Project HyLaddie

BEIS GREEN DISTILLERIES COMPETITION

PHASE 1 REPORT

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Glossary

BAT	Best Available Technology
BAU	Business as Usual
BEIS	Department for Business, Energy and Industrial Strategy
CAPEX	Capital Expenditure
COMAH	Control of Major Accident Hazards
COP26	The 2021 United Nations Climate Change Conference
CHP	Combined Heat and Power
DCC™	Dynamic Combustion Chamber
EPC	Engineering, Procurement and Construction
ESG	Environmental, Social and Governance
FD	Forced Draft
FDF	Food and Drink Federation
GHG	Greenhouse Gas
HESCO	Hydrogen Energy Services Company
HSE	Health and Safety Executive
HYCYMRU	Welsh Hydrogen and Fuel Cell Association
IED	Industrial Emissions Directive
I&C	Industrial and Commercial
ID	Induced Draft
MAGB	Malting Association of Great Britain
MEL	Master Equipment List
MFO	Medium Fuel Oil
MCPD	Medium Combustion Plant Directive
NTP	Notice to Proceed
NOx	Nitrogen Oxides
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
PFD	Process Flow Diagram
PM	Particulate Matter
RHI	Renewable Heat Incentive
SHFCA	Scottish Hydrogen and Fuel Cell Association
SO_X	Sulphur Oxides
TTW	Tank to Wheel
UKHFCA	United Kingdom Hydrogen and Fuel Cell Association
WTT	Well to Tank

Executive Summary

This report is the culmination of the HyLaddie Phase 1 study for the BEIS Green Distilleries Competition. The Phase 1 study was executed by the project partners Protium, Deuterium, Bruichladdich and ITPEnergised and presents a configuration for the demonstration of a novel and revolutionary zero emission boiler technology, the DCC™, at the Bruichladdich Distillery on Islay, Scotland.

The results of the Phase 1 study provide a technically feasible, commercially robust, and accelerated configuration for deploying the DCC™ technology and associated electrolyser and storage at Bruichladdich by the end of 2021. It is envisaged that this project schedule will also align equipment delivery to the Bruichladdich site with COP26 which can be used as showpiece for the distillery. The aim of the Phase 2 demonstration of the DCC™ will be to reduce the scale-up and roll-out risks identified in Phase 1 and refine the commercial viability of a full-scale project including dedicated renewables. In particular, the demonstration will look to:

- Show that the DCC™ system is a technically and commercially viable alternative to meeting the steam demand at Bruichladdich.
- De-risk uncertainty around the resilience of the DCC™ system during continuous operations.
- Increase understanding of how hydrogen is handled and consumed on a commercial distillery.
- Provide guidance for new DCC™ adopters to help them to understand the operational requirement of the system and how it can interface with their existing processes.

The Phase 2 demonstration project will reduce the CO_2e emissions at the Distillery by 15% with emissions to be reduced by 100% with the full scale. The estimated CAPEX of the Phase 2 demonstration project at £2,994,000, and subject to the final configuration the Phase 1 study indicates that there is a route to demonstrating a lower total energy cost from using the DCC™ and hydrogen even during the initial 12 months of operation. Modelling also indicates that as the project is scaled up and coupled with renewable energy, Bruichladdich can achieve significant cost and emission savings.

1. Project Overview

The HyLaddie project is a collaboration between Bruichladdich Distillery, Protium, Deuterium and ITPEnergised. Bruichladdich is located on the southwestern tip of the remote Hebridean Island of Islay, with operations dating back to the 1880s. The Distillery produces four unique spirits using locally grown barley and distributes its products globally. In April 2019 Bruichladdich announced its intention to run all operations on renewable energy, with a goal to decarbonise distillation by 2025.

The Bruichladdich Distillery currently operates one industrial-sized boiler which has the capacity to meet the sites steam demand of ~6 t/h, with limited variations throughout the year. The boiler is fed by medium fuel oil (MFO) since there is no natural gas connection to the island where the Distillery is located. A total of 922,000 litres of MFO were used by the distillery for steam generation during 2019, estimates put future demand at well over 1,200,000 litres annually. Hydrogen has been identified as an alternative fuel source to help reduce emissions at whisky distilleries.

The HyLaddie project assessed the feasibility of utilising a patented and revolutionary technology that combusts hydrogen with pure oxygen to produce heat and water, with a 100% elimination of air pollutants and Greenhouse Gas (GHG) emissions compared to other boilers. The technology includes a Dynamic Combustion Chamber (DCC™), in which hydrogen fuel combusts under vacuum at a stoichiometric ratio with oxygen. Hydrogen and oxygen are combusted in a burner with little or no radiant heat at a temperature of around 2800°C. The hydrogen and oxygen are provided to the boiler via an electrolyser which draws electricity from Bruichladdich's green contracted grid import connection.

The DCC^{TM} is a TRL 7 solution and while a pilot plant has been developed in the US, this would be the first unit in Europe and the largest DCC™ system produced to date. During the Phase 1 – feasibility stage, the technical and commercial viability of the DCC™ was assessed.

2. Description of the Demonstration Project

For Phase 2 of the Green Distilleries Project, power will be supplied to the electrolyser via the grid, using the existing connection from the distillery. This connection is a "guaranteed green" contract which theoretically means that 100% of Bruichladdich's electrical energy is supplied from renewable sources. Hydrogen and oxygen then will then be produced at night-time and stored on land adjacent to the distillery, known as "the Croft". During the day, the electrolyser will switch off and the hydrogen and oxygen from the croft will be fed onto the site and into the DCC™.

It is envisaged that after Phase 2, when the technology and configuration is proven, hydrogen and oxygen will be produced from a larger commercial scale electrolyser offsite, that will operate alongside a new renewable energy project on the island. Hydrogen and oxygen from this larger site can then be delivered to the croft and fed into the site. This configuration thus allows the HyLaddie Project to seamlessly move from pilot / trial into full commercial operations, without any additional changes required to the Bruichladdich site itself.

Deuterium, an affiliate of Protium Green Solutions Ltd, has the exclusive rights to develop and commercialise the DCC^{TM} technology in the UK and draws from the IP developed by Hydrogen Technologies Inc, a California based innovator of hydrogen heating technology. The DCC™ condensing process revolutionises traditional boiler applications in the following ways:

1. **It is a zero emissions technology;** The DCC™ emits no carbon-based or NOx pollutants when burning pure hydrogen with pure oxygen under vacuum conditions, setting a new Best Available Technology (BAT) benchmark. As such, it outperforms the Industrial Emissions Directive (IED) as well as the Medium Combustion Plant Directive (MCPD) emission limit values for CO and NOx emissions.
2. **It is quiet.** The technology does not require Induced Draft (ID) or Forced Draft (FD) fans, since there is no requirement for air in the combustion chamber and there are no flue gases that need to be directed through a smokestack. The lack of fans also eliminates heat lost to the atmosphere and significantly reduces ambient noise. Furthermore, the operation and maintenance costs relative to

conventional boilers. This could also lengthen the useful life of the boiler, which is typically 20 years for fossil fuel-based or typical hydrogen-powered boilers.

3. **It is efficient.** The system Delivers a boiler thermal efficiency of >97%, which is almost 20% higher than other conventional fossil fuel-based boilers.
4. **It is safe.** The configuration enables a natural process barrier to overcome existing challenges associated with hydrogen combustion, namely the risk of embrittlement of metals in the pressure vessel and at the burner head.

The proposed solution demonstrates the feasibility of retrofitting a zero-carbon solution to an existing site, rather than a greenfield site, which provides a replicable solution for fuel switching across the distillery sector. The project supply chain also is unique in that all main components will be manufactured in the UK. The DCC™ will and electrolyser will be manufactured in the UK and as such, the project supports UK ambitions to become a clean energy technology exporter and aligns with goals for the UK to retain its current trade surplus in boiler systems. The project partners believe that the local production, deployment, and maintenance of the boiler will result in significant direct and in-direct job creation in the UK.

Between manufacturing, assembly, installation and providing fuel to operate a DCC™ unit, Protium predicts an average of five jobs created per installation. This would equate to more than 1,800 direct and permanent jobs created across the UK if the proposed configuration were to become the new normal for the 360+ distilleries across the UK. Most of these jobs would be created in remote locations and industrial towns, thus supporting the governments levelling up agenda and expanding the UK supply chain for green hydrogen technologies.

Overall, zero air pollution (including CO_2, NO_X, SO_X, PM) from the DCC™ unit makes it a very attractive option compared to alternative MFO (which also releases particulates), gas-fired boilers and dual fuel boilers which blend hydrogen (as these can increase NOx emissions). The Protium and Deuterium teams will leverage these project benefits in addition to the momentum for decarbonising the UK industrial sector from policies such as the UK Industrial Strategy, to promote wider adoption.

The successful execution of this project aligns with the corporate strategies of all three of the project partners. Bruichladdich is the only Scotch distillery to be B Corp certified, which means it is validated as a business that balances profit and purpose and aims to decarbonise distillation by 2025. Protium is green hydrogen energy services company (HESCO). The company was established to provide hydrogen-as-an-energy-service solutions to commercial and industrial clients in the UK who are looking to achieve net zero emissions on their sites. ITPEnergised, established in the UK in 2013, is a technical and environmental consultancy whose core strategy to act as trusted adviser on net zero strategy and practical implementation for clients across the energy and manufacturing industries.

3. Design of the Demonstration Project

The following section provides an outline design for the implementation of the pilot scale demonstration. The objective of Phase 2 is to prove the technical viability of the DCC™ in the shortest timeframe so that the scheme can be scaled to a commercially viable configuration. This is reflected in the configuration of the presented in the following sections which includes a process description, tie-in locations, DCC^{TM} technical description, equipment lists and plot plans detailing the demonstration layout.

Demonstration Project Configuration Overview

The Phase 2 demonstrator will prove the technical viability of the DCC^{TM} while demonstrating a clear path to full commercial operations. The configuration will see a full scale DCC^{TM} unit deployed at the distillery, but in the first phase a small 250kW electrolyser will be connected behind the meter on the site. This unit will then produce hydrogen and oxygen at night and store them offsite. Hydrogen and Oxygen from offsite will then be fed into the DCC^{TM} during the day. This will provide Bruichladdich and Protium with operational data for a 12–18-month period, while allowing for a rapid deployment and reduction of on-site CO_2e emissions. Should this solution prove technically viable, then Protium will begin to develop the commercial phase of the project, under which a larger green hydrogen project will be built with dedicated renewables offsite. Hydrogen and oxygen from this larger site can then be delivered to the croft and fed into the site using the existing installed DCC^{TM} and associated piping/storage. This configuration thus allows the HyLaddie Project to seamlessly move from pilot / trial into full commercial operations, without any additional changes required to the Bruichladdich site itself.

The appeal of this approach is that it can be rapidly deployed, it provides clear steps to de-risk the project to all parties and has a demonstrable path to delivering reduced GHG emissions and fuel costs. Today the Bruichladdich distillery currently imports around 800 kW of electrical import capacity from the grid on Islay which is operated by SSE. However, this is not fully utilised and site demand is below 500kW during the evening, thus allowing a 250 kW system to sit behind the meter without the need for grid upgrades. Furthermore, Bruichladdich are currently in the process of converting their electrical connection from low to high voltage for Spring 2021 and this will increase the amount of excess electricity that is available from the import connection. The configuration also reduces the need for onsite storage on the distillery and associated risks.

The electrolyser and DCC^{TM} have a closed loop water system and the electrolyser is provided with demineralised water from the DCC^{TM} with a small water make-up system. The demineralised water enters the water purifying filter to remove any excess contaminants, producing high purity water. The high purity water and electrical energy is fed into the electrolyser, which splits water into hydrogen and oxygen. Downstream of the electrolyser, hydrogen is piped into a hydrogen / water separator to remove and entrained water. It is then cooled via the cooling heat exchangers and is further dried through a deoxo dryer. The oxygen stream from the electrolyser is piped to an oxygen / water separator to remove any entrained water. It is then cooled via the interstage gas coolers. Both the hydrogen and oxygen are piped into the DCC^{TM} boiler at 40 barg and 20 barg respectively. Before entering the DCC^{TM}, the hydrogen and oxygen are pass through a pressure reducing station and enter the DCC^{TM} at 3 barg. If the DCC^{TM} is not in operation, the hydrogen will be compressed to 500 barg and stored in canisters, the oxygen will be compressed to 18 - 36 barg for storage in canisters.

The hydrogen and oxygen enter the DCC™ boiler and generate high temperature hot water and steam, through combustion in a vacuum. A schematic of the DCC™ boiler is shown in Figure 1. The principle of operation is analogous to that of a conventional gas or oil boiler. Stochiometric combustion of hydrogen fuel and oxygen is an exothermic reaction, creating localised heat and water at the burner head. The combustion is stoichiometric or "perfect", meaning that two parts hydrogen and one part oxygen are fully reacted, producing only water.

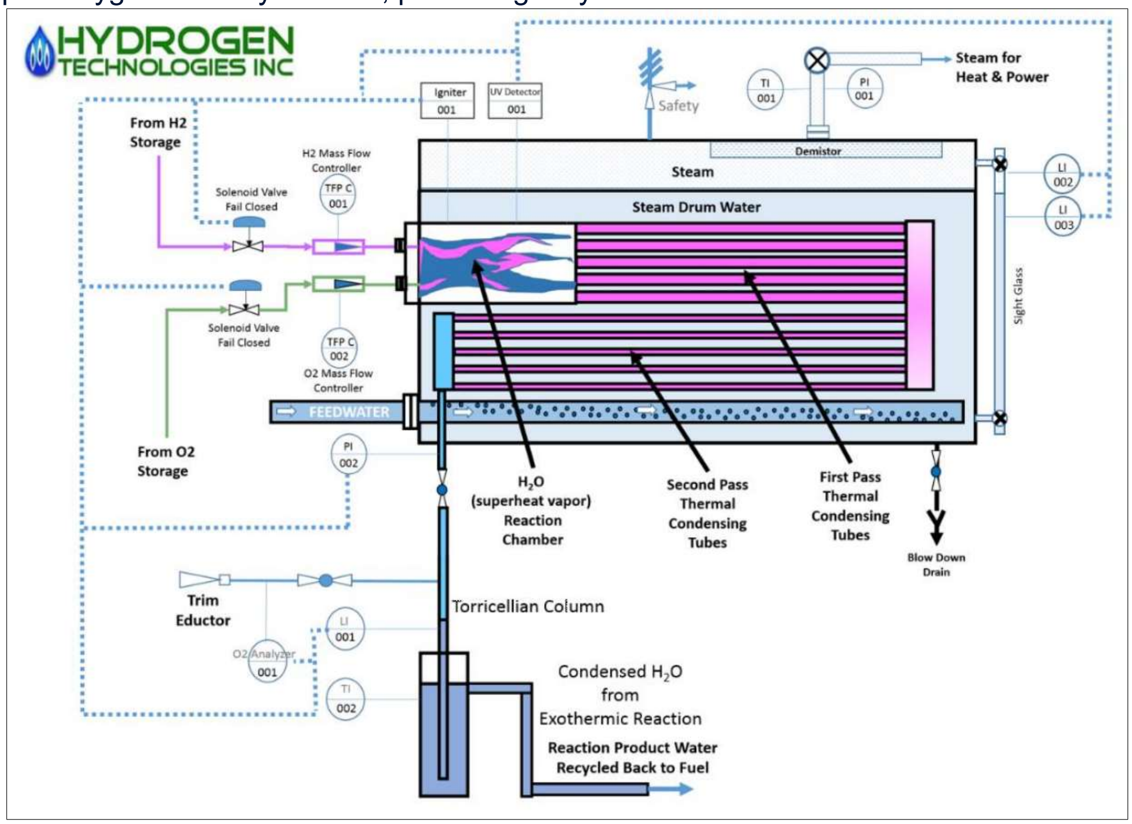

Figure 1: Dual Pass DCC™ Boiler Schematic

The water flashes to superheated steam, which contacts the boiler tubes, exchanges heat, and then condenses back to water. This mechanism of heat transfer facilitates the capture of almost all the reaction heat, which is used to create high temperature hot water and steam. The steam is then routed to the existing steam header.

The combustion condensate moves through a Torricellian column, which induces a vacuum in the boiler tubes. The vacuum characteristic is an important feature of the design because it enables zero emissions in operation. Natural Gas and Fuel Oil boilers produce harmful greenhouse gases including CO_2 and NOx emissions. Hydrogen boilers can eliminate carbon dioxide emissions, but the higher flame speed increases the flame temperature locally, which can generate high levels of NOx when combustion occurs in atmospheric air. The DCC™ solves this problem by combusting hydrogen in an evacuated environment. The natural vacuum formed by steam condensation within the heat exchanger tubes also has further benefits. The steam condensation acts as a natural process barrier to hydrogen and helps to mitigate the effects of potential hydrogen embrittlement.

The water created in the combustion process is condensed and collected. This water is then recycled by feeding it back into the electrolyser to produce more hydrogen and oxygen. This is the final innovation of the DCC™ boiler which enables an entirely closed loop process. This closed loop significantly reduces the requirement and cost for large water purification systems associated with electrolysis. The hydrogen and oxygen storage has been designed to store a week of production from the 250 kW electrolyser. This equates to around 0.8 tonnes of hydrogen and 6 tonnes of oxygen storage and will allow the DCC™ to run at maximum capacity for 10 hours continuously. The footprint for the hydrogen and oxygen storage is 25 m^2 and 13 m^2, respectively.

To assess the amount of MFO produced steam that can be displaced by the DCC™ during the demonstration phase the following basis and assumptions were used:

- **Current Boiler (provided by Bruichladdich)**
  - Model: 1 x Dunphy burner, model TH 415 YM RTSC Boiler YSXA6000-46 from Byworth.
  - Boiler Rating: 6,000 kg /hr of steam
  - Working Pressure of Boiler: 100 psig
  - Boiler efficiency: Approx. 70%
  - MFO HHV: 9.57 kWh/L
  - Average MFO Consumption per month: 1,106,901 kWh
- **DCC™ (Provided by Deuterium)**
  - DCC™ Rating: 500 kWe (3,422 kg / hr of steam)
  - Hydrogen Consumption: 71 kg / hr
  - Oxygen Consumption: 568 kg/hr

The analysis shows that the DCC™ running at full capacity for 10 hours per day can displace 24% of the current boiler capacity.

Equipment Footprint & Proposed Layout

The project partners undertook a virtual site visit during Phase 1 to determine the best siting option and tie-in location for the electrolyser and DDC™. The working site at Bruichladdich is very space constrained, outside the distillery perimeter is bounded by roads to the East and South with minimal land area for equipment and inside the distillery buildings, the existing equipment occupies all the available space. Bruichladdich also owns land adjacent to the distillery, known as “the Croft”, where equipment can be located “off-site”.

From the virtual site visit available space inside the distillery courtyard, adjacent to the boiler house was located for the DCC™. The benefit of this location is that it minimises the required piping and heat losses from the DCC™ to the existing steam header and locates the DCC™ within the distillery where it can be used as a showpiece for other distilleries to visit. As the electrolyser footprint is around 30 m^2 it is too large to locate in the existing, working courtyard. There are several locations around the distillery where the electrolyser could be located. The hydrogen and oxygen storage will be located offsite on the 16-acre croft. The storage will be as close to the DCC™ as reasonably practicable to minimise piping but while also adhering to the relevant safety codes and standards. The disadvantage of not co-locating this equipment with the DCC™ is the increase in hydrogen, oxygen and return water piping throughout the distillery, however the benefits include increased

safety measures and minimal disruption to the current operation of the distillery. The equipment siting will be finalised in Phase 2.
All tie-in locations and siting of equipment is to be confirmed in Phase 2 after a detailed site survey and constructability analysis.

4. Benefits and Barriers

This section provides an assessment of the benefits and barriers for the solution including capital and operating costs, process risks, the emissions reductions (in MtCO2e/year), and how the process could be scaled, against a counterfactual.

Emissions Reductions

The current Bruichladdich boiler uses MFO to generate steam, which has a significant carbon footprint. By switching to the DCC™, which utilises hydrogen and oxygen gas, the distillery could significantly reduce emissions if the gases are produced through the electrolysis of water using renewable energy. For Phase 2 of the project, the hydrogen and oxygen gases fed to the DCC™ will initially be produced by a 250 kW electrolyser that is connected to Bruichladdich's electrical import connection. While this connection is a "guaranteed green" contract which theoretically means that 100% of Bruichladdich's electrical energy is supplied from renewable sources, some of the power on the Scottish grid does come from natural gas (albeit a declining %). Fortunately, the GHG intensity of the regional electricity grid in Scotland is much lower compared to the national UK grid intensity, which means that the project still delivers greater GHG savings from grid-powered electrolysis in Scotland than continued use of MFO[1].

The smaller system and grid connection does mean that the emission reductions achieved will not be as high as the full-scale solution and green hydrogen sourced from dedicated renewables. However, this configuration will allow the project partners to prove the technology in the shortest timeframe possible and will still deliver GHG emission savings compared to Business as Usual (BAU). Developing renewable energy assets near the facility to provide power to the electrolyser will significantly increase the build-out timeline of the project. However, once the demonstration phase is successfully concluded and the technical solution is proven, the parties have identified opportunities to develop dedicated renewables to support a lower cost, full zero emission green hydrogen solution.
The emissions reduction for Phase 2 and for the potential scale up (including renewable power) were calculated.

To perform the calculation, the baseline emissions at Bruichladdich were calculated using the GHG reporting conversion factors for the MFO and the grid shown in Table 1 and the following assumptions:

- Annual Consumption of Fuel: 13,282,814 kWh (combustion emissions).
- Upstream fuel emissions (production, processing, and transportation of fuels).
- Boiler Efficiency: 70%.

To determine the CO_2 Reductions / kWh of heat consumed it was assumed that the DCC™ will replace the total baseline demand. This was calculated using the

[1] https://carbonintensity.org.uk/

greenhouse gas reporting conversion factors for the MFO and the grid shown in Table 1 and the following assumptions:

- Annual Consumption of Fuel: 13,282,814 kWh.
- DCC™ Efficiency: 97%.
- Electrolyser Efficiency: 75%.

Table 1: Grid and MFO Emissions Factors

Emission Source	Unit	kg CO2e
Fuel Oil (WTT)	kWh	0.052[2]
Fuel Oil (TTW)	kWh	0.28484[3]
Electricity Generation (Bruichladdich Green Electricity Contract)	kWh	0
Electricity Transmission & Distribution (Bruichladdich Green Electricity Contract)	kWh	0

The results for the total baseline emissions and the emissions reduction for Phase 2 of the project as shown in Table 2.

Table 2: Current and future CO_2 emissions for BAU and Hydrogen scenarios

	Baseline	Total Replacement of Boiler Demand	Phase 2 -Pilot Project
Actual Heat Energy Needed	9,297,970		
Boiler Efficiency	70%	97%	
Annual Consumption of Fuel (kWh)	13,282,814	9,585,536	2,190,000
Total emissions (t CO2e/ year)	4,474	-4,474	-690
% Reduction against BAU	-	100%	15%

Process Risks Register

The process risks register, has been produced based on the project concept design and is intended to act as a basis for more detailed future iterations as the engineering design for the feasibility stage is developed. For each part of the process, hazards are identified along with potential causes and consequences– the focus is on early identification to inform mitigation by design and the development of suitable operating procedures. Key notable hazards and mitigations identified in Phase 1 are shown in Table 3.

Table 3: Key Process Risks and Mitigations

Risk	Mitigation
Electrical failure, leading to electrocution or fire.	Implementation of an IEC61511 compliant safety instrumented system (SIS) is recommended to safeguard all aspects of hydrogen, oxygen and steam production and use.

[2] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/904215/2019-ghg-conversion-factors-methodology-v01-02.pdf

[3] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020

Hydrogen / oxygen leak, leading to fire or explosion.	Pre-existing potentially explosive atmosphere zones (ref. hazardous area classification document: E/B/52001) to be fully assessed regarding proximity to zoning of new equipment.
Pressure vessel rupture, leading to mechanical damage.	Design to consider proximity of members of the public.

Project Risks Register

The project risks register captures the project risks and potential barriers for the pilot scale project as well as potential mitigation strategies. This is a live document and has been and will continue to be reviewed and updated as the project progresses. The key project risks at this stage are:

- Grid constraints on Islay preventing a stable connection to the electrolyser.
- Potential change of hazardous rating of distillery due to the introduction of hydrogen on-site.
- Space and footprint restrictions at the distillery.
- Delivery timeline of DCC™ and Electrolyser.

Phase 2 Configuration CAPEX

An AACE Class V cost estimate was developed for the purposes of this report. A Class V cost estimate is common for pre-feasibility studies, where the project definition is at ~5 -10%. Typical accuracy ranges for Class 5 estimates are - 20% to - 50% on the low side, and +30% to +100% on the high side. The cost estimates are based on Protiums in-house costing data which includes quotes, industry norms and factors and stochastic estimating methods – such as cost / capacity factors. The cost estimate for the Phase 2 demonstration project is £2,994,000.

Scalability of Demonstration Project

After the successful execution of the Phase two and demonstration of the technical viability of the DCC™ at Bruichladdich, the configuration can be scaled to achieve a commercially viable solution for the distillery. This scale up will include the addition of a commercial scale electrolyser, estimated to be at least 2 MW, with a tie-in to a new build renewable power project. The remainder of the equipment supplied for the Phase 2 demonstration project will remain in-situ and be used for the commercial scale up, reducing the cost for scale up and the amount of dilapidations at Bruichladdich.

The solution deploys two technologies, an electrolyser which can be manufactured at scale and the DCC™ which is a novel technology with a TRL of 7. The DCC™ technology lends itself to scalability as it:

- Can retrofitted as a brownfield installation to existing facilities.
- Can be applied to remote locations that are grid constrained and may not have access or connection to a natural gas network. This is particularly the case in Islay and other remote parts of Scotland where distilleries are located.
- Uses stainless steel as materials of construction which are not exotic materials and are easy to source.
- Does not require any novel fabrication methods.
- Requires significantly less operation and maintenance vs. a traditional boiler due to the reduction of moving parts and the cleanliness of the products.

- Is modular in design, allowing for scale to meet any steam demand.

While the DCC™ technology has been proven in the lab and in the field at small scale, there are potential challenges in commercially scaling it for use throughout the industry and for other heat and steam applications. The scalability challenges and potential mitigation strategies are:

- Currently there is one manufacturer in the UK who is supporting HTI and Deuterium to prepare the fabrication drawings for the suite of DCC™ capacities. Once these are prepared the DCC™ will be able to be manufactured by a variety of companies and will be manufactured through a competitive tender process. This approach will achieve greater scalability.
- The DCC™ system's resiliency during continuous operations is not yet demonstrated however the system will be fitted with multiple monitoring systems so that the operating data can be collected and analysed throughout its use at Bruichladdich.

As the distilling sector is committed to achieve net zero by 2050, the counterfactual would require hydrocarbon fuel substitution for distillery steam-raising. There are several options to achieve net zero emissions in the distilling sector however these counterfactual options also have several barriers to scale including:

- Electrified heat is not suitable for all remote and / or grid-constrained locations such as Islay.
- Biogas requires interventions, retrofit or complete replacement of the boiler system. Liquid biofuel can be viewed as a like-for-like alternative to the fuel oils in use currently, however it has relatively high production costs, supply chain and reliability of supply issues, GHG emissions and potentially land-use sustainability issues which operators may wish to avoid on ESG grounds.
- Hydrogen blending can be utilised in systems that operate on natural gas to reduce the carbon emissions. However, this is not applicable for remote locations which do not have access or connection to the natural gas network, such as Islay.

5. Costed Development Plan

Provisional project schedule

The project partners aim to complete this project and begin supplying hydrogen to the Bruichladdich Distillery by Q4 2021. The overall project schedule consists of engineering, procurement, off-take contract negotiation, commissioning, and start-up. The schedule is indicative because there are various parties involved, and the project timelines could be impacted by delays in the completion of third-party tasks.

Prior to construction, the consortia will work with Bruichladdich operations and projects teams, selected Original Equipment Manufacturer (OEM) suppliers, Engineering, Procurement, and construction (EPC) contractors, financing partners, and planning experts to prepare for the construction of the project. The required tasks can be broken-down into primary work packages, with additional sub-tasks:

A. <u>Client</u>

- Relating to negotiations between Bruichladdich and Protium around formal contracting, including exclusivity and offtake contracts.

B. <u>Planning and Permitting</u>

- Protium to engage local and (where necessary) national authorities to secure planning permission and environmental permitting for the project and resolve any issues with local stakeholders.
- Protium to work with Health and Safety Executive (HSE) on the effect on current Control of Major Accident Hazards (COMAH) requirements at the site, and other required safety agencies to ensure all planned work is certified in accordance with required safety guidance.

C. <u>Technical Engineering</u>

- Protium to oversee the technical design of the proposed system and its integration with the existing systems at Bruichladdich.

Commercials

The distillery currently relies on MFO to feed the sites industrial boiler and produce steam for the distilling process which is an expensive fuel and has significant negative local air quality impacts when combusted. As there is no gas grid on the island, and the required energy for heating exceeds the sites current grid connection by several order of magnitude, the site will continue to consume MFO and will continue to produce significant GHG emissions absent of significant changes.

Beyond the reputational pressure on consumer facing brands to reduce their carbon emissions, the continued use of MFO could expose the Bruichladdich Distillery to price volatility from several factors. These include commodity price fluctuations, new regulations associated with air quality standards (and changes to the Medium Combustion Plant Directive) and increases in existing and new GHG emissions charges (Carbon Tax and Climate Change Levy). Given that the UK Government has stated its intention to significantly increase carbon related taxes and to support funding for low or zero emission solutions, the reliance on MFO is a financial risk for Bruichladdich as it prevents the distillery from decarbonising its steam creation process and locks the business into escalating carbon emission linked taxes.

Assuming a gradual increase in medium fuel oil (4% pa[4]), and projected increases in the CCL and Carbon tax (in line with the latest BEIS estimates), a long-term increase in the price of MFO is expected at Bruichladdich as shown in Figure 2.

[4] Protium has developed an internal cost model based on data from BEIS via DUKES. Each year DUKES publish industrial fuel pricing in a sheet titled "Annual prices of fuels purchased by manufacturing industry in Great Britain (excluding the Climate Change Levy)". While MFO pricing data is incomplete, Gas Oil price CAGR from the period 1999-2019 averaged 8% p.a. across all industry sizes, while HFO price CAGR averaged 9% CAGR p.a. across all industry sizes. We therefore see 4% as a conservative number, an assessment that has been validated through ongoing engagement with clients.

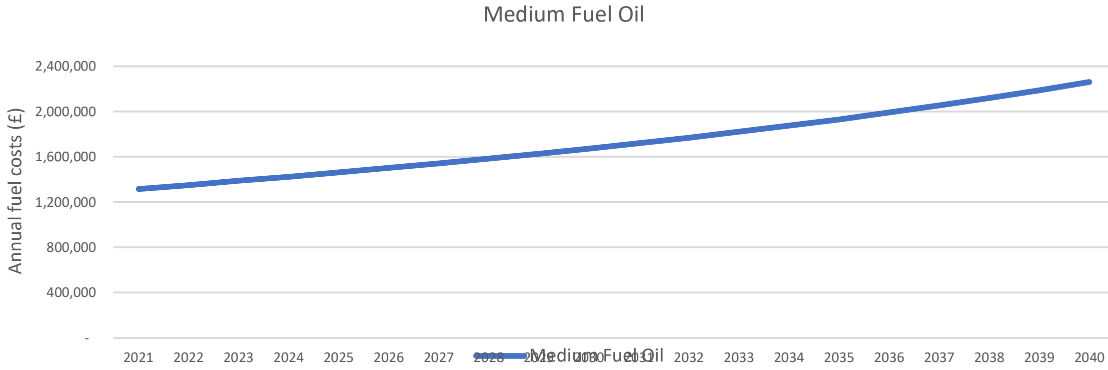

Figure 2: Long Term MFO Prices

BAU vs Hydrogen during demonstration / trial period

The consortium has evaluated the commercial proposition for the hydrogen and DCC™ project configuration during its initial demonstration phase, as a technically viable alternative to the continued use of MFO. The assumptions made to facilitate the modelling are detailed in Table 4.

Table 4: HyLaddie Commercial Model Assumptions

Factor	Assumption	Reason
MFO Energy usage	1,106,901 kWh	Working with Bruichladdich we ran an average fuel consumption based on three "normal" months of operation from August until the end of October 2020. Based off the 70% efficiency of the MFO boiler and the 97% efficiency of the DCC™ an equivalent kWh amount of hydrogen has been calculated.
Cost of MFO	5.28 p/kWh (wholesale fuel cost only) 9.90 p/kWh (delivered all in cost)	Due to data constraints HFO was used as a proxy for MFO, the price was then escalated at 4% per annum in line with energy inflation projections. The delivered price represents the actual cost of MFO delivered to Bruichladdich and includes assumptions around cost of delivery
Emission taxes	0.2 p/kWh (Carbon Tax) 0.003 p/kWh (CCL)	These numbers are as of 2020 and are calculated by using the tax cost, carbon intensity of the fuel and kWh equivalency of HFO. Prices increase as per BEIS's projections and reasonable growth assumptions have been used where projections are not available.
Electrolyser Load factor	50%	To maximise the competitiveness of the cost of hydrogen the technical team have proposed operating the electrolyser during the night to take advantage of the lower grid prices with hydrogen stored on land

		adjacent to the distillery. We assume operation for 12 hours at night
Electricity costs	10.33 p/kWh	Given the above consideration the consortium would manufacture hydrogen at night when the projected price (as provided by SSE) is lower. This electricity price is a PPA price for green electricity ensuring the hydrogen produced is green hydrogen.

From the above assumptions a scenario assessment of Bruichladdich's energy costs from 2021 were derived. As shown in Table 5 below, the cost per kWh of hydrogen will be significantly higher than that of MFO during the initial trial stage, but due to the increased efficiency the total fuel cost difference significantly closer. As such even without a significant carbon price, Bruichladdich could achieve zero emissions by paying a 15% premium under the demonstration phase low price scenario and would make a significant net saving if a dedicated renewable energy project was developed to supply green hydrogen.

Table 5: Bruichladdich Energy Costs 2022

Scenarios	Fuel Type	Fuel cost 2022[5] (pence/kWh)	Fuel needed to meet 100% demand (MWh)	Fuel cost per annum (£)	Delta BAU (£)
Current distillery use	MFO	10	13,283	£1,350,249	-
Demo phase Hydrogen (Low Price)	Grid Hydrogen	16	9,577	£ 1,559,372	£209,123
Demo phase Hydrogen (High Price)	Grid Hydrogen	24	9,577	£ 2,252,427	£902,178
Commercial phase Hydrogen expected price	Dedicated Renewables hydrogen	9	9,577	£866,231	- £484,018

Given that the average lifetime of a thermal heating asset for most distilleries is over 20 years, and indeed nearer 30 years for most commercial & industrial businesses, the costs to reflect expected prices in 2030 have been modeled. The resulting analysis in Table 6 below shows that despite a marginally higher fuel price (even with climate tax adjustments), the hydrogen DCC™ solution is cheaper than the MFO option in both the lower price demonstration scenario and the commercial phase scenario. Indeed, even under the high price scenario, the cost delta has narrowed from a 67% premium in 2022 to 40% premium in 2030.

[5] All prices have been rounded to the nearest pence (p)

Table 6: Bruichladdich Energy Costs 2030

Scenarios	Fuel Type	All in fuel cost 2030 (p/kWh)	Fuel needed to meet 100% demand in (MWh)	Fuel cost per annum (£)	Delta BAU (£)
Current distillery use	MFO	12	13,283	£1,671,526	-
Demo phase Hydrogen (Low Price)	Grid Hydrogen	16	9,577	£1,622,850	- £48,676
Demo phase Hydrogen (High Price)	Grid Hydrogen	23	9,577	£2,344,117	£672,591
Commercial phase Hydrogen expected price	Dedicated Renewables hydrogen	9	9,577	£901,493	- £770,033

Additional modelling was carried out over a 15 year period which showed that a Protium Hydrogen-as-an-energy service approach (HESCO) solution provides commercial savings in both the commercial phase and low price demo phase hydrogen scenarios.

6. Roll-out Potential

As of 2018, there were a total of 361 distilleries in the UK, of which 166 were in England and 160 in Scotland, a 210% increase since 2010. Further to this, there are In the UK around 500,000 commercial boilers which operate between the optimum DCC^{TM} size of 200kW – 1MW range in the UK. Whether from regulatory changes, carbon price increases, customer or shareholder pressures or other means, distillers, as well as other industries, will be expecting to replace fossil fuels over the coming decade and to achieve net zero 2050. Therefore, there is a significant potential for the technology roll-out. The DCC^{TM} technology has several technical factors which lend itself to ease of roll-out once successfully commercialised, these are detailed in Table 7.

Table 7: DCC^{TM} Factors for Successful Roll-Out

System Design	The physical similarities of the DCC^{TM} with the conventional fossil-fuel fired boilers it is expected to replace mean strong rollout potential with many distilleries, particularly those relying on fuel oil as a heat source. Scalability will, as discussed, be reliant on the successful identification of the necessary value chain for novel fabrications, which preliminary discussions with manufacturers suggest will not present material obstacles. The DCC^{TM} can produce very high-grade process steam up to 400oC and 580 psi, which is enough to power an electric turbine

	genset. The DCC™ has a fast cold start, 0-100% variable output, and full ramp up or down in seconds, making it suitable for almost any Combined Heat and Power (CHP), Industrial and Commercial (I&C) space heating and hot water, high temperature hot water, or process steam application.
Footprint	The footprint of the DCC™ is of the same order as a traditional boiler. Electrolysis and gas storage will require further space but not out of keeping with availability on a small to medium industrial site. The DCC™ can tie-in to the existing steam supply and providing there is physical space to accommodate the DCC™ it can be installed and commissioned alongside existing boilers means the transition can be gradual and there is risk of no prolonged outage for changeover. The DCC™ and conventional boilers can be run alongside each other, giving even greater flexibility and reliability.
Fuel Supply	In the short term (through the 2020s) the most viable supply vector for the hydrogen and oxygen fuel for the DCC™ will be electrolysis at or near the distillery site. In future as hydrogen transport becomes more energy efficient, sites may receive periodic deliveries of compressed or liquified gas, liquid organic hydrogen carriers, ammonia, or solid state hydrides from other locations. The necessary grid connection at certain remote distillery sites may require upgrading to accommodate larger electrolysers particularly on island sites. Whilst longer term the UK's net zero policies will lead to low and eventually zero carbon grid electricity supply and therefore green hydrogen, it is likely that in the interim operators will install some renewable energy generating capacity locally or via private wire and/or procure renewable energy via a PPA. Opportunities for wind and tidal power, especially in Scotland, are well documented.
Regulatory considerations	Hydrogen storage will be required to provide capacity to operate for a period in case of interruptions to supply, which depending on quantities may require a Hazardous Substance Consent under the Planning (Hazardous Substances) Regulations or COMAH Regulations – noting that many distilleries are familiar with and/or subject to COMAH due to the quantities of flammable liquids stored in maturation warehouses. There will be requirements for planning permission and Environmental /PCC Permits, requiring Variations or new Low Impact Installation permits for most users, which are relatively straightforward and inexpensive to implement.
Health and Safety	As the unit has no exhaust it improves the air quality of the site and removes the of asphyxiation or carbon monoxide poisoning. Furthermore, it operates with minimal noise and is significantly quieter than a traditional boiler system. This means the technology has very important and safety implications for other sectors beyond distilleries, such as mining and construction, which often require power in remote locations, or in closed environments or for

	industrial facilities near residential areas which have strict noise restrictions. A zero emission, low noise power source could also result in benefits for worker safety and health.
Operation and Maintenance	The DCC™ is expected to be a relatively low-maintenance system which is no more inherently complex that the traditional shell and tube boilers it will replace. Instruction and training in day-to-day operation will be similarly proportional.

7. Route to Market Assessment

Commercialisation

The value proposition for the DCC™ is the ability to provide a safe, reliable, affordable and emission free steam-raising technology. The technology could also transform how certain manufacturing business locate their production and engage with customers. The ability to operate on delivered hydrogen and oxygen canisters with zero emissions allows the DCC™ to provide industrial heat inside heavily built up, air quality restrictive, zones where large electrical demand and/or combustion of fossil fuels would be ither technically unfeasible or prohibited by regulations. This could allow distillers, brewers, and other consumer focused food & drink manufacturers to move their manufacturing closer to their end customers and provide a new experience for their brands/products,

Key steps to commercialisation of the solution will include:

- **Define the market:** all distillation processes which employ steam distillation; ultimately any steam user could make use of DCC™ technology.
- **Implement and present the proof of concept:** Develop "FAQ" during commissioning and the initial trial run to draw up clear answers to anticipated "what, how and how much" questions from interest parties.
- **Identify the means of production:** using the existing UK industrial base.
- **Skills and training:** opportunities for the IP holder to get involved in familiarisation, upskilling and potentially certification of inspection and maintenance workers.
- **Awareness:** raise awareness via sector institutions as presented in Section 8, Dissemination.

Barriers

The initial barrier is the actual deployment of 500 kWe demonstrator unit at Bruichladdich to document real-world performance and behaviours and set the parameters for product warranty. Throughout Phase 1 Protium engaged with insurance brokers to get a better understanding of what is required for an underwriter to accept the product warranty risk. At a high level, the DCC™ could be viewed as underwriters as a "fleet leader" and may require a minimum number of running hours and cycles prior to writing the technology. For example, for gas turbines, underwriters may look at 8,000 hours minimum running hours. Potential adopters will reasonably want to a set of FAQs to understand uptime, reliability, water top-up and treatment requirements, load flexibility and ramp up times, start-up / shutdown periods and achievable loads, steam temperature flexibility etc., and empirical data on efficiency and productivity.

Perceptions around safety (propensity for hydrogen leakage, combustion, embrittlement etc, must be addressed as part of the of which can be covered by suitable training) as well as preconceptions of cost compared to fossil fuels must be clearly addressed as part of the training and awareness steps.

Scope of wider usage

The technology will be suitable for any sector which makes use of hot water and steam: related food and drink sectors such as brewing, food processing, baking, vegetable oil extraction etc. Sites which may realise additional advantages from DCC^{TM} technology are those which:

- Are close to frequently curtailed renewables e.g., wind turbines which undergo significant periods of generation where power export is not possible due to grid conditions.
- Are close to tidal arrays where the diurnal profile can be buffered by hydrogen generation and storage.

8. Dissemination

To ensure the research and findings of the study is most effectively disseminated, multiple vehicles ideally with face-to-face interaction will be used. As the COVID-19 restrictions are due to be in place until June 21st, 2021, face-to-face meetings may not be appropriate and so remote meetings and seminars have been proposed at this time; however, these will be replaced by face-to face meetings if possible.

After the issue and publication of the Phase 1 report, the project partners will maximise exposure to industry and other interested parties using a variety of dissemination activities. It is envisaged that these activities will take place prior to the kick-off of Phase 2. This dissemination plan is a proposal and is subject to change based on acceptance and responses from potential parties. A proposed timeline of the activities is shown in Figure 3.

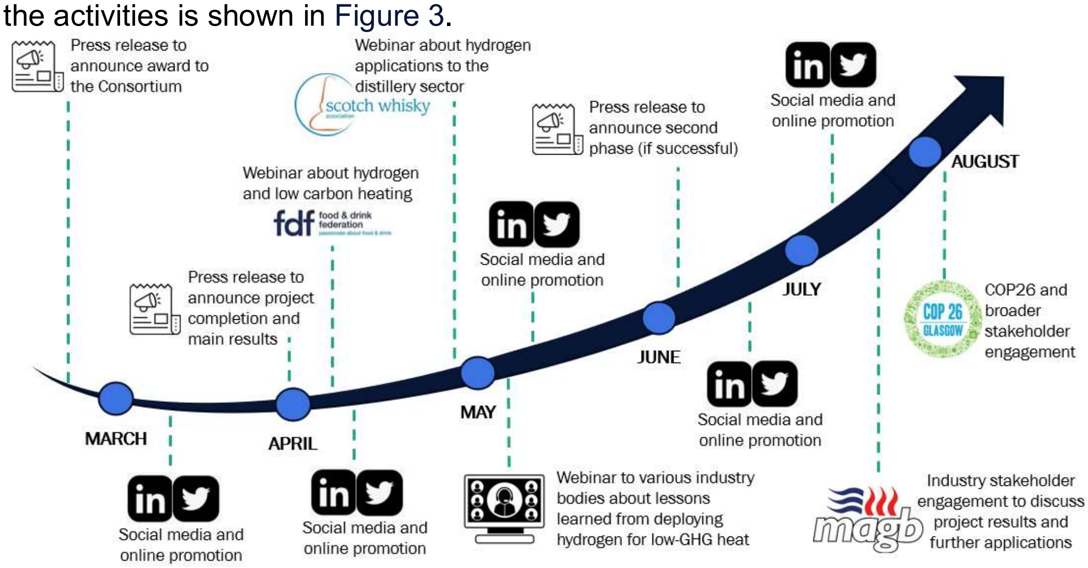

Figure 3: Dissemination Activities Proposed Timeline

More detail on the dissemination activities is provided in Table 8.

Table 8: Post Feasibility Study Dissemination Plan

Activity	Stakeholders	Lead Project Partner	Execution	Focus
Webinar	Food and Drink Federation (FDF)	ITPE	ITPE to reach out to contacts at FDF. Two webinars proposed, Introduction to Hydrogen. Hyladdie Case Study	Zero Emission Heating for Food and Beverage Manufacturing
	Scottish Whisky Association	Bruichladdich	Bruichladdich to utilise association with SWA to organise a webinar.	Bruichladdich's experience with integrating hydrogen for zero emission heating in the for-Distillery sector
	Industry body webinar (UKHFCA, SHFCA, HYCYMRU)	Protium / Deuterium	Protium is member of and has connections with all the listed industry bodies.	Lessons learned for deploying new technology for zero emissions heating
Press release.	General Public and project partners mailing lists	All Project Parties	All project parties will work with media partners to develop press release for the announcement of Phase 1 completion. These will build off our engagement from The Times and stated interest from The Guardian from the Phase 1 press release.	Announcements targeted at a national audience.
Direct online promotion	General Public	All Project Parties	Ongoing social media announcements (website, social	Continually update on the progress of the project and

			media, email, podcast) as project milestones are reached through all social media channels.	maintain engagement.

The project partners have also considered several key and ongoing dissemination activities for Phase 2 of the project including:

- Ongoing Press releases as appropriate.
- Malting Association of Great Britain (MAGB) optional stakeholder engagement. Protium has already spoken to the MAGB and will propose a deuterium webinar on DCC^{TM} technology in malting.
- Ongoing social media engagement.
- Local Stakeholder engagement:
  - The consortium will engage with local stakeholders to ensure concerns are addressed and benefits understood.
- Preparation for COP26 including:
  - Industry White Paper,
  - Presentation,
  - Site Visit to Bruichladdich.

9. Conclusions

This Phase 1 study presents the project configuration for the demonstration of a novel and revolutionary zero emission boiler technology, the DCC^{TM}, at the Bruichladdich Distillery on Islay, Scotland. The project configuration, consisting of a 250 kW electrolyser connected to the Bruichladdich electricity import and a 500 kWe DCC^{TM} provides a technical and commercial pathway for the project to be designed and deployed by the end of 2021 whilst also providing a large enough scale to demonstrate and prove the technical viability of the DCC^{TM} technology. The demonstration project will utilise existing green contracted electrical import capacity at Bruichladdich, and a small-scale electrolyser with hydrogen and oxygen storage to accelerate the project deployment timeline and reduce the overall CAPEX for the Phase 2 project.

The operating areas of the Bruichladdich distillery are congested and space limited however the phase 1 study identified sufficient space for the DCC^{TM} within the working courtyard of the distillery. This location will minimise the overall steam piping as it is adjacent to the current boiler room and showcase DCC^{TM} in the distillery which is scheduled to be on-site for COP26. For the electrolyser and storage, there are several siting locations available outside of the working areas of the distillery and on the croft that may be appropriate. The disadvantage of not co-locating this equipment with the DCC^{TM} is the increase in hydrogen, oxygen and return water piping throughout the distillery, however the benefits include increased safety measures and minimal disruption to the current operation of the distillery. All the proposed siting locations will be subject to a further site survey and constructability analysis in phase 2 before the final siting locations are selected.

The aim of the demonstration of the DCC™ will be to reduce the scale-up and roll-out risks identified in this phase 1 study and refine the commercial viability of a full-scale project including dedicated renewables. In particular, the demonstration will look to:

- Show that the DCC™ system is a technically and commercially viable alternative to meeting the steam demand at Bruichladdich.
- De-risk uncertainty around the resilience of the DCC™ system during continuous operations.
- Increase understanding of how hydrogen is handled and consumed on a commercial distillery,
- Provide guidance for new DCC™ adopters to help them to understand the operational requirement of the system and how it can interface with their existing processes.

The DCC™ technology is a zero-emissions boiler solution to produce steam in distilling process and is also suitable for any sector which makes use of hot water and steam for their manufacturing process or power generation including brewing, food processing, baking, vegetable oil extraction etc. Sites which are close to frequently curtailed renewables e.g., wind turbines which undergo significant periods of generation where power export is not possible due to grid conditions would be very suitable for the adoption of the DCC™ technology.