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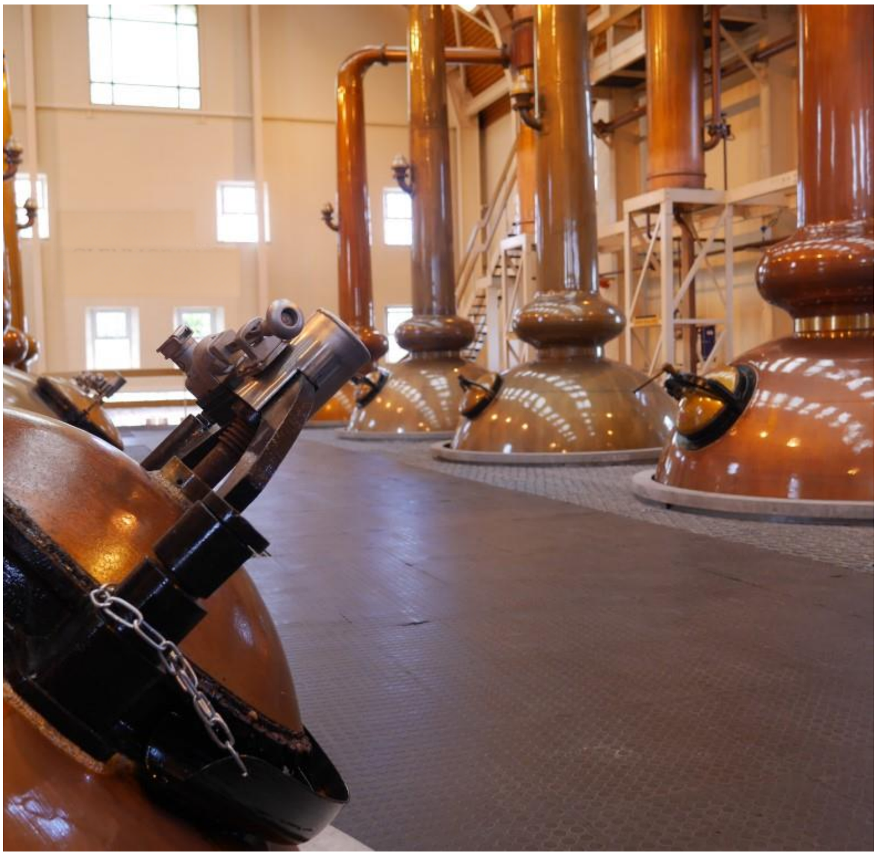

A Large-Scale Phase Change Material Thermal Store

Green Distilleries , Ref: GD147

ABSTRACT: Sunamp, along with project partner, Heriot-Watt University has demonstrated how high temperature thermal stores offer distilleries, both old and new, a safe and resilient pathway to adopting low carbon renewable technology as their main method of heat generation enabling the route to net-zero whisky.

Sunamp Ltd

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Title

A Large-Scale Phase Change Material Thermal Store

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Authors

Jamie Hillis

William Edrich

Sandy Gataora

Email

Jamie.Hillis@Sunamp.com

Number

01875 610001

Address

Macmerry Business Park, 1 Satellite Park, Tranent EH33 1RY

Acknowledgement

- **Dr John Andresen, Research Centre for Carbon Solutions (RCCS), Heriot Watt University**. John is an Associate Professor at Heriot-Watt University and Associate Director of Low-Carbon Systems within the Research Centre for Carbon Solutions. His main expertise involves systems integration and decarbonisation opportunities, sustainable fuels, optimisation of combined energy and water savings and life cycle analysis (LCA)
- **Dr Dawn Maskell**, The International Centre for Brewing and Distilling (ICBD) Dawn is an Associate Professor at Heriot-Watt University and Director of the International Centre for Brewing and Distilling. She works in process improvement for the alcoholic beverage industries.
- **Dr David Jenkins** is an Associate Professor leading the Urban Energy Research Group within the Institute of Sustainable Building Design. He works in areas of built environment energy modelling, building energy compliance, and energy system analysis. **Dr Peter McCallum** and **Dr Paraskevi Vatougiou** also work in this group, and are co-authors of this report.
- **Dr Wolf-Gerrit Früh** is an Associate Professor in the Institute of Mechanical, Process and Energy Engineering at Heriot-Watt University. He has expertise in Renewable Energy, ranging from resource assessment, systems design and systems integration including optimisation and nonlinear prediction.

Contents

Executive Summary

This report describes a Sunamp and Heriot-Watt University feasibility study as part of Phase 1 of the BEIS Green Distilleries competition. Sunamp's high temperature thermal storage unit is demonstrated as a technology to support the development of fuel-switch enabling technologies in the distilleries sector, adopting Phase-Change Material to enhance onsite thermal storage and provide additional flexibility and functionality for onsite renewable solutions.

This study will show that that in a small-scale demonstration site a 5kW PV coupled with 20kWh of storage where the solution will have a rapid payback time from savings on electricity and could pave the way for a net zero carbon distillery. In addition, the case study shows that this technology is scalable to MWh of storage linked to MW renewable energy generation capacity. The report also provides context and background in terms of the technology and policy drivers currently providing challenges and opportunities to this sector.

1. Introduction & objectives

1.1 Green Distilleries – Introduction

The challenge of decarbonising varied industrial sectors in the UK is vast. In particular, the non-homogeneous operations of different industries require tailored solutions to specific processes, making generic rules-of-thumb and benchmarks very difficult to apply. To provide context to this challenge, and a direction forward, the following report documents: the policy landscape faced by this sector; the technical challenges (and opportunities) that can be identified; a workable and scalable case-study of onsite generation with thermal storage as applied to the distillation process; and, by considering wider, future energy systems perspectives, a justification for how solutions identified here can have wider traction across the industry.

1.2 Energy-intensive industries

The UK industrial sector accounts for around 16% of the total national energy consumption with the most Energy-Intensive Industries (EIIs) involving the production of chemical and pharmaceuticals; food and drink; cement; paper and pulp; glass; iron and steel; ceramics; and oil and gas refining. Focusing on each of the eight sectors separately, suitable decarbonisation roadmaps were developed by the Department of Business and Industrial Strategy (BEIS, 2015), which were then evaluated to produce a Scottish focused assessment (Lenaghan and Mill, 2015). Nevertheless, the developed roadmaps refer to the pre-June 2019 UK's target of 80% emissions cut by 2050, thus requiring new pathways to be explored in order for EIIs (and the entire industrial sector) to be on track for the UK's net zero emissions commitment.

1.3 Distilling industry

Within the Scottish context, the Scotch whisky industry, consisting one of the most energy-intensive subsectors of the national "food and drink" industry (Scottish Government, 2020), has carried out substantial work so far to explore decarbonisation solutions and develop its individual net zero pathway. Currently, the production of Scotch whisky is estimated to be around seven times more energy-intensive than that of gin; the specific energy consumption for gin ranges between 1.7-2.3 kWh/litre, while this is between 12.7-13.9 kWh/litre for whisky (EMEC, 2019). In 2018, the total emissions resulting from whisky production within the UK was estimated around 530 ktCO_2e (Carruthers, 2020).

The Scotch Whisky Association (SWA) launched its first environmental strategy in 2009 setting targets for fuel-switching, energy efficiency, water efficiency, waste management and packaging. The most recent progress report of the Scotch Whisky Industry Environmental Strategy mentions that the industry went beyond its initial 2020 non-fossil fuel target in 2018, with 21% of the industry's energy use coming from non-fossil fuels, as opposed to almost 3% in 2008. More work is certainly needed to be done in the area of energy efficiency in order for the industry to reach its 2020 target of 7.6% energy efficiency improvement since 2008 (in 2018, energy efficiency improvement in distillery and maturation operations only amounts to 3% since 2008) (SWA, 2020).

The Scotch whisky industry is working to achieve net zero emissions by 2040, with this including all operations from maltings production to distillation, maturation, blending, bottling and warehousing. The recent work of Ricardo Energy & Environment consultancy (committed for the SWA) reviews the current environment strategy of the Scotch whisky industry and explores different fuel-switching scenarios, the scenarios combining anaerobic digestion, hydrogen, biomass and high-temperature-heat-pumps to provide a route to net zero emissions by 2045 (Ricardo Energy & Environment, 2020).

1.4 Heat generation processes

The generation of heat required for malting and distillation process is the main source of emissions within a distilling industry; heat requirement is met by raising steam and this, in most cases, is achieved through the combustion of fossil fuels or biomass. Using data provided by the SWA, it is estimated that around 85% of fuel consumption within the Scotch whisky industry is used for heat generation, while more than 90% of this heat is associated with distillation activities (Ricardo Energy & Environment, 2020). The same data suggest that 75% of the Scotch whisky industry's heating requirement is produced by fossil fuels, 17% from electricity (10% is grid electricity and the rest is provided through green tariffs and on-site generation) and 8% form bio-energy. Natural gas is the dominant fuel used for heat generation in sites that are connected to the grid, while distilleries located in some Scottish islands typical meet their heating needs with oil-fired boilers.

1.5 Decarbonising distilling

Given the context of the respective 2045 and 2050 carbon reduction targets of the Scottish and UK Governments, SWA's commitment for zero emissions by 2040 necessitates one, or both, of the following: some degree of on-site, community or cooperative renewable generation across its members, although not necessarily at every site; a commitment to specifically purchase 100% renewable electricity from the grid (likewise for biofuel, where required). Distilleries must therefore act above and beyond the decarbonisation of grid supply.

Even if SWA members and other distillers had more relaxed net-zero CO_2 targets, in-line with those of the Governments', significant barriers would still exist around the use of fossil fuels for process heat. There are two distinct challenges that must be delineated and addressed under separate discussions:

1.5.1 Fuel switching

In the case of switching to electrified heat, the main barrier is that this transition is not feasible without careful consideration of the type of heat generating plant, and the introduction of storage for actively managing the power drawn from the grid. This issue is exacerbated by the rural and island settings of many distilleries although this is also an opportunity as introduction of renewables can be technically easier than in urban areas and the cost counter-factual is oil and not gas. In addition increasing demand that can be flexibly controlled can assist grid management.

1.5.2 On-site generation and grid storage

This aspect comes with separate challenges around planning consents, DNO grid-connection permissions (or on-site active management systems for off-grid systems), space and infrastructure, and additional capital and operational costs. Including renewables will help advance CO_2 emission reductions of a given site beyond that of the grid. There are, however, compelling alternatives to on-site renewables, including community energy schemes, heat networks with 3rd-party customers, Virtual Power Plants (VPPs), and cooperative renewable energy schemes between groups of distilleries (such as [8]).

1.6 The role of storage

With respect to the challenges identified above, the integration of energy storage on a distillery site introduces four opportunities:

1. The peak power drawn from the grid can be suppressed and actively managed, decoupling industrial process-led consumption patterns from grid imports, which vary in terms of cost and CO_2 emissions throughout the day.
2. The industrial process-led consumption patterns can also be decoupled from intermittent renewable energy supply, whether from on-site plant or community/cooperative schemes.
3. Where PCM-based heat batteries are used, thermal plant capacity may be reduced considerably, allowing for reduced capital and operational costs, the potential for operational optimisation, and a reduction in plant space.
4. In batch processing production, the storage can significantly improve the in use efficiency of the heat source because it will not be necessary to switch on the heat source for each production batch. There is scope for reducing the batch processing time because heat will be available instantaneously from storage device.

To understand the wider value of storage, both for industrial organisations and the wider electricity network, a separate review has also been conducted by the project team to highlight how the technology being tested by this feasibility study will play an important role for future low-carbon energy systems. From the perspective of the electricity network, this review illustrates the role of storage for applications involving grid flexibility services and time-of-use tariffs. In relation to industrial consumers themselves, the review notes the existence of low-carbon building legislation and the challenges facing industry in meeting some of those targets.

2. Overview of project

Sunamp, along with Heriot-Watt University will demonstrate through the Green Distilleries feasibility study how phase change material (PCM) thermal storage, capable of storing heat at 118oC, offer distilleries, both old and new, a safe and resilient pathway of fuel switching to zero and low carbon renewable technology as their main method of heat generation.

Using energy and process modelling from Heriot Watt, with data from their on-campus distillery as well as industry input, we will show how a large-scale (MWh) PCM thermal store can be used to convert, capture and store renewable energy generation to be used at the point of demand, in effect decoupling generation from demand. In addition, we will demonstrate how PCM thermal storage can reduce the requirement for sizing to meet peak generation demands in operation. We will explore distilleries peak demands, duration, temperature, to determine the size of storage required to provide renewable energy derived thermal energy and the ability to peak shave.

We aimed to answer the following questions.

1. Does large scale PCM thermal storage allow us to size distillery heat generating technology to an average load rather than peak demand?

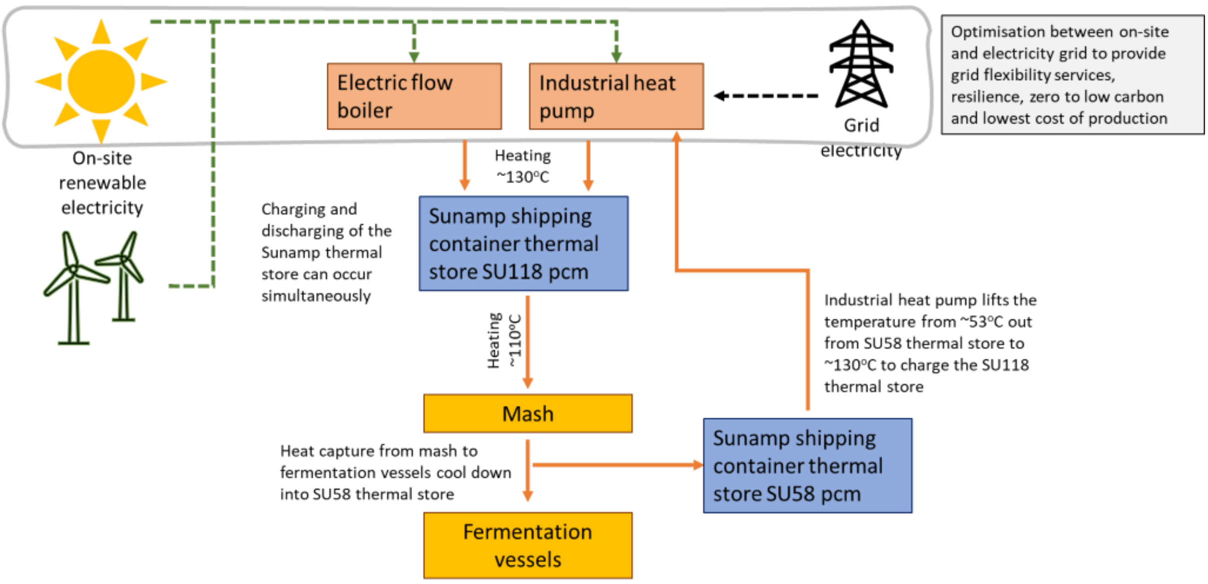
2. Consequently, does a smaller generating unit encourage the use of new zero / low carbon technology and/or enable more renewable options?

Highlighting in these questions the carbon savings available by adopting smaller generating technology and switching to renewable sources.

This study will scope the requirements needed to build and trial an industrial sized (Minimum 3MWh) PCM storage unit for Phase 2 of the Green Distilleries competition working with several charging methods, such as high temperature heat pumps, electric boilers, biomass etc that are specific to the geographic area e.g. Wind, Solar, thereby enabling holistic roll out across the UK and potentially for export to other regions across the globe.

3. Unit concept design for large scale PCM thermal storage to replace fossil fuel based distillery heat generating technology

The basic goals of introducing a PCM Thermal Energy Storage (TES) in a process is to match energy supply and demand regarding time, power and location. The selection of PCM materials depend upon the heat supply temperatures required for the process. For this application, SU118 PCM has been selected for the main TES and SU58 PCM for waste heat TES as shown in the diagram below.



The sizing of the TES will depend upon energy source (e.g. grid electricity, PV). The example scenarios are described below:

Generic TES application scenario 1: There is no overlap intime between loading the TES from supply and unloading the TES to demand as shown in Figures 1.1 and 1.2. (For example, if the night time cheaper electricity as the main energy source).

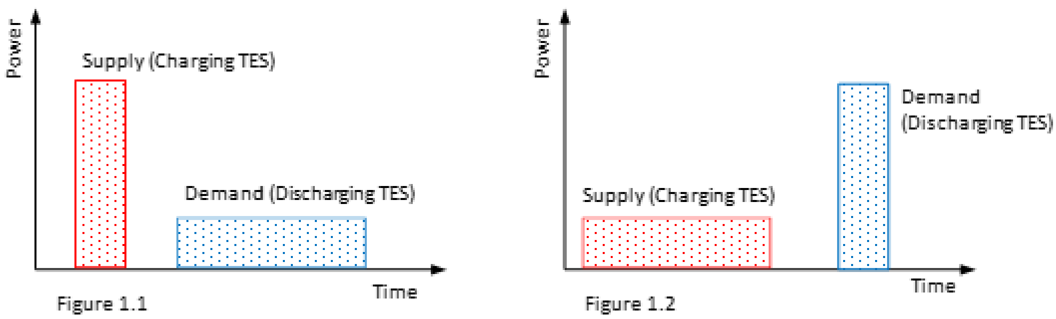


Figure 1.1 Figure 1.2

The advantage of a TES is that it can be charged at high power and discharged at low power and vice versa as shown schematically in Figures 1.1 & 1.2. In this application the TES will be sized to store all the energy required for the process during a 24h period.

Generic TES application scenario 2: There is overlap in time between loading the TES from supply and unloading the TES to demand as shown schematically in Figures 2.1 and 2.2. (For example: PV system, waste heat, low cost electricity which is available during day time hours).

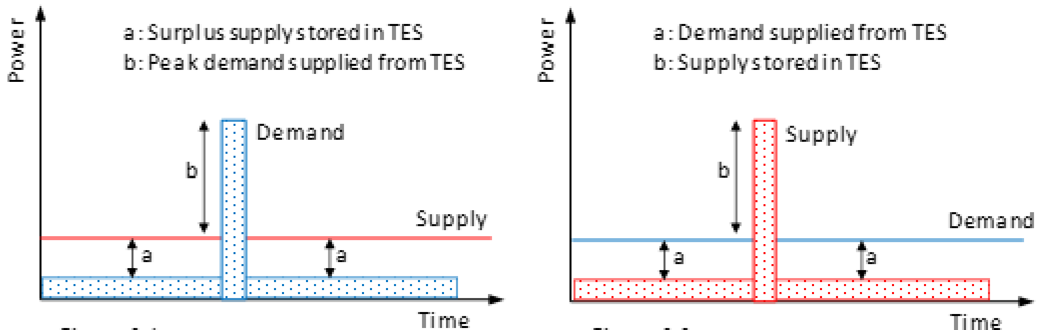


Figure 2.1 Figure 2.2

The target for sizing and designing the TES in these applications is to match different times of supply and demand including different powers for supply and demand at all times. Therefore, for sizing a TES for these applications, the following information relating the processes will be required:

a. 24h Demand power profile (Power Vs Time) for all the loads connected to TES
b. 24h Supply power profile (Power Vs Time) for all the supplies connected to TES
c. Supply and Demand selection rules for controlling the operation of TES
d. Target objectives for adding TES to the system

4. Modelling criteria for distillery heat generation need

4.1 Overview of current process.

In general and also for the pilot project at the Heriot-Watt distillery, the three main heat-consuming stages are

1.) production of the 'wash' from the grains and water in the mashing process, which involves heating the mash or wort in a 'mash tun' to typically to 72°C
2.) The first distillation of the wash in the 'wash still' with an alcohol content of around 6% ABV (alcohol by volume) into 'low wine', typically around 18% ABV.
3.) Second (and sometimes third) distillation in the 'spirit still', where the feedstock for the second distillation is a mixture of the low wine with the foreshots and feints from a previous run of the spirit still.

4.2 Where the heat loads are and why we are targeting them.

Of a typical net heat requirement of around 30 MJ per litre alcohol, the three main stages require about

- Heat for the 'mash tun': 4 MJ pLA or 13%
- Heat for the 'wash still': 20 MJ pLA or 66%
- Heat for the 'spirit still': 6 MJ pLA or 21%

Each of these heat loads are delivered at a fairly constant rate until the process is completed. Coupling the source of the heat to variable (renewable) energy sources or variable tariffs, the clear potential benefit of using thermal storage is to recharge the thermal storage when the resource is available or cheap while having full control over the heat delivery rate to the process.

This identifies integrating the thermal storage into the wash distillation as the clear target for this project. In addition, the temperature at which this heat is required is the highest, since the boiling point of the lowest-percentage alcohol is the highest.

4.3 Details of the modelling process.

Given that thermal storage separates the primary energy source in time from delivering it to the process, the heat delivery to the wash still from the thermal storage device can be modelled separately from the recharging of the storage device and the economic analysis of that recharging process

1. The heat delivery process modelling is traditional engineering analysis based on the heat and mass flow balances, starting with the heat delivered by pumping pressurised water at the output temperature from the thermal storage unit. This pressurised water system functions as a heating coil surrounded by the wash in the wash still. The heat flux into the wash is then balanced by the change in

temperature of the wash. When boiling temperature is reached the heat delivered to the fluid is transferred to the latent heat of evaporation which quantifies the production rate of the low wine.

2. For the recharging phase, the more important parameters are the energy availability or cost. Here the modelling process is to evaluate a range of scenarios against a benchmark of operating the wash still from mains electricity for a fixed but representative weekly schedule.

Scenario 1: The recharging is scheduled to exploit advantageous night-time electricity tariffs to quantify the savings from shifting electricity consumption from day tariff to night tariff.

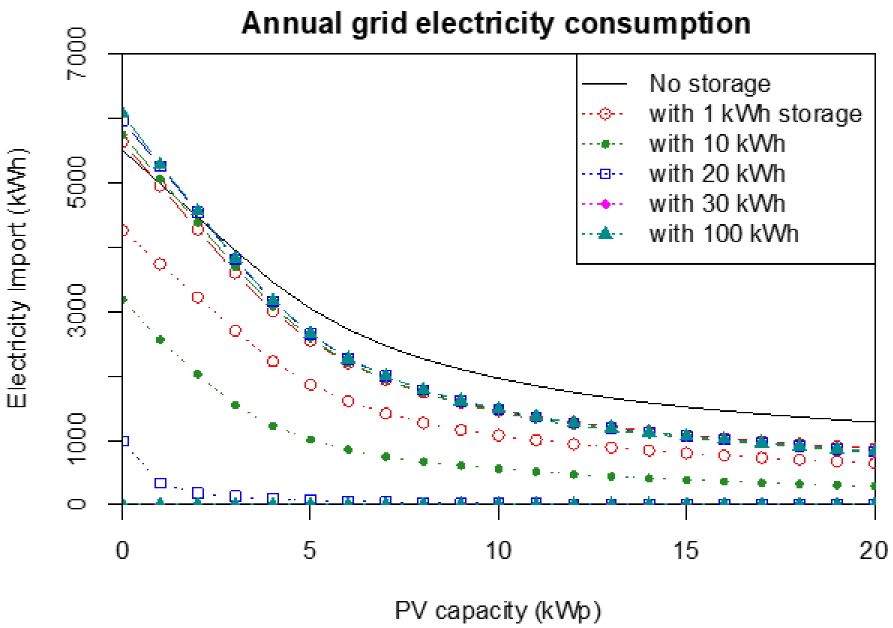
Scenario 2: the recharging is provided by or supplemented by, variable renewable energy, such as PV panels or wind turbines, a range of typical resource availabilities are used to quantify the statistics of renewable resource used to offset grid electricity or fuel consumption. Given that the resources are highly localised, the analysis will start with Edinburgh, the location of the Heriot-Watt distillery. The resource data utilise ERA5 global climate and weather data set, providing hourly data with a quarter-degree resolution. Once the model is developed, it can easily be applied to other locations worldwide.

These scenarios are the key model outputs to provide the comparisons described in the following section.

5 PCM generating unit encourage the use of new zero / low carbon technology and/or enable more renewable options:

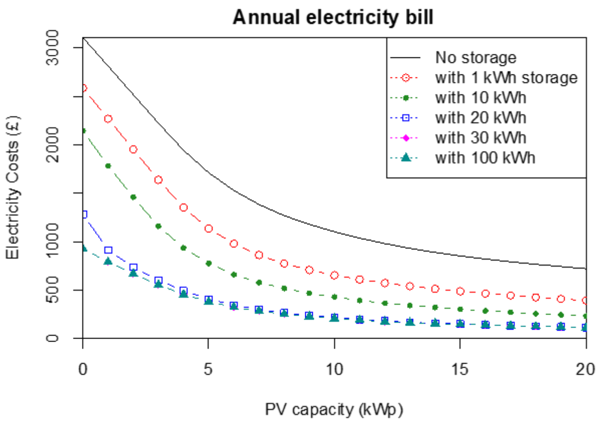
Having demonstrated a proof-of-concept of applying PCM thermal storage to the distillation process, it is also important to understand the benefits of thermal storage as a means of accommodating larger penetrations of low-carbon technology and/or fuel-switching in the distilling industry. This requires consideration of current building policy in the sector, the wider energy system context, reviewing the factors likely to impact commercialisation of such products, and how these factors will influence the design and control of distributed generation. Without accounting for these larger-scale challenges, but also exploiting the current opportunities for monetising the operational benefits of having onsite generation with thermal storage, the market in this sector will be very difficult to grow.

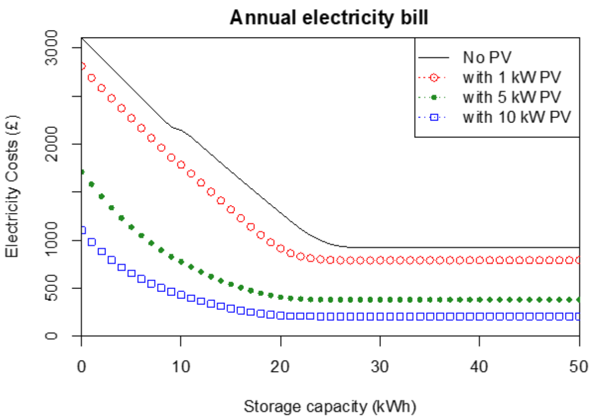
The following four scenarios were explored in this initial analysis. The reference scenario is represented by the top-left point on the solid line, with zero PV and zero storage. This shows that the assumed operation of the wash still would incur an annual consumption of 5500 kWh of grid electricity. Scenario b), of installing PV panels but not thermal storage follows the solid line. Initially, the electricity import is offset in proportion to the installed capacity, reducing to about 3500 kWh with a 4kW PV installation. Beyond this, the benefits from adding more PV panels tails off.



Scenario c), where only thermal storage but without low-carbon energy sources is installed is illustrated by the set of symbols on the left of the graph. For each storage installation, the electricity consumption is separated into that used by directly, given by the dashed line and the remainder to charge the storage element during the night. The red circles are the electricity consumption if the thermal storage has a capacity of 1 kWh, much less than the assumed consumption of 20 kWh. With a storage capacity of 10 kWh, the total electricity consumption has increased somewhat to just under 6000 kWh, which accounts for the losses incurred in charging and discharging the storage module. At the same time, the split in electricity is that about half is consumed during night times and only half during daytime hours. This illustrates the effectiveness of the thermal storage as a load-shifting device. Increasing the storage capacity to the daily consumption exploits this opportunity fully with all electricity import shifted to times of cheap electricity.

The final scenario combines thermal storage and low-carbon generation. Initially, the addition of low-carbon generation quickly outweighs the losses occurred in the use of the thermal storage. This mutual benefit is demonstrated by the steeper decline of the solid curves. However, that mutual benefit does seem to be mainly affected by the size of the PV installation and very little by the size of the thermal storage.





Converting the electricity consumption into financial savings, shown in the figures above (the left against installed PV capacity and the right against thermal storage size), the benefit from using the thermal storage becomes clearer as the overall electricity bill is now clearly reduced by both, the PV capacity and the thermal storage capacity. For the PV capacity the main benefit is exploited by an installed capacity about twice that of the power requirement for operating the still. A secondary benefit from the installed PV capacity is the occasional production of surplus PV electricity, especially in the summer months, which cannot be used for the distillation process but is available for serving in-house electricity demand or export to the grid.

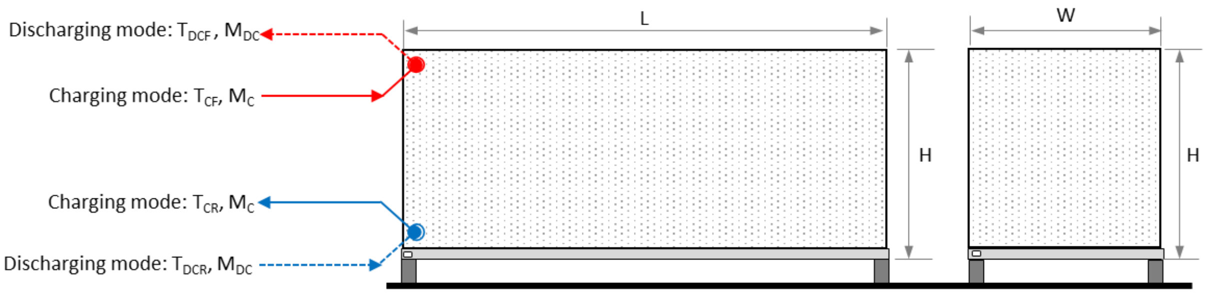
The main benefit from the thermal storage is exploited with a storage capacity to serve a day's operation. While these two benefits are expressed here as a financial benefit, it can be translated into carbon savings for the distillery, mainly from the use of low-carbon electricity, and a carbon saving for the grid system operator since the thermal storage allows them to deploy more low-carbon generation in the grid.

The modelling data indicate that an ideal demonstration site would be based on a 5 kW PV coupled with 20 kWh of storage where the storage will have a rapid payback time from savings on electricity and could pave the way for a net zero carbon distillery.

The sizing of suitable installations for other distilleries scale up directly with the volume and operating hours of their stills.

6 Thermal storage optimised unit design

The modelling work has allowed us to determine the thermal storage capacity needed to positively impact distilleries of various sizes. Concept of data modelling to feed directly into the sizing of the Heat Exchanger for the MWh unit concept as shown in the drawing below.



We anticipate the thermal storage to be available in 10, 20 and 40ft shipping container modules. These units will follow a similar configuration and will have the ability to be used in multiples. This will allow the storage to be easily retrofitted into growing plants.

Scaling storage capacities of Sunamp heat batteries

Currently Sunamp manufacture heat batteries with storage capacities ranging from 3kWh to 12kWh for the domestic market and an 80kWh model for the commercial and industrial applications. All these batteries use the same basic scalable technologies and construction.

The heat battery consists of an insulated container which contains PCM and heat exchanger. Therefore, for example if a 160kWh heat battery is required, then 80kWh design can be linearly scaled for the trial prototypes which can then be optimised for production models. Sunamp have successfully used this approach for building their current product range.

The Sunamp design & development process for a container size 3 – 4MWh heat battery with SU118 PCM is outlined below:

a. Sunamp will agree the outline performance specification for the container size heat battery (TES) with end user which will include:
    - Operating temperatures and pressures
    - Location, weather, and ambient conditions
    - TES Charging and discharging powers.
    - Safety and risk assessments
    - Transport and site requirements
b. Sunamp has already tested SU118 material in UniQ 80 heat battery for performance and material compatibility studies have been carried out by the Sunamp Chemistry team. We will use this information to specify the heat exchanger and heat battery enclosure materials for the large heat battery.

c. Sunamp have PCM heat exchanger modelling tools and real life heat transfer data and this information will be used to design and specify the heat exchangers to meet the design specifications.
d. Where and when necessary, Sunamp will use external consultants and subcontractors to deliver the container size TES.

7 Phase 2 implementation.

A number of prospective partners have been identified and the search continues for distilleries and companies who can be involved in collaboration efforts. Each of these partners will play a significant role in the development of Phase 2, which we break down into 3 stages;

Stage 1 Heriot Watt University demo: To illustrate the effectiveness of the thermal storage operating either alongside low-carbon energy sources or using grid electricity, a generic operating regime of operating the Wash still at Heriot-Watt every working day from 10am until 4pm was assumed as a simplified benchmark. This results in an electricity consumption of about 20 kWh on a working day. Alongside this, a tiered tariff was taken to evaluate the economic benefits of the storage. This illustration only shows the benefits from the systems but not the associated costs with installing such systems.

The figure below indicates the ease of concept demonstration project at the Heriot Watt distillery site. Using 20Kwh storage unit, it could be deployed immediately on Phase 2 successfully. This will enable industry a “seeing is believing” validation of the concept which will make the conservative industry comfortable towards implementing the net zero technology.

On approval of Phase 2 Sunamp will produce our UniQ80 store for the Heriot Watt demo site. This will be installed, commissioned and operational by Quarter 3 of 2021.

Stage 2 Pilot site: 4MWh storage concept to be deployed into testing facility for further analysis by an Industry leader. Discussions with the site operations team are scheduled between March and May to keep momentum of the project, build a requirement brief, and ensure unit prototype build in the first 3-6 months of Phase 2. We will seek to utilise the learnings of the feasibility study and build on the concept of sizing the storage to a daily demand, understanding if this is an optimal solution when working at scale.

Sunamp will provide technical assistance in the operation of the thermal store to ensure the full effects are being utilised.

Site studies and operational meetings are expected to take place in the initial months of Phase 2, the work to build the 4MWh storage unit is expected to begin in the fall of 2021. Commissioning work will take place in the first quarter of 2022.

Stage 3 Commercial unit: Install and commission at a working distillery. Contacts ongoing with several independent distilleries and larger corporations are ongoing. This part of the project will take the learnings of the concept and demonstration site to determine the storage capacity that will deliver the biggest advantage to the distillery. By structuring our Phase 2 bid as a progression we reach our third stage in a position where our unit has been tested in controlled environments in larger capacities. By having the unit pilot at a testing facility, we will be able to mimic various operational details. Learning of which will feed directly into the site selection of the final trial site.

8 Conclusion.

This report set out to investigate how a high temperature, large scale thermal storage unit could be used by distilleries to enable fuel switching to low carbon or zero emission technology.

The Sunamp and Heriot-Watt University feasibility study, as part of Phase 1 of the BEIS Green Distilleries competition, sought to answer our questions.

1.Does large scale PCM thermal storage allow us to size distillery heat generating technology to an average load rather than peak demand?

2. Consequently, does a smaller generating unit encourage the use of new zero / low carbon technology and/or enable more renewable options?

Through the work of our feasibility study, we have answered the questions of how Sunamp thermal storage can reduce the size of heat generating technology and improve overall efficiency in a real case scenario. As well as showing how the storage substantially improves the impact of having onsite renewables.

Our study shows that that an ideal demonstration site would be based on a 5kw PV coupled with 20Kwh of storage where the storage will have a rapid payback time from savings on electricity and could pave the way for a net zero carbon distillery.

The modelling work carried out at Heriot Watt shows a dramatic cost benefit of adopting a smaller 5kW PV system with Storage rather than opting for a larger 10 or 15kW system. By scaling this concept, we can expect to make real savings to distilleries CAPEX and OPEX.

We intend to build on these findings in Phase 2 through the installation of several demonstration sites to prove that our conclusions are applicable at scale and that Phase Change Material Thermal Storage can be an important enabling technology that will allow distilleries to switch to low carbon heat generating technologies. These findings have been significant and holds tremendous potential for the industry.

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