DECARBONISING THE DISTILLATION PROCESS VIA DIRECT FUEL SWITCHING FROM FOSSIL FUELS TO HYDROGEN

BEIS GREEN DISTILLERIES PHASE 1 – GD143

LOCOGEN LTD

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Executive Summary

Locogen Ltd have partnered with Logan Energy Ltd to deliver a BEIS green distilleries Phase 1 study investigating the techno-economic feasibility of converting an operational distillery that uses gas oil for distillation, to one that uses hydrogen as the primary process fuel. Arbikie Highland Estate Distillery are determined to find a low carbon alternative to gas oil to further improve their already impressive sustainability and environmental credentials. Arbikie was therefore used as a real world test case with which to conduct the feasibility study.

The technical solution found that will supply Arbikie with a zero carbon fuel is to produce green hydrogen onsite using electrolysis from wind and solar generation. The final design comprises the following elements:

- Byworth Yorkshireman2 3,000 kg/hour boiler with Limpsfield dual fuel burner that can burn hydrogen as well as biodiesel;
- 2 x 500 kg hydrogen storage vessels;
- 2.18 MW electrolyser;
- Compressor and compression skid;
- 3 x EWT DW-61 wind turbine generators (WTGs) with a total combined capacity of 3 MW;
- Ground-mounted 1.75 MW solar PV;
- Cabling, trenching and electrical infrastructure;
- Control systems; and
- Upgrade to the site's electrical grid infrastructure.

The use of hydrogen as a fuel to displace gas oil was found to be a relatively simple technical conversion. In this case, a separate dual fuel burner and boiler is required as the existing system in place does not meet the safety requirements for burning hydrogen. There is adequate space for a new boiler and burner system and this can be connected to the existing pipework leading to the distillation process. There is no retrofit needed to replace any pipework after the boiler. There will therefore be no disruption to business as usual operations and in production of the spirit.

As most operational distilleries have similar steam systems to Arbikie, the technical solution of using green hydrogen as a fuel is readily replicable and can be applied across the industry. Any other industrial process that requires process heat can also use hydrogen to displace the counterfactual fuel oil.

The opportunity to develop onsite renewables is dependent on the distillery's location, land availability and constraints to the onsite/near-site development of renewable generation. As the UK dramatically expands its installed capacity of wind, particularly offshore, up to 2030 and beyond, the opportunity to create green hydrogen at a competitive price will become greater. Distillery conversion to hydrogen offers an important future market for green hydrogen. Providing a route to market for green hydrogen will act as a catalyst for accelerating the wider hydrogen economy based on the UK government's Hydrogen Pathway to Net Zero which will see the wider uptake of hydrogen as a fuel for transport, peaking plants, process heat and potentially blending into the gas network.

Variable	Without grant funding	With grant funding
Total project capex [£]	£8,442,500	£5,422,500
Total project opex (p.a) [£]	£206,375	
Payback years	23	16
Carbon savings (25yrs) [tCO_2]	19,977	
CO_2 saved per capital [$kgCO_2$/£]	2.4	6.7
CO_2 saved per LOA [$kgCO_2$/LOA]	4.2	
Cost savings per LOA [£/LOA]	3.10	

Glossary

AEM	Anion Exchange Membrane
BEIS	UK government Department for Business, Energy & Industrial Strategy
Capex	Capital expenditure
DNO	Distribution Network Operator
FECV	Fuel cell electric vehicle
GIS	Geographic information system
GSP	Grid Supply Point
HES	Historic Environment Scotland
HGV	Heavy good vehicle
HH	Half-hourly
IRR	Internal Rate of Return
ISO	International Organization for Standardization
KPI	Key Performance Indicators
LEL	Lower explosive limit
LOA	Litres of alcohol
LPG	Liquified petroleum gas
MCB	Miniature circuit breaker
MCP	Medium Combustion Plant
MOD	Ministry of Defence
NATS	National Air Traffic Services
NPV	Net Present Value
Opex	Operational expenditure
P&ID	Piping and instrumentation diagram
PEM	Proton Exchange Membrane
PSV	Public service vehicle
PV	Photovoltaic
SPA	Special Protected Area
SNH	Scottish natural Heritage
SSEN	Scottish and Southern Energy Networks
SSI	Site of Special Scientific Interest
SWA	Scotch Whisky Association
WTG	Wind turbine generator

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1. Project overview

Distillation is energy intensive with high temperature heat required at the heart of the process. The fuel required to provide this heat has traditionally come from either mains gas or burning imported fuel oil, making distillation also a carbon intensive process. For operational distilleries to replace their reliance on existing fossil fuels with a low carbon alternative, there is often the requirement for extensive retrofit and replacement of existing distillery infrastructure with new low carbon technologies. This can incur prohibitive capital cost, an increase in operational costs and disruption to ongoing business.

This project is a detailed feasibility study looking at the opportunity for conversion of an existing distillery using fuel oil to using hydrogen instead. Combustion of hydrogen creates only heat and water as a by-product. There are therefore no carbon emissions associated with the burning of hydrogen. Hydrogen can be produced via electrolysis and the electricity for this can be sourced from renewable energy systems thereby making the hydrogen zero carbon, which is termed as 'green hydrogen'. Hydrogen can also be stored and dispatched for use as required and any excess production can be either sold to third-parties or utilised onsite for uses other than provision of heat (e.g. to power fuel cell electric farm vehicles).

This project will explore the technical and financial feasibility for decarbonising the distillation process via direct fuel switching from fossil fuels to green hydrogen, using Arbikie Highland Estate Distillery as a project demonstration site.

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

Arbikie Highland Estate Distillery ('Arbikie') are one such operational distillery that presently use gas oil as their fuel to raise steam for the distillation process. Arbikie are an independent family-owned distillery located on the working Arbikie Highland Estate farm. Provenance, traceability and sustainability are integral to Arbikie's ethos which is one of 'field to bottle' with all ingredients for their spirits planted, grown and harvested on the farm and all water taken from a naturally fed private reservoir. Maturation, bottling and packaging are all conducted on the premises and waste is minimised as much as possible with waste product from spirit making going to draff for livestock feed. Arbikie also have roof-mounted solar photovoltaic (PV) installations at their site which provides a significant proportion of onsite electrical usage. Arbikie are determined to find a low carbon alternative to gas oil to further improve their sustainability and environmentally conscious credentials.

Locogen Ltd ('Locogen') are the 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 hydrogen, district heating, low carbon heat solutions, wind, solar and hydro 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.

Locogen have partnered with Logan Energy Ltd ('Logan Energy') for exploring the feasibility of hydrogen system design. Logan Energy specialise in delivery of integrated hydrogen engineering solutions including production, refuelling, storage, distribution, fuel cells and heat generation. They offer turnkey service from project inception and feasibility to design, development, manufacturing, installation, operation and maintenance. Logan Energy are manufacturer independent and are able to analyse and select any appropriate equipment based on proven experience in delivering hydrogen energy projects. A team of expert engineers and commercial professionals deliver optimally sized hydrogen systems to maximise future return on investment and have developed economic models that capture the evolution of hydrogen technology.

1.2. Aims and objectives

The project aims to design a green hydrogen energy system that can be applied at an operational distillery currently reliant on fossil fuels. To do this, the following objectives were identified:

- Define Arbikie's energy use and existing infrastructure;
- Conduct a constraints mapping exercise for deployment of renewable energy technologies;
- Create costed engineering design for a hydrogen-based energy system;
- Undertake a route to market assessment for excess hydrogen production;
- Conduct financial feasibility assessment;
- Identify risks to the project; and
- Create dissemination strategy.

1.3. Technology options appraisal

A comparison of different low carbon technologies and energy systems was conducted that were applicable to direct fuel switching of an operational distillery running on fuel oil. It was found that a hydrogen-based distillation process offers a novel technological solution to decarbonising distilleries that offers greater simplicity and replicability in comparison to other technology options as well as providing an opportunity to generate additional revenue through the selling of green hydrogen as a by-product and tying into a wider hydrogen economy. The rationale for proposing hydrogen for fuel switching is provided below in Section 1.3.1 with a discussion of alternatives in Section 1.3.2.

1.3.1. Technology proposed

The use of hydrogen as a fuel source is well understood and has been proven in many industrial settings, however not in an operational distillery. The use of hydrogen at distilleries has been previously investigated, such as at Kirkjuvagr Distillery in Orkney through BEIS' HySPIRITS project (EMEC, 2019), but no commercialisation of a hydrogen fuelled distillery has been advanced.

Commercial hydrogen burners, boilers and storage vessel products are all readily available to allow the use of hydrogen as a fuel source. The creation of green hydrogen via an electrolyser is also an established process with readily available items on the market. The different components required to construct the engineering solution are 'off-the-shelf' products and can be procured, constructed and installed with relative ease. This factor is a key advantage over other possible technological solutions to decarbonising the distilling sector.

Hydrogen can be burned either directly or indirectly to fuel distillation. The indirect process would be to burn hydrogen to raise steam in a boiler. Combustion of hydrogen creates steam directly therefore this can be used for distillation rather than having the intermediate step of the boiler. The use of hydrogen burners, either direct or indirectly fuelling the distillation process, is extremely adaptable and scalable and can therefore be applied across the country to distilleries of differing sizes and geographies. The engineering design can also be applied to other industries using process heat.

Hydrogen is stored at pressure in vessels and can be readily dispatched as easily as current fossil fuel burners. The process for distillation is therefore unchanged with no disruption to operation or existing infrastructure after the boiler, if existing. There will therefore be no impact on the quality of the end product.

The combustion of hydrogen creates only heat and water as a by-product. There are therefore no carbon emissions associated with the burning of hydrogen. Therefore, the novel project has a positive impact on air quality and the surrounding environment compared to a business as usual scenario.

Renewable energy can be used to produce hydrogen through electrolysis. The switching of fuel from fuel oil to hydrogen offers the exciting opportunity for integration of renewable power into the distillation process to fully decarbonise the operational distillery. Renewable sources of power can be obtained through development of onsite renewables, through potential private wire arrangement from nearby operational assets or importing green hydrogen via transported containers from production elsewhere. There is a distinct opportunity for onsite electrolysis at distilleries as they already have an available water source for making their product.

The production of hydrogen onsite leads to other potential onsite uses and means of generating revenue for the distillery. Arbikie is also a working farm, and many other distilleries are located in rural locations near farmland. There is therefore an opportunity to use hydrogen as a fuel, in pure or blended form, for farm vehicles. There is therefore an opportunity to decarbonise the wider carbon footprint of the distilling sector by lowering the carbon emissions in the supply chain and enacting a circular economy approach. Hydrogen can also be sold on for Fuel Cell Electric Vehicle (FCEV) or dual fuel vehicle use and as feedstock for the chemical industry for the production of ammonia and refrigerants, for example.

1.3.2. Alternative technologies

Heat pumps also present a low carbon option for distilleries, and potentially have smaller energy demands due to the compressor efficiencies. Systems have been developed which are able to raise steam, but at lower pressures than the design of most currently utilised stills, which therefore require refurbishment or replacement of the still. Where high temperature systems are available, they are also not able to operate with rapid ramp rates utilised on most current distillery processes, and therefore require either large steam accumulators or modifications to the process methodology. Depending on the type of heat pump to be used, site specific conditions may limit the utilisation of industrial heat pumps across the industry.

Biomass and biofuel systems have also been utilised on other distilleries to reduce carbon emissions in replacement of oil-fired steam systems. Fuel supply and transport is a key limiting factor in the feasibility of these schemes, and both still have considerations related to local air quality. The low carbon credentials of these fuels are also questionable as they must be sourced from sustainable plantations. Though such a system may work for a single distillery, the scale up would demand excessive quantities of land and would have the potential to create significant land use conflicts. Lack of available land within the UK to support wide adoption of biomass and/or biofuels in the distilling sector would lead to sourcing offshore which would result in increased carbon emissions from transport and would not add any value into the UK economy.

Electric steam boilers are another option for decarbonisation to switch distillery energy dependence from fuel oil to electricity. When using commercial electricity rates, the running costs for this option is however extremely expensive. The carbon savings are also modest given the equivalent carbon content associated with grid imported electricity at present, although this will reduce over time. Onsite or private wire electricity from renewable energy sources could be used to provide zero carbon electricity, however the intermittency of the resource would require an onsite energy storage. Such electric battery systems would be an expensive means of decarbonising the energy system. There is also the risk of extended downtime of renewable energy generators onsite or via the private wire meaning the requirement for expensive grid import and/or fossil fuel back-up generation.

2. Feasibility results and conclusions

2.1. Modelling

2.1.1. Baselining energy use and operation

Arbikie's historical production and forecasted future energy use was determined through recorded purchasing and production alongside a review of technical capacity of installed distillation systems and discussions with the distillery owners and distillers.

Steam is used as the heat supply medium for distillation, as is most common within the industry, and there are four distinct product types; single malt whisky, single grain whisky, gin and vodka.

The distillation process involved to produce these spirits varies and there are therefore varied quantities of steam and durations associated with each product. Further, the properties of the raw ingredients for each product are variable on account of the specific crop characteristics and there is therefore variability in the energy required to produce spirit between runs of the same product.

At present, distillation for a given week begins at 4:30 am on Monday and runs continuously until 4:30 am on Friday, with no production taking place at weekends. It is Arbikie's intention to increase production and operation to a 24/7 process within the next two years.

Once the operation moves to a 24/7 process, then the total annual energy use is estimated to be 2,538 MWh/a, with a peak demand of 1,475 kW. Using gas oil to provide heat for this process would results in the emission of 652 tCO_2/a.

2.1.2. Energy flow modelling

An annual primary energy demand profile was created subsequent to the above assessment. The volume of hydrogen required to supply this annual demand was then also calculated. This was compared to the volume of hydrogen that could be created via onsite renewable energy generation. The opportunities and development restrictions to installation of onsite renewable energy systems were identified through undertaking a constraints mapping exercise.

The volume of hydrogen produced for different sizes and combinations of wind and solar developments and electrolyser sizes were modelled. An optimisation process was conducted that assessed adequate storage size for maximising provision of hydrogen throughout a year but keeping within reasonable scale for site availability and risks. From this analysis, the optimal technical solution, offering the greatest carbon abatement for cost of installation, as presented in Section 2.2 could be determined.

It was found that the optimal size of system is able to provide 99% of the required fuel for distillation. The remaining would be provided by a back-up source. The back-up source can be the business as usual gas oil fuel or biogas, which would improve the carbon abatement credentials of the project further and lead to a zero emission distillation.

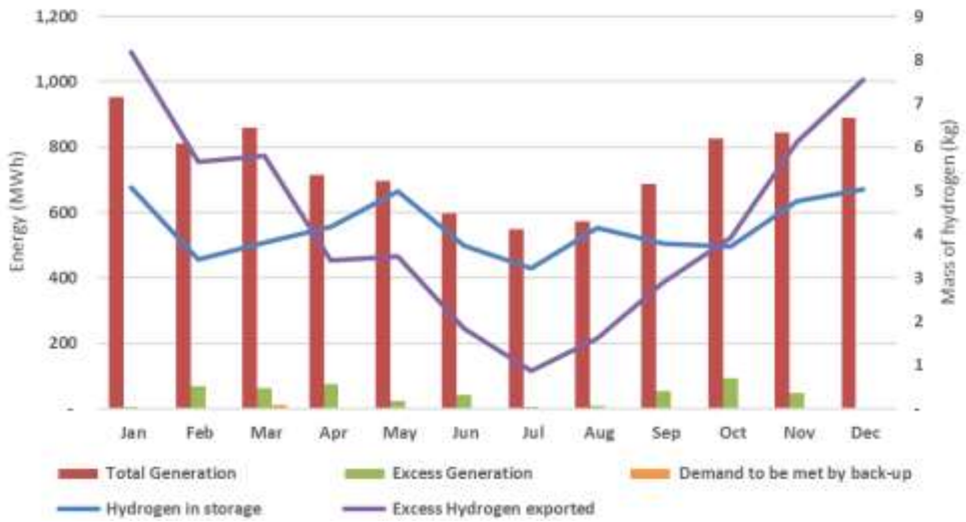

Figure 1: Energy flow modelling summary

2.1.3. Revenue generation opportunities

Excess renewable generation and excess production of green hydrogen are by-products of the proposed technical solution. Revenue from export of renewable energy generation to the grid and sale of green hydrogen, as well as onsite usage, were quantified and provided in Section 2.3.

2.1.4. 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 operational expenditure (opex) are inputted along with other assumptions. 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, is 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. Financial modelling results are presented in Section 2.3 below.

2.2. Technical solution

A techno-economic feasibility study for creating a green hydrogen renewable energy system for replacing fuel oil as the distillation fuel source at Arbikie was conducted. An optimal technical solution was found that could deliver a distillery fuelled almost entirely (99%) by green hydrogen and comprises the following elements:

- Byworth Yorkshireman2 3,000 kg/hour boiler with Limpsfield dual fuel burner that can burn hydrogen as well as biodiesel;
- 2 x 500 kg hydrogen storage vessels;
- 2.18 MW electrolyser;
- Compressor and compression skid;
- 3 x EWT DW-61 wind turbine generators (WTGs) with a total combined capacity of 3 MW;
- Ground-mounted 1.75 MW solar PV;
- Cabling, trenching and electrical infrastructure;
- Control systems; and
- Upgrade to the site's electrical grid infrastructure.

2.2.1. Costs

The total estimated capex for the proposed optimal solution is £8,442,500. Annual opex for the additional installed components is estimated to be £206,375 per year. A breakdown per cost item is provided in Table 1 below.

Cost Item	Breakdown	Cost	Total
Capex	3 x EWT DW-61 WTGs	£3,753,000	**£8,442,500**
	1.75 MW ground-mounted solar PV	£1,050,000	
	2.18 MW electrolyser	£2,179,500	
	Hydrogen storage vessels	£300,000	
	Boiler	£200,000	
	Compressor	£210,000	
	Design	£200,000	
	Ancillary hydrogen infrastructure	£250,000	
	Grid connection upgrades	£300,000	
Opex	2 x EWT DW-61 WTGs	£90,000	**£206,375**
	1.75 MW ground-mounted solar PV	£7,400	
	2.18 MW Electrolyser	£108,975	

Table 1: Technical solution cost breakdown

2.3. Financial feasibility

Table 2 below summarises the financial modelling results for the technical solution with and without grant funding. It is apparent from the financial modelling results that, without BEIS Phase 2 grant funding, the project has a negative NPV, even after 25 years of operation. With grant funding support, the project is considered to be financially viable by offering a moderate payback period of 16 years which is aligned with the long-term vision of Arbikie.

	No Grant Funding	Phase 2 Grant Funding
Capex (£)	£8,442,500	£5,442,500
Annual opex (£)	£206,375	£206,375
Annual spend on energy (£)	£6,626	£6,626
Counterfactual spend on energy (£)	£160,377	£160,377
Annual savings on energy spend (£)	£153,751	£153,751
Revenue from export of hydrogen and power (£)	£430,689	£430,689
Payback years	23	16
IRR (10 years)	-17.4%	-10.4%
IRR (25 years)	0.7%	4.8%
NPV (10 years)	-£5,509,990	-£2,644,167
NPV (25 years)	-£2,461,482	£404,341
Carbon savings (10 years) [tCO_2]	8,038	8,038
Carbon savings (25 years) [tCO_2]	19,977	19,977
CO_2 saved per capital [$kgCO_2$/£]	2.4	6.7
CO_2 saved per LOA [$kgCO_2$/LOA]	4.2	4.2

Table 2: Financial modelling results

2.3.1. Impacts on product costs & carbon emissions

Due to the distillation process being unchanged, there will be no impact on the product quality, nor on the production line operational timings and management.

It is further calculated that approximately **£3.10/LOA** can be saved over the course of a year, which includes revenue. Not including revenue still results in a saving of 82 p/LOA. These savings can be reinvested in other aspects of Arbikie's operation and used to further finance sustainability projects. The production of hydrogen leads to other potential onsite uses and means of generating revenue for the distillery through selling to other users. As a working farm, there are opportunities at Arbikie to use hydrogen as a fuel, in pure or blended form, for farming vehicles. The crops from the farm are used for producing the spirit products and therefore there is an opportunity to decarbonise the wider carbon footprint of the distilling sector by lowering the carbon emissions in the supply chain and enacting a circular economy approach.

The project is calculated to save over 800 tCO_2 per year and approximately **20,000 tCO_2** through a project operation of 25 years. There is a carbon emissions saving of **6.7 $kgCO_2$/£** of BEIS money spent and **4.2 $kgCO_2$/LOA** produced. With the social value attributed to this carbon emissions abatement and the return on investment for BEIS over the project lifetime, this represents a positive investment for the UK government in achieving its carbon emission targets and the green economic recovery from the Covid-19 pandemic.

3. Demonstration project description

Following on from the Phase 1 feasibility study, Phase 2 will be critical for testing the hydrogen burner and boiler infrastructure and ensuring that the storage vessel's piping connection to the electrolyser and burner works seamlessly and integrated correctly with the site's existing steam distillation system and site electrical works. Figure 2 below displays a schematic of the whole project energy system, which has been designed by Logan Energy and their subsidiary H2Tec. Options including expansion for a hydrogen refuelling station and an electric vehicle are shown to further illustrate how low carbon transport could also be integrated into the system

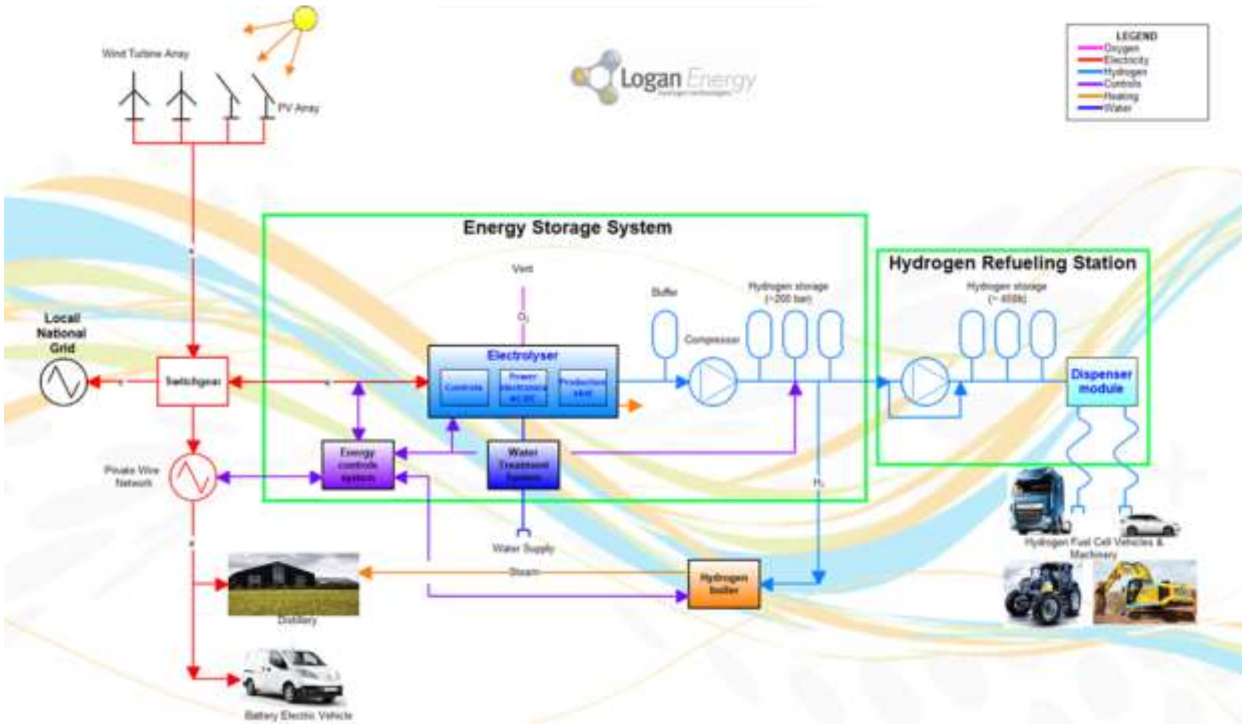

Figure 2: Project energy system schematic

Private underground electrical cables will run from the wind and solar generation site to Arbikie's electrical distribution board, where the electrolyser will also be electrically connected. A control system using a current transformer will be used to send a signal for the electrolyser to draw power only when there is renewable generation, ensuring that the electrolyser will only consume energy generated by renewables and not through import from the grid.

Green hydrogen is produced via electrolysis in the electrolysers and fed via piping to the hydrogen storage vessels. A compressor will be attached before the inlet to the storage vessels to compress the hydrogen. Piping will direct hydrogen from the storage vessels to the hydrogen burner and boiler to raise steam. The distillation process will then remain unaltered. The existing burner and boiler will be retained for back-up to ensure a 24/7 production process.

In instances where hydrogen production exceeds the storage capacity, the excess hydrogen will be sold to users offsite (see Section 8.2.2). There is scope for also finding innovative means of using this hydrogen onsite. When renewable generation exceeds the electrolyser capacity, the additional will be used in the first instance to satisfy Arbikie's instantaneous electrical demands. The remaining will be exported to the grid (when export capacity is available, see Section 5.2.3).

The performance of the technology will be evaluated against expectations and improvements to the design and/or controls altered as necessary to improve performance. Conclusions about final design will be drawn from experimentation as well as the operational costs fully documented so that a clear understanding of the technology's commercial performance is obtained. The replicability of the final engineering design solution will be assessed and commented upon to discuss how it can be applied across other distilleries and industry.

4. Design for demonstration project

This section describes the design for the technical solution. The installation consists of a compression skid, electrolyser skid(s) and fixed hydrogen storage. The hydrogen storage may be provided either by a number of high-pressure cylinders, tubes or bundles manifolded together or by medium pressure vessels. The proposed site layout can be seen in Figure 3. The layout satisfies the minimum safety distances from other objects as recommended in BCGA CP31 (BCGA, 2015).

Figure 3: Design layout

4.1. Electrolyser

An alkaline electrolyser, using a highly concentrated alkaline electrolyte, is the preferred option for the final design based on cost and reliability. The electrolyser will have a total installed capacity of 2.18 MW and be housed in 3 x 40ft ISO (International Organization for Standardization) containers Compression, & storage.

4.2. Compression & storage

Alkaline electrolysers produce hydrogen uncompressed at 30 bar. The compression skid will compress the hydrogen from the electrolyser from 30 bar to 200 bar allowing for high pressure hydrogen storage on site. The compression skid will be installed in a 20 ft ISO container and will include the miniature circuit breaker (MCB) to control the storage.

4.3. Boiler & burner

The currently installed Byworth boiler at Arbikie was manufactured in 2014 and therefore has a very long operational life still left. The feasibility of replacing the existing Riello burner with a hydrogen burner was investigated, however this was found to not be possible. Hydrogen boilers need to be 10-15% larger to account for a larger furnace chamber. The larger furnace is required to allow for the excess air needed to burn hydrogen and to reduce nitrous oxide (NOx) emissions and comply with the Medium Combustion Plant (MCP) Directive (EU, 2015). Therefore a new hydrogen boiler and burner system is required. There is ample space within the boiler room to house two boilers, with the existing proposed to remain to ensure redundancy and a 24/7 process.

Byworth boilers are renowned for their high-quality engineering and are manufactured in Yorkshire. The Yorkshireman2 (Y2SX3000) 3,000 kg/h F&A 100°C boiler specified by Byworth is a newer version of the currently installed Yorkshireman model at Arbikie. Byworth claim the Yorkshireman2 is the most fuel efficient steam boiler of its type in the UK today. Limpsfield are Byworth's chosen burner manufacturer for this application and have been firing hydrogen for over 20 years. A dual fuel (hydrogen/biodiesel) burner was found to be the best solution, which enables the fuel source to be changed simply via a switch, allowing for a seamless changeover in the case that the backup fuel needs to be used.

4.4. Hydrogen fire and detection

Hydrogen detection and ATEX extraction fans will be installed at roof level of the boiler room to ensure there is no build-up of hydrogen. At 20% lower explosive limit (LEL) of hydrogen the system is designed to shut down and the fans will extract any build up of hydrogen. A 40% LEL of hydrogen will trigger an emergency stop and will cut power to all equipment except for the extraction fans. Fire detection will be installed and in the event of fire, all systems will be shut down and the fans will not be permitted to operate.

4.5. Hydrogen piping system

The hydrogen pipework will be made of 316 stainless steel tubes, assembled with compression fittings. There will be no welded joints in the pipework. The hydrogen stored at 200 bar will be reduced to <500 mbar before entering the boiler room. The piping system will include the following components:

- Shut off valve;
- Pressure regulating valve;
- Safety relief valve;
- Pressure gauge and transmitter;
- Temperature sensor; and
- Flame arrestor.

4.6. Renewable energy generation

The electricity for electrolysis will be provided via renewable generation onsite through the development of three EWT DW-61 1 MW WTGs and 1.75 MW ground-mounted solar PV. A constraints mapping exercise and first pass assessment has been conducted to identify the proposed locations shown below in Figure 4.

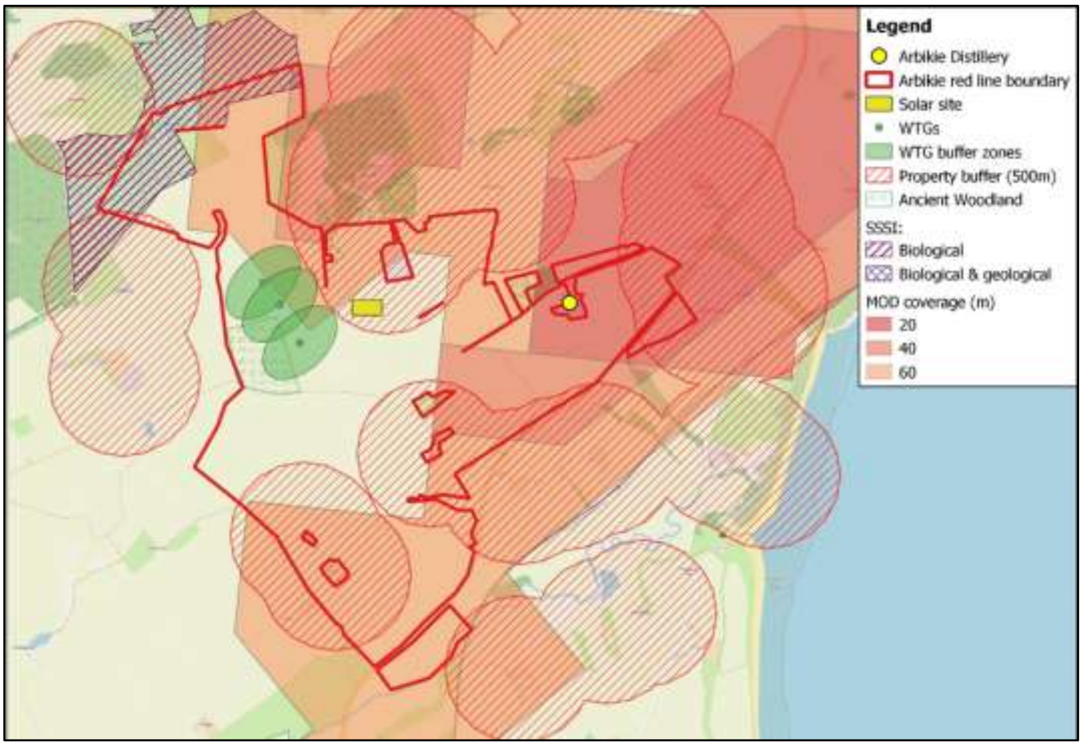

Figure 4: Proposed renewable energy generation sites

5. Benefits and Barriers

5.1. Benefits

5.1.1. Ease of integration

A significant benefit of the technical solution is that there will be no impact on the operation of the distillation process. Once the hydrogen burner and boiler are installed, there are no additional changes to the distillery's infrastructure. Steam created through the burning of hydrogen will be used in the same quantities and same stages as the business as usual case of retaining the existing system.

5.1.2. Emissions reduction

The primary benefit delivered by this project will be a significant reduction in carbon emissions in relation to business as usual. The operation of the distillery will have no carbon emissions for the distillation process. By using hydrogen as the combustion fuel in place of gas oil, there is no carbon emitted by the heating system. The plan for this hydrogen-fuelled distillery is to use hydrogen produced via electrolysis from onsite renewable energy generation. The project is calculated to save over 800 tCO_2 per year and approximately 20,000 tCO_2 through project operation of 25 years.

5.1.3. Technology readiness level

The different components that make up the engineering solution are all well-established commercial products. The innovative approach to this project is combining these different components to provide a zero-carbon solution to process heating in a distillery setting. This project therefore benefits from offering a novel and innovative approach to decarbonising the distilling sector whilst minimising risk due to untested and untried technology components. This factor is a key advantage over other possible technological solutions to decarbonising the distilling sector, as outlined in Section 1.3.1.

The hydrogen infrastructure components that will be installed at the project are all readily available from multiple different manufacturers. This includes hydrogen burners (also capable of burning fuel oil and biodiesel), boilers, storage vessels and electrolysers. The creation of green hydrogen via an electrolyser is also an established process and the use of wind power to provide the renewable energy for this is well understood.

5.1.4. Replicability

The use of hydrogen burners for providing heat is easily replicable and scalable. Switching existing distilleries to hydrogen burners can therefore be applied at distilleries of all different sizes and geographies. Distilleries that use fuel oil are off the gas grid network and coincide with more remote rural areas that are often also suitable for wind energy development. This synergy provides opportunity to co-locate wind energy developments with off-grid distilleries for provision of green hydrogen for process heat fuel. Hydrogen is compatible with many existing installed burners and boilers in operational distilleries and therefore can displace fossil fuels with minimal disruption.

The rollout potential of the technical solution and route to market is discussed further in Sections 7 and 8 respectively.

5.1.5. Future-proofing

Having an energy source created locally greatly reduces the risk of external factors determining the price and availability of supply. Fossil fuel prices have historically been 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 ever 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.

5.1.6. Accelerating regional & national hydrogen economy

The volume of hydrogen that can be used at the site will be limited by the size of the storage vessel. When excess hydrogen is created that cannot be stored onsite then this can be sold to third parties. Through the cost-effective production of green hydrogen, the project will be able to accelerate the expansion of the hydrogen economy in Aberdeen, Angus and Dundee. The growing hydrogen economy of Aberdeen is extremely important for the UK's Hydrogen Pathway to Net Zero 2050 by transitioning the local economy from oil and gas to hydrogen. This is discussed further in Section 7.2.

The project produces an excess of 51,370 kg of hydrogen per year which can be sold to nearby hydrogen markets. It is calculated that this hydrogen can be sold at a delivered price of £8/kg and therefore generate an income revenue stream of £410,960 per year. This selling price is below the current prices that are being paid by Aberdeen City Council to produce hydrogen for the existing and emerging hydrogen bus fleet and is therefore considered to be a ready market.

A recent survey by Scottish Renewables (Scottish Renewables, 2020) found that over 75% of offshore oil and gas workers would be willing to move to the renewables sector but that there are limited opportunities to do so. Additionally, 91% of respondents had not heard of the term "just transition", which is an approach to protect workers' rights and ensure social equality during the transition from a fossil fuel based economy to a sustainable, low carbon one. A hydrogen economy would have an enormous benefit to the UK economy by finding skilled workers jobs in industries that help in achieving climate change targets, ensuring a just transition by protecting long term employment. Given Aberdeen and the surrounding areas' dependence on the oil and gas industry, the importance of a just transition to a hydrogen economy cannot be understated. As well as providing a low carbon alternative to the current Aberdeen energy industry, long term future work prospects could be secured, avoiding damaging wider social implications from economic depression.

The advancement of the hydrogen economy will have important international consequences for the UK. The Committee on Climate Change identified potential industrial opportunities for the

UK from being an early mover in hydrogen engineering and technologies with benefits of creating a local supply chain and exporting product, knowledge and creating jobs.

5.1.7. Excess renewable generation

The volume of hydrogen that can be created is limited by the electrolyser size which is 2.18 MW. The installed capacity of wind and solar combined is 4.75 MW and there will therefore be instances when generation exceeds hydrogen production capacity. This is particularly relevant over winter months where wind speeds are consistently higher. Excess generation will be utilised to initially satisfy the distillery's instantaneous onsite electricity demand. This will save on the site's electricity import costs and further improves the carbon emission savings of the project. These carbon savings are included within carbon emission saving calculations in Section 5.1.2.

Further excess generation will then be exported to the grid. It is calculated that approximately 413 MWh of generation will be exported to the grid in an average year (once export capacity is secured, see Section 5.2.3) and this will equate to an annual revenue stream of £19,729 in addition to the savings on electricity bills from import. The export of zero carbon energy into the grid is not included within the carbon emission calculations of this project and these calculations can therefore be regarded as conservative.

5.2. Barriers

5.2.1. Capital

The total capital cost for the proposed technical solution is £8,422,500. A maximum amount of £3m is available from BEIS to support this project in Phase 2, which leaves an effective minimum project capex of £5,422,500. A business case has been developed that will provide this additional funding and attract investors.

5.2.2. Planning & property

Planning permission will need to be granted for wind and solar energy development. The constraints mapping exercise has identified the lowest risk location for development and minimised the risk for objection. In addition, the scale of wind technologies proposed for development are small for a commercial development so should mitigate the risk of objection from the Ministry of Defence (MOD), whilst also presenting a reduced landscape and visual risk at planning consideration. There are a number of similar scales of wind turbine developed as farm scale developments across Angus and the use of the resulting generation for an innovative project for a local business and employer is considered to present a strong positive case for development. Arbikie own the land identified for development of the renewable technologies and connection of these technologies to the site is over land controlled by Arbikie or public highway. Therefore the proposed project has avoided the risk of a third-party landowner refusing to provide the necessary permissions to lease or cross their land.

5.2.3. Grid

There is a risk that the ability to export excess electricity generation back to the grid will not be available within the timescales of the project becoming installed. This view is based on in-depth conversations with the Distribution Network Operator (DNO), Scottish and Southern Energy Networks (SSEN). However, only a minor proportion of the energy generated will be excess to requirement and exported to the grid and therefore a worst case scenario is that the generation is curtailed on occasions for the first three years of operation until 2026 when export capacity is assumed to be secured.

5.2.4. Safety risk mitigation

Hydrogen is an extremely flammable and light gas and therefore safety concerns and hazard identification form part of the feasibility study. Identified risks through the production, storage, transport and combustion of hydrogen need to be identified and risk mitigation measures implemented. This has been accounted for in the system design.

5.2.5. Hydrogen market

Finding reliable end consumers of excess hydrogen to provide important revenue streams is an important factor in the business case for the project. Price and supply terms must be agreed that accounts for the compression and transport of the hydrogen to customers. There is high confidence of producing hydrogen at a competitive selling price to give immediate access to existing and emerging hydrogen markets in Aberdeen and Dundee respectively.

5.2.6. Industry confidence

The distilling sector is traditionally heavily resistant to change down to fear of jeopardising end product quality and brand. Despite there being vocal support of transitioning to renewable energy, distilleries have been reluctant to part with their own money in a novel design. This principal barrier can be overcome by using the green distilleries grant to showcase the solution with minimal disruption to operations at an operational distillery. Proving the technology works at this scale and in this setting through Phase 2 will provide the confidence the wider industry needs for widescale adoption whilst minimising risk of expenditure to BEIS.

6. Costed development plan

The BEIS Phase 2 grant would be used to install a working renewable energy system that produces green hydrogen from renewables to fuel distillation at Arbikie.

The Phase 2 project duration will be 22 months which will include testing and commissioning of the different components. The following three months will then be used to continue dissemination work and performance monitoring of the system will continue indefinitely. The following development costs are anticipated to deliver the Phase 2 demonstrator:

- Project management: £150,000;
- Design (including P&IDs (piping and instrumentation diagram) and layouts): £200,000;
- Ancillary hydrogen infrastructure (including installation): £250,000; and
- Dissemination activities: £20,000.

Development costs including planning and construction project management of wind and solar PV energy systems is already included within the capex for each item. Further, design and installation costs of the hydrogen infrastructure are accounted for in the project capex breakdown.

Figure **5** shows the timeline of capex that will be spent during the project period and Figure 6 displays the Phase 2 demonstrator project plan.

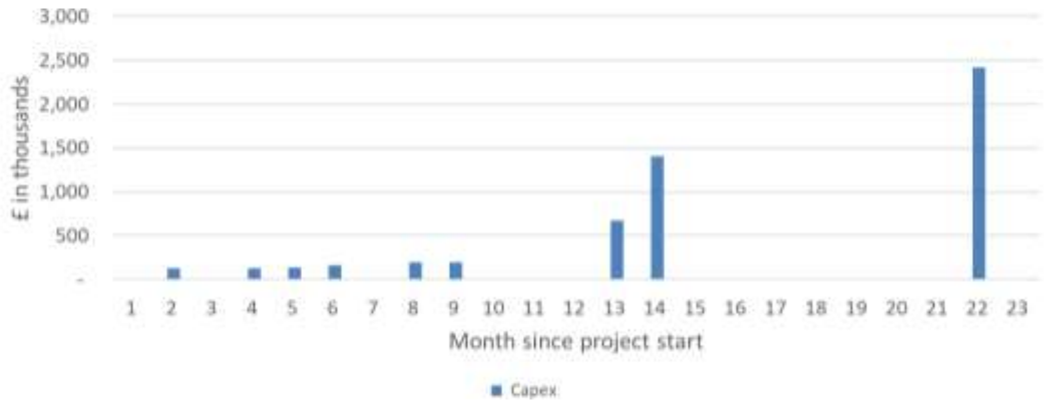

Figure 5: Capex over Phase 2 demonstrator timeline

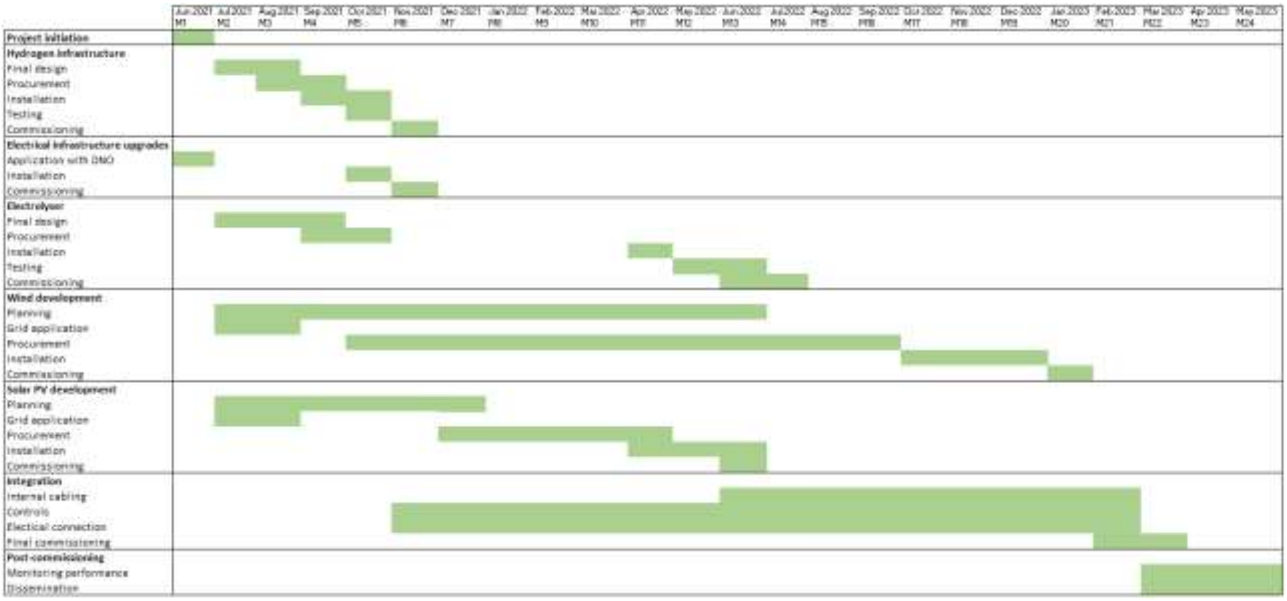

Figure 6: Phase 2 demonstrator project plan

7. Rollout potential

The rollout potential of the technical solution of hydrogen burners with green hydrogen is directly applicable to the distilling sector as well as wider industry.

7.1. Whisky industry

Under the aegis of the Scotch Whisky Association (SWA), the industry is cooperating on a Sustainability Strategy (Scotch Whisky Association, 2021) to reduce carbon emissions and promote sustainability across the sector.

A key goal within the strategy is to cut greenhouse gas 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 SWA has commissioned research to identify pathways to achieve net zero which will require exploration of new technologies.

Within the stated vision the 2040 status is targeted to be:

> *“Many of our distilleries are completely self sufficient in energy. Some are bio-refineries, using by-products to create new raw materials for other sectors.”*

It is clear from this vision are the 2040 target that the technical solution of using hydrogen created by renewable energy sources is completely aligned with the industry’s direction and will be supported in efforts to offer a decarbonisation solution.

7.2. Hydrogen Pathway to Net Zero

Hydrogen is projected to be a crucial fuel of the future low carbon energy mix in the UK, tackling the industry, heat and transport sectors specifically.

Industry: There are processes that require high temperature heat that are presently met by fossil fuels, where hydrogen can provide an efficient alternative where it can be generated and stored on site. This is particularly the case where the high temperature heat demand is intermittent and provision of adequate electrical supply capacity to meet these peaks is problematic and / or cost prohibitive. This situation is directly applicable to distilleries but also includes welding or metal forming and major chemical and materials industries.

Hydrogen has the ability to store energy and provide generation and high temperature thermal energy when required. Through the installation of hydrolysers, storage and generation at strategic locations within the national grid network, most likely through the adaption of existing gas peaking plants, excess supply can be converted to hydrogen and stored to be used to fuel peak demands. At a more local level, this use of hydrogen can also be a route to replace diesel back-up and peaking generation on more remote or independent grid networks.

Heat: Another potential role for hydrogen in the decarbonisation of UK energy which is through its use to displace natural gas as a piped fuel to homes and businesses for use in space and water heating in conventional gas boilers. On the face of it, the conversion of electricity to hydrogen, pumping it to point of use and then burning it to generate low grade heat would appear inefficient when compared with using the electricity in an air source heat pump. However there is such a large embedded investment in gas infrastructure that this may be an expedient route to achieve the high level of take up needed to meet the UK's necessarily ambitious carbon reduction targets.

Transport: Hydrogen offers an effective alternative to diesel fuel for large transport such as buses and road freight.

In all these instances, availability to green hydrogen as well as transport and storage to point of use and purchase for a competitive price are all barriers to uptake. The implementation of a green hydrogen energy system for provision of industrial heat gives industry and investor confidence in applying the technology in these other areas.

7.2.1. UK & Scottish hydrogen policy

The role of hydrogen as an energy vector is a key part of UK Government policy for decarbonisation as laid out in the Clean Growth Strategy updated in 2018 (BEIS, 2018). The Hydrogen pathway to decarbonisation uses the existing gas infrastructure which is adapted to hydrogen use and as a fuel for long distance transport.

BEIS currently operate a number of initiatives to support technology growth and demonstration in application of hydrogen. Of particular relevance to this project is the HySPRITS project on Orkney (EMEC, 2019) that assessed the feasibility of switching a distillery to hydrogen as a fuel and the potential for this approach across the distilling industry. Logan Energy designed the hydrogen delivery system for this project.

Within the Scottish Government energy strategy (Energy & Climate Change Directorate, Scottish Government, 2017), a similar approach has been taken to hydrogen as a part of the decarbonisation of the energy system. More recently, two more specific reports have been published on Scottish Hydrogen (Energy & Climate Change Directorate, Scottish Government, 2020) and the opportunity for offshore wind to green Hydrogen (Energy & Climate Change Directorate, Scottish Government, 2020).

All hydrogen strategies include support for decarbonising the distillery sector using hydrogen, generated at point of use, to displace fossil fuels. This is particularly relevant to the project as "distillery sites are often remote and not connected to the gas distribution network".

7.2.2. Hydrogen policy support in Aberdeen, Dundee & Angus

Aberdeen has had a commitment to hydrogen for some time, having published its Hydrogen Strategy and Action plan back in 2015 (H2 Aberdeen, 2015). This focus has continued with publication in May 2020 of a Net Zero Vision and Infrastructure Plan for the City (Aberdeen City Council, 2020). This puts a strong dependence on the ability for Aberdeen and Angus to develop as a hydrogen production and storage hub and through this delivering hydrogen for heat and transport.

Within this positive policy environment there are a number of specific initiatives/projects that are underway or in advanced planning. Aberdeen City Council approved the creation of a Hydrogen Hub in the city in October 2020 (Aberdeen City Council, 2020). This initiative sets out the plan (Element Energy, 2019) to deliver the hydrogen production and storage element of the strategy with the Hub operational by the end of 2022. Whilst the initial focus of the Hub is providing transport fuel for public service vehicles (PSVs), the ambition is also to explore uses in industry and for local heat.

Angus Council commissioned Cenex to assess the transition of their vehicle fleet to low carbon alternatives. This study is expected to be completed in March 2021 and early indications are that the report will conclude that fuel cell electric vehicles (FCEVs) are the most suitable technology choice for heavier vehicles (e.g. bin lorries, trucks and large vans) due to the improved energy density, of hydrogen over batteries. The report is also expected to identify that the pattern of use of many smaller vehicles within rural local authority fleets, for example the longer miles travelled and overnighting at employee residences, may also suit FCEV vehicles better. It is likely that the outputs of this assessment will demonstrate a significant requirement for FCEV and help guide the future vehicle strategy of the Council as they move towards meeting the target of cutting council fleet emissions to 'net zero' by 2030.

7.3. Available market

The available market for the proposed technology can be assessed with reference to the scotch whisky industry initially but taking in the wider market for low carbon distilling across the global industry. This industry represents £4.9bn of exports, 21% of all UK food and drink exports and employs over 10,000 people directly in Scotland.

The SWA are very active in promoting carbon reduction within its membership and have recently commissioned a detailed assessment of the pathway to net zero for the industry (Ricardo EE, 2020). This provides a reliable assessment of the potential take-up of hydrogen as a fuel to displace higher carbon alternatives. The report covers 127 sites including 70 malt distilleries, 5 grain distilleries and 11 packaging sites.

The analysis states that 88% of emissions are related directly to distilling and this matches the energy use from gas, oil and LPG. The industry currently uses 19% oil fuels and LPG which can be taken to be locations off the mains gas grid. At 56% gas is the preferred energy source when available due to its significantly lower cost. The remaining is split as 17% electricity and 8% as renewable heat – biomass combustion or biogas from anaerobic digestion on site.

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. The 19% on oil can be targeted immediately as the infrastructure to burn fuel oil is very similar to that required for hydrogen. The distilleries currently reliant on oil would comprise approximately 50 Highlands and Islands distilleries that produce 20% of total annual scotch whisky production.

Those distilleries that use electricity can be convinced to switch to a hydrogen system given the large cost of energy they will be on. It is also probable that longer term, even distilleries currently using mains gas will be converting to hydrogen to decarbonise, making 92% of the entire existing distilling market potentially available to this technology.

8. Route to market assessment

8.1. Technology route to market

The proof of concept will enable the technology to be applied at all operational distilleries that are presently dependent on fuel oil for distillation heat. These distilleries are typically located in rural areas and can have access to space on their site for installation of additional hydrogen infrastructure and onsite renewable development. These sites will be targeted in the first instance and presented with the Arbikie case, and made aware of through dissemination previously, to show how such a solution could be replicated.

The long-term development plan will target owners of multiple distilleries. Such owners are more likely to have the 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 of the technology.

In addition to distilleries, other industrial processes that use heat such as factories, chemical plants and processing plants will be contacted to also convert them to the technology. Hydrogen is flexible in being able to be used in many existing burner and boiler systems across different industries and can therefore displace fossil fuels with minimal disruption to ongoing processes and operations. Many multi-national industrial organisations have committed to net zero emissions over their operations including smaller companies within their supply chain. These companies have already investigated onsite renewable energy. Those companies that use process heat and have made a commitment to net zero will be targeted to showcase the possibilities of using green hydrogen produced onsite through renewables as their fuel source. Adoption by major industrial users will have an enormous impact on carbon abatement and will increase confidence in the wider industry, causing a cascading uptake throughout industry.

8.2. Hydrogen route to market

Having available routes to market for hydrogen will incentivise the rollout of hydrogen technology and increase production from renewable generation. The potential applications for excess hydrogen have been assessed and provided below, with a focus on relevant regional considerations of the project.

8.2.1. Market value of green hydrogen

This business model for hydrogen fuel is best suited to distilleries that can develop and own their own renewable energy projects or are located close to other operational renewable generation sites. Scottish distilleries that run off fuel oil are often co-located in rural areas with high wind development potential and there is therefore a synergy with producing hydrogen for fuel from wind farms. If there is high curtailment of existing wind sites due to grid constraints then hydrogen can be produced at a significantly lower cost which is further advantageous for the distillery owner and the wind farm owner to make revenue from otherwise wasted energy. For Arbikie, the renewable generation will be owned by the distillery and therefore fuel will be essentially free at point of use. The savings accumulated from not spending on gas oil imports can be invested back into the business operation. Oil prices are volatile and likely to rise as more penalising carbon emissions taxes are introduced in the future.

This business case will see hydrogen exported to Aberdeen and other markets for as low as £8/kg delivered. Renewable Transport Fuel Obligation Certificates (RTFCs) would be able to be claimed as part of the transport of hydrogen. These have not been included within the financial assessment and would provide a further upside. At present, Aberdeen Council and others produce their own hydrogen using electricity purchased from the grid which is significantly more expensive than this price and will therefore be a favourable purchase price compared to grid produced hydrogen. As the hydrogen economy advances, there will be greater availability of blue and green hydrogen. Those distilleries and other industries that were unable to benefit from green hydrogen produced locally will benefit from a fall in wholesale green hydrogen prices. This is discussed in greater detail in Section 7.2.

8.2.2. Potential uses for excess hydrogen

Potential applications for excess hydrogen have been assessed and two main routes identified. Transport is considered to be the primary market that excess hydrogen will be sold to. Longer term, as more green hydrogen becomes available from replication of the project at other sites, opportunities will arise to supply green hydrogen for other process industries and potentially in peaking power plants.

Transport fuel

The use of hydrogen as a transport fuel has been extensively trialled, for example in Aberdeen's public buses. The issue of using electric vehicles for local delivery/collection was that a typical round trip of 100-120 miles for a delivery vehicle would require a recharge partway through a day. This is a particular issue for heavy good vehicle (HGV) delivery/collection (e.g. refuse) and PSVs. PSVs would normally operate continuously through the working day and the recharge time is an issue. Several hydrogen powered FCEV buses are now available on the market and these offer 350-400 mile range and benefit from refuelling in minutes.

Aberdeen has a vision to be a world leading hydrogen city and the Council are focused on developing a commercial supply of hydrogen to support its requirements to decarbonise transport, heat and industrial applications. Aberdeen has recently announced that they are seeking 500kg/day to supply the move to FCEV for Aberdeen's bus and public sector fleets. The initial demand will increase to 3.5 tonnes of hydrogen by 2030 to meet expected transport use as well as for heat and industry applications.

As Aberdeen's hydrogen bus fleet expands and demand for green hydrogen in particular increases across the city and the wider region, there is a potentially lucrative market to access if green hydrogen can be produced locally and sold for a competitive price. The economics of this projects offers that opportunity. Therefore the creation of a local hydrogen production station is proposed to displace fossil fuel usage at Arbikie and sell excess hydrogen to Aberdeen and other nearby hydrogen markets. For clarity, the system is sized so that Arbikie can displace all its distillery gas oil use. The excess green hydrogen is an unavoidable by-product of the process due to storage limitations and the inherent intermittency of renewable generation. The business case is not based on producing more hydrogen than could ever be required for Arbikie. Arbikie is not on a main public transport route, therefore there would be limited opportunity for refuelling local HGV or PSV fleets.

Wider industry

BEIS identified industry as being the second largest contributor to annual greenhouse gas emissions (after transport) with approximately 110 tCO_2/a (BEIS, 2019). Hydrogen as a fuel presents an enormous opportunity to greatly reduce the associated emissions from industry through displacement of fossil fuels. To produce green hydrogen on the necessary scale, and at the required cost, will most likely require a rapid increase in offshore wind generating capacity.

There is presently approximately 13.7 GW and 10.4 GW of installed capacity of onshore and offshore wind energy in the UK. The UK government has made a target of having 40 GW of installed offshore wind capacity by 2030. There will be a demand for this power from many competing sectors (continued decarbonisation of the electricity network, meeting future increases in demand from the electrification of heat and transport, etc.) but the decarbonisation of industry is likely to be a key area of focus given the impact on the Net Zero 2050 law-binding target.

Great Britain curtailed over 3.6 TWh of wind energy in 2020 (LCP, 2021). This could be used to create zero carbon hydrogen to be dispatched for industrial, heating and transport use. With the increase in offshore wind capacity by 2030, there is the potential for an expansive green hydrogen market.

Grid support

The technical solution applied to distilleries across the UK will result in large volumes of excess hydrogen which the sites will not have the capacity to store. A long-term market for this excess hydrogen could be to balance the UK grid as fuel for peaking plants.

As the proportion of renewable generation grows on the UK network, there is an increasing need for a plan to provide short term support to the grid when supply exceeds demand. Known as 'peaking plant' the typical configuration is a natural gas-powered standby generator. These systems earn revenue from being available on standby to support frequency response and can also earn from supporting the balancing mechanism. Peaking generators can be converted to run on hydrogen, however the cost of electrolytic green hydrogen is currently too high to make a strong financial argument to utilise for this purpose.

9. Dissemination

9.1. Completed dissemination activities

Locogen and Logan Energy 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 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 hydrogen as a fuel for decarbonisation, combined with onsite renewable generation.

Logan Energy's influence in the hydrogen industry has successfully made other companies involved in hydrogen interested in this potential route to market for green hydrogen and deployment of hydrogen infrastructure.

Marketing materials have been created covering the following areas:

- Description of the green hydrogen solution and Arbikie Highland Estate Distillery;
- Integration of the hydrogen fuel into an operation distillery;
- Creation of hydrogen using renewable energy developed onsite;
- Carbon savings 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 Scotch Whisky Association 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;
- Logan Energy dissemination to the UK Hydrogen & Fuel Cell Association;
- Individual conversations with distilleries and other industry operators;
- Arbikie 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 (e.g. renewables) and industry (e.g. whisky / distilling press.

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 and hydrogen solutions to the decarbonisation of the distilling sector and wider industrial processes. Logan Energy are members of the UK Hydrogen & Fuel Cell Association and will use established contacts within this membership to circulate information about hydrogen's role in decarbonising distilling and how these learnings can be applied to other industries and integrated with the Hydrogen pathway to Net Zero. Access to these member organisations will allow for dissemination across the whole supply chain, from manufacturers to developers and industry producers of goods.

Locogen, Logan Energy and Arbikie are all active in a number of social media channels such as LinkedIn, Twitter and Facebook and will share and discuss the various findings on these platforms.

10. Conclusions

This feasibility study assessed the ability for hydrogen to act as fuel for distillation and how it could be readily integrated for use within an existing steam based distillery. The technical feasibility for creating the hydrogen onsite through deployment of renewable energy generation was assessed and the carbon and financial savings, compared to a business as usual scenario, calculated. Arbikie Highland Estate Distillery was used as a test case, which currently uses gas oil as fuel for the steam distillation system.

The opportunity to develop onsite wind and solar PV generation to create green hydrogen through electrolysis was found to be feasible. The use of hydrogen as a fuel to displace gas oil was identified as requiring a relatively simple conversion. In this case, a separate dual fuel burner and boiler is required as the existing system does not meet the safety requirements for burning hydrogen. The existing system can however be kept to build in redundancy to the system and act as a back-up. There is adequate space for a new boiler and burner system and this can be connected to the existing pipework leading to the distillation process. There is no retrofit needed to replace any pipework after the boiler. There will therefore be no disruption to business as usual operations and in production of the spirit.

As most operational distilleries have similar steam systems to Arbikie, the technical solution of using green hydrogen as a fuel is readily replicable and can be applied across the industry. Any other industrial process that requires process heat can also use green hydrogen to displace the counterfactual fuel oil. In the early years after implementation of the Phase 2 project, distilleries that are also off the gas grid will be targeted, with further priority given to those with potential space for onsite renewable energy development to ensure suitable supplies of low cost renewable electricity. Distilleries that are off the gas grid and use fuel oil are often co-located in areas that are favourable for wind energy development, therefore offering a synergistic opportunity. Such regions can also suffer from grid export constraints, but if the generation is focused on hydrogen production for local use, export to the grid can be minimised.

Opportunity to develop onsite renewables is dependent on the distillery's location, land availability and constraints to onsite development of renewable generation (primarily wind energy). It is also possible to use existing renewable generation assets through a direct private wire grid connection, however this requires the sites to be in relatively close proximity and purchasing power for a price higher than the asset would receive from otherwise exporting electricity to the grid. As the UK dramatically expands its installed capacity of wind, particularly offshore, up to 2030 and beyond, the opportunity to create green hydrogen at a competitive price will become greater. As distilleries convert to hydrogen, this offers an important market for green hydrogen.

Giving a route to market for green hydrogen will act as a catalyst for accelerating the wider hydrogen economy based on the UK government's Hydrogen Pathway to Net Zero which will see the wider uptake of hydrogen as a fuel for transport, peaking plants, process heat and potentially blending into the gas network.

For this project it was found that 20,000 tCO_2 would be abated over 25 years. A business model has been devised to deliver the project, which includes grant funding from BEIS' green distilleries Phase 2