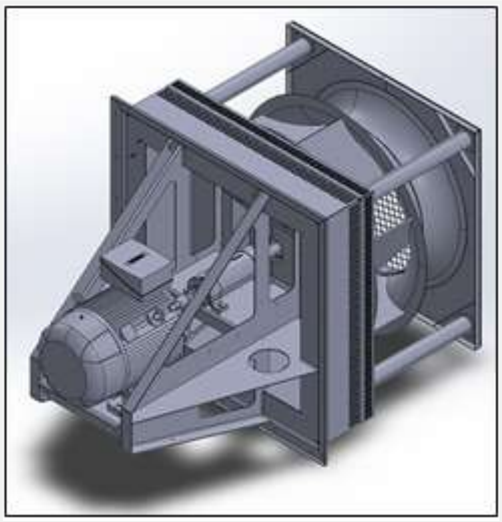

Figure 10: High temperature radial fan

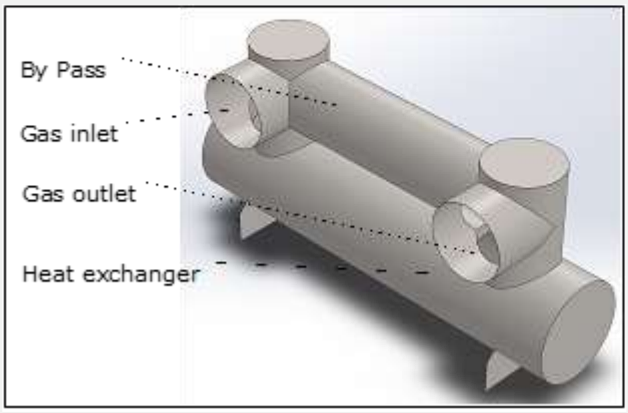

Figure 11: Heat exchanger

Within the casing shown above in Figure 4 to Figure 6 there is a steel core. The steel core is of modular design which allows for mass production of the core modules and ease of scalability. Furthermore, this modular design allows for simple assembly, thereby minimising installation cost. Figure 7 shows the design for a 3.2t steel module. For the project assembly, 48 of these modules will be stacked in six columns as shown in Figure 8, giving a total weight of 153.6t.

Industry standard resistive heating elements are arranged between core modules. These allow for rapid switching on and off when charging and discharging. Figure 9 displays these resistive heat elements. Industry standard heat exchangers will be installed at the back of the steel cores to raise steam for the distillation process. These are displayed in Figure 11. In terms of safety considerations, the plate heat exchanger for raising steam will be a proprietary unit typical to steam operation. The system design and steam safety requirements are within BG01 and the Pressurised Equipment Directive. All key operational safety features and requirements have been considered.

A single radial fan will be required for the 6 MWh GSHTES. The fan will be free running and have variable speed and is shown above in Figure 10. For guiding the gas flow around the core to ensure an even distribution, ducts and diffusors are required, which follow industry standard design.

The GSHTES requires insulation which will be provided as a metal sheet, ceramic wool, rockwool and trapezoidal sheet metal for the outer casing. Whilst providing the required insulation, this layered structure will also allow for ease of access for any maintenance. The insulation can be mounted directly to the storage or be free standing to control thermal expansion effects. With the insulation installed, losses are calculated to be less than 100 W/m2. The GSHTES will require to be installed upon a custom foundation. The surface pressure on this foundation is calculated to be 2.8 N/mm2. The foundation will be constructed out of C25/30 quality concrete which will support the structure's loadings.

5. Benefits and Barriers

5.1. Benefits

5.1.1. Alleviating grid constraints

Benbecula Distillery is situated in an area that is highly grid constrained as production from wind energy regularly exceeds local demand. The GSHTES can import wind power that would otherwise be curtailed, at a very low cost. The presence of the GSHTES will help the grid to balance and relieve the stresses that are currently present. Locogen have discussed this with Scottish & Southern Energy Networks (SSEN), the local distribution network operator (DNO), who have confirmed that the additional load would be advantageous to the local grid and would be able to be connected.

Improving the grid infrastructure in this way will reduce the necessity for installed renewable energy assets to be curtailed and increase the penetration of renewable power onto the grid. Additionally, strengthening the grid in this way will support an increase in installed capacity of renewables onto the grid. This model can be replicated across the UK, where many distilleries are located in areas with poor grid infrastructure and curtailed wind farms in the surrounding area. Such storage technologies are vital for the UK to reach its 2050 Net Zero target

5.1.2. Ease of retrofit & integration

Considering that steam is the working fluid of choice for present day distilleries, this solution would require minimal replacement and/or retrofitting of existing infrastructure at operational distilleries. This results in a saving in capex and savings in lost production during the installation phase compared to other potential technological solutions to decarbonisation. The high energy density of the thermal store means that there is a limited physical footprint, thereby minimising environmental impact onsite and operational disruption whilst not posing a planning permission issue.

Due to the distillation process being unchanged, there should be no impact on the product quality. As the heat store can be immediately dispatched on demand, there will also be no impact on the production line operational timings, therefore having no impact on the structure of shifts and operational management.

5.1.3. Scalability

As the design of the solution is very much based on conventional vessel design principles and standards, scaling into units with higher storage capacity should not pose any major challenges. The modular design of the GSHTES system allows it to be scaled across a wide range of sizes and capacities, both in terms of the size of the storage medium, but also the rate of incoming power required. Unlike many other technologies, it is less limited by minimum physical sizing or modular limits, or the minimum investment cost for fuel transport, supply and storage that can be required. Unlike battery storage, the core of the store does not age as the steel elements do not undergo any form of re-crystallization, when heated up to a maximum of 650^{o}C.

5.1.4. Financial

The layout of the store aims at reducing every aspect of life cycle cost. The modular design of the core allows for mass production and transport to site on standard lorries. All components follow well established industry standards which helps reduce capex. Operations are simple and can easily be integrated into existing process schemes. At the end of the useful lifetime, decommissioning is again simplified by the modular design. The absence of hazardous materials means there is no special waste that would otherwise cause extra cost to dispose of. The steel used as storage material does not wear. This not only allows for long useful lifetimes of plants but also for a high residual value at decommissioning. The steel can then be either reused in another plant or sold as scrap steel, for which there is an established international market.

The opex for the GSHTES is low as there is minor risk of breakdown and the design has limited mechanical components. The technology is easily accessible, and materials are readily available therefore unplanned maintenance will not incur huge costs. Through the Phase 2 demonstrator project, these cost assumptions can be validated to increase investor and purchaser confidence and in creating a robust and viable business plan.

Cost savings on energy use can be made through the offering of grid balancing services and participation in grid balancing markets.

5.1.5. Local supply chain

Practically all manufacturing and parts can be sourced in the UK with a strong focus on Scotland, where the majority of distilleries that use fuel oil and have poor surrounding grid infrastructure but in close proximity to wind farms are located. Jobs will be created as the bulk of the manufacturing, and all the considerable on-site work will be completed in the UK. Construction work will be available for steel fabricators, civil contractors, electrical contractors, and the network operators. Ongoing operations will require a UK based operations and maintenance team, most likely provided by one of the UK based project partners. It is estimated that more than 80% of the total value added can be local, with the absolute minimum being 70%.

Having the GSHTES manufactured locally adds value through social and economic benefits. Many distilleries are located in rural communities which suffer from depopulation and lack of stable employment prospects. Industrial sites are also often located in areas of greater social and economic deprivation and are often faced with economic uncertainty. The GSHTES solution offers manufacturing and skilled operational engineering work near the installation site. Increasing manufacturing of GSHTES close to their deployment will have a positive impact on the local economy and will contribute towards a just transition in line with the UK's Net Zero 2050 strategy by protecting vulnerable workers, consumers and rural and island populations.

Benbecula Distillery is committed to enhancing the local economy by providing 25 fulltime jobs including highly skilled engineering and management jobs. Many further jobs will be created in the distillery construction and 60-70 indirect jobs in the supply chain including crofters, transport, hospitality, accommodation and retail. The low carbon solution will be a key part of the distillery tours and overall story to promote sustainability to visitors and consumers. The interest that will occur as a result of this, following on from the dissemination strategy (Section 9), will have an enormous wider economic impact for the area with visitors bringing positive economic impacts for the islands in terms of accommodation, restaurants, cafes, crafts and recreation. The creation of a low carbon distillery will be a catalyst for retaining native young people on the islands and encourage them to bring up their families, thereby safeguarding the islands' culture, language and identity. The local tourism industry has been decimated due to ongoing lockdown restrictions imposed during the COVID-19 pandemic. The project creates an opportunity for the local area to benefit from the UK government's Green Recovery strategy to boost the local economy whilst aligning with national carbon reduction targets.

5.1.6. Energy reduction

The efficiency of the GSHTES heat exchanger is 95% in converting stored electricity to process heat. This is significantly higher than conventional boiler systems as are installed in most distilleries today and leads to approximately 11% savings in primary energy requirements. For the project, it is estimated that installation of the GSHTES would save over 475,000 kWh/a.

5.1.7. Environmental

If Benbecula Distillery were to install a business-as-usual fuel oil burner and boiler to raise steam, it is calculated that there would be approximately 1,210 tCO_2/a of carbon emissions once at full production. Installing the GSHTES is estimated to save 748 tCO_2/a initially. This value is calculated using BEIS' UK electricity emissions factors, therefore the associated carbon emissions with importing from the grid will reduce over time as the UK grid receives greater renewables penetration. The project will abate over **23,000 tCO_2** through a project operation of 25 years. This equates to carbon emissions savings of **15.5 $kgCO_2$/£** of BEIS money spent and **2.1 $kgCO_2$/LOA** produced. This calculation does not account for the high renewables penetration on the local grid and the likelihood that the cheapest electricity prices will coincide with excess renewable generation. Therefore these results are considered to be conservative.

As the GSHTES system utilises electricity as its energy input rather than the onsite combustion of a fuel, there are no local emissions for air quality considerations. The GSHTES process for distillation also produces no harmful nitrous oxide greenhouse gases. There are also no transportation requirements associated with the regular deliveries of liquid or biomass fuels. Both of these provide good long-term local emissions and air quality benefits. As the working medium of the system is nitrogen, there is no potential for harmful system leaks as can be seen in compressor systems utilising hydrocarbon refrigerants. The construction of the system is from mild steel, meaning it is easily recycled at the end of the system life.

The GSHTES contains no hazardous materials and therefore poses no risk to the wider environment in terms of ecology and air quality. Nor does it pose any additional danger to workers in the distillery. It does not produce any special waste, neither during operations nor at de-commissioning.

5.1.8. Futureproofing

Fossil fuel prices are extremely volatile and uncertain. They are tied to external political influences and it can be hard for a business to financially plan for the future if they are dependent on fossil fuels. With the increasing pressure on governments to take further action to decarbonise and replace fossil fuel reliance there is also a future risk of increased costs of emitting carbon, purchasing fossil fuels, omission from future certifications marking carbon credentials and the possibility of an outright ban.

5.1.9. Electrification of Heat Pathway

Extensive electrification of heat and transport is a scenario for hitting the UK Net Zero 2050 target. BEIS (2019) identifies industry as being the second largest contributor to annual greenhouse gas emissions (after transport) with approximately 110 MtCO2e/a. Decarbonising this sector via electrification through implementation of GSHTES presents an enormous opportunity (around 76 TWh per year) to greatly reduce the associated emissions from industry. The adaptability, scalability and relative technological simplicity of the proposed solution can make a rapid impact on the greenhouse gas contributions of the heating and industrial sectors. Figure 12 provides a breakdown of the energy use that could be provided through the widespread and direct deployment of the GSHTES.

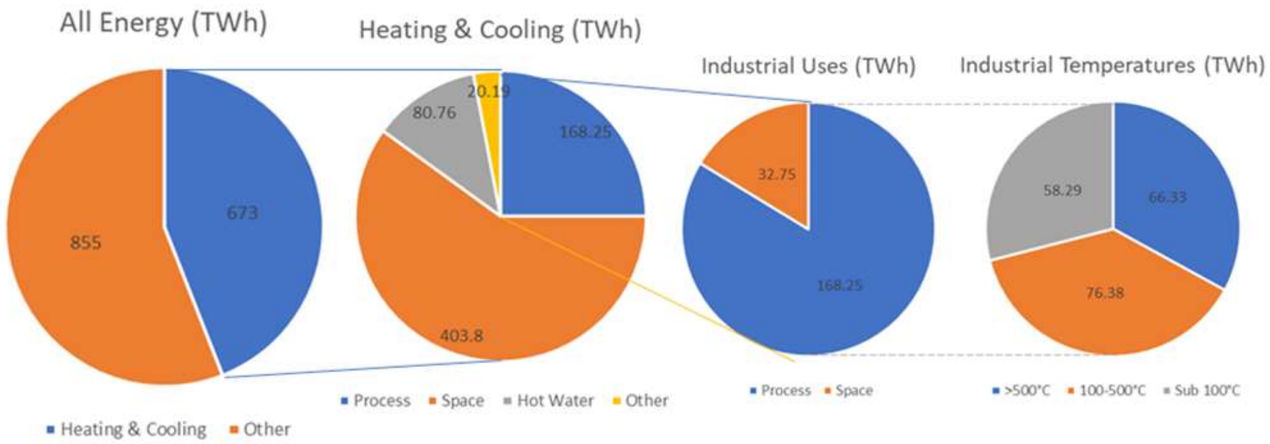

Figure 12: Breakdown of industrial settings applicable for GSHTES (BEIS, 2019)

5.2. Barriers

A number of potential barriers have been identified by the project partners which are discussed below.

5.2.1. Energy running costs

Installation of the GSHTES will result in higher running costs than the counterfactual case of running the distillery using fuel oil and a boiler. This may be regarded as prohibitive to some distilleries. With BEIS green distilleries Phase 2 grant funding, the savings on capex can be reinvested in initial running costs to make savings in this area.

5.2.2. Planning

Planning permission will be required for the GSHTES. The planning risk is regarded to be low generally given the non-obtrusive nature of the technology, low footprint, low carbon credentials and positive wider environmental impact. With regards to the project specifically, the development land is owned by TUDC and therefore the risk is regarded to be even lower.

5.2.3. DNO constraints

There are grid constraint issues at the Benbecula Distillery site meaning that no export from the site is allowed. This immediately ruled out the potential for the GSHTES to partake in additional ancillary services to which it could be well suited.

5.2.4. Local supply chain

Given the location of the distillery, finding the right skills in Benbecula may be difficult. Furthermore, if workers must travel to site, there will be additional costs. Given this, it may be a challenge to find construction companies that will tender at competitive rates. Lumenion have discussed the manufacture, transport and installation with companies based on mainland Scotland who are able to deliver the GSHTES.

5.2.5. Policy & regulations

There is a clear opportunity to deliver a strong regulatory signal to decarbonise process heat, however policy today is limited, and this creates a barrier to innovative solutions like the heat store. For example, the UK Net Zero 2050 target is a very distant one and permits the burning of fossil fuels until then. The price of electricity will likely remain higher and provide a disincentive to electrification unless resolved. Furthermore, the Non-domestic Renewable Heat Incentive (RHI) is coming to an end in March 2021, yet the Government has not announced how it will encourage low carbon heating after this. Continuity of subsidies and long-term certainty are required to support industrial customers meeting net zero targets.

5.2.6. No definition of storage or GSHTES in policy

Ofgem (Ofgem, 2020) currently define storage as the "conversion of electrical energy into a form of energy which can be stored, the storing of that energy, and the subsequent reconversion of that energy back into electrical energy". The GSHTES is now capable of both feeding electrical energy back into the electrical network but also heat into the networks of district heating or industries, so does not fit into the definition of energy storage.

Ofgem states that "Storage providers that have been granted a licence will not be subject to payment of the final consumption levies" and that "The licensee shall not have self-consumption as the primary function when operating its storage facility". This would be key to providing CO_2 free heat from renewables in competition to gas. Extending this regulation to storage technologies that provide carbon free heat, together with various services to the distribution networks, would be required. Further conversations of the GSHTES with Ofgem Innovation Link initiative would be required prior to commercialisation.

6. Costed development plan

The total cost for the Phase 2 demonstration project with the proposed technical solution is estimated to be £1,500,000. A costed development plan has been created by the project partners which shows when activities will occur and the associated cost with each. The Phase 2 project duration will be 21 months, including six months of monitoring of the operational performance. In addition to the project capex, the following development costs are anticipated to deliver the Phase 2 demonstrator:

- Project management: £150,000;
- Establishing supply chain: £50,000;
- Development of documentation and manuals: £80,000;
- Development of dissemination materials; and
- Dissemination activities: £20,000.

Figure 13 displays the Phase 2 demonstrator project plan.

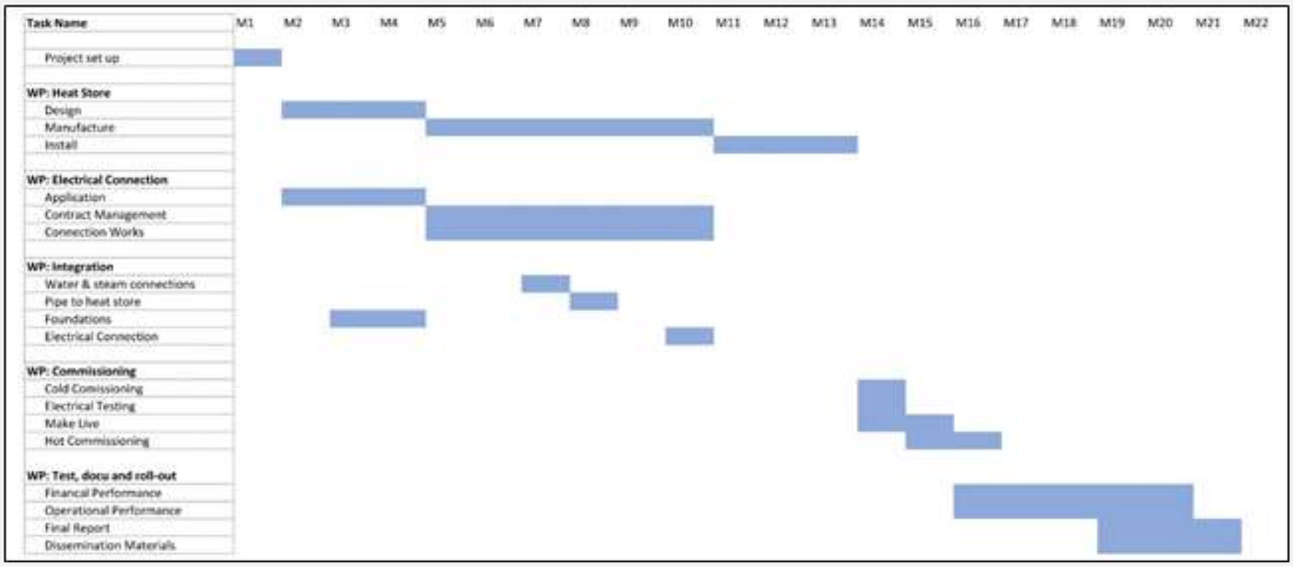

Figure 13: Phase 2 demonstrator project plan

7. Rollout potential

Once successfully commercialised, there is significant potential for the GSHTES given the scalability, replicability and applicability of the technology to not only distilleries, but also more widely to industrial-scale process heat, found in many sectors.

7.1. Support for decarbonising heat

7.1.1. UK industrial heat policy

It has been outlined that for the UK to meet its Climate Change Act commitments it will need to decarbonise most industrial processes, by using low carbon technology (BEIS, 2019). Looking further ahead the UK has committed to bring all emissions to net zero by 2050. Both targets require the use of clean technologies in distilleries and other process heat industries.

7.1.2. Whisky industry

Led by the Scotch Whisky Association, the industry is cooperating on a Sustainability Strategy (Scotch Whisky Association, 2021) to reduce carbon emissions and promote sustainability across the sector. Within the strategy the industry has set four goals, the first being on tackling climate change and setting an aim to cut GHG emissions to achieve net zero emissions by 2040. This requires a complete move away from the use of fossil fuels as a primary heat source for the distilling process. In the latest industry report on sustainability progress to 2020 (Ricardo EE, 2020) it states that the Association has commissioned research to identify pathways to achieve net zero which will require exploration of new technologies.

Within their vision the 2040 status is targeted to be:

> *"Distilleries are completely self-sufficient in energy. Some are bio-refineries, using by-products to create new raw materials for other sectors".*

Using the GSHTES will help deliver this vision. By taking intermittent generation sources (wind and PV) and storing as thermal energy, this can be matched to the intermittent high temperature controllable heat demand of the distilling process.

7.2. Addressable market

The GSHTES system is scalable across a wide range of sizes and capacities. This means that the GSHTES system has the potential to be viable for both large industrial distilleries as well as smaller craft scale production facilities. The heat store also has the potential to benefit many (if not, all) other industrial-scale process heat sectors too.

7.2.1. Distillery market

There are ~122 whisky distilleries in Scotland and they contribute a gross value added of £5.5 billion. An estimated £4.9 billion of this is from exports, which accounts for 21% of all UK food and drink exports. Distilleries employ over 10,000 people in Scotland. Whisky production is seven times more energy intensive than gin and emits approximately 530,000 tCO_2e/a.

The SWA recently published a detailed assessment of the pathway to net zero for the industry (Ricardo EE, 2020). The report covers 127 sites including 70 malt distilleries, 5 grain distilleries and 11 packaging sites and so provides a reliable assessment of the potential take-up across UK distilleries. Approximately 88% of emissions are related directly to distilling and this matches the energy use from gas, oil and LPG (Ricardo EE, 2020). As shown in Figure 14, distilleries currently use 19% oil fuels and LPG, likely due to their location being off the mains gas grid. At 56% gas is the preferred energy source when available due to its significantly lower cost. A further 17% use electricity, which is mainly from the grid and 6% using a green electricity tariff.

There is therefore 36% of the available market that uses oil fuels or electricity that can be targeted as a priority for conversion to green hydrogen as a fuel. Those that currently use electricity can be targeted as a priority as their running costs will be above that of the GSHTES. As the technology and supply chains mature, the costs will fall, making the technology more competitive with fuel oil, particularly if carbon is priced. Given the direction of heat decarbonisation policy, it is also probable that longer term, distilleries will need to move away from natural gas, making the entire market potentially available to this technology. There are over 400 distilleries in the UK, with a gross value added of £8.25 billion, that the GSHTES is directly applicable to.

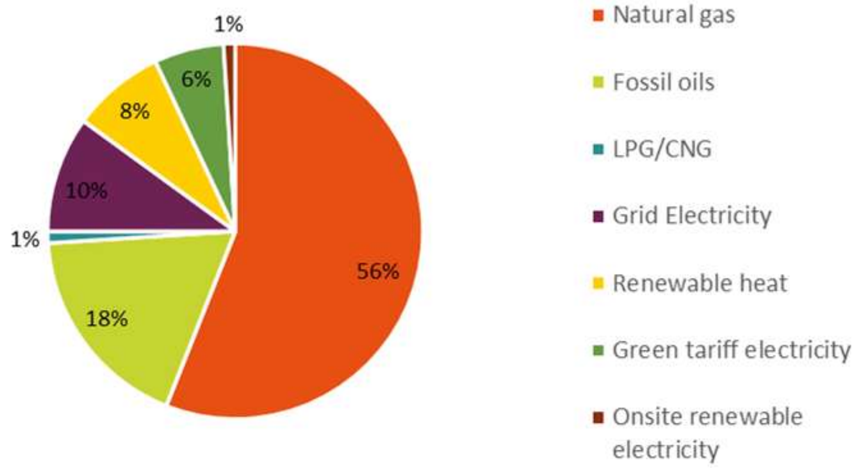

Figure 14: Fuel consumption in UK distilleries (2018). Source (Ricardo EE, 2020)

7.2.2. Process heat for UK industries

Heat is the largest energy consuming sector in the UK today accounting for 44% of final energy consumption and 37% of total UK emissions. Industry accounts for 24% of all heat use, with process heat accounting for 75% of this (~120 TWh) (BEIS, 2018b). With 15% of industrial energy consumption coming from oil and coal and a further 39% from natural gas, there is a very large scope for fuel switching (see Figure 15). Heating processes are the leading driver for industrial emissions. To meet the 2050 emissions target, the biggest contribution to overall emission abatement across all industrial sectors, will come from fuel switching. Switching fuels for steam generation should be of priority, given that over 80% of the abatement from fuel switching relates to indirect heating processes using steam (Ricardo EE, 2020).

The heat store has the potential to benefit many (if not, all) other industrial-scale process heat sectors. The addressable market is very much defined by the temperature levels of the process heat used by the end customer (see Table 4). The GSHTES system can operate across all process heat temperature ranges, however the best fit is for those industries operating with process heat temperatures between 150 – 550˚C. At this temperature, heat can be provided by the heat store at high efficiency and meet the full demand of the customers processes. Distilleries fit well with a demand for steam at ~170˚C. From Table 4, the key industries in this temperature range are food, rubber and plastic, paper and printing, vehicle production, metal and chemical processing. These sectors are also some of the most energy intensive (see Figure 15).

With manufacturing industries accounting for a gross value added of £191 billion in 2018 (10% of the UK total economic output), 42% of exports and employing 2.7 million people (8% of jobs) (UK Parliament, 2020), it is clear that the opportunity for the GSHTES is significant.

Industry Sector	<150°C	>150 500°C	>500°C
Food	■	■	
Rubber & plastic	■	■	
Paper & printing	■	■	
Machine & vehicle production	■	■	■
Metal processing	■	■	■
Chemical processing			■
Glass & ceramics			■
Metal production		■	
Existing CHP plants		■	
Fossil fuel power plant		■	

Table 4: Process heat temperatures for different industries

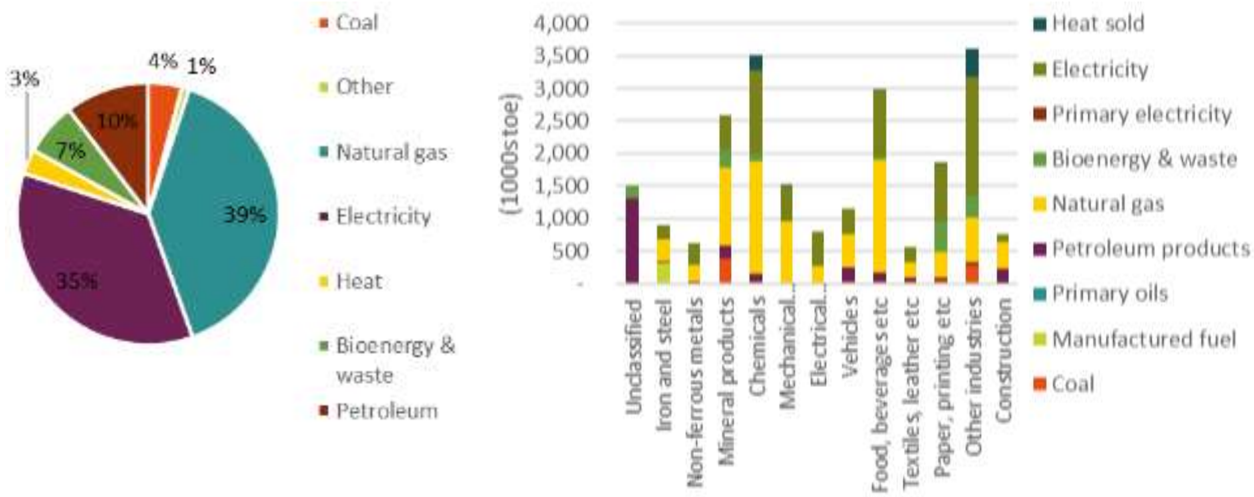

Figure 15: [Left] UK Industrial final energy consumption by fuel. [Right] Final energy consumption by industry sector (DUKES 2020).

The GSHTES system works up to 550˚C, so for processes with demand for higher temperature levels at >550˚C, the heat store can be boosted with conventional heaters. Process heat temperatures at <150˚C are generally found in space or district heating. Most industrial processes provide excess heat at these temperature levels which can then be utilised for such applications, but the GSHTES system can also feed heat into non-industrial district heating schemes, especially for urban, or space constrained areas. The GSHTES can be combined with other technologies for process coupling which is a more efficient way of delivering heat to two different demands.

The GSHTES also has the ability to integrate with combined heat and power (CHP) and fossil fuel plant temperatures. A heat store increases CHP plant flexibility, providing options for arbitrage between the CHP and the heat store. The heat store provides a bigger opportunity for peak shaving and generating revenues from TSO grid services, whilst subsequently increasing CHP lifetime and decreasing fuel consumption. Converting intermittent renewable electricity from wind and solar at the site, into a reliable and steady steam supply can replace fossil fuels at such plants. This could avoid closure of plants, protects jobs in surrounding regions and enhances the competitiveness of resident businesses.

8. Route to market assessment

8.1. Technology route to market

The initial development plan will target other distilleries that are at the pre-construction stage which could readily install the GSHTES solution, establishing the design as a blueprint for new distilleries. Existing operational distilleries that run off electricity (17%, see Section 7.1.2) will also be targeted initially as there are significant operational savings they would make with the GSHTES. Those distilleries across the Scottish Highlands & islands that are off the gas grid and responsible for 20% of all whisky in the UK will then be targeted once the technology and supply chains have been established.

Another criteria will be proximity to operational wind farms and the strength of grid infrastructure. Great Britain curtailed over 3.6 TWh of wind energy in 2020 (LCP, 2021). There is presently approximately 13.7 GW and 10.4 GW of installed capacity of onshore and offshore wind energy in the UK and the government has made a target of having 40 GW of installed offshore wind capacity by 2030. The grid balancing market that the GSHTES can participate in is therefore expected to become more lucrative, offering ever cheaper (in real terms) costs to run the distillery. Distilleries that run off electricity or fuel oil are often co-located in areas with high wind development potential or existing capacity and there is therefore a synergy with installing the GSHTES at distilleries in more remote locations.

The long-term development plan will target owners of multiple distilleries given their access to capital and resources to undertake multiple installations across the country. Many of the distilleries that are owned by a wider group are also some of the largest production facilities with the largest associated carbon footprint. Having such owners adopt the technology would accelerate the decarbonisation of the industry and further improve the supply chain and costs.

Lumenion’s heat store has been successfully prototyped at HTW Grid Simulation Laboratory in Berlin (450kWh) and demonstrated at Vattenfall’s site Bottroper Weg in Berlin (2.4MWh) feeding heat into the district heating system. The results from the modelling can help Lumenion build a bespoke heat store design for the distillery sector and apply the learnings to the UK market and realise a local supply chain.

8.2. Key constraint considerations

The distilling sector is traditionally heavily resistant to change down to fear of jeopardising product quality and brand. Despite there being vocal support of transitioning to renewable energy, distilleries have been reluctant to part with their own money. This principal barrier can be overcome by using the green distilleries grant to showcase the solution at an independent working distillery. Proving the technology works at this scale through Phase 2 will provide the confidence the wider industry needs for widescale adoption whilst minimising risk of expenditure to BEIS by limiting the size of the technology. The technology is easily scalable and therefore the technology can be increased in size once there is investor and purchaser confidence.

8.3. Identifying target customers

Industrial-scale process heat users who are based in geographical locations where generation exceeds the network’s capability, are ideal candidates for this technology. Often called Active Network Management (ANM) zones or Flexible Distributed Generation Zones, these highly constrained areas, provide an opportunity to use the heat to solve specific network problems such as on Orkney, The Isle of White, Swansea, Alverdiscott, Blyth, Driffield, Seal sands, and in much larger parts of the distribution networks such as most of Norfolk, Cambridgeshire, Bedfordshire, Essex, Kent, Sussex, the Scottish Borders and North Wales. ANM zones can be used to gain insight to identify industries in the right area to target with the technology.

9. Dissemination

9.1. Completed dissemination activities

The project team have completed joint and individual press releases following the BEIS announcement of the successful Phase 1 competition projects. The joint press release was distributed across multiple platforms, websites and industry and regional press. Unprecedented traffic volume and 'hits' occurred on the Locogen website and LinkedIn pages.

In the wake of the press releases, there have been numerous enquiries made from other distilleries interested in the technical solution offered and wanting a similar decarbonisation strategy implemented at their site(s). Locogen have submitted proposals for other distilleries to look at the GSHTES as a route to decarbonisation.

Marketing materials have been created covering the following areas:

- Description of the storage system, the electrical network and Benbecula Distillery;
- Integration of the GSHTES system into the distillery;
- Integration of the GSHTES system into the local grid network;
- Carbon saving compared to a business as usual case; and
- Business case of the creation of a zero carbon distillery.

9.2. Planned dissemination activities

Planned dissemination activities upon completion of Phase 1 and award of Phase 2 will include:

- Presentation of findings to BEIS;
- Locogen Press Release for report launch;
- Social media campaign, including LinkedIn;
- Joint public webinar with all project partners;
- Locogen webinar with distilleries – Working through members of the SWA and the Institute of Brewers and Distillers. Targeting distillery owners, developers, operators and investors to attend and share the knowledge and learn how they too can benefit from the carbon and financial savings;
- Individual conversations with distilleries and other industry operators;
- Benbecula Distillery will use their own marketing to publicise the transition to a low/zero carbon distillery and promote this in their products. The technology will be showcased on tours and website space will be dedicated to the zero carbon solution; and
- Promotion of report and findings to both technical and industry press:
    - Scottish Enterprise & Scottish Renewables;
    - ENA Energy Networks Association;
    - Industry publications;
    - Utility Week & IET magazine; and
    - Brewer and Distiller International magazine, the trade publication of the Institute of Brewing and Distilling.

Locogen's Managing Director, Andrew Lyle, is acting chair of Scottish Renewables and Locogen are therefore excellently placed to contact the wider renewables industry to accelerate the uptake of low carbon solutions such as the GSHTES to the decarbonisation of the distilling sector and wider industrial processes. Lumenion GmbH is a member of the Renewable Energy Association (REA). It has been agreed that this distillery related initiative and follow up initiatives with other industries get full access to the various platforms provided by the REA. Access to these member organisations will allow for dissemination across the whole supply chain, from manufacturers to developers and industry producers of goods.

Locogen, Lumenion GmbH and Flexitricity are all active in a number of social media channels such as; LinkedIn, Twitter, Facebook and will share and discuss the various findings there.

10. Conclusions

This feasibility study assessed the opportunity for distilleries to use an innovative high temperature and flexible heat store to provide a pathway to decarbonisation. The technical and financial feasibility of installing the GSHTES at a new build distillery was investigated and compared against a business as usual scenario of using fuel oil. The project used Benbecula Distillery as a test case, which is at the pre-construction stage.

Benbecula Distillery is a new build distillery in Benbecula, North Uist at the pre-construction stage. The local electricity grid is highly constrained, and installation of renewable energy generation is severely limited as a result. This is due to a current excess of renewable generation from existing operational wind sites and lack of matching demand. The GSHTES can operate flexibly to consume power when it is cheap, which coincides with periods of excess renewable generation. Thereby resulting in a low carbon and cost-effective option for providing the distillery with energy. The GSHTES also therefore alleviates strain on the grid by helping to balance supply and demand and also enabling greater penetration of renewable generation onto the grid as well as development of new generation.

A modelling exercise was conducted to forecast the lowest expected annual energy costs when optimising grid import of the GSHTES. It was found that substantial savings could be made by optimising the GSHTES through an aggregator as opposed to importing electricity following an instantaneous demand profile. However, the overall running costs were found to still be greater than the counterfactual business as usual case of using fuel oil. This analysis confirms that government policy is required to offer monetary reward for installation and use of a low carbon heating system and that fossil fuel alternatives need to be charged based on carbon emissions for there to be a parity in price and allow low carbon heating solutions to be competitive.

The GSHTES solution offers many significant benefits compared to business as usual. The project is calculated to save 748 tCO_2 per year and over 23,000 tCO_2 through a project operation of 25 years. There is a carbon emissions saving of 15.5 $kgCO_2$/£ of BEIS money spent and of 2.1 $kgCO_2$/LOA produced. This calculation does not account for the high renewables penetration on the local grid and the likelihood that the cheapest electricity prices will coincide with excess renewable generation and can therefore be considered conservative.

Many distilleries are located in remote locations with poor grid infrastructure but with excess renewable generation nearby. The GSHTES helps to balance the local grid and will reduce the necessity for installed renewable energy assets to be curtailed and increase the penetration of renewable power onto the grid. Additionally, strengthening the grid in this way will support an increase in installed capacity of renewables onto the grid. The GSHTES offers an elegant solution to displace fossil fuels by simple integration with existing distilleries. The GSHTES can be housed outside a boiler room and can be easily integrated with the existing steam system to deliver required heat. For distilleries running off electricity already, there is an immediate cost saving benefit of installing the GSHTES.

Lumenion's business plan is to add value to the local supply chain by manufacturing the GHSTES as close to the place of installation as possible. Manufacturers have been engaged with in detail for this project and delivery and installation can be provided by the same companies.

The modular design of the store allows for ease of scalability across sizing and demands. This allows the GSHTES to be directly applicable to other industries that use process heat such as food, rubber and plastic, paper and printing, vehicle production, metal and chemical processing. With industry accounting for 24% of UK heat use, and process heat responsible for 75% of that, the GSHTES has the potential to make a very significant impact on the UK's carbon emissions and in reaching the Net Zero 2050 target.


DISTILLERY