Department for
Business, Energy
& Industrial Strategy

Decarbonising the InchDairnie Distillery

Feasibility Report

March 2021

BEIS GREEN DISTILLERIES COMPETITION: PHASE 1 **(TRN 2564/08/2020)**

INCHDAIRNIE
DISTILLERY

ARUP

John Fergus & Co Ltd

Decarbonising the InchDairnie Distillery

Feasibility Report

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ARUP

Contents

Glossary

Acronym	Full Name
AD	Anaerobic Digestion
CHP	Combined Heat and Power
PEM	Proton Exchange Membrane
PV	Photovoltaic
RHI	Renewable Heat Incentive
Tn/hr	Tonnes per hour
WP	Work Packages

References

[1] Resource Efficient Scotland, 2019, Resource Opportunity Assessment InchDairnie Distillery

[2] Eunomia, 2019, InchDairnie Distillery Carbon Footprint

Executive Summary

This report describes the pre-feasibility of the decarbonisation of InchDairnie distillery in Glenrothes, Fife, using hydrogen gas. This hydrogen would be produced either onsite or be imported via larger scale local hydrogen suppliers. This hydrogen would be burned within a boiler that was configured to run either a blend of up to 20% hydrogen by volume in methane, or 100% hydrogen.

The report summarises the work carried out by the project team of John Fergus & Co and Arup. This work included a review of both data available on site and that available in literature and from key stakeholders. This information was used to create a design concept to produce and utilise hydrogen onsite at InchDairnie. A techno-economic model of that concept was built to determine how this system might behave if installed. Finally, the project's Phase 2 development plans were created including analysing the rollout potential and route to market for this approach.

This Phase 1 pre-feasibility study has completed all the outcomes that were set out within the application. These outcomes included:

- Developing a complete understanding of the current operation of the site at InchDairnie including the potential for solar PV, the nearby AD plant and the current site energy usage.
- Engagement with key stakeholders including the AD plant operator and hydrogen equipment manufacturers.
- Creation of a system design concept and located that design on the site that will support the decarbonisation of InchDairnie distillery out to 2030.
- Techno-economic modelling of the system design concept to show how such a system might operate.
- Assessed of different site ownership models could be implemented for the system.
- Determined that a transitional model for the project's development was likely to be the most successful, which reduces the Phase 2 capital expenditure significantly.

As a result of this work, we believe that decarbonising the InchDairnie distillery utilising hydrogen is a technically feasible project that can be delivered within the likely timescales of Phase 2 funding. Additionally, the transitional approach proposed here could be a lower capital cost way of rolling out zero carbon infrastructure for distilleries. However, economic challenges remain with the large operational costs of running the system even when most of the system is owned by others.

1 Introduction

This report describes the pre-feasibility study into decarbonising the InchDairnie Distillery in Glenrothes, Fife. It summarises the outputs of Phase 1 funding from the Green Distilleries competition and sets out how Phase 2 could be successful.

This project focussed on hydrogen within the energy system for both production and utilisation. The hydrogen could be produced by converting the gas generated at the AD plant to hydrogen onsite, through electrolysis of local renewables onsite or it could be delivered to site from other local larger scale producers. The site's process heat would be provided by a hydrogen boiler.

Phase 1 of this project was split into three work packages (WP):

- WP1 – Discovery (Section 2)
- WP2 – System Concept Design (Section 3)
- WP3 – Techno-economic modelling (Section 4)

The report concludes by describing how this system could be implemented during Phase 2:

- A description of how Phase 2 will be implemented (Section 5)
- An explanation of how this is was designed (Section 6)
- A discussion on the benefits and barriers of the Phase 2 system (Section 7)
- A costed development plan for Phase 2 (Section 8)
- A summary of how this process could be rolled out to further distilleries and its route to market (Sections 9 and 10)
- The projects dissemination plan is described the Section 11

1.1 InchDairnie Distillery

The InchDairnie Distillery is a relatively new distillery, located in Glenrothes, Fife. Production commenced in 2016, with an annual production capacity of 2 million litres of alcohol (m l alc.).

The distillery incorporates the latest process technologies and consequently the distillery's energy consumption is comparatively low, at less than 5 kWh per litre of alcohol. Much of the energy is recycled and re-used within the distillery, and the distillery's co-products, draff and pot ale, are being processed in a nearby anaerobic digestor (AD), which is supplying gas into the same grid from where the distillery takes its own supply. Figure 1 shows the site layout.

Figure 1.Site drawings of the InchDairnie site showing the distillery process buildings on the right and the warehousing on the left.

1.2 The decarbonisation project

The InchDairnie distillery has the potential to showcase different technologies to reduce the carbon intensity of its whisky production and ideally to decarbonise completely. The warehouses on site present areas capable of supporting solar photovoltaic (PV) panels to generate electricity The distillery has already carried out a study to estimate the electrical energy that could be generated from PV, but this showed that renewable electricity from PV onsite alone would not be sufficient to decarbonise the whole distillery, particularly in relation to process heat. Moreover, a self-contained, purely electricity-based solution would not be possible without significant import of electricity, which would necessitate an increase in the site's grid capacity.

The co-location of the distillery with the AD plant creates another potential opportunity to zero carbon, but the excess quantity of biomethane from the plant alone is not sufficient to provide the distillery's process heat from a renewable energy source.

Alternative or supplementary measures are required to decarbonise the distillery, and this pre-feasibility study focuses specifically on testing the production of hydrogen from different sources and using it onsite to decarbonise the distillery's process heat requirements.

The aim of this approach to decarbonising the distillery would be to displace the site's natural gas demand by using hydrogen within either the existing natural gas steam boiler (after conversion) or in a newly installed hydrogen boiler.

1.3 Aim of this pre-feasibility study

This pre-feasibility study investigates three methods of supplying hydrogen to replace natural gas. The study focuses on the potential to utilise hydrogen onsite to reduce the carbon impact of the heat required for the distilling process. The three methods for hydrogen generation are:

1. **Converting the gas generated at the co-located AD plant**.

   Hydrogen could be produced by converting the gas generated at the AD plant to hydrogen onsite

2. **Generating hydrogen via electrolysis**

   The data from the distillery's PV study will be brought into this project to determine the potential hydrogen production capacity from on-site PV generated electricity.

3. **Delivery of hydrogen to the site from other local large-scale producers.**

   Other potential local producers will be engaged to discuss their ability to supply the site with additional hydrogen.

1.4 Study boundary & approach

This pre-feasibility study for the InchDairnie decarbonisation project covers four main aspects of the potential hydrogen-based system, as shown in Figure 2:

1. Hydrogen generation by electrolyser, with power from local PV;
2. Requirements for the AD plant to produce any additional hydrogen required;
3. Hydrogen storage; and
4. The boiler system.

The distillery's carbon footprint is the subject of a previous study and this has been used to help to confirm the potential carbon savings of the proposed approach.

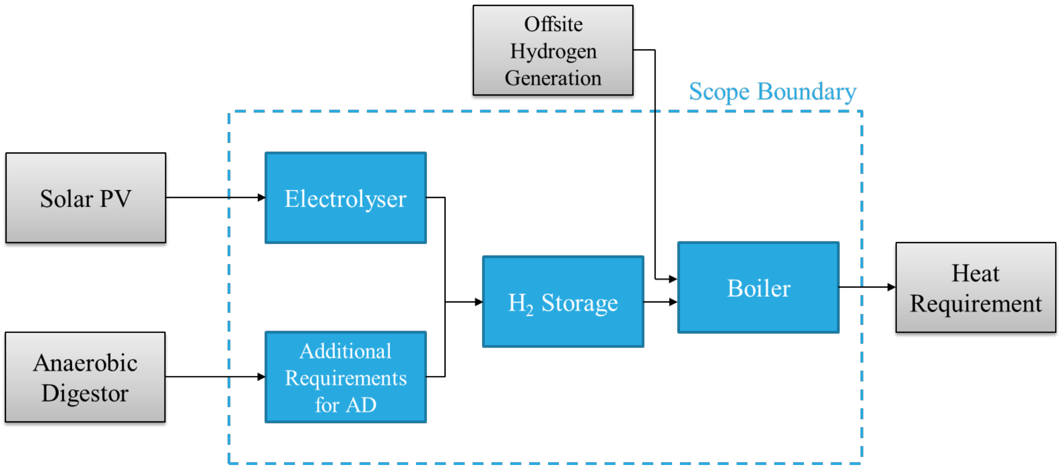

Figure 2: The overall project scope including hydrogen generation from the electrolyser, hydrogen from the AD plant, hydrogen storage and hydrogen use in the boiler.

The pre-feasibility study was carried out in three phases:

1. **Discovery** – A review of site data was undertaken alongside a literature review and stakeholder engagement to define a 'basis of design' for the hydrogen system;
2. **System design concept** – Using the basis of design to create a scenario for the deployment of hydrogen at InchDairnie;
3. **Techno-economic modelling** – Creation of a techno-economic model of the system to analyse in simple terms how it will operate, both technically and economically.

2 Discovery

2.1 Introduction

The discovery stage involved reviews of useful site data, including for energy consumption, work done previously to estimate electricity generation capacity from on-site PV, estimates of biogas available from the AD plant serving the distillery, and relevant literature, together with engagement with key stakeholders.

The InchDairnie site is already monitored extensively to ensure that the overall distilling process is as energy efficient as it possibly can be. The data available included both gas and electricity consumption over the past 12 months, estimates of electricity generation from the potential solar PV resource on-site, the carbon footprint report and the process flow diagram for the current distilling system.

2.2 Energy demand

Energy data for InchDairnie were analysed to determine how heat is used in the distillery. Currently, natural gas provides the fuel to a steam boiler that provides steam for two stills and the mashing process. The existing boiler is a 2.8Tn/hr system operating at 10bar pressure. There are plans to increase distilling capacity in the future, which would require an additional 3Tn/hr system to be installed onsite.

The gas consumption rate throughout a distilling cycle can be characterised roughly by three modes related to the requirement of steam for the stills: start-up, production and shutdown. This sequence of operation is continued throughout the year except for certain periods of shutdown, such as for planned system maintenance. The data show that, on average, four process cycles are completed each day, each one lasting a period of seven hours.

Figure 3 shows the actual half-hourly gas consumption on the InchDairnie site for a day, based on the current system and operating arrangement. This profile is representative of gas consumption on the site across the year's data that were available to review. The annual data show there is very little variation in the profile throughout the year and the peak demand does not differ with the seasons. The absolute peak consumption is just under 1,850kW.

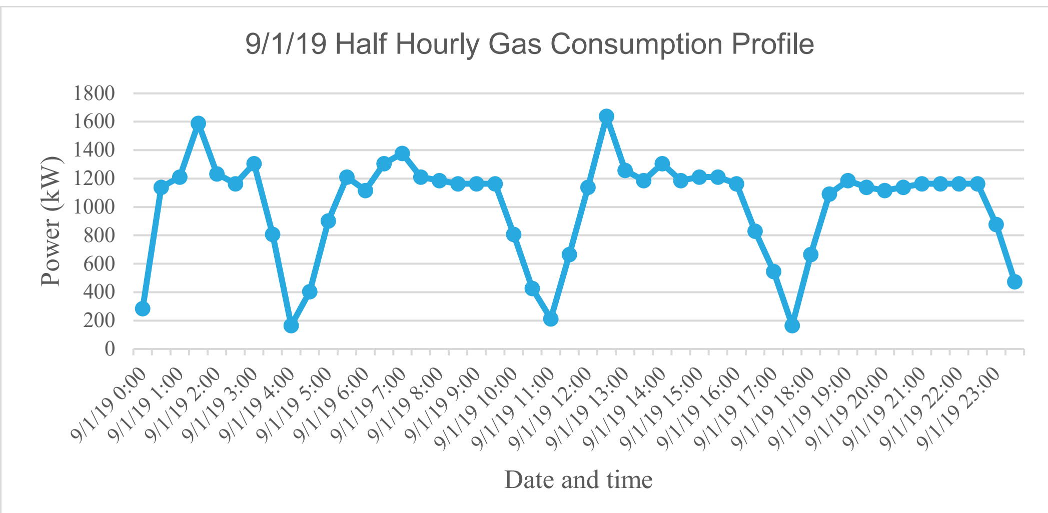

Figure 3. Half hourly gas consumption on a characteristic day

2.3 Energy generation potential on-site

2.3.1 Solar PV

The obvious and most likely location for solar PV at the distillery is the roofs of the warehouses, which currently provide approximately 12,000m^2 of available space for PV installation. A solar resource assessment has already been carried out, which estimated a potential peak generation capacity of approximately 500kWp [1].

Additionally, there are plans for InchDairnie to expand the amount of warehousing onsite in the future, which would more than double the existing warehouse roof space over the next few years and potentially extend this even further, thus increasing the area available for PVs.

2.3.2 Anaerobic digestion plant

The co-products from the distillery, draff and pot ale, are used to produce biogas in a nearby AD plant, which has a total capacity of 1MW. Further discussion of how the AD plant could integrate into InchDairnie's decarbonised energy system is provided within Section 2.5.

2.4 Literature review

A brief literature review was conducted on the 'current state-of-the-art' in terms of hydrogen production from electrolysis, hydrogen from AD and hydrogen usage in boilers.

2.4.1 Electrolysis

There are currently two market leading chemistries for electrolysis: alkaline and proton exchange membrane (PEM).

Alkaline is the more mature, with a positive operational history. An alkaline system generally has limited flexibility in terms of electrical input, i.e. rate of power change. This may make its application unsuitable for InchDairnie, where electricity output from the PV could vary very quickly due to cloud cover.

PEM systems are a relatively new technology but have emerged as a strong commercial option in recent years. They can accept variable input power easily but have a limited track record showing reliability in sustained use. This pre-feasibility assessment (Phase 1) is predicated on a PEM electrolyser, and the actual decision on the most beneficial electrolyser chemistry would be taken in the next stage (Phase 2).

2.4.2 Anaerobic digestion

Anaerobic digestion is the process whereby organic substrates degrade in the absence of oxygen, with carbon dioxide and methane as the primary products of this process. In theory, the AD process can be changed to produce hydrogen as the primary product, but a review of the readiness of current technology for hydrogen production from existing AD plants demonstrated, however, that this requires major and very lengthy conversions.

The AD plant serving InchDairnie produces biogas, which (again, theoretically) could be converted to hydrogen after the biogas has been extracted from the plant via steam methane reforming (SMR), for example. In general, however, SMR requires operation at larger scales than an individual distillery. Dry reforming could also potentially be applicable at the scale of the InchDairnie AD plant, but dry reforming remains at an early stage of development at this scale, owing to the high energy requirement and concerns over longevity.

2.4.3 Hydrogen boilers

Technological development of hydrogen boilers has previously focused on smaller domestic scale or very large industrial scale systems. There have been limited applications for either blended or pure hydrogen boilers at the low MW scale. The type of burner and the boiler shell size are the two key aspects to consider when deploying a hydrogen boiler.

For this pre-feasibility study technical advice was sought from burner and boiler manufacturers for their input during the stakeholder engagement phase.

2.5 Stakeholder engagement

Focussed stakeholder engagement helped to gauge the current state of readiness both of the site and the market for the key technologies being considered for deployment. Discussions were carried out with two solar PV developers, the AD plant operator, several boiler and burner manufacturers and other local hydrogen project developers.

The key information from the engagement includes:

- Gas usage makes up 35% of InchDairnies total carbon footprint [2].
- A potential solar PV system of around 500kWp in 2022, with the potential to add more as additional warehousing was built onsite.
- The AD plant would be unable to convert to hydrogen production. However, there is capacity in the plant to increase biomethane production that could be used by the distillery.
- The boiler and burner manufacturers were clear that the technology already exists to produce a system that can burn a blend of hydrogen and methane or 100% hydrogen. Either could be deployed in 2022.
- The main potential provider from outside the site, H100 Fife, is unlikely to be exporting hydrogen until at least 2026.

3 System Design Concept

3.1 Introduction

The original intention of this study was to look at how InchDairnie could become net-zero for its process heat through one project. However, it was clear from the work undertaken in Discovery that this will not be possible at this time, owing to several key factors:

- Multi-MW PV won't be available onsite until all the remaining warehousing is completed – likely to be late 2020s
- Catalytic reformer technology at the scale required would require further investigation over the coming years to determine viability
- The potential to start to import hydrogen to site is restricted to late 2020s.

Therefore, a realistic scenario has been developed that would see the site become net-zero by 2030 utilising both biomethane and hydrogen. Most of the equipment required will be located on site, on an area of land to the north of the main distillery building.

The following sections describe how the system could be developed between 2022 and 2030, and this deployment timeline is used in the subsequent analysis.

3.2 System in 2022-2025

Figure 4 shows a schematic of how the proposed system will be developed in 2022.

As discussed above, the only source of hydrogen at the beginning of the project will be using the electricity from the 500kWp solar PV system to electrolyse water. The electrolyser is therefore matched to the 500kW of the PV system to take advantage of the increased PV output in the summer months. Despite this, the amount of hydrogen produced in this system would be insufficient to provide a continuous 20% by volume hydrogen blend with methane. There would be a minimal amount of hydrogen storage onsite that would primarily be used during the summer months where the excess solar PV generation could lead to excess hydrogen production.

A biomethane pipeline would be constructed between the AD plant and the distillery. In 2022, this will allow the direct supply of biomethane to the site, which will be blended with the hydrogen from the solar PV.

A new 3TN/hr hydrogen ready boiler would be installed onsite alongside the existing natural gas boiler. This system would need to have the ability to operate across a range of blends (0, 5%, 10% and 20%) and would need to be controlled in real time to ensure that the system was always firing the correct blend. Utilising different blends when there is a different availability of hydrogen would minimise the use of electrical grid import.

The existing boiler will remain onsite to act as a backup system. The boiler output would follow the same profile as in Section 2.2 as there would only be two stills onsite.

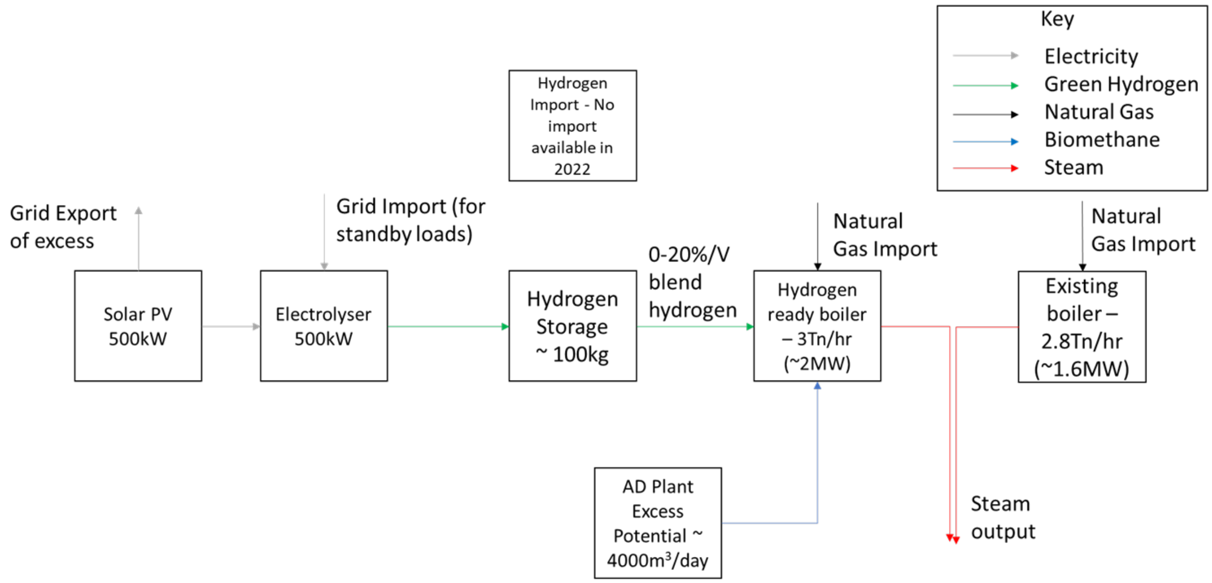

Figure 4. Schematic of the system modelled in 2022

3.3 System in 2026-2029

Figure 5 shows a schematic of how the envisaged system will be developed in 2026.

In 2026 the additional warehouses will have been built onsite together with an additional $1MW_p$ solar PV system, bringing the total onsite PV to $1.5MW_p$. An additional 1MW electrolyser would be installed to continue to ensure that as much energy supply from the PV as possible is captured during the summer. A greater amount of hydrogen storage would be deployed onsite, although this wouldn't be able to smooth the seasonal differences in hydrogen production.

The biomethane supply to site would be converted to hydrogen using an onsite catalytic reformer. This could produce up to 500kg of hydrogen per day and would be a near continuous supply.

The addition of two new stills would see the boiler operate continuously rather than in a batch process. The additional electrolytic hydrogen and the new reformed hydrogen would be combined to ensure a continuous 20% blend being fired by the boiler. As in 2022, the existing boiler would remain onsite as back-up.

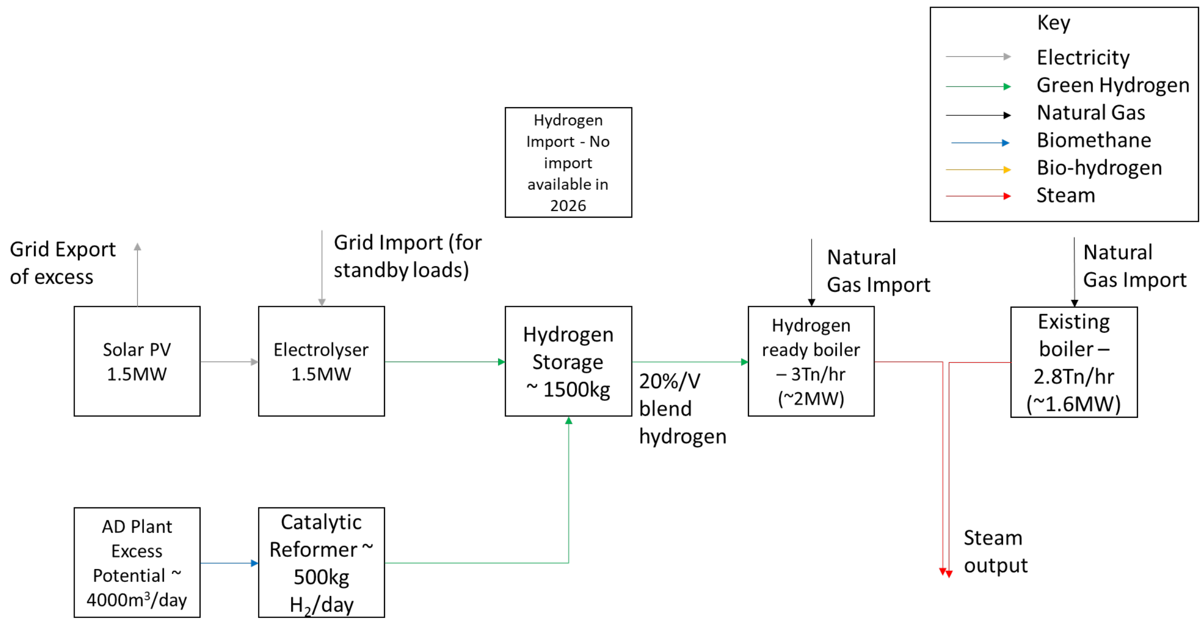

Figure 5. Schematic of the system modelled in 2026

3.4 System in 2030 and beyond

Figure 6 shows a schematic of how the envisaged system will be developed in 2030.

In 2030 more warehousing is expected to be developed onsite together with an additional 1.5MW$_p$ solar PV system, bringing the total onsite PV to 3MW$_p$. Similarly, a 2MW electrolyser would be installed, with the removal of the 500kW unit, which is likely to be obsolete by then. This would bring the electrolyser capacity to 3MW to match the solar PV capacity. This again will continue to ensure as much as possible of the electricity supplied from the PV during the summer is captured. More hydrogen storage would be deployed onsite to take advantage of the increased hydrogen generation.

The catalytic reformer would remain in place continuing to produce up to 500kg of hydrogen per day. Small-scale CCS would be deployed on the system to create a carbon negative project.

The boiler remains operating continuously rather than in a batch process. To reach 100% hydrogen for process heat by 2030, some electricity grid import would be required. It is anticipated that by 2030 the Scottish electrical grid will be decarbonised, providing net zero electricity. The original natural gas boiler would be swapped out to a hydrogen-ready boiler that could operate with a hydrogen/methane blend if required as a backup. Some ability to use methane direct from the gas grid is retained onsite for resilience. It may also be that there is a percentage of hydrogen blended within the gas grid by this point, so installing a hydrogen ready boiler will help to future proof for this possibility.

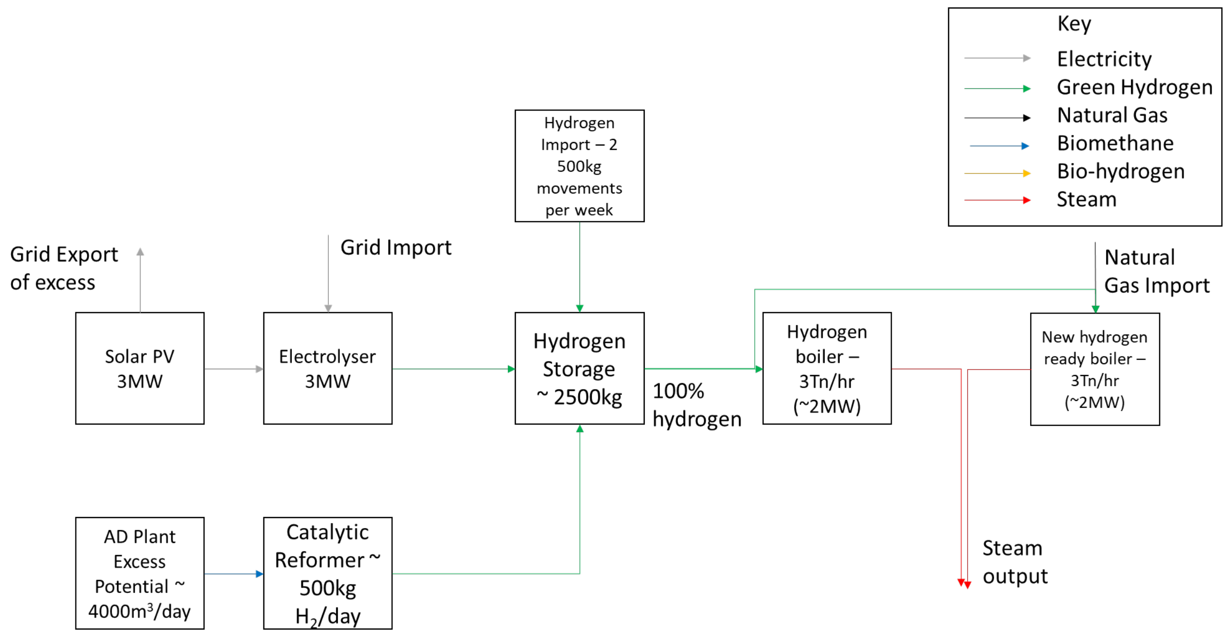

Figure 6. Schematic of the system modelled in 2030

4 Techno-Economic Modelling

To examine in more detail the scenarios presented in Section 3, a discounted cashflow model has been built to compare and test the operational constraints of the technology options, and consequently, compare the economic results and ownership options.

4.1.1 2022 results

In 2022, the solar PV and electrolyser system can't always produce sufficient hydrogen to allow for a 20% blend. Having a constant 20% blend restriction would require too much grid electricity (~60% of total electrolyser requirement from grid). Due to the significant drop off in PV output during the winter months, even a continuous 5% blend would require some grid electricity (~10%).

The system was initially modelled at 5%, 10% and 20% blend set-points, as set out above, to determine how different blends would impact on the site's ability to produce sufficient hydrogen given there is no biohydrogen available in 2022. To provide a continuous 20% blend, over 620,000kWh of grid import would be required. This effectively meant that the electrolyser would be almost continuously running, even when there was no solar. Additionally, at 5% continuous blend, there were times during the summer where the electrolyser would be switched off, despite availability of PV. This resulted in only around 50% of the potential hydrogen being produced.

The difficulty with sticking to a single hydrogen blend resulted in the development of a model where the blend was changed between 0, 5%, 10% and 20% depending on what hydrogen was available. This was to mimic the use of a smarter control system. This eliminated the requirement for grid electricity during this stage and allows all the PV to be used to produce hydrogen. The model also verified that 100kg of hydrogen storage is sufficient at this stage to ensure all the hydrogen can be used. However, this system is still primarily powered using methane (75%) or biomethane (22%) with 97% of the required energy in 2022 coming from these sources. This small reduction still produces a significant carbon saving over the early years of the project.

4.1.2 2026 results

By 2026, the two new stills installed would result in the hydrogen demand from the boiler becoming near continuous. The addition of the continuous hydrogen from the catalytic reformer allows hydrogen to meet 20% of this demand. Any excess hydrogen produced with solar PV electricity is stored in a larger storage tank for when there might be biomethane interruptions from the AD plant, e.g. during AD plant maintenance. This maximises the use of storage onsite. However, running at 20% restricts the total amount of hydrogen that can be used to provide energy. Only 1,000,000kWh of hydrogen are used in this phase despite a much larger production capacity.

Given the restricted hydrogen usage, a further scenario was developed to investigate how the system would work if the boiler was converted to 100% hydrogen in 2026, with the remaining energy being provided through the existing natural gas boiler. This allowed the system to have a much higher utilisation of hydrogen with over 6,800,000kWh being burned in 2026 scenario B. The amount of hydrogen storage required in this scenario also drops substantially as you are using hydrogen as and when you have it. Despite having to utilise the existing boiler at 100% methane, this scenario also sees a significant drop in the amount of gas grid methane required onsite – down from 13,500,000kWh to 7,500,000kWh. Due to the late development of this scenario, it was not possible to incorporated it into the economic modelling carried out.

4.1.3 2030 results

At this point all the primary energy onsite is supplied by hydrogen. However, a substantial amount of grid electricity is required to power the electrolyser when there is no PV derived electricity available. It is envisaged that by 2030 this grid electricity will be zero carbon and that any emissions associated with this would be offset by the addition of CCS to the catalytic reformer. Additionally, hydrogen can now be imported from other local sources. However, given the added cost of this, it is restricted to two 500kg tube trailers per week. This would allow the system to import significant quantities of hydrogen during the winter months due to the drop off in PV output.

4.1.4 Technical results - summary

One of the key parameters from the modelling is the percentage of the site's energy that comes from hydrogen and how this evolves throughout the transition. Figure 7 shows how this changes from 2022 to 2030.

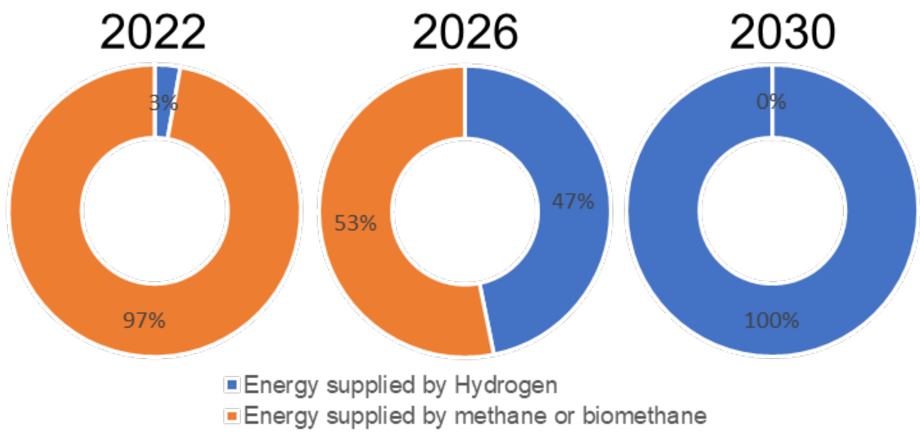

Figure 7. The proportion of hydrogen used within the system between 2022 and 2030

4.2 Carbon emissions

The primary motive of this project is to reduce carbon emission associated with process heat used in the distillation process. A comparative graph showing the impact of hydrogen blending on the carbon emissions 2022 to 2026 is shown in Figure 8. As would be expected the higher the hydrogen blend, the lower the resultant carbon emissions, expressed as kg CO_2.

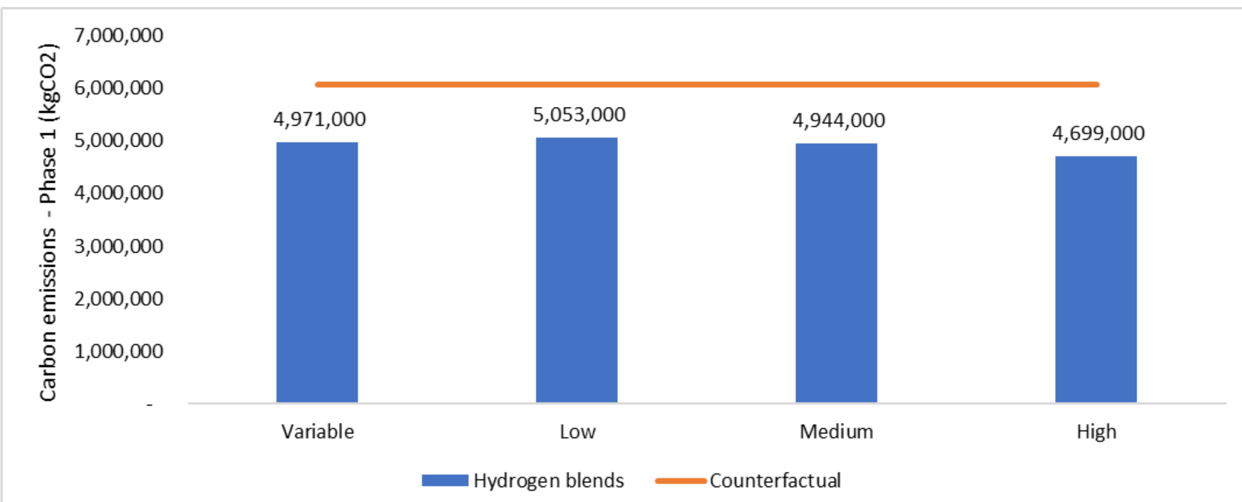

Figure 8. Carbon emissions from the system during the first four years of operation compared to the counterfactual (continuing with the current natural gas system).

The overall carbon emissions over a 40 year project lifetime are shown in Figure 9 in comparison to the potential emissions from a gas boiler. By converting to hydrogen from biomethane and using CCS, the emissions reduce significantly. If small-scale CCS exists in 2030, deploying it on this site would be a significant additional benefit and allow the site to be carbon negative. Both Figure 8 and Figure 9 show that the blending of hydrogen during the first phase of the project, has little impact on the overall carbon emissions compared to what can be done utilising the technology deployed in 2030.

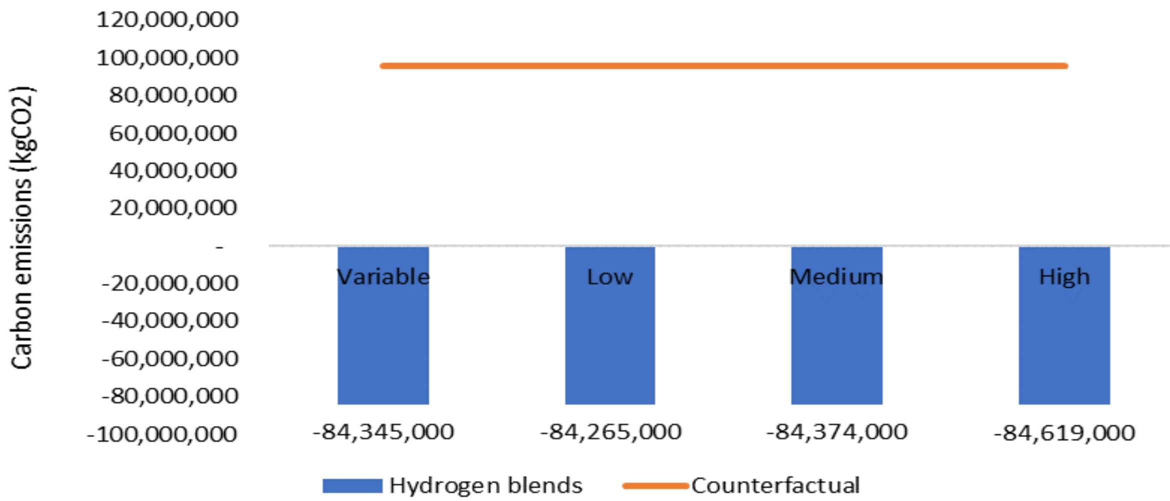

Figure 9. Whole system carbon emissions over a 40-year lifespan. This assumes that from 2030 onwards carbon capture technology can be installed onto the catalytic reformer resulting in the system becoming carbon negative.

4.3 Economic model

The economic assessment was carried out for several different ownership structures. Impacts of differing ownership models on the capital and operational costs are described further in this section.

Understanding the potential economic costs and benefits of the project is important at this stage to optimise the commercial approach. Results shown in the following graphs and tables are based on the variable blend of hydrogen and they show that the hydrogen blends have a minimal impact of the economic results. Based on the assumptions described above, the capital costs of each ownership structure are shown in Table 1.

Table 1 Total capital costs across the whole transitional project (2022-2030)

Capital Costs	**Full ownership**	**PV rental**	**Rental max**
Catalytic reformer (£)	653,600	653,600	-
Solar PV (£)	2,008,400	-	-
Electrolyser (£)	2,322,300	2,322,300	-
Hydrogen Storage (£)	649,800	649,800	649,800
Hydrogen Ready Boiler (£)	120,000	120,000	120,000
Hydrogen Boiler (£)	82,000	82,000	82,000
CCS (£)	213,800	213,800	-
Hydrogen boiler conversion (£)	26,100	26,100	26,100
Total (£)	6,076,100	4,067,700	878,000

The first option modelled was the full ownership structure. This resulted in higher capital and replacement costs but lower resultant costs for fuel. In the PV rental option, the capital costs are slightly reduced, although the high cost items, such as the electrolyser are still purchased by the distillery. The cost projections of this ownership structure are like full ownership. The final ownership structure modelled is rental max. In this option the electrolyser and catalytic reformer are paid for by a third party. The Capital costs are significantly lower than in both other options. The operational costs are higher. A discount rate of 3.5% is applied across all scenarios. Therefore, the cost incurred in the future will be less than the initial capital costs.

In Table 2, the economic results of each of the scenarios are presented. All the results are shown as net present costs (NPC), after discounting. This also shows the revenue that could be obtained by purchasing the PV plant. This is comparatively low when compared with the outgoing costs of the project. The levelised cost of energy is a useful metric to compare the scenarios against. Options 1 & 2 have similar levelised costs of energy at c. 8p/kWh. The rental option is significantly lower at 4.8p/kWh. As the spend is more evenly distributed across a 40-year period the costs are overall less than the high capital investment options.

Table 2 Economic results between 2022 and 2062

Economic Results	Full Ownership	PV Rental	Rental Max
CAPEX NPC (£)	5,862,000	3,854,000	878,000
REPEX NPC (£)	3,484,000	2,285,000	508,000
Project Costs NPC (£)	3,019,000	1,985,000	452,000
OPEX NPC (£)	27,484,000	33,194,000	22,245,000
TOTEX NPC (£)	39,849,000	41,317,000	24,083,000
Revenue NPC (£)	32,000	-	-
Levelised cost (p/kWh)	7.9	8.2	4.8
Cost of Carbon avoided (£/tCO2)	225	233	136

All these options result in a significantly higher operational cost than the current site running costs for natural gas. The rental max option is clearly the most appealing economically. Potential roles and responsibilities for ownership, investment and operation of this system for InchDairnie will be explored through stakeholder engagement in follow-on work in Phase 2.

This concludes the feasibility work completed during Phase 1. The following sections provide information to support the potential Phase 2 of the project.

5 Description of the Demonstration Project

‘Not just another distillery’ was InchDairnie’s vision from the outset and the ability to produce a traditional product with a low carbon footprint is part of its differentiation strategy in challenging markets.

A new distillery, designed to be energy efficient and low carbon, and removed from the need to retrofit ageing infrastructure, means InchDairnie is free to use different and more energy efficient technologies throughout the process and supporting services.

Given InchDairnie's clear low carbon philosophy, adding in a zero-carbon energy system is a logical extension of the current highly efficient process. Phase 2 of InchDairnie's decarbonisation project would see the beginning of the implementation of a gas system that would remove carbon from its process heat. The pre-feasibility work carried out in phase 1 demonstrated that an immediate jump to a zero-carbon system would not be possible owing to a number of constraints onsite including:

- Limited space available for solar PV outside of the warehouse roofing
- No possibility of installing wind power
- Limited excess biogas production from the AD plant
- Importing green hydrogen from other local projects is likely to be unavailable before 2026.

Therefore, the best approach is to implement the system in steps out to 2030.

InchDairnie is relatively small in terms of the Scotch Whisky industry and it has outsourced many of its support functions. This enables the management team to focus on both producing and developing a premium whisky brand. Whilst sustainability is one of the core pillars of the brand's proposition, it must not create a 'tail wagging the dog' situation. Moreover, the health and safety of the team at the distillery and all visitors is paramount, and the addition of new technology may present risks needing additional site management during the implementation and operational stages.

InchDairnie is primarily a distillery and has no wish to enter the energy supply market. Therefore, the full rental option for the system is thought to be the best fitting ownership model. During the initial part of phase 2, Inchdairnie would seek a partner who could build, own, and operate the system that would power the distillery including the PV, electrolyser, storage and biomethane supply. Based on the modelling presented in Section 4, the system built during Phase 2 would be the 2022 system as described in Section 3 and summarised here:

- Solar PV installed on all available warehouse roof spaces, which would likely total over 500kWp.
- 500kW electrolyser, which wouldn't require any additional grid capacity.
- 100kg of hydrogen storage to improve resilience in ability to blend.
- New pipeline from the AD plant to supply biomethane to create the required blend.
- A 3Tn/hr hydrogen ready boiler with a burner that can accept a blend and a gas train for 0-20% hydrogen mixtures. The control system will be designed such that the boiler can transition from one blend to another during drop in output required between processes.

- Ancillary systems including water purification, hydrogen pipework, electrical infrastructure, health and safety systems, and controls

This system would be an exemplar, demonstrating how distilleries could make a transition from natural gas to hydrogen. Most sites will find it a challenging step both technically and economically to move straight from natural gas to methane. Demonstrating a transitionary technology will be beneficial to the distilling sector as it will show reaching net zero can be achieved in steps rather than in one leap.

The routemap to 2030 detailed in the scenarios set out in Section 3 would allow Inchdairnie to reach net-zero process heat.

6 Design of Demonstration Project

The following section sets out how the design process will proceed into Phase 2 of the project including how such a demonstration could be built.

6.1 Basis of Design

Following the review of site data and relevant literature and stakeholder engagement, a concept design was developed and set out in a reference ‘basis of design’ document. An update to this document would be the first step of Phase 2, ensuring all the key data for the subsequent system design was captured.

To develop the concept design, three key pieces of information were required:

- The site energy usage (see Figure 3)
- The site’s PV potential (500kWp was used following stakeholder engagement)
- The site’s AD potential (4,000m^3 per day excess biogas was used following stakeholder engagement).

6.2 Phase 2

Detailed design of the system will be completed in Phase 2, with the main system components comprising those listed in Section 5.

The solar PV directly feeds the electrolyser system with a very limited amount of excess PV production being exported to the grid. The electrolyser will require a grid connection, but this will only be used to supply the electricity the electrolyser requires during standby operations. The current grid connection onsite would be sized appropriately for this purpose. The hydrogen from the electrolyser will first be stored prior to usage within the boiler. No hydrogen import is available at this stage although discussions will continue to be had with potential suppliers during Phase 2. The hydrogen will be blended with biomethane with any additional methane required supplied by the gas grid. The biomethane/hydrogen blend will then be burned in the hydrogen ready 3Tn/hr steam boiler. The existing boiler will remain onsite to provide added resilience.

Figure 10 shows the layout of the system within the InchDairnie distillery site. The hydrogen system including the containerised electrolyser and hydrogen storage, has been located in an area away from the maturation warehouses, and therefore a potential of overlapping hazardous areas, to the north of the main distillery buildings. The boiler is located on the strip of land where space for a second boiler was located in the initial site design. This will be close to the existing boiler and so work will need to be undertaken in Phase 2 to determine whether these can be safely located this close to each other.

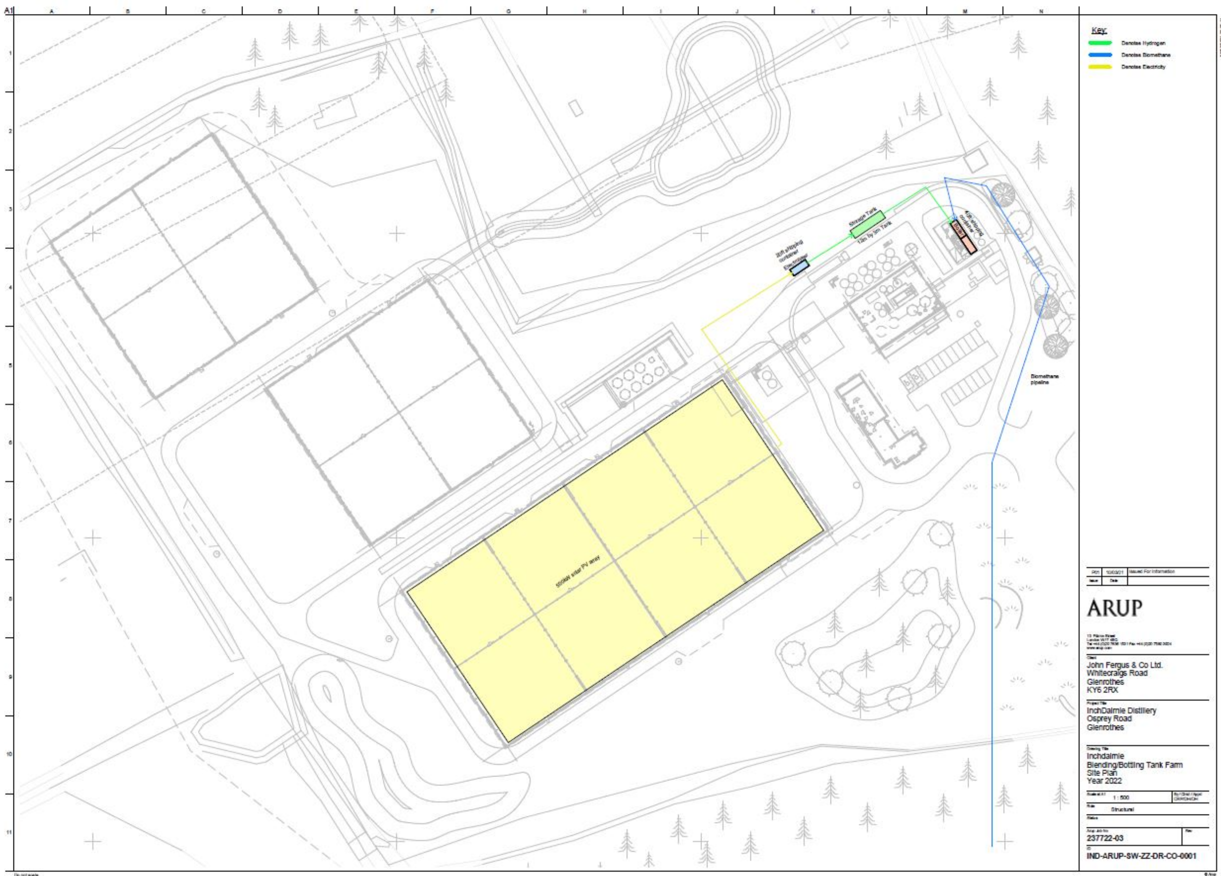

Figure 10. Phase 2 installed system including PV, electrolyser, storage, boiler and biomethane pipeline.

7 Benefits and Barriers

There is a clear routemap for how a system like this can be deployed at other distilleries. This section sets out the barriers and the benefits of deploying this system at InchDairnie.

7.1 Benefits

This system will allow InchDairnie to meet the zero-carbon vision that it is striving towards. Doing this in a transitional way will reduce the burden on the distillery across the early stages of the project. It will delay the most significant capital investments to a period where the company will have started to sell whisky. In addition, compared to single source hydrogen projects, utilising hydrogen from multiple sources will greatly improve the site's resilience and remove any potential barriers from the intermittency of renewable generation.

This transitional system could be built with a capital expenditure in the region of £1.3M with additional project associated costs of around £300k. The cost of detailed design, planning and procurement is expected to add approximately £450k. This would include the required solar PV, electrolyser, hydrogen storage and hydrogen boiler. This is a comparatively small investment to begin the decarbonisation process. The ultimate (2030) system would see InchDairnie's process heat be supplied from 100% zero carbon sources, whilst allowing the current high cost of these options to reduce. The Phase 2 system would see carbon emissions reduce by around 18%, with the carbon emissions coming from the grid imported natural gas required to support the biomethane.

This process could be used as a blueprint of how to decarbonise a distillery in a step-by-step way. This can be both scalable and replicable across many other distilleries. Ensuring a consistent approach to decarbonisation of these sites will be better value for money than many different bespoke approaches. Installing similar installations at a similar time will also result in benefits from being able to reach economies of scale. The hydrogen ready boilers will reduce in price as more are required due to no longer requiring individual assembly.

Additionally, a multi-source method for procuring hydrogen would improve the resilience of the system. Other distilleries may use wind energy, rather than solar energy or use both rather than an AD plant. However, having a multi-source supply chain reduces the chances of system downtime occurring due to a lack of hydrogen, which has been a common theme on the current generation of hydrogen demonstration projects. There is also the potential to use either the oxygen or potentially and carbon dioxide produced onsite. Both of these products, when properly produced, could bring added value to the system.

7.2 Barriers

This system is not without barriers to a successful implementation. The primary barrier is the economic competitiveness of the system compared with the current natural gas heating system. Even assuming the Rental Max option preferred by InchDairnie, the modelling suggests the operational cost to the distillery would be in the region of £400,000 per year between 2022 and 2026. This is significantly more than InchDairnie pays now for natural gas. This consists mainly of the increased cost of the hydrogen gas when compared to natural gas. This is a known issue with a conversion to hydrogen and some support mechanism is required to help bring this gap in the short term for any site attempting to utilise hydrogen.

Other barriers that would need to be addressed in Phase 2 would be:

- Health & Safety risks – There are particular risks associated with installing solar PV systems on the roof of a maturation warehouse due to the increased fire risk that such a building poses. The addition of hydrogen to the site could also complicate processes required under COMAH regulations. These risks will be repeated at any distillery site that includes maturation warehouses. Therefore, this project can set the standard for how to deal with these issues.
- Replicability of this approach on some distillery sites – InchDairnie is not necessarily representative of most distilleries in the UK. The distillery matures its own whisky, which means that it has a significant amount of warehousing upon which to place solar PV. Additionally, it is on the mains gas grid, which means the system already has access to lower carbon heat sources (i.e. natural gas) than many other distilleries (i.e. fuel oil). However, the multi-source and transitional process is still likely to be applicable to other sites.
- Continued requirement for grid electricity – although only minimal grid electricity would be required during the Phase 2 build, as the routemap reaches 2030 further grid electricity will be required despite some hydrogen being imported from other producers. The need for this would be significantly reduced if the main gas grid in the area was to be converted to either a hydrogen blend or 100% hydrogen.
- Catalytic reformer technology – further stakeholder engagement would be required to determine the likelihood of implementing a small-scale reformer onsite before 2026. It would be possible to deploy current technology as there are some providers who offer this. However, further work is required to understand the detail of how this might integrate within the energy system.
- Regulation and Standards – a gap remains in the regulation and standards around hydrogen energy systems. Even though this is a small-scale hydrogen production site, it is likely that it will require a Pollution Prevention and Control permit. Additionally, there are few clear standards for hydrogen systems at this scale.

8 Costed Development Plan

This section details how the Phase 2 project would be carried out including key tasks, a programme and budget costs.

8.1 Key tasks & programme

Table 3 provides a breakdown of the key tasks proposed for Phase 2 and shows the programme for Phase 2, which should see successful implementation of the initial elements of the overall project by the end of 2022.

One of the key drivers of this timeline is the likely lead time on electrolyser systems. Current evidence suggests a likely electrolyser lead time of 12 months from the point of purchase. This purchase would be carried out following the detailed design process and a procurement process.

Key early pieces of work in Phase 2 would include:

- Reach out to potential ownership partners – It is clear from the economic model that the best return for InchDairnie would be if an external company owned and operated all the energy systems onsite. This project would require a new partner to take on this role.
- Further engagement with AD plant operator – to determine the likely cost point for the supply of biomethane. It wasn't possible to reach this level of detail in feasibility.
- Engagement with Electrolyser and Reformer OEMs – to understand the detail of potential electrolyser performance, what the likely lead time for the system would be and to determine the likely timeframe for potential implementation of a catalytic reformer onsite beyond Phase 2.
- Complete detailed design – the current design is a feasibility level design and would need further work prior to implementation.
- Develop planning and consents strategy – the system will likely require planning permission, despite all the components being containerised, so early engagement with the Fife Council will be vital.

Table 3. Phase 2 work package tasks

Work Package No. 1 - Detailed Design	
• Update Basis of Design • Further data analysis • Stakeholder engagement • Market study • Update system design for procurement	• Solar PV design • Electrolyser design • Biomethane design • Hydrogen boiler design • Hazard identification and assessment
Work Package No. 2 - Planning & Consenting	
• Assess planning and consenting requirements • Develop strategy	• Create and submit any permitting requirements • Third party arrangements such as SPEN and Scottish Water

• Create and submit planning application	
Work Package No. 3 - Procurement	
• Develop procurement strategy • Procure long lead items such as electrolyser	• Procure system installation
Work Package No. 4 - Installation, Testing and Commissioning	
• Site set up • System deliveries • Construction • Electrolyser installation	• Boiler installation • Storage installation • Site commissioning
Work Package No. 5 - Project Management	
• Engage with prospective owner/operator partners • Day-to-day management	• Programme management • Final reporting

Table 4. Phase 2 programme

Work Package	Task	2021							2022												
Detailed Design	Project Kick Off	■																			
	Update Basis of Design	■																			
	Stakeholder engagement	■	■	■	■																
	Market study		■	■	■																
	Procurement level system design		■	■	■																
	Full system design including hazards					■	■	■	■	■	■	■									
Planning & Consenting	Assess planning and consenting requirements	■	■																		
	Develop strategy			■	■	■															
	Planning application						■	■	■	■	■	■									
	Permits and consents						■	■	■	■	■	■									
	Third party agreements		■	■	■	■	■														
Procurement	Develop procurement strategy	■	■																		

	Procure long lead items – develop tender
	Electrolyser lead time
	Procure system installation
Install, test and commission	Site set up
	System deliveries
	Boiler installation
	Electrolyser installation
	Storage installation
	Site commissioning
Project Management	Refine programme
	Engage with prospective owner/operators
	Reporting

8.2 Budget costs

Table 5 shows the budget cost breakdown for Phase 2 i.e. the 2022 system assessed above. These cost estimates are feasibility level estimates and therefore the final costs could differ significantly from these presented here.

Table 5. Phase 2 estimated cost breakdown

Work Package	Cost
Detailed Design	£150,000
Planning and Consenting	£150,000
Procurement	£50,000
System Capex	£1,300,000
Install, Test and Commission	£260,000
Project Management	£150,000
Total	£2,060,000

9 Potential for Rollout

The distillery sector is one that could see significant growth in the coming years with spirits in high demand. Scotland has a clear heritage selling point for whisky and this gives it great potential to increase output and hence value to the economy. Unfortunately, the sector remains comparatively carbon intensive, with few distilleries having undertaken energy efficiency measures or switched to a low or zero carbon fuel.

When determining how to support distilleries to reach net zero, whole site energy systems must be considered, including the potential for onsite energy production through renewable electricity, the use of distillery waste to provide energy and the potential use of other local decarbonised fuel sources. This study looks at all three of these options at InchDairnie.

Once successfully commercialised, hydrogen has massive potential to be the key link to whole energy system integration. This will make distillery sites both zero carbon and more energy secure. When combined with energy efficiency measures, like those already deployed at InchDairnie, hydrogen can allow a distillery to become the key energy vector for these sites. This approach could ultimately be replicated in several sectors where decarbonisation through renewable electricity is particularly challenging. For example, in sectors where high temperatures are required or in areas where there are constraints on the local electricity grid.

In particular, the selling point of this project is the multi-vector nature of hydrogen production methods. The approach presented could be applied to other sites on a similar scale to InchDairnie to understand how, and when, hydrogen could become a viable decarbonisation option. By taking a whole system view, there is potential to see additional revenue streams from taking this type of multi-source approach. The oxygen produced from the electrolysis process could be sold locally for a variety of purposes. If using a catalytic reformer, perhaps the CO_2 could be captured and sold for carbonation to other food and drinks organisations.

This solution is equally applicable for new build or retrofitting distilleries. The technical challenges around running InchDairnie’s existing boiler on a hydrogen blend should not be repeated at other sites as this is a site-specific problem. Clearly energy efficiency measures on either a new build or retrofit would be the first step towards reducing the overall energy required. This is particularly important with hydrogen as every kWh saved at the point of usage reduces the amount of input energy required by around 50% given the conversion efficiency of an electrolyser system.

10 Route to Market Assessment

The information gathered through Phase 1 and Phase 2 could be used to support the use of hydrogen across the distillery sector. This transitional approach, where distilleries wouldn’t need to find large capital sums in the early stages of the decarbonisation journey, could be applicable to many sites including non-distilleries. This concept also mirrors the wider political decarbonisation process where smaller steps are taken in the early years to gather the evidence for use and reduce costs.

The modelling carried out on this system shows clearly that such a system and approach can be used from a technical viewpoint. However, issues remain around the economic viability of using hydrogen to offset natural gas usage. Understanding how some of these economic issues could be avoided or alleviated would be a key challenge for Phase 2. The observed reduction in costs of hydrogen systems overtime will help to encourage more deployment, which will in-turn help to reduce costs.

11 Dissemination

During Phase 1, the project team has already undertaken several dissemination activities, ranging from national exposure for the project on television hitting the largest possible audience to presenting at industry specific conferences. Other activities proposed include:

- A PR campaign will be initiated with press releases to the global press contacts already known to the company.
- The Institute of Brewing and Distilling publishes a monthly magazine the 'Brewer and Distiller International' which reaches a global network of distillers. Articles will be proposed for publication in the magazine.
- The industry's trade association the SWA will actively disseminate the information throughout its membership.
- The Industry holds a conference every two years the Worldwide Distilled Spirits Conference The opportunity will be taken to present a paper and or poster at this conference.
- The company will publish this report on its website and will run a PR campaign sign posting the report.

During Phase 2, we will continue to showcase how a hydrogen economy can support the decarbonisation of the distillery sector. The results generated from running the system will be disseminated to as wide an audience as possible through similar channels to those developed during Phase 1. We will continue to identify key stakeholders and, where possible, engage with them to disseminate knowledge, develop opportunities, and consider constraints.

12 Conclusions

Phase 1 has shown that the technologies proposed present a technically feasible way for InchDairnie distillery to achieve net-zero process heat by 2030. Stakeholder engagement has shown that the technology for this transition is already available, but it maintains a cost premium due to the one-off nature of the system elements.

The Phase 2 system design would consist of solar PV electrolysis and a biomethane pipeline. The techno-economic modelling suggests that transitioning to a net-zero system over several years is possible and can result in significant carbon savings. The use of hydrogen on site would rise from 3% of the energy in 2022 to 100% in 2030. Carbon savings of around 18% would be made by installing the Phase 2 system from both the use of hydrogen and biomethane. By 2030, due to the possibility of using carbon capture when reforming the biomethane, the site could be significantly carbon negative.

Economic barriers to the implementation of such a system remain, however, and this has been observed throughout most of the current generation of hydrogen projects. The Rental Max delivery option appears to be the most economically appealing for InchDairnie. However, the potential owner/operator in this scenario would still face considerable challenges.

This transitional approach is likely to be replicable across several distillery sites throughout the UK. It can decrease initial capital costs, whilst still reducing carbon dioxide emissions. It requires a lower initial capital investment that a jump straight to zero carbon. Additionally, sourcing hydrogen from multiple sources will improve the resilience of any hydrogen system. These sources could be from distillery waste products, as this project, they could be from either wind or solar PV electrolysis, or they could even be from the gas grid if that moves towards hydrogen.

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