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Hy/BioDDP

Hydrogen/Biofuel Burners for Distillery Decarbonised Power

Colorado Construction & Engineering
CBS // University of Leeds

///CleanBurnerSystems

UNIVERSITY OF LEEDS

Green Distilleries Phase 1 Competition
(TRN 2564/08/2020)

Hy/BioDDP: Hydrogen/Biofuel burners for Distillery Decarbonised Power

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Glossary

AD	Anaerobic Digestion
A/F	Air to fuel ratio by mass
A/FØ=1	Stoichiometric A/F by mass
BECCS	Bio Energy with Carbon Capture and Storage
BGG	Bio-gasification gas (the LCV output gas from the biofuel gasifier)
Biofuel	Solid or liquid products derived from plants, crops or trees
Biomass	Solid products derived from plants, crops or trees and including draff
Bio-oil	Liquid biomass derived fuels including PAS, biodiesel (FAME), crude ethanol, VOs, UCO or crude glycerol which is a by product of FAME (10% by mass)
Blue Hydrogen	Hydrogen from NG SMR with CCS
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CNG	Compressed Natural Gas (from high pressure cylin-ders)
DD	Dry Draff
FAME	Fatty Acid Methyl Ester bio-oil
GCV	Gross Calorific Value, MJ/kg
Green Hydrogen	Hydrogen by electrolysis of water using renewable or nuclear electricity
HVO	Hydrogenated Vegetable Oil
L	Litre of whiskey
LCV	Low Calorific Value
LPG	Liquified Petroleum Gas
NG	Natural Gas (from the gas mains)
PA	Pot Ale
PAS	Pot Ale Syrup (taken as 9% of PA)
SMR	Steam Methane Reforming of NG
SWA	Scottish Whisky Association
UCOME	Used Cooking Oil Methyl Ester
UCO	Used Cooking Oil
VO	Vegetable oils
WD	As received Wet Draff
Ø	Equivalence Ratio, <1 excess air (burner condition) and >1 excess fuel (gasification condition)

1 Executive Summary

The climate emergency cannot be ignored or left for later, which is what will happen if we wait for grid hydrogen to be available, as part of a hydrogen only decarbonised power strategy.

This proposal gives a transition to decarbonised power in distilleries using axially staged combustion of NG/bio-oils, with a change to hydrogen/bio-oils as green/blue hydrogen becomes available. A second immediate decarbonised power strategy will be developed using crude ethanol as the more reactive upstream fuel and the burner will operate on NG, hydrogen and ethanol in any ratio depending on the hydrogen availability and the client decarbonisation requirements.

The upstream burner will be a lean low NOx multi-fuel burner, with difficult to burn bio-oils injected into the 1200K 16% oxygen discharge gases which will burn any bio-oil, irrespective of their boiling point. For immediate use of hydrogen, electrolysers using green electricity will produce green hydrogen, a technology that can be utilised on any distillery with a local source of hydrogen or generated from renewable sources such as wind-farms, hydro or photovoltaic. One of these options will be suitable for all distilleries, so that decarbonised heat can start in 2023.

For successful decarbonisation of distilleries the ability to take the project from conception through to a deliverable working product is of paramount importance, to enable the maximum savings and reduced carbon footprint to be achieved. Colorado construction has the required expertise for this, having built 9 modern distilleries in recent years.

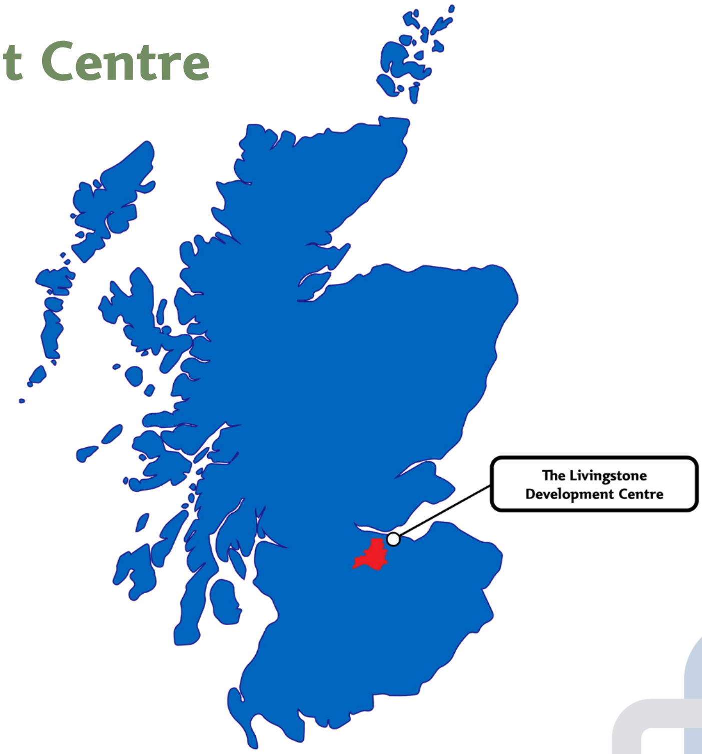
For effective decarbonisation now the distillery heat supply changes have to be cost effective for the distillery and this project aims for the ideal position of complete decarbonisation with production cost savings. Our vision for this is set out below.

1. Livingston Development Centre

This facility will enable the distilleries and other industries that desire decarbonised heat, to work with the consortium without any adverse effects to their businesses and therefore remove some of the blockers to market that have hindered development in the past.

This new centre will allow for the testing, designing and fine tuning of the burner module matched to their existing steam boiler or other heating plant, without effecting their production.

Based in Livingston with ample office space, just off the M8 and ideally located for Edinburgh/ Glasgow transport networks, this will act as the HUB for decarbonised heat innovation for the whole of Scotland and northern England.



2. Modular Delivery

Key to the ability of this project is not just the design and development of hydrogen/ethanol - bio-oil gas burners, but the ability to ensure that this new equipment can be installed and work perfectly for any process heat application. A modular approach to the product will be developed: green hydrogen production; multi-fuel burners and control systems; external storage for green/blue hydrogen and for biofuels.

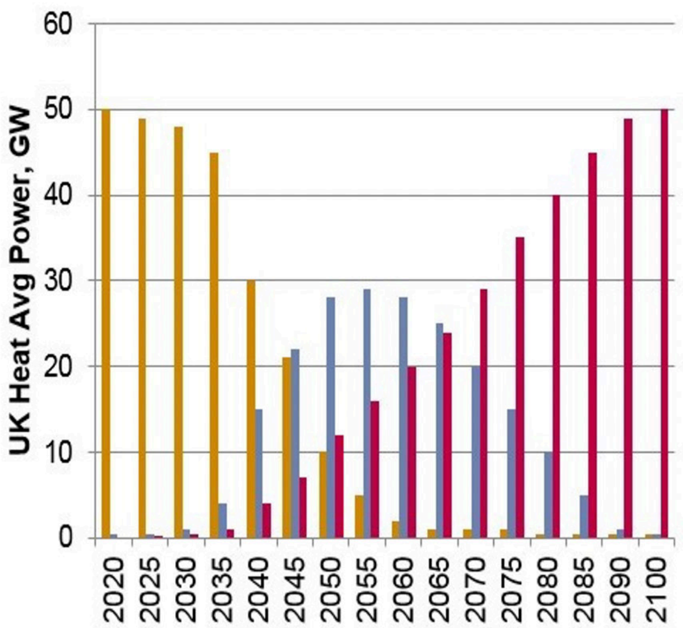
There will also be an optional pot ale clean up module to produce PAS and clean water.

Given the vast diversity of distilleries in size, location and energy requirements, then without such an ambitious approach only a small select few would benefit and the majority would only be able to move forward when they had substantial investment planned. This approach will have the maximum effect on the maximum number of distilleries and can start to happen now rather than in 10 years' time, whilst the global heating clock is ticking.

2 Project Overview

INTRODUCTION This novel proposal is directed at achieving an early transition to the decarbonisation of distillery heat, so that waiting for hydrogen in the gas grid does not result in little decarbonisation for the 10 years or more that this will take to achieve. The proposal is for bio-oils to be used for distillery heat with hydrogen used in a two stage burner, when hydrogen is available at a competitive cost. In the meantime a 100% bio-oil solution is proposed. The practicality of this is shown by the January 2021 100% bio-oil operation of the Encirc container glass plant in Derrylin in N. Ireland, as part of the BEIS Glass Futures fuel switching programme.

Fig 1. UK heat power forecast by source

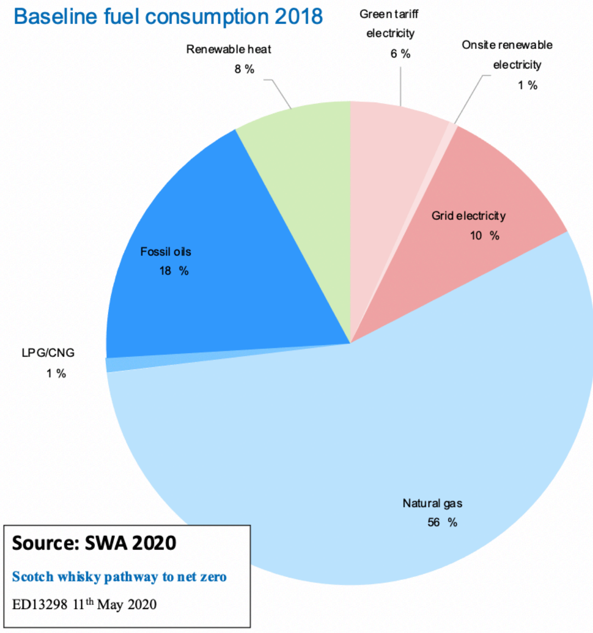


Heat source dominates – Year
Natural Gas – until 2045
Hydrogen from NG SMR – 2045 -2063
Hydrogen from wind – 2063 onwards

First use – Hydrogen SMR – 2030
Hydrogen electrolysis - 2035

Source: ORE Catapult, 2019. (BEIS Report) Feasibility Study of Large Scale Hydrogen Production from Offshore Wind in the UK, Offshore Renewable Energy Catapult.

Fig 2. Baseline fuel consumption in 2018



The production of heat is the dominant energy requirement in distilleries.

In 2018 heat represents approximately 82.7% of fuel consumption with electricity at 17.3%.

The distillation heat requirement accounts for approximately 91% of the heat-related fuel consumption with around 8% for non-distillation activities, like malting.

A small fraction of fuel consumption is associated with space heating and low temperature hot water requirements.

Bioenergy is around 7.8% of fuel consumed, which is primarily from the processing of distillation byproducts as well as combustion of wood chip and pellets.
Most of the zero carbon electricity consumed is electricity purchased under a 'green tariff'.
Exports of electricity from gas-fired CHP plant offset a small proportion of the sector's fuel use.

Fuel switching for distillery heat is proposed from fossil fuels in conventional single fuel injection location non-aerated burners to a novel axial staged burner with a reactive first stage fuel burning in a very lean well mixed low NOx mode, with downstream secondary fuel injection into the hot discharge gases from the first stage. This will enable difficult to burn bio-oils to be used as secondary fuels, such as PAS, crude glycerol, VOs, UCO, UCOME and bio-diesel.

The lean primary zone of the burner will be operated at about 1200K and 14% oxygen, which at 300K air temperature is a Ø of about 0.3 for NG with 100 kW heat release. A new primary stage burner, with the ability to operate with a stable flame outside the normal flammability limits for combustion, is part of the innovation in the new burner design. At 1200K any high boiling point viscous bio-oil will burn, but they will not burn in ambient air temperature burners. This leaves 250 kW heat release from the second stage bio-oil burner.

For the initial development work the upstream more reactive fuel will be NG and with second stage bio-oils this will give 71% reduction in GHG emissions. For some distilleries this may be sufficient and this product will be the easiest to bring to market quickly. For complete decarbonisation the upstream reactive fuel has to be green and two options will be demonstrated: crude ethanol from the automotive fuel supply industry and green/blue hydrogen.

The axial staged burner design can be used with hydrogen in both stages (or ethanol) and this type of burner design has low NOx characteristics. High NOx with hydrogen is an undesirable problem, that would make hydrogen non-viable as a route to decarbonisation if low NOx hydrogen burner designs could not be developed. In the 100% hydrogen phase of this work only low NOx designs will be investigated and the consortia will initially use a 100 kW hydrogen burner for the upstream flame (Jet Mix) developed at Leeds University that has already demonstrated ultra-low NOx at 1200K for 300K air inlet temperature.

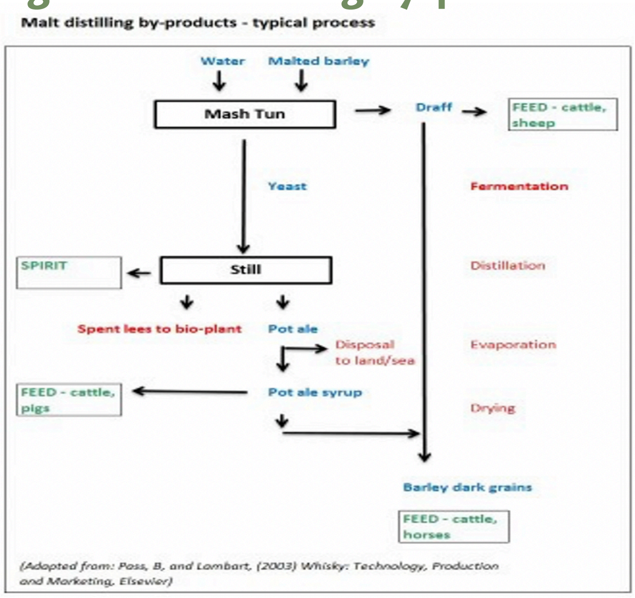
This approach will enable complete decarbonisation of distilleries and enable a start on this from the end of this project. Until hydrogen is available through the grid or from wind farms via electrolysis, NG or crude ethanol will be a transition fuel that enables difficult to burn bio-oils to be used. As most distilleries use steam boilers for indirect heating of the distillery, the work will be carried out on a new dedicated burner and steam boiler test facility at the Colorado HQ in Livingston. This will enable a working package of burner/boiler combination to be developed off-site for any distillery and this will minimise distillery production interruption that would be entailed if the work was carried out at a working distillery. We have discussed this project with several distillery operators and all favour the dedicated off site development of the axially staged burner and steam boiler combination and are unwilling to allow potentially hazardous hydrogen burner work to be undertaken in a working distillery.

This proposal will also help the transition to zero carbon in the distillery industry to be achieved in the next decade and is not reliant on a supply of green hydrogen, but can use hydrogen when it is available. NG/Bio-oils will be the easiest route to carbon zero and could achieve 70% decarbonisation in a 2023 installation. If zero carbon is required on a timescale to which grid hydrogen cannot be delivered, then a dual fuel ethanol/bio-oil approach is feasible, although ethanol costs are higher than for NG. If only a limited supply of green hydrogen is available and the rest of the green energy requirements are supplied by green bio-oils, then the multifuel radial swirler burner that is part of these proposals could cope with hydrogen, NG, ethanol, bio-oils in flexible combinations.

This would allow a smaller delivery of green hydrogen from local electrolysis using surplus wind power to be installed in distilleries and when combined with bio-oil combustion will enable a distillery to decarbonise. However, distilleries only have PAS as a waste bio-oil and this can only supply about 6% of the energy requirements, so 94% of the bio-oils will have to be supplied from other sources.

Hydrogen can only be used now if an onsite electrolyser is used with green electricity, which is part of this proposal. However, hydrogen will not be available in the gas grid for at least 10 years and NG will be initially used as the upstream more reactive fuel, with ethanol burners used where complete decarbonisation is desired in 2023. Hydrogen and NG have similar Wobbe Index and so can use the same fuel injection and burner system, which aids the transition from NG to green hydrogen when it is available, without changing the gasifier burner.

Fig 3. Malt distilling by-products - typical process



0.818 kg of draff and pot ale (77% pot ale) are produced per L of whisky (Grandy and Hinton, 2018). The pot ale is evaporated to pot ale syrup (PAS) with a CV of 14.5 MJ/kg and PAS is produced at 9% of the pot ale mass (Grandy and Hinton, 2018). This PAS energy is then 0.82 MJ/$L_{whiskey}$ or 5.7% of the required energy input.
The draff is produced at 0.19 kg per litre of whisky. Dry draff measured GCV was 20.5 MJ/kg in this work and so this is an energy of 3.90 MJ/litre of whisky. This combined energy is 4.72 MJ/L_{whisky} and if the gasification efficiency was optimised at 70% then the energy produced by the burner would be 3.30 MJ/L_{whisky}.
At the whiskey production rate of 0.066 l/s this is a burner power of 0.218 MW.
Currently NG is used at 14.4 MJ/L and the draff and PAS could displace 22.9% of this energy with renewable biomass energy at no fuel costs, as both draff and PAS are waste products.
For complete decarbonisation the rest of the energy would be provided by other low cost biofuels.

S. Grandy and S. Hinton, Whisky by-products in renewable energy, Ricardo Energy and Environment, Report 16210-2017, 8.2.18. Client ClimateXChange.

OBJECTIVES (as set out in the application)

The objective of Phase 1 is to design hydrogen and dual hydrogen/biofuel burners for distilleries.

The first objective in Phase 2 is to demonstrate that hydrogen and biofuel burners, as single fuels or dual fuel are practical fuels for both directly fired and steam heated distillation.

The second objective of Phase 2 will be the demonstration of hydrogen and dual-fuel burners on a small distillery (~350 kW).

This Phase 1 work has shown, after discussions with distillery operators, that the demonstration of the technology should be done in the new Colorado Livingston experimental test facilities using a steam boiler that is in common use in distilleries.
The 350 kW initial size has been agreed as a sensible size to start with and to scale up to the 1-2MW size used in the largest distilleries.

TECHNOLOGIES THAT WERE CONSIDERED.

We consider that 100% hydrogen and biofuels or hydrogen/biofuel combinations are the only viable options for decarbonising heat in the distillery industry. 100% hydrogen burners, designed for low NOx, is the obvious solution if the gas grid has changed to supplying hydrogen. However, this is at least a decade away and decarbonisation is required now and the use of biofuels is the best route to decarbonise distillery heat.

The CCC (Biomass in Low Carbon Economy, Nov. 2018) advocates that biomass should only be used with BECSS and this involves converting the biomass to hydrogen via gasification, conversion of CO to CO_2 and then capturing the CO_2. Together these two processes deteriorate the thermal efficiency by at least 10% each, so for heat instead of an 80% thermal efficiency there would be 60% at best and more biomass would be required to achieve a given heat output, so costs would go up. Also, these processes need large scale regional plants with expensive transport energy and gas delivery energy losses. They are not feasible for individual distilleries to do. In the real world there are no BECCS plants and no biomass to hydrogen plants in operation, so this type of advanced technology would result in no decarbonisation in the near future, so would prevent zero carbon targets from being achieved in the timescales required. If realistic options, such as the present proposal, were ignored because there might be a more optimum way of using biofuels or we should wait for green hydrogen to be available in the grid, then it will just accelerate global warming as action will not be taken now. We propose a relatively small-scale solution to the decarbonisation of individual distilleries, with the benefits retained by the distilleries and the process under the control of the distilleries.

For biofuels for heat there are three options: gasification boilers, biomass combustion boilers including bio-oil burners and AD.

1. Domestic and commercial gasification boilers are currently on the market by several manufacturers with >90% thermal efficiency for hot water and we have a proposal in the Green Distilleries Phase 2 in this area. However, gasifiers are large and often larger than the steam boiler and their installation together with the biomass stores is a larger change to the distilleries than might be acceptable. However, biofuel gasification boilers are much more biofuel source flexible compared with the present proposal for bio-oils only, although these are in plentiful supply. They could use lower cost biofuels such as farm straw.

2. Biomass combustion in direct fired boilers have good thermal efficiencies comparable to those for gasification boilers. The EU BASIS project (2015) reviewed working thermal efficiencies of biomass plants and for heat applications these were 75% - 84% for 1-5 MW plant, 65-91% for 5-20MW plant and 78-90% for >20MW [BASIS (basisbioenergy.eu)]. These, thermal efficiencies are better than those published for conventional large scale steam injected gasifiers where the review by Andrews et al. (ASME GT2019-90196) has a range from 62% to 72%.

Scotch whisky distillers are burning their unwanted grain by-products, wood chips and other types of biomass for a source of energy, in remote areas of the Highlands, where gas links are scarce and fuel oil is expensive. Diageo Roseisle, Cameronbridge and Glendullan distilleries produce 50% of their energy requirements from internal biomass sources and have raised this to 80% with external supply of wood chips and pellets. [Nina Chestney, Reuters Environment APRIL 4, 2014].

The biomass boiler sizes that are used range from 10 – 30 MW. The smaller scale Tomatin distillery used a biomass wood pellet boiler for its energy requirements in 2014 but in 2017 had to add an LPG fired boiler as the heat output from biomass was insufficient.

The direct combustion of bio-oils in steam boilers in distilleries is currently not used. The problem is that bio-oils are high boiling point viscous liquids and are very difficult to burn, so that burners do not exist for these fuels. The present work is based on a novel burner design that is capable of burning bio-oils downstream of a more reactive fuel such as ethanol or hydrogen/natural gas. These novel burners will be connected to the existing steam boilers and should have the same thermal efficiency of the existing steam boilers which is >90%. Biomass boilers cannot match this performance.

3. The present direct fired burner for biofuel steam generation will have the same >90% thermal efficiency of the baseline steam boiler. This has a much superior thermal efficiencies to those from offsite AD plants with <30% for AD which is the current biofuel technology used by some distilleries. These efficiencies are worse when the transport energy to take the biofuel to the AD plant is taken into account, together with the energy loss in pressurising the bio-gas to be injected into the gas grid and transported by the distillery. Overall efficiencies are then <20%.

CHOSEN TECHNOLOGY.

The University of Leeds had published on axial staged dual fuel NG/bio-oil burners, so it was known that this was a design approach that could be used to burn high boiling point bio-oils. Biodiesel and raw vegetable oils had been demonstrated as viable fuels in the Leeds University work. They had also published work on kerosene as the more reactive fuel with biodiesel downstream. Thus ethanol/bio-oil is a combination that should perform well, although previous work has not been done to verify this. 100% hydrogen burners at 100 kW power had also been developed and published by Leeds University for lean burner operation with low NOx.

Also, axial staging of NG burners had been shown to give low NOx emissions on NG up to near Ø=1 operation and it is likely that 100% hydrogen burners with axial staging will have low NOx emissions at near Ø=1, as used in steam boilers.

The chosen technology for decarbonisation is a multi-fuel burner that uses axial fuel staging with an upstream reactive fuel (hydrogen, crude ethanol or NG) and a downstream bio-oil (biodiesel, crude glycerine, UCO, UCOME). Olleco have agreed to supply crude glycerol, UCO and UCOME to the project. This burner would operate in the existing distillery steam boiler and only the existing burner and air and fuel supply systems would need to change. All this technology had been demonstrated in work relating to low NOx gas turbine combustion at Leeds University.

For 100% decarbonisation now, ethanol will be used as the more reactive upstream fuel. The burner will be designed to enable two stage hydrogen to be used when sufficient hydrogen supply is available in the gas grid or a dedicated local hydrogen supply is available. The multi-fuel capability of the burner will enable low quantities of green hydrogen to be utilised, with the remaining energy input met by bio-oils or NG. Hydrogen and NG have a similar Wobbe Index and so can use the same fuel injection system, which aids the transition from NG to lean/lean axially stage burner design, that has been investigated for NG at Leeds University.

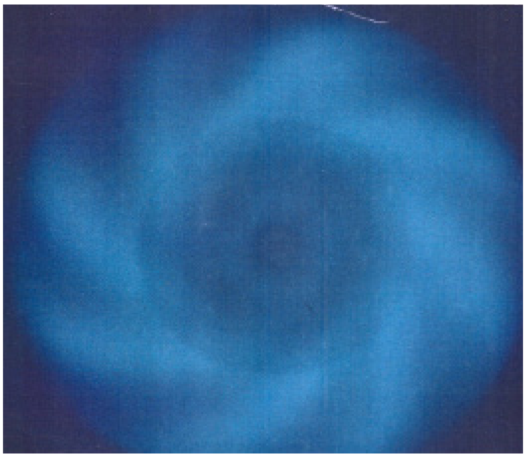
3 Experimental Results

The Jet Mix Hydrogen Burner

The jet mix design hydrogen burner developed by the University of Leeds for lean burning gas turbine application achieved excellent low NOx. This will be used as the upstream burner in an axially staged low NOx hydrogen burner installation in the Livingston Development Centre. Previous work with this burner using a range of up to 600K air temperature confirmed the burner operated at 300K with no problems.

Radial Swirl Multi-fuel Burners

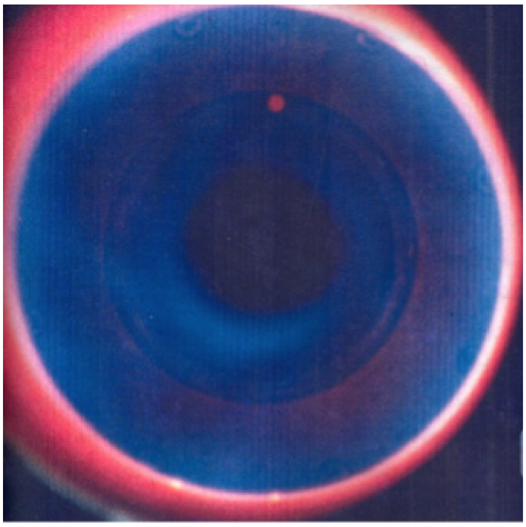
Radial swirlers have five locations of fuel injection and can operate on gas and liquid fuels in the same burner and at the same time if the availability of green fuels is limited. This burner is an option that will be investigated alongside the Jet Mix burner in the axially staged burner. It has been operated on bio-oils and may enable a shorter burner to be used. Ignition and flame detection through the rear face of the swirler is easier in this design than for the Jet Mix. However, only the Jet Mix design has been operated on hydrogen and only the radial swirler design has been operated on bio-oils. This is why both burner design concepts will be evaluated in this application. The lean burning flame pictures for two methods of fuel injection are shown below.



Lean primary radial swirler with central radially outward fuel injection of NG with ∅ = 0.43 at 600K air temperature.

Note: the swirling shear layer, one for each vane passage.
The central fuel injector had 8 radial holes aligned with the 8 radial vane air passages.

This is typical of the lean flame that would be upstream of the secondary bio-oil fuel injection flame.



Well mixed combustion in an 8 bladed radial swirler with swirler outlet throat wall fuel injection with 8 discrete holes.

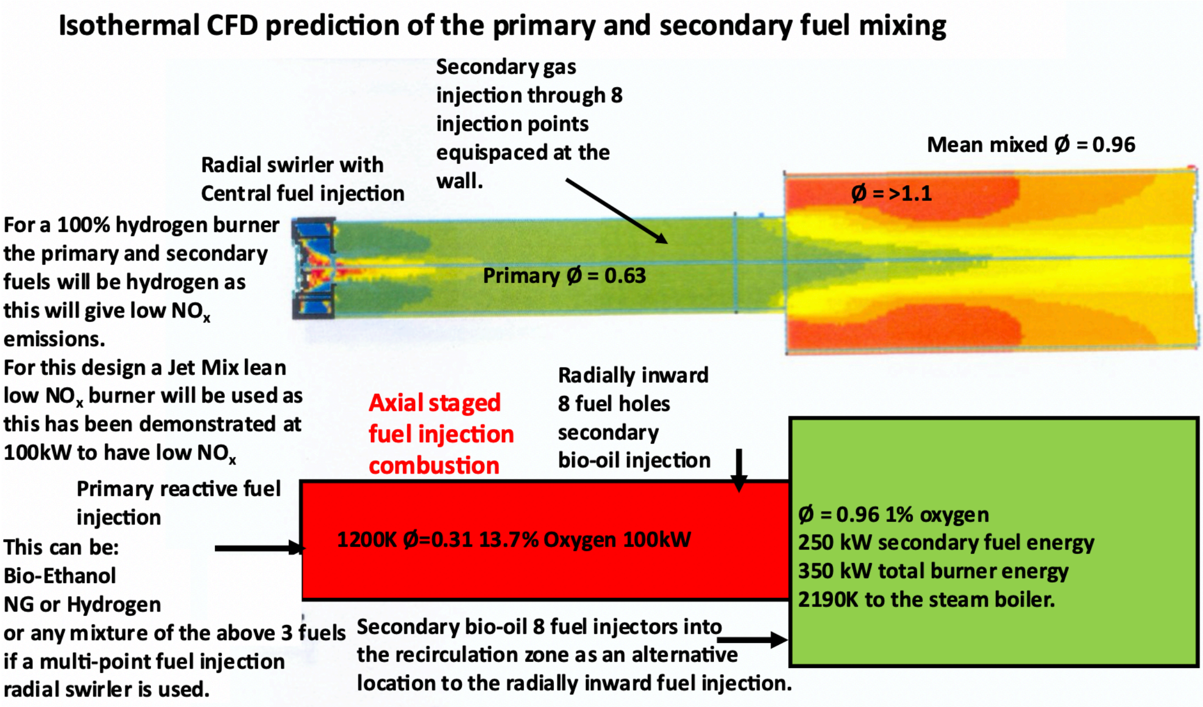
Natural gas — air at ∅ = 0.46 at 600K air temperature.

Δ P/P = 4.2%

Axial Staged Combustion

The 100 kW primary burner will have a 330mm downstream flame development distance and then there will be a combustor flow expansion that will generate a recirculation zone that will stabilise the secondary combustion flame. The initial Leeds University design was for a 76mm diameter primary combustor diameter. For the 350 kW burner this would be a 100mm diameter burner. The 140mm diameter secondary combustor will still be of sufficient size for 250 kW heat release, as no more air is added. The fuel would be injected either at the wall radially inward or it would be injected into the dump flow expansion recirculation zone through the flat wall of the flow expander. This is an annular ring and the number of bio-oil fuel injection points would be at least 8 to achieve good mixing.

Fig 4. Isothermal CFD prediction of the primary and secondary fuel mixing



In principle the two stage burner concept could operate with any primary burner and the Jet Mix and multi-fuel radial swirler burners will be investigated. The primary Ø was 0.58 and fuel was added in the second stage with no increase in NOx.

A CFD study of this configuration at process burner conditions was carried out. This models a NG process burner with two stage combustion and 0.64Ø primary burner lean combustion with the secondary fuel giving 0.96Ø overall. This shows the rich corner recirculation zones in the secondary combustion.

One of the risks in this project is that burners will overheat on hydrogen and so an alternative burner design will also be investigated for the first stage combustion. This is the use of a radial swirler, which allows a range of fuel injection locations and so can operate as a multifuel burner.

4 Description of the Demonstration Project

The principle of this fuel switching proposal is the combustion of low cost difficult to burn bio-oils in a lean/lean axially staged combustor with a reactive fuel in the first stage that will generate 1200K with about 15% oxygen which will easily burn any bio-oil irrespective of it's boiling point. This type of fuel will not burn in conventional burners in ambient air as they are difficult to atomise and vaporise.

Currently a modern distillery uses 14.4 MJ of fossil fuel energy to produce one litre of whisky (John Fergus, InchDairnie). In this proposal up to 6% of this energy would be replaced by burning PAS in a two stage gas/biofuel burner, to be confirmed from tests.

Currently a modern distillery uses 14.4 MJ of fossil fuel energy to produce one litre of whiskey.

This is the only waste bio-oil on the distillery and this has problems in the separation process from pot ale. In this project the burning of PA directly as the secondary fuel together with additional bio-oils will be investigated, as the level of water involved is similar to that used for water injection for low NOx emissions.

Also PAS will be separated from PA by gravity and the residual contaminated water will be cleaned up using air/oxygen bubble treatment and by char absorption of the residual VOCs. Which is adopted will depend on the relative costs of each option.

Complete decarbonisation will be achieved by using other bio-liquids with ethanol as the first stage reactive fuel. Green/blue hydrogen can be used as the first stage combustion in the axially staged burner, when the grid delivers hydrogen. Both these primary decarbonisation options will be demonstrated in the project, as will the 70% decarbonisation that occurs if NG is used for the upstream reactive fuel. For distilleries not connected to the NG grid ethanol/ biofuel burners will be developed to replace the current fuel oil burners, which will be capable of operation on hydrogen when this is available. The axial staged burner will be used for 100% hydrogen operation to demonstrate that this can be achieved without a major NOx problem. The burner will be designed to enable gas and liquid fuels in the lean primary stage as well as gas and liquid fuels in the axially staged secondary combustion. This will ensure that the burner does not change when the fuel changes.

The burner configuration will be that of reverse flow combustion, which will give some pre-heating of the inlet air by cooling the burner tube wall. Higher air temperatures will assist in burning the low volatility bio-oils. The burner will be located outside the steam boiler and fuel staging will not be inside the boiler, so no changes to the boiler are required other than to fit the new burner. The burner length is about 0.7m which will be outside of the boiler. Without the reverse flow air supply the hot combustion tube would be exposed, so the reverse flow configuration is also a practical necessity. The burner ignition and flame detection will all be in the primary burners, accessed through the front wall of the reverse flow burner enclosure. No flame detection will be required on the second stage as 1200K will auto-ignite any fuel that is injected.

The control of the multi-fuel burners will be via direct measurement of the air mass flow using a fan separated from the steam boiler and a venturi flow meter. The thermal output of any burner is controlled by the air flow and this will be the primary control. Normal single fuel burners use flue gas oxygen measurements to control the burner together with fuel flow measurements. This is more difficult with multi-fuel burners, including hydrogen, as the oxygen level indicates a different Ø for each fuel. A combination of flue gas oxygen measurements and air flow measurements will enable the burner to be controlled without the need to separately measure each fuel mass flow. These will be measured but will not be the primary burner control.

As the burner air flow will be the same as for NG, the air mass flows and velocities in the boiler will not change and so there will be no effect of the fuel switching on the steam boiler performance. The only problem area could be the ash content in crude glycerol, which might form boiler deposits. This would require a cleaning protocol, which is not a major problem.
Livingston is representative of those currently in use.

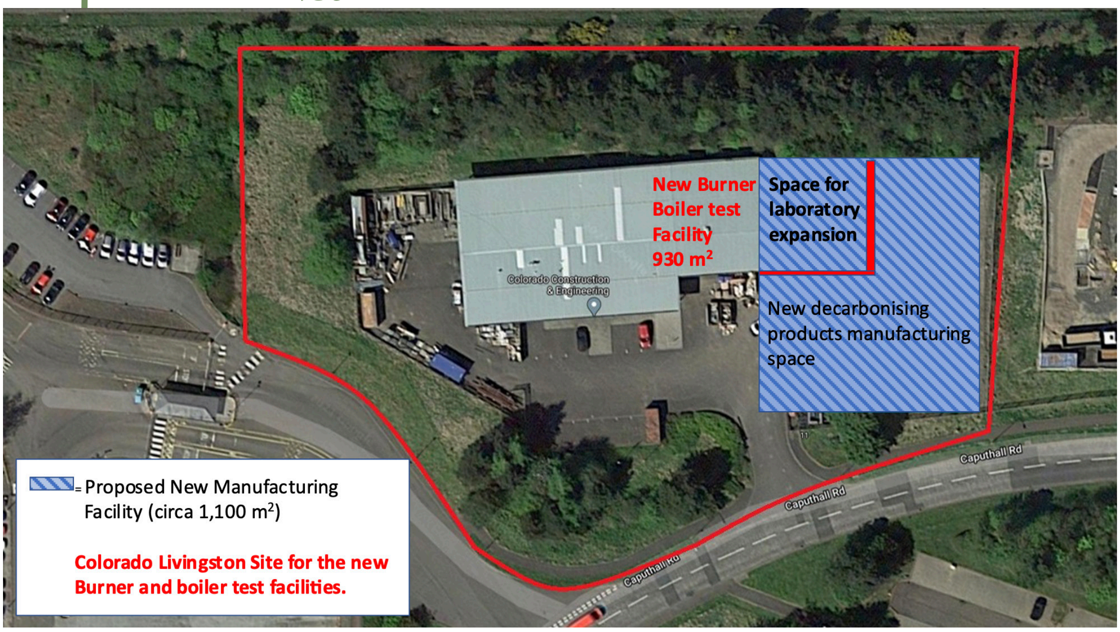
For direct fired distilleries a representative heated enclosure will be built at Livingston and similar axially staged multi-fuel burners will be fitted into the forced draft air supply to the existing heaters. We will work with users of direct firing burners to ensure that the test rig at Livingston is representative of those currently in use.

CONFIRMATION OF HOW THIS DEMONSTARTION PROJECT FITS WITH OUR CORPORATE STRATEGY

Colorado Construction and Clean Burner Systems' Corporate strategy is to benefit the environment through efficient process plant design and low emission burner design. They are committed to contributing to the UK's decarbonisation strategy, through designing and building new energy efficient distilleries. They play a leading role in the Hy4Heat programme developing low NOx hydrogen burners for the domestic gas fire market (3 contracts). As a burner manufacturer they are committed to developing the burners required for hydrogen for heat. The corporate strategy is to develop products in the area of decarbonisation that can be sold now and hence make a difference to decarbonisation immediately. They are not a research organisation, but work with the University of Leeds as an academic partner who have worked with them to develop solutions for decarbonisation of industrial processes.

Fig 5. 20 distilleries within 50 miles of the Livingston Innovation Centre

Fig 6. Aerial view of the Livingston site with the space for future development market



5 Design of Demonstration

350 kW Burner Design with a Primary burner of 100 kW

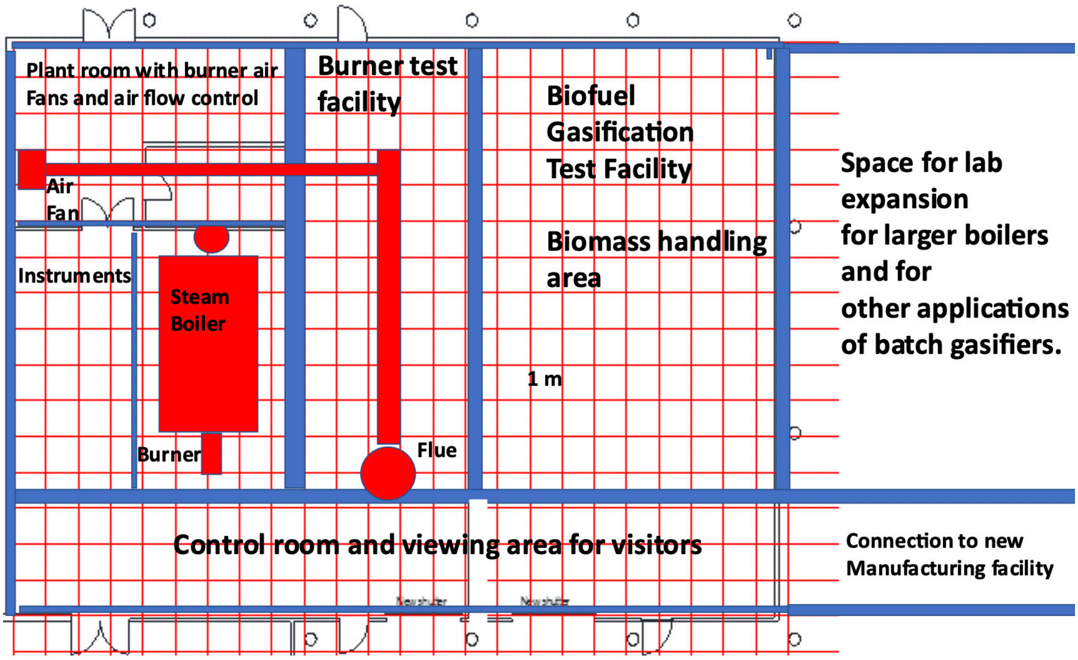
It is intended in this project to demonstrate a 350 kW burner in a steam boiler. The existing Leeds University 76mm burner is too small to generate this, unless the air flow is increased, which would be undesirable from a flame stability point of view. To scale up the burner we need to design 10% excess air to ensure complete combustion. Thus, we need 350/262 x 1.1 more air flow at the same air velocity, which requires a burner with 47% more flow area and a diameter of 92.4mm. This will be increased to a practical burner tube size of 100mm and a new burner will be manufactured to this design. This will generate a burner flow velocity of 13.9 m/s or a Mach number of 0.040, which Leeds University has considerable experience of operating burners at. These design principles can be used to scale the burner to any size.

However, work at Leeds University has shown that scaling up the Jet Mix burner too much, generates very high NOx due to the large recirculation zone downstream of the Jet Mix central baffle, which gets bigger as the size of a single burner is increased. For a burner of 4 times the capacity four 350 kW Jet Mix burners would be used with 1.4 MW total burner output. The secondary bio-oil burner would be the same in different burner sizes, just using more fuel injection points.

Radial swirlers are easier to scale up by increasing the vane passage depth, the diameter can be increased without affecting the NOx.

Radial swirlers of 140mm combustor diameter and 76mm diameter outlet swirlers have already been operated at 350 kW and scaling up to 250mm diameter will be sufficient for 1.1 MW and a 0.5m radial swirl combustor will be sufficient for 5MW.

Fig 7. Proposed Livingston development centre layout



6 Benefits and Barriers

6.1 An assessment of the benefits

The key benefit of this fuel switching proposal is that it could be implemented as soon as this phase 2 two year development project ends, as it does not depend on a supply of hydrogen being available, but can switch to hydrogen when it is available, if it is cost effective to do so. This proposal enables a start to be made on significant decarbonisation of the distillery industry. Even if NG is used for the primary burner, there will still be a substantial decarbonisation, as 70% of the steam boiler energy will come from the bio-oils. This proposal is deliberately targeted at the use of bio-oils and waste bio-oils such as crude glycerol, which are low cost and have little other use other than in the feed of cattle. For example the current industrial cost of NG is about 1p/MJ compared with 0.5p/MJ for crude glycerol and 1.4p/MJ for green hydrogen (MIT estimate for 2030 and the ERM Dolphyn Hydrogen project, BIES Project 0500255 Report 9.10.2019). Ethanol will be used in the primary burner to give complete decarbonisation now and has a current price of 1.85p/MJ. PA is a waste product from the distillery and PA currently costs the refinery to dispose of it. The proposal to burn the PA in the second stage combustion would be a low cost solution to a waste disposal problem, whilst recovering the energy in PAS. Other bio-oils that will be investigated, if their price is reasonable, are HVO, VOs, UCO, UCME. HVO could be obtained from the USA at low cost as it is subsidised there but available for export. Suppliers of UCO and UCOME have been arranged as well as for crude ethanol. It is clear that biomass sources can be obtained that are cost competitive with NG, with no subsidy for their use.

It is thus possible that fuel switching to bio-oils with the present axially staged combustion could reduce energy costs as well as decarbonising the distillery industry. With the PA waste being free and sufficient to displace 6% of NG energy, the fuel switching to bio-oils for the remaining energy to give 100% decarbonisation, is likely to reduce the operating costs of a distillery. However, the more reactive fuel for the primary burner will be a higher operating cost item, as for complete decarbonisation this has to be either hydrogen or ethanol and both are a higher cost than NG or any of the bio-oil supplies. However, the primary heater was shown above to be about 30% of the energy input and so the overall energy costs should be lower than current NG costs.

6.2 Barriers for the solution

A barrier to the proposed solution is the unconventional novel nature of the proposal. However, the demonstration facilities at Livingston should enable this resistance to change to be overcome, especially if we can demonstrate decarbonisation, cost reduction and a solution to the PA disposal problem, whilst recovering the PAS energy.

Crude Glycerol has a composition that includes water, methanol, ash and sulphur which could create problems with SO_2 emissions. However, it is one of the lowest cost bio-oils available and so the extent of the problem will be determined and a solution developed if emission limits are exceeded.

Although the use of PA to generate PAS as a waste bio-oil source is not a critical feature of these decarbonisation proposals, it is critical in the economics of distillery operation and hence a lower cost solution to the PA problem would be useful. The simplest solution is to use the PA directly as a form of water injection into the secondary burner region, which will achieve a large NOx reduction at the expense of a thermal efficiency penalty. It will also release the energy content of the PA without the cost of separation of PAS. The alternative solutions that involve separating PAS are difficult and possibly not lower cost.

6.3 Assessment of the capital cost of the proposed solution

Capital costs will be discussed with the Partner Distillery as the project is developed at the Livingston facility. Clearly dependent on the size of the distillery, base costs could be to the order of £100k per 2 stage burner, either for the steam boiler or direct fired distilleries.

In addition there will be design, manpower costs and capital purchases of;

- Steam boiler burner conversion
- Bio-oil storage
- Control systems
- Hydrogen electrolysis supply system and storage

6.4 Assessment of the Operating Costs

We anticipate that the operating costs will not be greater than those for NG or fuel oil as the fuel and could be lower. This is mainly because of the use of the waste PA from the process which has 6% of the required energy and the low cost of bio-oils that can be purchased locally or from biodiesel manufacturers who produce waste crude glycerol with a low price (0.5p/MJ). Ethanol and hydrogen will be the higher cost primary combustion fuels, but they are only 21% of the total energy consumed and as the bio-oils will be lower cost than NG the final costs is still likely to be less than current NG costs.

6.5 Assessment of the Process Risks

A key process risk is the development of the burner for ethanol, which should not be a high risk as it is a volatile fuel and easy to atomise by air blast atomisation. The optimisation of the burner air flow split and the development of fuel injection systems for bio-oils could be a difficult area.

6.6 How the process could be scaled, against a counterfactual

The design of a 350kW thermal output gasifier has been outlined above and the same principles can be used to design for any thermal output. A scaling of the burner thermal output by a factor of 9 only requires a burner of three times the diameter so the burner equipment will not be a major change. The burner at 350kW will be contained in a 140mm diameter burner tube so a 3.1MW burner would only be 0.42m diameter burner. Scale up of the hydrogen supply is more problematic, but if ethanol was used scale up would be relatively simple. As the steam boiler in the larger plant would not be changed, the new burners are the main change. Conventional biomass heat requires a new boiler to scale up the process, which is more expensive.

6.7 The greenhouse gases mitigated (in $MtCO_2e$/year)

This proposal offers 100% decarbonisation of whisky distilleries. 57% of distilleries in Scotland use NG (including CNG, LPG at 1%) as the fossil fuel [SWA]. With a GCV of 50MJ/kg this is 0.29 kg of NG per litre of whisky which emits 0.80 $kgCO_2$ per litre of whisky. Many distilleries in Scotland are not connected to the NG grid and use fuel oil (18% of whisky production) with a GCV of typically 43 MJ/kg and 0.33 kg of fuel oil per litre of whiskey, which will produce 1.07 $kgCO_2$ per litre of whisky. This is an average of 0.865 $kgCO_2$/L. Scotland produced 778M litres of whisky in 2020 and this released 672,970 tonnes of CO_2 in 2020 [SWA for 2018, 528,792 tonnes]. This proposal could eliminate all of this CO_2 with no increase in operational costs, but with higher capital costs.

6.8 Estimated change in production costs in £/bottle of whisky

It has been shown earlier that 100% decarbonisation can be achieved in this proposal at a similar cost to a NG fired steam boiler. The bio-oils will be lower cost than NG or fuel oil, but the more reactive first stage hydrogen or ethanol will be a higher cost than NG. However, these reactive fuels are only 21% of the process energy input and this will be balanced by the lower cost of the biofuels. As PAS is a zero cost process waste fuel and has 6% of the required energy, it is likely that cost will be reduced. In addition, the cost of disposal of PA may be avoided which will further reduce the overall costs. Thus, we do not envisage any increase in the cost of whisky, other than due to the finance costs of the capital investment to change to gasified biomass burners.

SWA (2020). Scotch whisky pathway to net zero, Report for Scotch Whisky Association by Ricardo Energy & Environment, Date 11th May 2020, Ref: ED 13298 (unrestricted publication).

Bell, J., Farquhar, J, and McDowell, M., Distillery by-products, livestock feed and bio-energy use in Scotland: A Review commissioned under the Scottish Government RESAS Policy Underpinning: Special Economic Studies. SRUC (Scotland's Rural College), July 2019.

Gandy, S and Hinton, S., 'Whisky by-products in renewable energy', Ricardo Energy & Environment: Ref: ED10564- Issue Number 2, 08 February 2018, Customer: ClimateXChange (unrestricted publication).

SWA, Scotch Whisky Association, available at - http://www.scotch-whisky.org.uk/what-we-do/facts-figures/

7 Costed Development Plan

7.1 A costed development plan for each process.

The project will be delivered as a series of components:

(a) Burner development test rigs for the burner first stage and second stage. This will enable low NOx burner designs to be developed and will use a heated Horiba gas analysis system that can analyse the total hydrocarbons for liquid bio-oil applications, where unburnt fuel may be a problem.

(b) Integration of the 2 stage burner into the steam boiler.

(c) Development of the direct fired burner/distillery test facility.

• A detailed focus on the component(s) to be piloted in Phase 2,

In addition to the above processes the following components will be developed:

(d) Two stage burner manufacture.

(e) Bio-oil store and transfer system to the burner.

(f) Burner flame detection and flame management system for the primary burner of the axially staged burner.

• A project delivery plan.

TASKS

1. Commission the burner test rig for the primary burner of the two stage burner using NG, ethanol and hydrogen. Optimisation of the primary burner Ø.

2. Commission the secondary combustion fuel injection burner system.

3. Commission the steam boiler and two stage burner integration.

4. Commission the direct fired burner test facility.

5. Optimisation of the burner excess oxygen for peak thermal efficiency and minimum emissions.

6. Determination of the feasibility of injecting PA directly into the secondary combustion zone co-fired with another bio-oil such as biodiesel.

7. Operation of the two stage burner on different bio-oils.

7.1 Biodiesel - UCOME.

7.2 Pot Ale and/or PAS.

7.3 Crude Glycerol.

7.4 UCO.

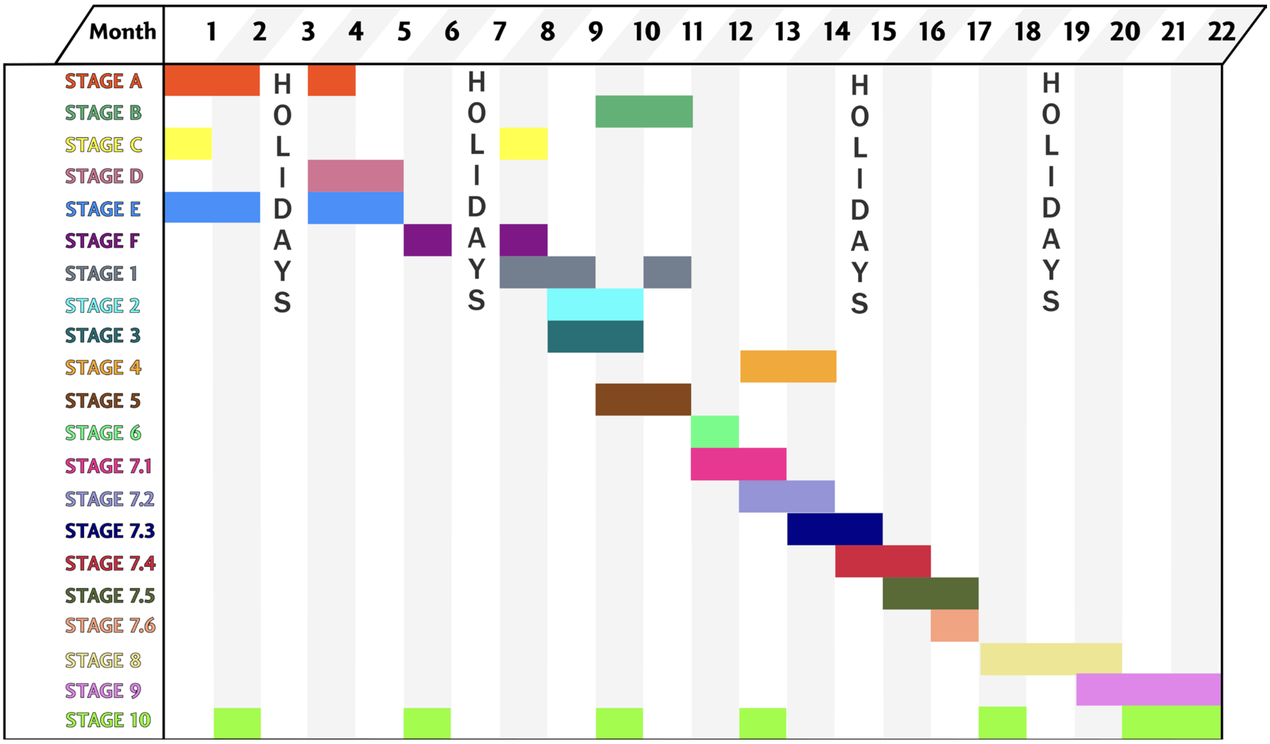
7.5 UCOME.

7.6 Mixed biofuels.

8. Integration into the steam boiler and tests on a representative range of bio-oils.

9. Operation on the direct fired burner test facility with axially staged combustion on a range of bio-oils.

10. Report, data analysis and project management meetings.



- **Detailed cost estimates for the demonstration**

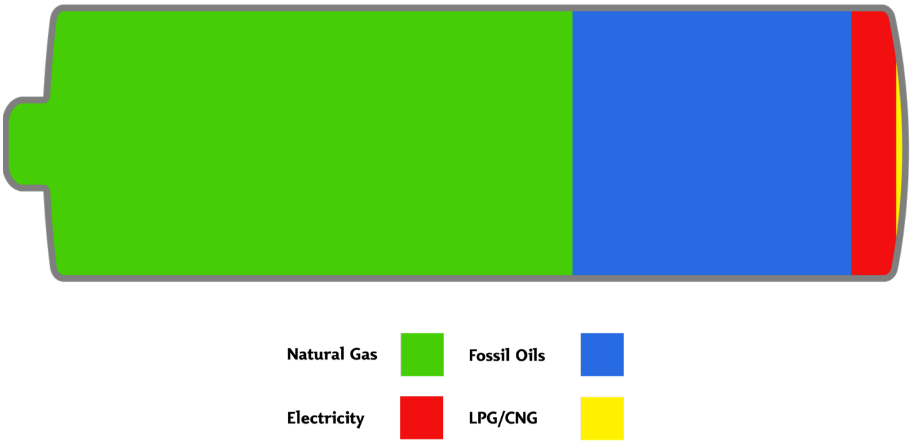
- **A business plan for how the process will continue to be developed after the funding for the pilot ends.**

We anticipate that the end of this programme the two stage ethanol/hydrogen and bio-oils burner route to decarbonisation will have completed its development and will be ready to take orders from distilleries that wish to decarbonise using bio-oils in 2023. The product development will thus be self-funding from sales. The product also has applications in other areas that use steam for heat.

8 Rollout Potential

The Livingston Development Centre will be designed and operated to show a working arrangement to distillery owners and managers of a set of modules combining to a complete pilot line, using hydrogen, gas from waste gasification, feeding a gas burner, connected to a steam boiler, providing energy to the distillation process, local heat and light.

The distillery industry currently use a mix of energy resource, with 63% of distilleries on NG from the grid, and the remainder a mix of fossil oils, LPG, and Electricity.



This diversity can be brought together in discussions and involvement at the Livingston Development centre, leading to individual distilleries picking the best route for hydrogen / Bio-fuel decarbonisation.

Working on the theory that distilleries make whisky, and the energy requirement for production, local light and heating can be managed and delivered to the various points of use from a local source in container modules will be valuable.

Discussions with distilleries will include both the hydrogen source available, exampled at Livingston, and the logistics of the Biomass.

Potential sources of hydrogen for discussion with partners can now include the 'Green hydrogen hub' proposed for the Highlands, strategically placed for supplying the whisky industry.

MODULE 1.

We have agreed in principle that hydrogen will be supplied to the Livingston development centre.

For distilleries typically, Hydrogen generation from electrolysis can be purchased, or leased, and installed in a distillery as a separate stand alone container, external or internal to the production area, becoming green as renewables, solar or wind are added to the site. Or a tanked supply of green hydrogen, also adjacent to the production area will be an option, connected to the same pipe work route. Large containers for Hydrogen are already designed and available from current sources.

MODULE 2.

The hydrogen supply from the stand alone unit will be piped to the burner through stainless steel pipework and fittings, complete with flow meters and all necessary safety components, as used and displayed in Livingston.

MODULE 3.

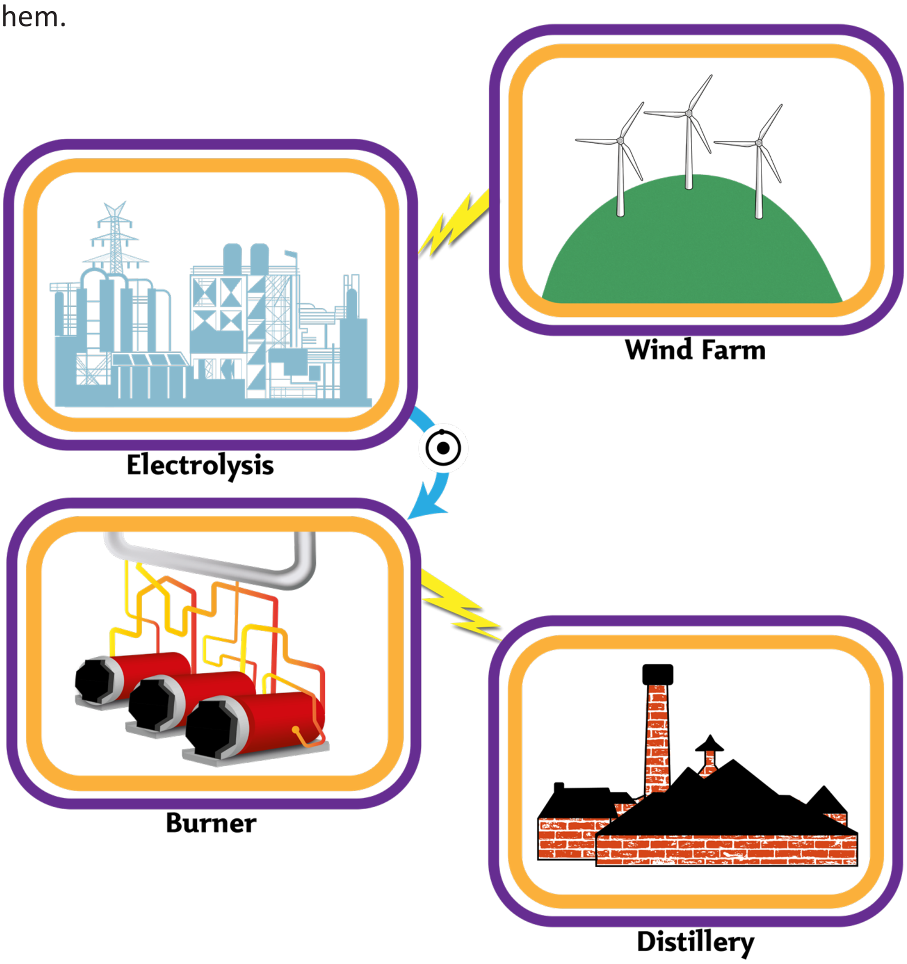
The hydrogen burner, running hydrogen, bio-fuel, or a mixture depending upon application choice, will be installed in a 350kW steam boiler in the Livingston Development Centre, and can be developed or scaled up to suit a distillery site for production, or for enhanced local trials, using a boiler as demonstrated, or using a boiler preferred by a distillery. All the necessary instrumentation and safety requirements will be incorporated and showcased for all the modules and the complete working system.

MODULE 4.

All the necessary instrumentation and safety requirements will be incorporated and showcased at Livingston for individual modules or for the complete working system from a self-contained room that can be housed in a container similar to the hydrogen generation module, located inside or outside the distillery.

MODULE 5.

Dual fuel will have a number of options ranging from hydrogen, ethanol, hydrogen mix, biofuels of different formulation of distillery waste.
Dual Fuel gas burners will be the route to immediate reduction of the distillery carbon footprint and the way forward to decarbonisation.
When green hydrogen becomes available, from whatever source, the burners will seamlessly move to operate on hydrogen.
This is a credible route to market, immediately reducing the distillery carbon footprint, that does not have to wait for hydrogen to be delivered through the Nat Gas grid.
Designed to offer options allowing individual distilleries to decide the best route to decarbonisation for them.



9 Route to Market

The steps to commercialisation of the project processes, start with our Livingston Development Centre. Located in buildings alongside Colorado Construction and Engineering, who have years of experience in building and commissioning distilleries and of welcoming customers to the site.

Delivering 100% decarbonisation of distillery power requirement will be a demonstrable technology at the Livingston development operation, or "Centre of Excellence" where the energy requirement of a distillery will be replicated in style and conditions typical of a production unit. The distillery industry per se can be a part of this demonstration process leading to carbon zero, rather than such a demonstration taking place in a single distillery.

Recent estimates indicate that there are over 130 whisky distilleries that are currently operational, with more planned. Livingston will be an industry showcase that can both prove the technology of dual fuel hydrogen/biofuel gas burners and show that the process involved can be moved out to individual distillery operations as a scaled package.

So we work with the best 130 plus, rather than with a selected one or two distilleries.
Hydrogen production or availability on site and the operational control centre housed in modular container size structures convenient to the building.

This operation can be delivered on site to a distillery, scaled to size, delivering decarbonisation immediately with bio-fuel gas feeding the dual fuel burners from day one.

The majority of distilleries use indirect firing of gas burners into steam boilers, and this will be replicated with a pilot plant in the Livingston facility.

The boiler choice in the facility will be a steam boiler used extensively by distilleries, but custom boilers preferred by some can be incorporated into a bespoke programme. Direct firing burners are also used in the industry where a direct flame plays against the distillation vessel walls.

Direct firing is used in only three distilleries and whilst a commercial development with so few targets will be questionable, the technology will be available from the CBS dual fuel burners.

The three direct fired distilleries will be a part of our commercial offering, with a view to agreeing the route to carbon zero, either working in one of the distilleries, or finding a way to replicate and demonstrate the new Carbon Zero process in the Livingston Development Centre.

Livingston gives us the benefit of bringing a route to decarbonisation to the whole of the industry, rather than a particular distillery in the outset.

It is core to the process of development to decarbonisation, and core to the route to market.
Colorado Construction and Engineering in partnership with CBS is a unique combination.
Colorado have constructed 9 of the new distilleries in Scotland, from Glen Turner producing 40 million litres per year, InchDairnie in Fife, Kings Barns St Andrews, Torabhaig on Skye being examples.

Designing burners and installing equipment is what we do as a group, what we do not do are science projects without application.

This strong contact base throughout the distillery industry is reinforced by opportunities in many other process industries, from food processing to Hotels and Corporate buildings where the use of steam heat will require to be decarbonised in line with government plans. All giving the Group a head start in promoting the Livingston Development Centre, delivering both processes and equipment to a distilleries path to Carbon Zero.


Colorado Distilleries

There are strong links throughout the industry and the dissemination of information is a well worked path, but rather than read about such developments, distillery owners and managers can meet with us in Livingston, be a part of the process, and consider how it can be a brought to use in their individual route to carbon zero.

These contacts and market awareness will be key in promoting the Livingston development Centre. The contact base extends internationally into the Japanese, US and French markets in particular, through current ownership structures in the distillery industry, and as we are seeing already the keen worldwide interest in decarbonisation, opens up opportunities for Colorado / CBS in international markets.

The Scotch Whisky Association is a powerful voice sitting as it does between the distillery and the consumer, publicly driving the route to Carbon Zero with pressure from its customers in the wholesale markets, consumers want to know what the industry is doing about decarbonisation.

The Livingston Development Centre will be a significant response to the road to Carbon Zero.

However in assessing the downside risks and barriers to this project meeting its considerable objectives, the key issues must be:

- The government driving the route to decarbonisation. The big target has already been set, Zero carbon by 2050, early stage dividends by 2030 the clear, the multiple options still to be finessed, has to be the main barrier.
- The supply of green hydrogen to those distilleries not on the grid in sufficient quantities to support batch production, local Modules for electrolysis, linked to buffer storage, that might not be practicable for all. Investment in 'Green hydrogen hub' for the Highlands actually going ahead.
- The availability of skilled labour resources to make this a nationwide success.
- Capital investment does not appear to be an issue, with recent published investments
- by distilleries of £70M - £140M…. Not insignificant amounts, but still relatively minor compared to the costs of decarbonisation.

A final word on the positive side, to pursue this to a carbon zero solution will make the industry the envy of the world.

10 Dissemination

The academic partners are experienced in the dissemination of the results of research projects to industry using CPD training courses, usually of one week duration. For this project a CPD course will be operated at the Livingston site, which would include demonstrations of the decarbonised heating equipment. Our intention would be to generate a new CPD course on 'decarbonisation of the distillery industry'. We would have a combination of University and industrial speakers on the course, as in our range of existing CPD courses. The distillery part of the consortia (Colorado, Ian Palmer and others) will be invited to lecture on the CPD course. The structure of this course will include lectures on lesson learnt in decarbonisation and the challenges in delivering the hydrogen and bio-oil solutions.

Some relevant CPD course we have operated over many years are:

- Combustion in Boilers and Furnaces
- Ultra-Low NOx Gas Turbine Combustion
- Explosion Mitigation and Modelling
- Fire and Explosion Investigation
- Diesel NOx and Particulate Emissions
- Energy from Biomass

Also we would present the results of the work at industrially relevant conferences and in the research Journals.
A paper will be presented at the World Wide Distilled Spirits conference.
Articles will be written for the Brewing and Distilling International magazine. A paper will be written for the European meeting on Combustion in Furnaces and Boilers.

11 Conclusions

Multi-fuel burners will be developed that have separate fuel feeds of NG, hydrogen and different biofuels in the same burner. Biofuels such as HVO, UCO, UCOME, PAS and crude glycerol are difficult to burn, which is why these fuels have not been considered previously for the decarbonisation of heat in distilleries [SWA]. Biofuels will be burnt as axially staged downstream of a more reactive fuel such as NG initially, but green/blue hydrogen or ethanol for complete decarbonisation. The axially staged burner will also be capable of two stage low NOx hydrogen operation, once hydrogen is available in the gas grid.

This work will be carried out in a new centre of excellence for decarbonisation of distilleries in Livingston, part of the Colorado Construction operating site. This will consist of a burner test facility, with an initial burner size of 350kW with a matched green hydrogen supply, and a steam boiler test facility for combined burner and boiler demonstrations. A 350 kW boiler in common use in distilleries will be used for this work. Also, direct fired heated distilleries are still in use and a test facility for this application will be built at Livingston with a similar axially staged dual fuel combustion strategy.

SWA (2020). Scotch whisky pathway to net zero, Report for Scotch Whisky Association by Ricardo Energy & Environment, Date 11th May 2020, Ref: ED 13298 (unrestricted publication).