HIGHLAND PARK GREENSTILLS DEMONSTRATOR

GD137 Phase 1 Report

Abstract

Led by Edrington alongside consultants Allen Associates.

High Temperature Heat Pumps (HTHP) have the potential to convert low-grade heat into steam for use in a variety of distillery applications. They have the benefit of improving overall energy efficiency as well as enabling fuel switching to renewable electricity from fossil fuels.

Edrington aim to investigate this technology on an industrial scale, at Highland Park distillery and maltings in Kirkwall. The project will develop an innovative stillhouse heat recovery system with a HTHP at its core. The steam produced will be used to heat the malt drying kilns, replacing coke as the fuel source for this process and eliminating the associated carbon emissions.

Contents

Glossary

BFD – Block Flow Diagram	LOPA – Layers of Protection Analysis
CDM – Construction, Design and Management	NMS – New Make Spirit
CHP – Combined Heat & Power	NPV – Net Present Value
COP – Coefficient of Performance	MVR – Mechanical Vapour Recompression
HAZOP – Hazard and Operability Study	PFD – Process Flow Diagram
HTHP – High Temperature Heat Pump	TVR – Thermal Vapour Recompression

1. Executive Summary

In order to decarbonise the whisky industry fuel switching technologies need to be implemented at scale, along with significant improvements in energy efficiency. To contribute to this strategy, the aims of this project are to:

- Remove the coke currently used in the maltings kilns at Highland Park Distillery
- Switch the fuel source to renewable electricity
- Reduce the overall input energy required for the site by recovering input heat

The GreenStills proposal is to install an innovative stillhouse heat recovery system with a High Temperature Heat Pump at its core, which will convert recovered heat into low pressure steam. From modelling the existing process, it has been shown that converting one wash still condenser could provide 199 GJ of recovered energy per week. Combined with an electrical input of 131 GJ a HTHP was specified to convert this into 323 GJ of heat output for the process. This would offset the full energy demand from the maltings kilns, as well as 13% of the kerosene used in the distillery package boilers.

The demonstrator system would reduce the overall site energy demand by 13%, and CO_2 emissions by 23%, assuming renewable electricity is used to run the heat pump. This saving means that despite switching to a more expensive fuel source the demonstrator will not significantly increase site energy costs (within 1% of current).

The total capex required for the demonstrator is estimated at £2,982,000. The NPV over the project lifespan, assumed to be 25 years, is -£2,747,000 which highlights the value of public funding to the feasibility of this project.

The system can be readily expanded at Highland Park by converting the remaining 3 stills to heat recovery, providing more hot water to the system which can be converted to steam via additional heat pumps. Furthermore, it can be rolled out and applied at most whisky distillery sites; heat pumps have been projected to contribute a reduction of up to 100,470 tCO2e/year across the industry by 2045.

Commercialisation of the GreenStills system will act as an enabler for other Net Zero fuel sources. Lowering the overall energy input for the distillery will help to reduce the risk associated with switching any remaining requirement to alternative sources. This could be of benefit to hydrogen technology, CHP generation and fuel cell technology, with applications across the food & drink industry and beyond. GreenStills can play a significant role in securing the longevity and sustainability of the UK distilling sector, deriving benefit both for distillers and the wider economy.

2. Project Overview

The Highland Park site in Kirkwall comprises a traditional floor maltings, a four still malt distillery, a visitor centre and extensive storage warehousing. The maltings typically processes four batches of malted barley per week, supplying a portion of the feedstock for the distillery. Current distillery spirit production runs over a 7-day week producing approximately 2.5M litres of alcohol per annum.

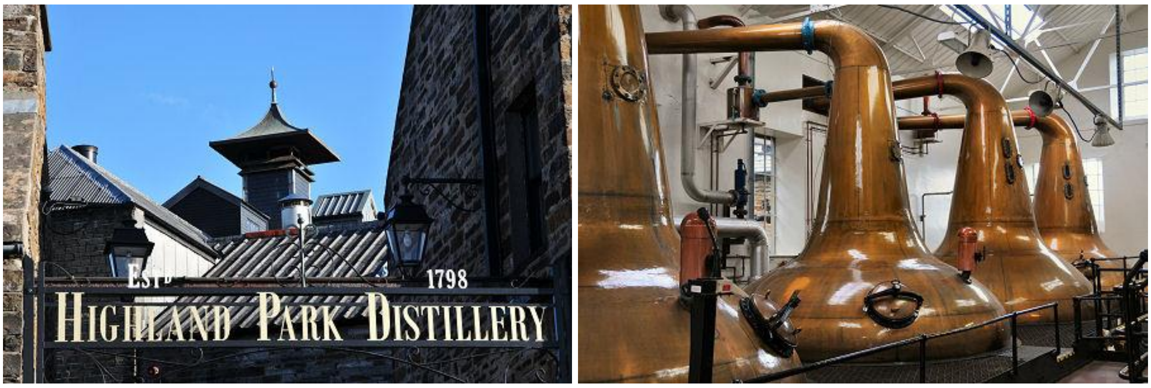

Figure 1: Highland Park pagoda roofs on the maltings kilns (L) and stillhouse (R)

The most energy intensive step of the malting process is kilning, where germination of the grain is halted by reducing its moisture content from around 45%w/w to under 5%.

The kilns at Highland Park are very traditional, a schematic is shown in Figure 2. Air is heated directly by burning coking coal and peat in the "fire box". The peat smoke generated during this process contributes an important component to the final product. The coke acts predominantly as a heat source.

The warm air from the fire rises through the malt which is loaded on a perforated floor. Drying progress is monitored by temperature probes above and below the bed; the temperature drop observed indicates the drying rate. A turning arm ensures even drying of the malt throughout the course of the batch. The humid air is drawn out of the kiln through a fan in the roof and into the surroundings.

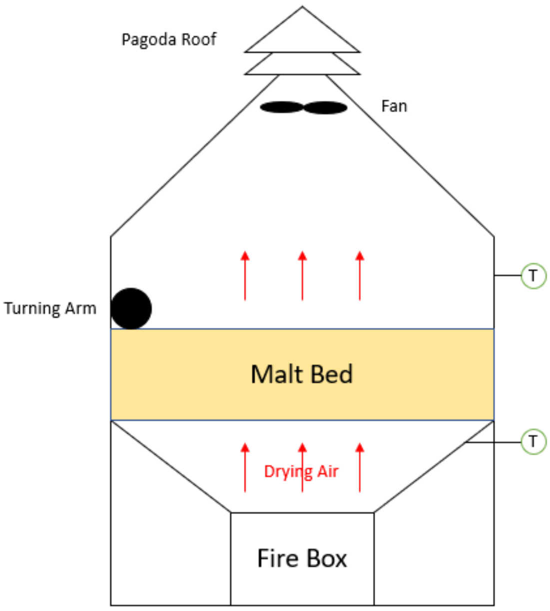

***Figure 2:** Schematic of malt drying kilns at Highland Park*

The most energy intensive step of the distillery process is the batch distillation of ethanol and water in the copper pot stills. The stills are heated via a steam heat exchanger. The steam is raised via a package boiler which is fuelled by kerosene. As well as the stillhouse the process steam feeds a range of other heating duties throughout the distillery.

The current fuel usage at Highland Park is summarised in Table 1 below:

Table 1: Highland Park Energy Use and CO_2 emissions

Fuel	Annual Energy as % of Site	Annual CO_2 as % of Site
Kerosene	85%	83%
Coke	8%	11%
Peat	2%	1%
Electricity	5%	5%

A major cause of energy inefficiency within a malt distillery is the large quantity of low-grade heat which is produced when condensing the vapour products of the distillation process.

Adjacent to each pot still is a shell and tube condenser which carries out this operation, a schematic is shown in Figure 3. On the shell side, the vapour is condensed into a liquid and cooled to the desired temperature for the next stage of the process. On the tube side cooling water is introduced at ambient temperature, which increases as heat is transferred from the vapour stream.

This process uses hundreds of thousands of litres of water per day. There are some limited opportunities for utilising this heated water within the distillery, but the majority is sent to a cooling tower to lower its temperature and meet discharge consent limits.

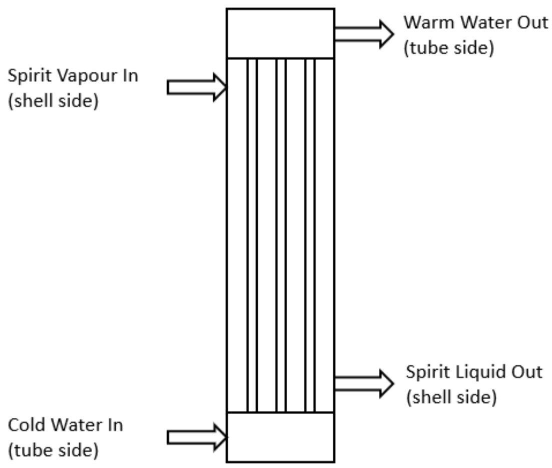

Figure 3: Shell and tube condenser in Stillhouse

The processes described above are typical for many sites of Highland Parks size. In order to decarbonise the sector fuel switching technologies need to be implemented at scale, along with significant improvements in energy efficiency. To contribute to this strategy, the aims of this project are to:

- Remove the coke currently used in the maltings kilns at Highland Park
- Switch the fuel source to renewable electricity
- Reduce the overall input energy required for the site by recovering input heat

3. Modelling Results and Conclusions

The intention of this project is to integrate the energy streams of the processes described in Section 2 to reduce overall energy consumption and assist with fuel switching transition at Highland Park. The first step in this process was to model the energy and mass flows associated with the kiln and the still house.

Figure 4 shows a Block Flow Diagram of the current Highland Park Distillery still house and the separate malt drying kilns. The two processes are energy intensive and any heat or energy dissipated is simply lost by removal of heat through the cooling tower, or through the hot air vented at the top of the kiln pagoda.

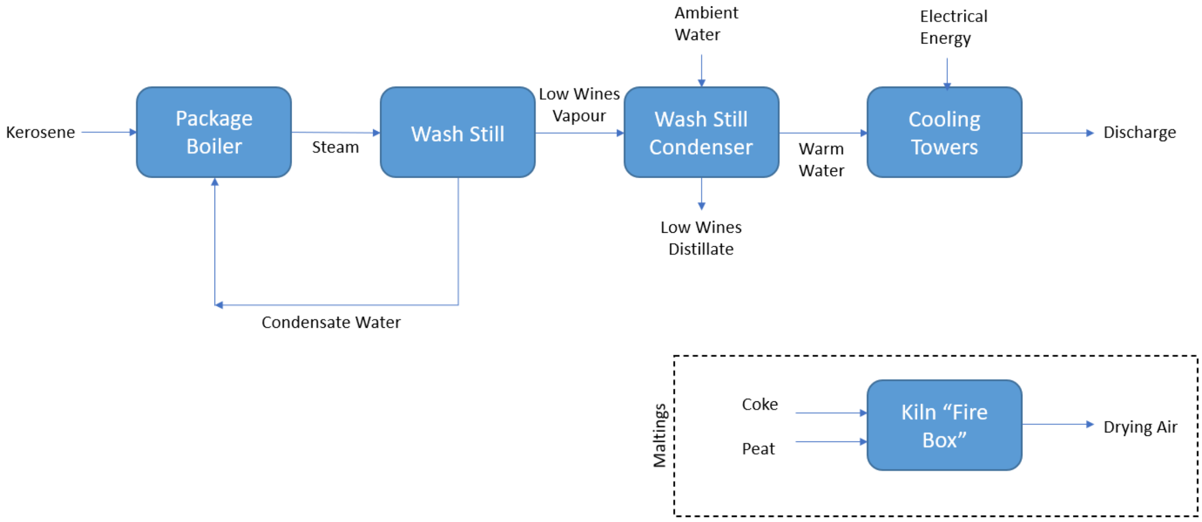

Figure 4: BFD of existing process at Highland Park

3.1. Kiln Energy Requirement

The energy requirement for kiln heating was established by three methods:

- Coke consumption per kiln run
- Energy balance over kiln air flow
- Consulting specialist kiln heating design and supply company

Coke Consumption

This figure was calculated from the total amount of coke consumed over approximately two years divided by the number of kiln runs for the same period. The amount of coke used on any given batch is subject to variation due to environmental conditions and the manual nature of the process. As such an average was obtained to give a representative value. From site operating data:

- Total coke consumed = 281 tonnes
- No. of kiln runs = 217 kiln runs
- Coke per run = 1.3 tonnes

- Calorific value of coke = 29,800 MJ/tonne
- Energy used per kiln run = 38,740 MJ

It should be noted that during the kiln run the temperature is controlled by venting some of the hot air into the surroundings from below the malt bed. Consequently, the kiln energy derived from the coke consumed will be higher than the actual energy requirement to dry the grain.

Energy Balance over Kiln Air

The air flow through the kiln can be estimated from the induced draft fan data. The fan curve was available, and it was understood that the fan runs at a speed of ~60% of maximum. Using these values, the air flow through the bed could be estimated.

The ambient air temperature was taken as reasonable worst case and the supply temperature was taken from kiln operating data.

From site operating data:

- Estimated air flow = 13,530 kg/hr
- Ambient air temperature = 0 °C (design case)
- Kiln bed on temperature = 65 °C (average)
- Running time = 35 hours
- Energy used per kiln run = 30,780 MJ

Kiln Energy Confirmation

In order to verify these calculations a specialist kiln designer was approached to provide an estimated energy requirement for the process at Highland Park. Don Valley Engineering were selected based on their extensive experience in this area and established working relationships with the site from previous proposals to modify the kilns. Based on the information provided a value of 32,896 MJ was supplied, which compares well with the above figure.

It was concluded to move forward with the requirement of 32,896 MJ for a kiln batch. The number is slightly higher than the theoretical value, allowing for potential efficiency losses. The sizing basis for the kiln heating system is therefore as follows:

- Energy consumption = 32,896 MJ
- Typical operating hours = 35 hours
- Average kiln duty = 261 kW
- No. of kiln runs = 4 per week
- Weekly kiln energy requirement = 131,584 MJ

3.2. Energy Available from Stillhouse

The energy available to the system from the still condensers was calculated from a still house energy balance. The balance used is proven for multiple malt distilleries.

The heat available for recovery to the system is the latent heat of condensation of the distillate (e.g. low wines). The heat from sub-cooling is not suitable as it is not at a high enough temperature. However sub-cooling is minimal with the latent heat being ~95% of the cooling duty.

From the balance the following was confirmed:

- Latent heat of condensation from one wash still run = 10,520 MJ
- Assumed overall efficiency = 90%
- Energy available from one wash still run = 9,468 MJ
- Number of wash still runs per week = 21 per still (conservative estimate)
- Total heat available from one wash still per week = 198,828 MJ

3.3. Conclusions

From the results of this modelling three initial conclusions can be drawn:

- All of the coke used for kiln heating can be displaced by recovered heat.
- Converting just one of the sites two wash stills to heat recovery will provide sufficient energy to cover the full requirement of kiln heating (199 GJ vs 132 GJ).
- There is excess recovered heat available (67 GJ) for other processes in the distillery. The study scope will therefore increase to supply recovered heat to other points of use.

4. Description of the Demonstration Project

Edrington is committed to achieve Net Zero by 2030 and in doing so, contribute to the Scotch Whisky Association and UK Government's own Net Zero Pathways. Therefore, the opportunity to install a demonstrator project which enables fuel switching and enhanced energy efficiency closely aligns with the corporate strategy.

The proposal is to use an innovative Condenser Hot Water Recovery System (GreenStills) to enable low-grade, recovered heat to be converted into low pressure steam for kiln heating at Highland Park distillery. From the modelling in Section 3 it has been proven that all the coke can be displaced by recovered heat, and there will be an excess remaining that can be used elsewhere in the distillery. There are three key components to the demonstrator:

1. GreenStills System - innovative Condenser Hot Water Recovery System combined with a High Temperature Heat Pump (HTHP) to produce steam that can be used in the distillery process (e.g. kiln heating)
2. Kiln Heating System – A new, indirect kiln heating system that will use steam to dry the malted barley (replacing coke).
3. Steam Supply System – As per the modelling section steam will be supplied to the kiln heating system as well as other users in the distillery e.g. stills. Supplying to the stills will further reduce CO_2 emissions as kerosene use will be offset.

GreenStills System

The GreenStills System combines condenser hot water with a HTHP to produce low pressure steam that can be used for distillery heating duties, as shown in Figure 5. The system enables the recovered heat from the still to be "upgraded" so that it can be utilised throughout the distillery. Without the HTHP the recovered hot water would not be at a sufficiently high temperature to be used across the whole distillery, including kiln heating. The HTHP tied in with a higher temperature recovery system is vital for this system to produce steam at the correct conditions and for improved efficiency.

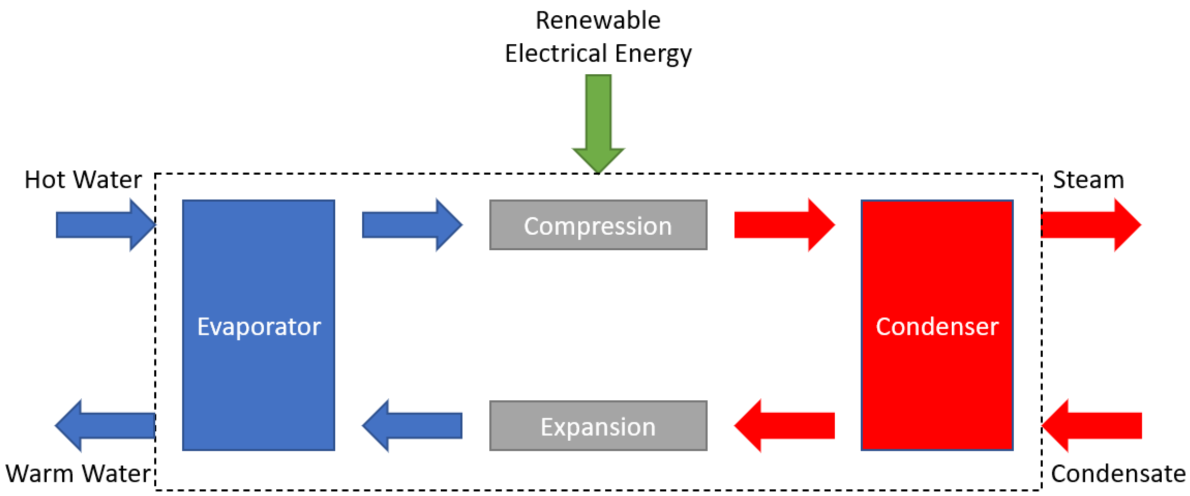

Figure 5: BFD of High Temperature Heat Pump

The efficiency of HTHPs is measured by their Coefficient of Performance (COP). In this case the COP depends on the water temperatures being supplied to/from the HTHP and the raised steam temperature and pressure. For the GreenStills system to reach a high COP it requires high water temperatures and a low steam pressure. However, the steam pressure must be balanced with what is practical for use in distillery operations.

The kilns heating system could operate at a steam pressure of 0.7 barg however this is not suitable for the other distillery users which operate at 2.5 barg. Producing steam at 0.7 barg would give a higher COP but would result in a false economy, since despite the system being more efficient, it would be of limited use throughout the distillery.

Another important factor to consider is that if steam is produced at a higher pressure and therefore a lower COP, more electricity is being consumed. However, the energy is not being lost as the electricity is being used to generate steam and the system is still recovering all the heat available from the still. In the case of Highland Park, running at a steam pressure of 2.5 barg with a slightly lower COP will allow a greater quantity of recovered energy to be used for heating processes.

HTHP suppliers Star Renewable Energy and Olvondo Technology were consulted during preparation of this design.

Kiln Heating System

The kiln heating will be modified so that the system utilises steam as opposed to coke. A new heating system will be installed on both kilns with a force draft fan, heating battery and associated flue ducting. The flue ducting will connect to the existing peating system at the kilns so that this important part of the kilning process can be integrated with the new set-up.

Don Valley Engineering were consulted during the preparation of this design.

Steam Supply System

Steam will be supplied from the GreenStills system to the kiln heating batteries and to the still house steam header, downstream of the existing pressure regulating valve. The steam will be supplied at the same pressure as the still house low pressure steam which is 2.5 barg. This ensures it can be utilised across all areas of the site.

Condensate from both the kiln heating battery and the stills will return to the existing boiler feedwater tank where it will be pumped back to the HTHP.

A Block Flow Diagram of how the demonstrator integrates with the existing process is shown in Figure 6.

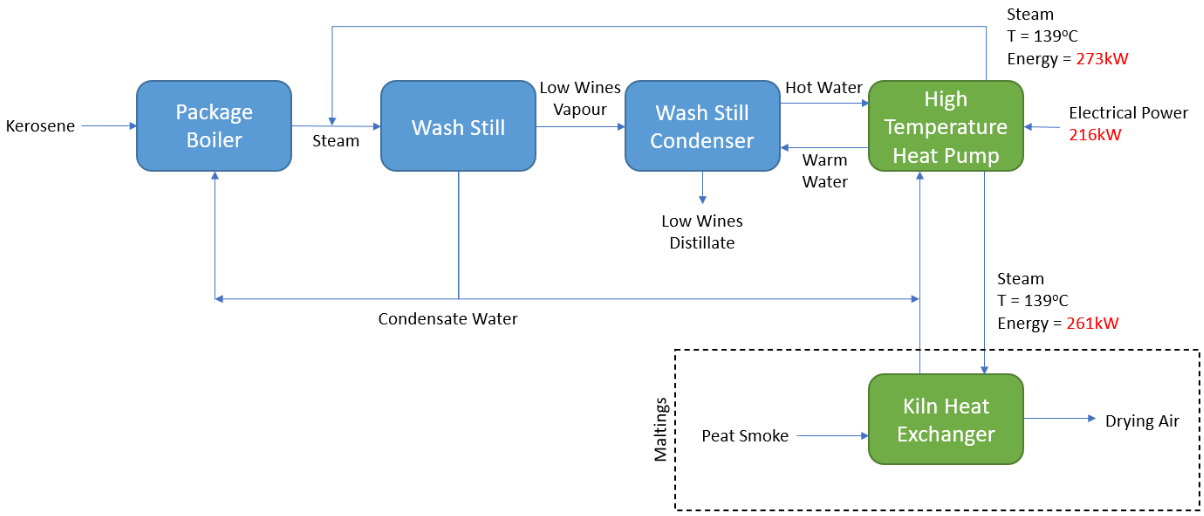

Figure 6: BFD of proposed demonstrator system at Highland Park

5. Design of the Demonstration Project

As described in Section 4 there are three key components to the demonstration project:

1. GreenStills System
2. Kiln Heating System
3. Steam Supply System

GreenStills System

The main components of the Greenstills system are as follows:

- Wash still hot water condenser
- Wash still distillate sub-cooler
- Hot water tank (60m^3)
- Warm water tank (60m^3)
- Warm water cooler
- High Temperature Heat Pump HTHP

The demonstrator project will convert one of the two Highland Park wash still condensers to a multipass condenser, suitable for recovering hot water from the distillate. While hot water recovery from wash still condensers is in place across the distilling industry, a new design will be a prerequisite to deliver the required system temperatures.

The flow of water to the condenser is controlled by flow and temperature so that the required hot water return temperature is reached. At the start of distillation there will be a “heating up” period where the water returning from the still will flow to the warm water tank as it will not be hot enough for the HTHP. As the design flowrate is met the water temperature will increase and then be diverted into the hot water tank where it is stored / buffered prior to being supplied to the HTHP. After being supplied to the HTHP where the water is cooled (transferring its energy), it is returned to the warm water tank which feeds the condenser via the warm water cooler. The warm water cooler ensures that water being supplied to the condenser is at the desired temperature to prevent condenser overheating.

Subcoolers are used in the hot water recovery design due to the higher water system temperature requirements limiting the amount of subcooling that can be achieved in the condenser. The condenser will remove all the latent heat and a subcooler will be required to cool the distillate from ~80°C to the desired spirit safe temperature. A plate and frame type subcooler is proposed for this duty and will be located in the lower stillhouse.

The GreenStills system is a closed loop where water is being heated up by the still and then cooled in the HTHP. The water tanks are required to maintain this loop as the wash still is a batch operation and will only produce hot water for approximately five hours per eight-hour shift, whereas the HTHP is a continuous operation so has a full-time demand for the water. The tanks have been sized to provide sufficient buffering capacity for the system to work on this basis.

For sizing the HTHP the following was established in Section 3:

- Total heat available from one wash still per week = 198,828 MJ

It is known that this covers the full kiln demand and there is excess heat available so this total figure will be the sizing basis for the HTHP. For HTHP specification the energy available is calculated from the cooling demand which must be specified as a running load (duty). Highland Park operates 24/7 giving 604,800 seconds of running time, thus the cooling duty for the HTHP is as follows:

- Cooling demand per week = 198,828 MJ
- Weekly running time = 604,800 seconds (24/7)
- HTHP water cooling duty = 329 kW.

As discussed in Section 4 the HTHP will supply steam to the distillery at 2.5 barg. This pressure together with the above cooling duty and required water temperatures was issued to a HTHP supplier and the following specification was proposed:

Heating side	
Heating output duty	534 kW
Hot fluid type	Water / Steam
Steam outlet pressure / temp	2.5 barg / 139°C
Cooling side	
Cooling input duty (heat from wash still)	329 kW
Cold fluid type	Water
Heat Pump COP	2.6
Heat pump electrical running load	216 kW
Heat pump standing load required	550 kW

The HTHP will recycle hot water from the wash still condenser, using electrical power to produce steam. Each unit of electricity is converted into 2.6 (COP) units of heat. Once efficiency factors are taken into account, 216 kW of electricity will generate 534 kW of steam 24/7 which will give a total weekly energy production of 323,094 MJ.

From Section 3; 131,584 MJ will be used for the kiln heating, leaving 191,510 MJ of heat for the stills. Displacing 191,510 MJ of steam used in the stills with steam from the GreenStills system will result in offsetting 13% of the energy which would otherwise be generated through burning kerosene in the existing boiler.

Kiln Heating System

The kiln air heating system is outlined in Figure 7 which shows a preliminary 3D layout.

The new kiln system has been designed to retain Highland Park's peat furnaces which deliver peat smoke to the malting bed. This was a fundamental requirement as peat smoke delivers phenol compounds which are key components in Highland Park's whisky flavour profile.

The heat exchanger (steam battery) will take in 2.5 barg (139 °C) steam from the HTHP to provide the necessary heat to warm up atmospheric air to between 60 and 85°C depending on the kiln drying stage. The warm air is delivered below the malting bed at a maximum rate of 13,500 m^3/hr through a forced draft fan.

The peat furnace will be boxed in and a duct will direct the smoke into the main air duct between the steam battery and the air suction fan. As such, the peat smoke will not be exposed to the heat of the steam battery, limiting any potential losses in phenols. The smoke inlet can also be controlled by adjusting the fan speed.

A recycle duct above the bed will enable further energy efficiency by allowing the re-use of unsaturated off-kiln air during the final stages of the drying process.

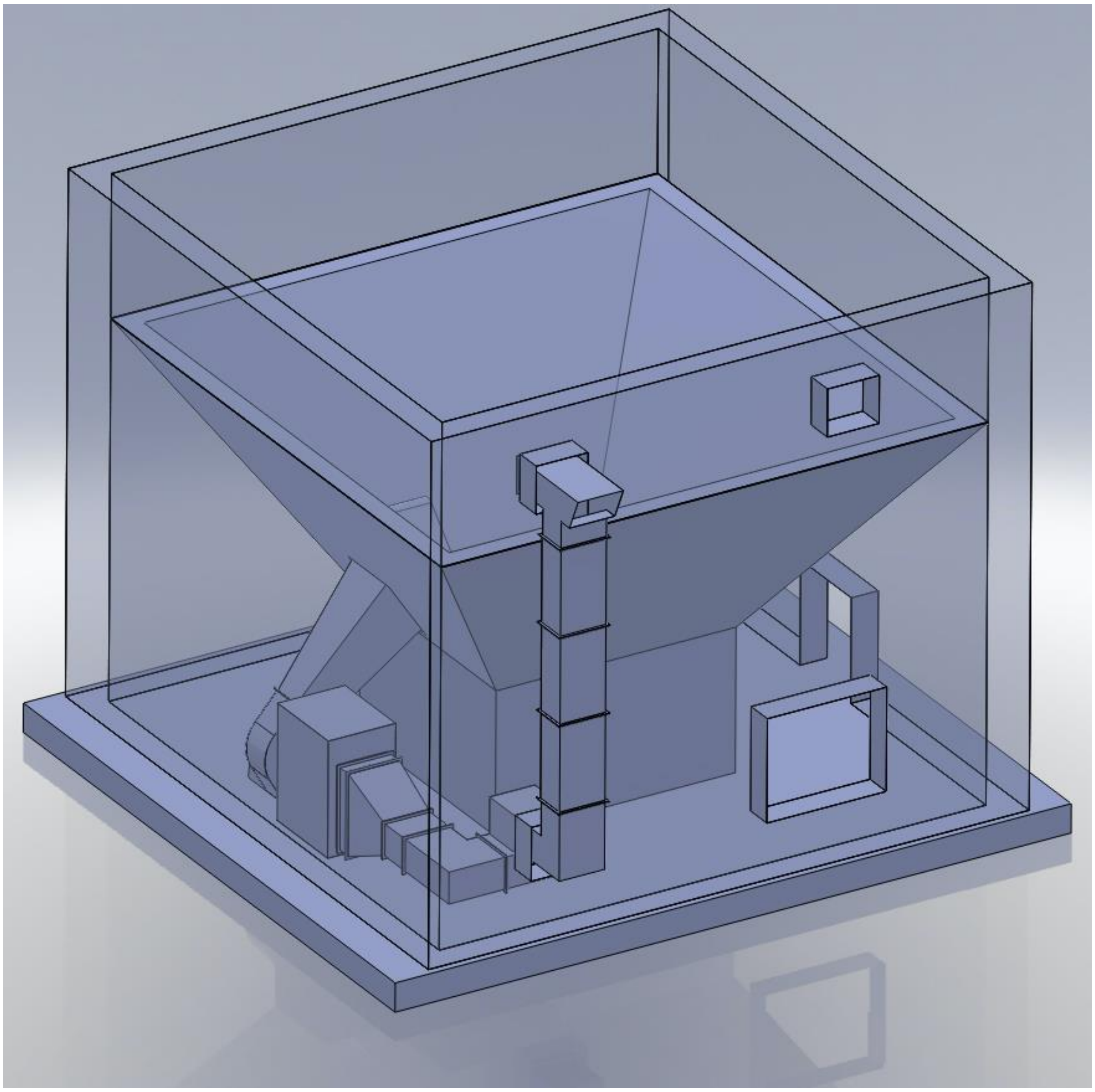

Figure 7: 3D layout of Kiln Heating System [prepared by Don Valley Engineering]

Steam Supply System

Steam will be supplied from the HTHP at 2.5 barg. A new steam header will run from the HTHP to the main distillery area where it will split; a supply will be run to the new kiln heating batteries and a supply will be run to the still house. The steam tie-in at the still house will be downstream of the existing pressure regulating valve, ensuring that the system pressures match. Once supplied to the header the steam can be utilised for any of the four stills.

Both the kiln and still house steam supply lines will be sized for full steam capacity as there will be times when neither kiln is running so all the steam from the HTHP will go to the still house. Likewise, if both kilns are running together all the steam will be supplied to the kiln batteries. Under the current operation schedule only one kiln is heated at a time, however flexibility to allow both to operate together is required, particularly during periods where peat quality is variable as this directly impacts the batch time.

The condensate from both the still house and the kiln heating batteries will be returned to the existing boiler feedwater tank. From the feedwater tank a new pump will be installed to supply the required feedwater to the HTHP for producing the steam.

Plant Layout

Suitable space is available for the GreenStills system adjacent to the main site water tanks. The location is favourable as it has sufficient space for future expansion by installing further HTHPs to utilise the heat generated form the remaining still condensers.

The hot and warm water tanks, HTHP and warm water cooler are all to be located on a new plinth installed in this area. This ensures a centralised GreenStills system. Additional space is left for future HTHPs as required and the water tanks and coolers have been sized for further expansion. The diameter of the hot water tanks was chosen as 4m to ensure vessels can be delivered by road to keep tank manufacturing costs down.

In the stillhouse area, a larger condenser is required for the system with slightly larger footprint. Condenser size was modelled based on the design criteria and footprint added to drawing to ensure sufficient space was available. The proposed subcooler location is in the existing stillhouse.

The layout for the kiln area is shown in Section 5. New ducting is required which can be accommodated around the existing plant.

6. Benefits and Barriers

6.1. Benefits

The main benefits to implementing a successful demonstrator at Highland Park are as follows:

1. Sustainability - reduction in CO_2 emissions, energy consumption and cooling requirement
2. Energy Transition Enabler – for both electricity and hydrogen
3. Product Quality - less invasive than other energy saving alternatives.
4. Proving System for scaling and application in other distilleries

Sustainability

From the modelling results, Table 2 summarises the predicted savings based on a four-batch week in the maltings:

Table 2: Sustainability Savings

	Energy Savings	*CO_2 Savings	Cooling Savings
Total per week	249,457 MJ	31.1 tonnes	198,827 MJ
No. weeks / yr	47	47	47
Total per year	11,724 GJ	1,462 tonnes	9,344 GJ
% of site usage	~13% reduction	~23% reduction	~26% reduction

**CO_2 savings assume electricity from renewables is being used to run the HTHP, causing zero Greenhouse Gas emissions.*

These savings are significant and prove that the demonstrator not only enables transition towards net zero carbon emissions, but it reduces both energy and cooling requirements. The initial scope of the project was to demonstrate that the GreenStills system would offset the coke used in the kilns. As the study progressed, it became clear the system also had the potential to offset a proportion of the energy generated by Highland Park's kerosene boiler, which is included in the above figures.

There is a direct relationship between energy saved and the reduction in cooling requirement because the energy that is now being recovered and used in the HTHP was previously being dissipated in the distilleries cooling tower.

These savings and the fact the system can be extended to offset kerosene across the site proves that the system will allow for the transition to a sustainable future for Highland Park Distillery.

Energy Transition Enabler

Renewable electricity comes at a significantly higher cost per unit of energy than fossil fuels. (1) This acts as a barrier to energy transition via electrification as operating costs will increase. However, because the GreenStills system reduces the input energy required, this barrier reduces, and in the case of Highland Park it is shown to achieve near cost parity. Table 3 summarises the operating costs for the demonstrator:

Table 3: Summary of operating costs using HTHP and recovered energy

	Net Cost per year
Coke	£111,934 saving
Kerosene	£113,933 saving
Electricity	£235,362 cost
Net cost to operate	**£9,495 cost**

As shown, despite switching to a more expensive fuel the demonstrator will not significantly increase site energy costs due to the amount of recovered heat being utilised. This is important as it proves recovering heat in the distillery process can offset additional unit fuel cost for energy transition to net zero. The economic argument is strengthened when future projections are considered for the convergence between fossil fuel and electricity prices. (1) On this basis the system is projected to provide a small energy cost saving within 4 years of installation, which will increase thereafter.

The steam generated from the HTHP could be supplied directly from an electric boiler. However, without the energy reduction from the recovered heat the net costs would be as shown in Table 4:

Table 4: Summary of operating costs from electric boiler

	Net Cost per year
Coke	£111,934 saving
Kerosene	£113,933 saving
Electricity	£684,826 cost
Net cost to operate	**£458,959 cost**

This demonstrates that without the recovered energy through a HTHP the costs to decarbonise directly with electricity are prohibitive. With other Net Zero fuels such as Hydrogen also commanding a price premium over kerosene, the value of the GreenStills system as an enabler to the business case for wider energy transition is clear. Maximising the distillery efficiency by recovering as much of the input heat as possible should be considered a precursor to the sizing and installation of new energy sources.

Product Quality

The GreenStills system can be implemented with less risk to product quality than other energy saving methods such as Thermal Vapour Recompression (TVR). The complexity of plant is centred around the HTHP itself which can be remote from the still house. This is opposed to TVR plants where the equipment must be installed adjacent to the stills which is challenging for existing distilleries.

With TVR (and Mechanical Vapour Recompression) systems the condenser is modified to operate as an evaporator so that it can produce vacuum steam which is then recompressed. These systems require significantly more complex equipment to be installed in the still house and operating a condenser as an evaporator causes excessive copper wear on the tubes. They also alter the contact time between the spirit vapour and copper, leading to potential impact on spirit character.

The GreenStills system is deemed a more elegant solution as condenser modifications are required only to produce hot water meaning both less wear on the condenser and reduced impact on the final product.

Scaling and Application in Other Distilleries

The GreenStills system can be readily expanded to offset even more kerosene at Highland Park. It can also be rolled out to other distilleries. The system enables Combined Heat and Power (CHP) application in malt distilling which could be fuelled by hydrogen.

Roll out and route to market are further discussed in Sections 8 and 9.

6.2. Barriers

The main barriers to the demonstrator are as follows:

1. Technical Risks
2. Product Quality Risks
3. Higher Unit Cost of Electricity vs Fossil Fuels
4. Availability of Electrical Supply

Technical Risks

The technical risks associated with the system are unavoidable as they centre around installing a novel system which has not been piloted elsewhere. The risk is mitigated by having each of the individual elements in operation in some form in other sectors. This demonstrator project aims to bring these together in a functioning system within the whisky industry.

There will also be modification to the distillery's heating and cooling systems which, as well as having technical challenges, will provide additional process safety hazards that will need to be addressed.

These risks will be mitigated through a thorough design process in Phase 2. The demonstrator will be designed using specialist companies who have robust design procedures and will provide rigorous risk assessment studies (e.g. HAZOP & LOPA) to ensure all process safety hazards are identified and mitigated.

Product Quality

Product quality risks are a concern to all distillers. Running the condensers at higher cooling water temperatures alters the vapour contact time with the copper and this can have an impact on spirit character. A successful demonstrator project would aim to fully analyse the impact on product character and mitigate this risk for future projects across the industry.

The change from direct peat/coke firing to air drying and indirect peat addition represents a risk to the phenol characteristics of the malt. The demonstrator project aims to prove that the malt characteristic changes do not impact the product character.

To mitigate these risks Edrington have carried out detailed benchmarking of key product specifications and process parameters, and their impact on spirit grading. Maintaining these will be a key user requirement of any system modification. The analysis covered:

- Phenol content from malt, wash and New Make Spirit (NMS) sampling. Total and individual phenols analysed including 4-Ethyl- Guaiacol; 4-Ethyl-Phenol; 4-Methyl-Guaiacol and o-Cresol
- Total higher alcohols and esters in NMS
- Process parameters such as wash still boil up and run times, along with spirit still boil up and run times for spirit and feints

Higher Unit Cost of Electricity

The existing high price differential between the cost of electricity and fossil fuels means the installation of a GreenStills system may not go ahead on an economic argument – despite the large energy and CO_2 emission savings. This is currently a major barrier in implementing a demonstrator project. An NPV calculation quantifies this in Section 7.

Funding for the demonstrator would allow the system to be installed and the technology proven in practice. This would increase the speed at which the technology can be rolled out as the economics become more viable by helping reduce system costs.

Availability of Electrical Supply

If the system is expanded and more electrical energy is required, there may not be existing infrastructure available on site to support the demand. This could also be the case if the system is rolled out to other distilleries - particularly in remote locations.

However, as is further discussed in Section 9, the system enables CHP plants to be installed in the malt distilling sector which can be fuelled using hydrogen. Installing a CHP plant to generate electricity on site for the HTHP and provide heat for the process could help to remove the both the electrical cost and infrastructure barrier.

7. Costed Development Plan

A summary cost estimate is shown in Table 4:

Table 4: Capital cost summary

COST SUMMARY		
1	GreenStills package supply cost	£1,572,000
2	GreenStills installation costs	£744,000
3	Kiln heating costs	£419,000
4	Other/Civil costs:	£247,000
	Total	**£2,982,000**
5	Power supply costs:	TBC

The costs have been split into five main sections:

- Section 1 – Costs for equipment required for the GreenStills system including the high temperature heat pump, hot water tanks, the new wash still condenser and all other required equipment. This cost also allows for the process design of the system and project management and commissioning fees.
- Section 2 – Costs for the installation of the GreenStills system. This includes for positioning of all the equipment in section 1, required pipework, electrical panels, electrical cabling and control works.
- Section 3 – Costs for modifying the two kilns from a coke heated system to a steam heated system. This includes the heating batteries, fans and associated flue ducting. It also allows for re-sheeting of kiln 2 (to ensure it is sufficiently sealed for the new fans) and for modifications to the peat furnace for integration to the new system.
- Section 4 – Costs for the civil works for the new base that is required for the water tanks and HTHP. This cost also includes for an allowance for CDM associated work as the project will be managed under the CDM 2015 regulations.
- Section 5 – A new electrical supply from the site's main switchboard to the HTHP location. This cost is yet to be confirmed but will be undertaken by Edrington as part of planned upgrades to the site infrastructure.

The total capex required for the demonstrator project is estimated as £2,982,000.

Operational costs for maintenance and servicing of the HTHP have been estimated as £38,700p.a. However, it is expected corresponding opex savings provided by the system will largely offset this, for example: kiln ash disposal; coke transport; reduced boiler servicing due to reduced run time; reduced cooling water chemical use and cooling tower packing degradation and replacement.

As discussed in Section 6, the existing high price differential between the cost of electricity and fossil fuels means the installation of a GreenStills system may not go ahead on a purely economic argument. To quantify this the NPV for the project was calculated, allowing for future convergence in energy prices. After 25 years the NPV is -£2,747,000 which highlights the value of public funding to the feasibility of this project.

7.1. Project Plan

A start date of June 2021 is assumed with completion in January 2023. This gives a two-month contingency to ensure the project is completed by 31st March 2023. The longest lead item is the HTHP so final tendering and procurement of this unit must be prioritised.

7.2. Continued Development

The HTHP supplier would be on site during the installation and commissioning phase to optimise the system. It is proposed to install extra instrumentation with the demonstrator unit to record and trend as much operating data as possible on an ongoing basis. This will allow the HTHP supplier to further develop the design and plant interfaces going forward.

Moreover, the system will also be installed to allow remote access by the HTHP supplier team. This would allow regular monitoring and review of performance, to further optimise the system and minimise the electrical requirement for maximum steam output.

8. Rollout Potential

The GreenStills system can be readily expanded across Highland Park Distillery once the demonstrator system has been proven. The remaining wash still and two spirit still condensers can be converted to heat recovery, providing more hot water for the system. There is footprint available for additional HTHPs to be added which will provide more steam to supply the still house. This will further reduce the overall energy consumed on site and facilitate energy transition away from fossil fuels. It is estimated that having all four stills converted to GreenStills will result in approximately 85% of the kerosene energy and CO_2 emissions being displaced. This assumes some optimisation of the distillery's weekly demand profile to maximise the HTHP utilisation.

One of the key aspects of the demonstrator design was to select a HTHP that generates steam at 2.5barg. As described in Section 4, this lowers the COP but allows integration with the existing low-pressure steam header on site, meaning full utilisation of the system when the kilns are not in use. The wider impact of this selection is that the HTHP will demonstrate to Edrington and other distillers that a the GreenStills system can be integrated into existing distilleries without substantial redesign of steam systems. This is a crucial aspect in demonstrating the viability of this technology to the industry as a solution to all distilleries and not just those with their own maltings.

As stated in the SWA 2020 'Pathway to Net Zero' report heat pumps are required to make a significant contribution to achieving industry targets, alongside Hydrogen fuel, and more mature technologies such as Biomass and Anaerobic digestion. (2) This could range from a balanced scenario of 9% to a maximum of 19% based on current emissions levels. Based on 2045 emissions, once baseline projection and planned progress are considered, this represents 20 - 41% of the remaining gap to net zero. The higher projection represents a saving of 100,470 tCO2e/year.

These figures include several assumptions on technical barriers which could limit the uptake of HTHP across the industry, such as high capital cost, operating cost, availability of grid capacity and installation constraints. If these considerations are addressed as described in Section 9 then much wider roll out and significantly higher CO_2 savings would be provided. The referenced report also highlights the need for commercial scale demonstrator projects to allow heat pumps to fulfil their potential.

GreenStills with its combination of heat recovery and high temperature heat pumps can play a significant role in securing the longevity and sustainability of the UK distilling sector deriving benefit both for distillers and the wider economy.

9. Route to Market Assessment

A Phase 2 demonstrator project would result in a proven route to market for this novel technology by March 2023. Combined with the industrial scale of the proposed application, accelerated commercialisation would be inherent in the delivery of the Phase 2 project, rather than a theoretical future goal. The ripple effect of the technology being replicated more widely will then similarly be brought forward in a shorter timeframe. It is expected the system can be further applied in any industry which carries out heating and cooling duties using low pressure steam or hot water, such as brewing, industrial ethanol production, food manufacturing and pharmaceuticals.

Possible barriers to commercialisation of HTHPs are capital costs, electrical supply and the perceived risks inherent with applying a novel technology. Implementing a project via the Green Distilleries fund will strengthen the case for HTHPs and lower these barriers for others. In discussions with HTHP suppliers the consensus is that once a system is installed in a distillery and the roll out begins, costs could decrease by up to 20% due to heat exchanger optimisation and reduced product design time. This underscores the value of public funding to enable the commercialisation of this technology.

The potential barrier of electrical energy unit cost compared with fossil fuels is expected to be removed due to the increasing costs of fossil fuels, including potential carbon taxes. (1) In addition, as heat recovery is an integral part of the GreenStills system the higher electrical costs are largely offset – as shown in Section 6. These factors mitigate the risk high electrical prices pose to commercialisation.

The barrier of electrical infrastructure can be overcome by increased opportunities for local, renewable generation. By having a distillery with a stable and consistent demand, new renewable energy projects can be justified and incentivised. This effect at Highland Park could permit further renewable electricity generation on Orkney which is currently curtailed when supply outstrips demand.

It would also be possible to generate electricity using CHP or fuel cells. Both could be fuelled using hydrogen and provide waste heat for use elsewhere in the distillery. CHP plants are not currently used in malt distilling due to the high ratio of heat demand to electrical demand – typically 20:1, however the GreenStills system moves this to a region of 1:1 which is ideal for CHP operation. This would allow malt distillers in remote locations, with limited access to electrical power, to use CHP to provide electricity for the HTHP and heat to top up the steam to the distillery. Running these CHP plants using hydrogen would provide a net zero solution.

As described in Section 6 commercialisation of the GreenStills system can act as an enabler for other Net Zero fuel sources. Lowering the overall energy input for the distillery will help to reduce the risk associated with switching any remaining requirement to alternative sources.

10. Dissemination Activities

This demonstrator project would create a world-leading, sustainable malting and distilling site at Highland Park. As a significant operator in the industry with many established communication channels, Edrington can ensure the benefits of these relationships are used to encourage other distillers to replicate the system both within Scotland and globally.

Working with Allen Associates on this project will also provide a benefit for dissemination and future roll out. Allen Associates are a Process Design company dedicated to the distilling sector working throughout Scotland, UK and beyond. They are in contact with most distillery company's production or engineering teams and so can easily engage with peers on the demonstrator project discussing how the technology could be implemented at various sites.

Dissemination activities are progressing in line with the plan laid out in the Phase 1 application, however some industry events, such as the Worldwide Distilled Spirits Conference have been delayed due to COVID-19.

Product	Target Date	Audience	Lead Contributors	Status
Internal comms and project reports	December 2020 – March 2021	Edrington stakeholders, Sustainability committee	Edrington	In progress
Presentation of feasibility study results	March 2021 (rescheduled to Sep 21)	Worldwide Distilled Spirits Conference	Allen Associates	Delayed
Presentation of feasibility study results	Spring 2021	Malt Distillers Association Working group	Edrington	Planning
Presentation of feasibility study results	Spring 2021	SWA Environment and Energy working groups	Edrington	Planning
Site Visit	Phase 2	Institute of Brewing and Distilling members	Edrington	Not Started
Press release & updates on Edrington corporate website	Phase 2	Other industries Public	Edrington	Not Started

11. Conclusions

High Temperature Heat Pumps are favourably positioned in the industry's Net Zero Pathway as they provide energy efficiency improvements through recovered heat, as well as enabling fuel switching to renewable sources.

Using the hot water recovered from one wash still condenser, a High Temperature Heat Pump system installed at the Highland Park site could replace 100% of the coke fuel used in the maltings kilns and 13% of the kerosene used in the distillery package boiler, saving 1,462 tonnes CO_2 per year.

A site-wide energy efficiency improvement of 13% would be achieved by recovering the heat from the condenser water rather than discharging via cooling towers

The estimated capital cost of the system is £2,982,000. If the system was to be implemented at today's utility prices energy cost parity can be achieved within 1% of the current value. The site would be future proofed against the convergence of fossil fuel and electricity prices, which is projected to result in a net saving within 4 years of installation. However, an NPV of -£2,747,000 after 25 years highlights the value of public funding to the feasibility of this project.

The system can generate steam at a suitable pressure to allow scalability and applicability to most malt distillery sites, providing suitable electrical supply infrastructure and available space. Heat pumps have been projected to contribute a reduction of up to 100,470 tCO2e/year across the scotch whisky industry, although this figure could be higher if the following mitigation measures are considered:

- Proven commercialisation via a demonstrator project would reduce capital costs which could currently be deemed prohibitive.
- Grid constraints can be relieved by increased incentive for local, renewable generation and the increased viability of CHP to malt distillation process, resulting from HTHP application

In the absence of a viable demonstrator project HTHPs will continue to be viewed as a risk within the whisky industry. The successful delivery of such a project will catalyse the potential to maximise distillery efficiency and take a significant step on the fuel switching pathway to a Net Zero future. As set out in this report GreenStills can play a significant role in securing the longevity and sustainability of the UK distilling sector, deriving benefit both for distillers and the wider economy.

12. References

1. **Department for Business, Energy & Industrial Strategy.** Annex M: Growth assumptions and prices. *Updated energy and emissions projections: 2019.* [Online] 23 12 2020. https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2019.

2. **Ricardo.** *Scotch Whisky Pathway to Net Zero.* 2020.