colorado construction

BatGasDW

Batch Gasification of Distillery Waste Biomass for Renewable Distillery Fuel

Colorado Construction & Engineering
CBS // University of Leeds

///CleanBurnerSystems

UNIVERSITY OF LEEDS

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

BatGasDW: Batch Gasification of Distillery Waste Biomass for renewable distillery fuel.

Industrial Lead	Colorado Construction & Engineering Ltd (CCEL), Livingston, - James Maxfield (Project Lead)
Technical Lead	Professor Gordon E. Andrews, University of Leeds
Distillery Lead	Ian Palmer, John Fergus & Co Ltd, InchDairnie Distillery

Table of Contents

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

In Jan. 2021 the BEIS Glass Futures fuel switching programme successfully demonstrated a 100% bio-oil firing of the Encirc container glass plant in Derrylin in N. Ireland. Hence, the present proposals to decarbonise the distillery industry on biofuels, or hydrogen/biofuels staged combustion, are practical and offer a solution to early decarbonisation.

This proposal offers the potential for an immediate start to the decarbonisation of Whisky distilleries, by fuel switching to gasified biofuels. A novel burner is used to heat the gasifier to 800-900K and supply 20% of the overall steam boiler 350kW thermal input, with 280 kW added from the biomass gasification gas (BGG). The gasifier burner will operate at 0.2Ø using a reactive fuel (NG, green hydrogen or ethanol) to deliver the hot gas with 16% oxygen to produce rich flames in the gasifier at about 2Ø which will produce the BGG with high CO, hydrogen and hydrocarbons. The batch gasifier uses the same principles as domestic and commercial gasification log boilers, which are successful small-scale gasifiers for high (90% available) thermal efficiency heat generation. The LCV gas will directly heat the existing steam boilers in the distillery and a 350 kW boiler will be used, as they are typically in common use in distilleries, and a new CBS burner for LCV BGG will be developed for the boiler.

A biomass to steam energy conversion thermal efficiency of >60% is possible, which is at least twice the overall thermal efficiency of AD bio-gas supply with an off-site AD plant. It also has the added benefit of operation on mixed bio-liquid/biomass feedstock such as draff, PAS, barley straw and bio-oils such as VOs, HVO, UCO, UCOME and crude glycerol, which are all low cost biofuels. In phase 1 it has been demonstrated that draff, PAS, crude glycerol and VOs can be gasified, including mixed biofuels. The phase 1 GCV measurements show that 23% of the energy in the biomass could come from distillery waste Draff and PAS and these are essentially free energy sources. Thus, not only could decarbonisation be achieved, but at lower operating costs. Crude glycerol and UCO are low cost bio-oils and barley straw is a locally available low cost bio-mass. A start on this complete decarbonisation of distilleries could be made in 2023 and we have current interest from distilleries to lead on this.

For complete decarbonisation now, we are proposing that the fuel to heat the gasifier will be crude Green Ethanol, which will also be used in the demonstration plant at Livingston. In the transition period to zero carbon the gasifier could also use NG as the reactive fuel and a dual fuel NG/Hydrogen burner option will also be developed for this. The advantage of this approach, rather than installing a biomass fuelled boiler, is that the existing distillery steam boiler would probably only need a new burner and space to locate the gasification module close to the boiler, which most distilleries should have.

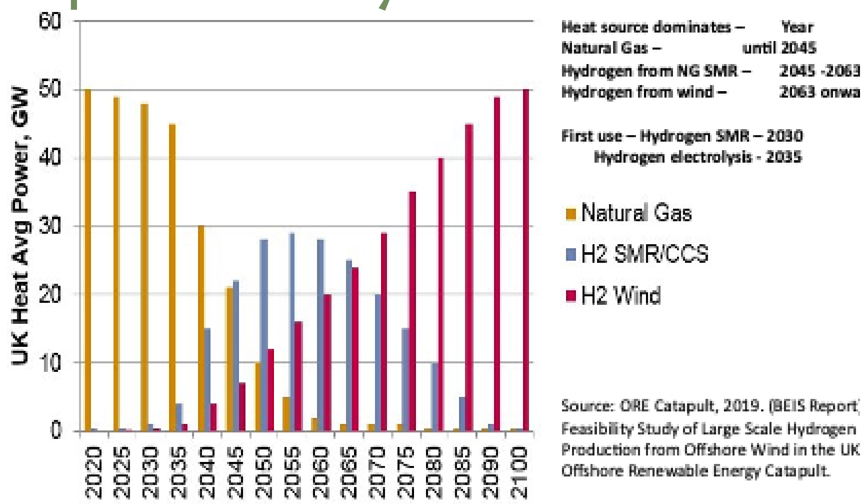
This work will be carried out in a new centre of excellence for decarbonisation of distilleries in Livingston, part of the Colorado Construction operating site. This will consist of a gasifier test facility, with an initial gas output of 350kW. There will be a burner test facility to develop the gasifier reactive fuel burner and the steam boiler LCV burner. There will be a steam boiler test facility for combined gasifier and LCV gas burner and steam boiler demonstrations to the distillery industry. Scale up of the process to higher thermal powers is straightforward and requires a larger gasifier and larger burners.

2 Overview of the project

INTRODUCTION

This novel proposal for fuel switching from NG to biofuels is based on gasification of biofuels, as this is a process that can utilise a wide range of low cost difficult to burn biofuels. A reactive fuel with about 20% of the overall energy input will be used to heat a furnace with the biofuel to be gasified preloaded. The reactive fuel will heat the gasifier furnace to 800-900K, where any biofuel material will gasify under rich burning conditions. Initially the reactive fuel will be NG but this will be replaced by crude bio-ethanol for 100% decarbonisation. This avoids the wait for green hydrogen in the gas grid which would result in little decarbonisation for the years that this will take to achieve. However, the reactive burner will have dual fuel capability with NG and hydrogen, due to their similar Wobbe number and this will enable hydrogen to be used as the reactive fuel when it is available and if it is cost competitive with ethanol.

Fig 1. UK heat power forecast by source



Gasification of distillery waste biofuel and other biofuel is directed at achieving an early transition to the decarbonisation of distillery heat. Biofuels generated 31% of electricity in 2019 [DUKES, 2020] compared with 37% from wind, so biofuels should be a major consideration in the decarbonisation of distilleries. Currently biofuels are used for 8% of the energy requirements in distilleries [SWA 2020], mainly using offsite AD, which has a poor (<30%) overall thermal efficiency. This proposal aims to take this use of biofuels to 100% of the energy requirements, with some distilleries converting to zero carbon using this technology in 2023/24.

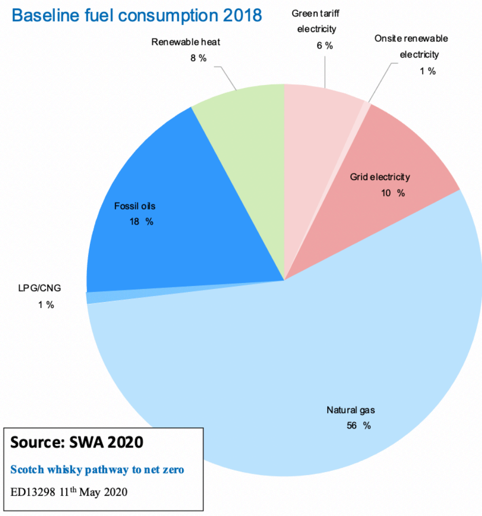
The gasifier will be developed and tested on different biofuels using NG as the gasifier burner flame. Once optimum operating conditions have been found the heating of the gasifier will be switched to crude bio-ethanol. The gasifier will operate on low cost difficult to burn biofuels including distillery waste draff and PAS as well as other biofuel sources: barley straw, crude glycerol, VOs, UCO or any other low cost biofuel. The benefit of the gasifier approach to decarbonisation is that both solid biomass and bio-oils can be gasified, as well as mixtures of feedstock. This will enable the lowest cost solution to biofuel supply to be achieved.

DUKES 2020 - DIGEST OF UNITED KINGDOM ENERGY STATISTICS 2020 www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

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).

By the end of this project the gasification technology could be rolled out across the industry and as most of the difficult to burn biofuels are also low cost, there could be economic as well as environmental benefits of this work. Over a period the whole distillery industry could be converted to zero carbon using gasified biofuels.

Fig 2. Baseline fuel consumption in 2018



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

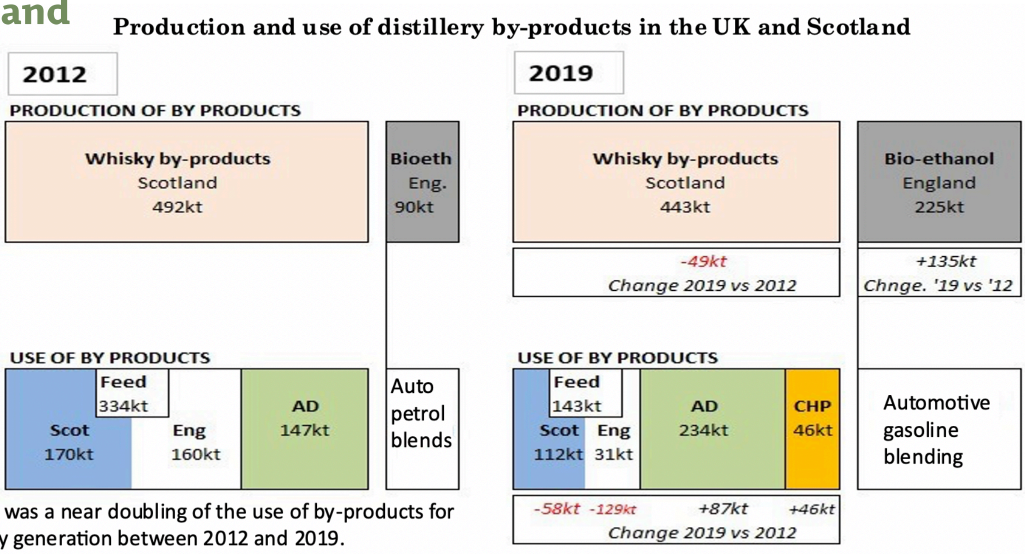
In 2018 heat represents approximately 82.7% of fuel consumption with electricity at 17.3%.

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.

Fig 3. Production and use of distillery by-products in the UK and Scotland



There was a near doubling of the use of by-products for energy generation between 2012 and 2019.
Note that crude ethanol from the automotive sector will be available for other uses by 2030, due to end of production of gasoline and diesel vehicles and replacement by electric vehicles in 2030.
Modified diagram from:
Source:Julian Bell, John Farquhar, Mary McDowell, Distillery by-products, livestock feed and bio -energy use in Scotland , SRUC – Scotland's Rural College, July 2019.
A Review commissioned under the Scottish Government RESAS Policy Underpinning: Special Economic Studies

This proposal is an outcome of Leeds University's work on compartment fires, where all the fire load is in the compartment at the start of the fire and the fire heat release is controlled by the air access to the compartment. The fire load undergoes gasification with the generation of high concentrations of CO, hydrogen and hydrocarbons. These gases burn in the external air as the gases leave the fire through windows and are seen as an external flame. This is the energy that passes to the steam boiler in the present proposal. Similar principles are also used in log boilers or gasification boilers, where a gasifier is preloaded with wood and ignited, often using a pilot gas flame, and the gasified gases are then passed to a secondary burner with air addition. This gasification boilers are available from several manufacturers with >90% thermal efficiency. This is the basis of the present larger scale bio-gasifier gas (BGG) for combustion in a steam boiler, which is based on a previous prototype at Leeds University. Surplus BGG will occur when the distillation is changing batches and this will be used to generate water pre-heating in a separate water heater. It has been shown in this Phase 1 work that draff and PAS can be gasified as well as crude glycerol and vegetable oils and mixtures of any of these.

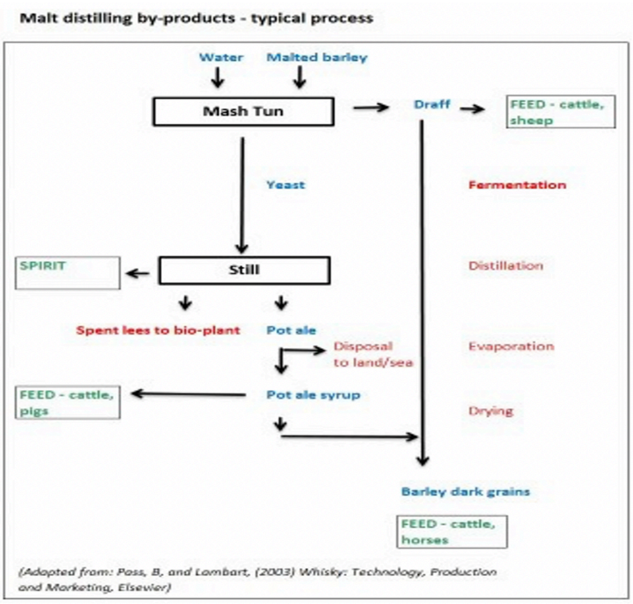
Co-firing with another fuel is possible and this is used for light up, but will continue to operate to enhance the gasifier performance.

In the present proposal the air flow will be forced draft, as in existing steam boilers, but the gasifier inlet burner operating lean will provide all the oxygen for the gasifier and there will be bypass air flow providing the air for the BGG LCV burner. This will enable the total air flow to be controlled as this controls the overall thermal power to the steam boiler.

The advantage of the gasification mode of operation is that existing steam boilers can be used with the BGG and they are more tolerant to a wide range of Biomass and Bio-oils, so they are more suited to using Draff and PAS as well as other agricultural and industrial waste biofuels.

As most distilleries use steam boilers for indirect heating of the distillery, the work will be carried out on a new dedicated burner, gasifier and steam boiler test facility at the Livingston Development Centre. This will enable working package modules of burner/gasifier/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 proposal with several distillery operators and all favour the dedicated off-site development of the gasifier and steam boiler combination and are unwilling to allow potentially hazardous gasification work to be undertaken in a working distillery.

Fig 4. 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/$_{Lwhiskey}$ 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.

PROJECT OBJECTIVES (as set out in the application)

The objective is the conversion of waste distillery draff and pot ale into a gasification-gas for steam generation or direct heating in a distillery.

A novel rich burning air gasifier will be used with medium (800K -900K) temperature rich burning gasification with a secondary green fuel (biodiesel or hydrogen) for heating the gasifier. The rich burn gasifier is at TRL4/5 at the University of Leeds and in Phase 1 the objective will be to demonstrate that draff and pot ale can be converted efficiently into a gas.

In Phase 2 the objective will be to move the process to TRL6 in a larger scale gasification rig and then install in a small distillery.

In this report some changes to the above have been made. Crude ethanol (from manufacturing for addition to gasoline) has been added as an additional secondary fuel for the gasifier heating, as biodiesel is difficult to burn on its own in ambient temperature air and renewable crude ethanol is volatile and easily burnt at ambient air temperature. Crude glycerol has been added as an additional waste biomass suitable for gasification, as draff and PAS are not sufficient on their own to provide all the energy for distillation. All of this is necessary to achieve 100% decarbonisation now and as well as in the future, until the option of green/blue hydrogen being available in the gas grid for the gasifier heating fuel.

Distilleries are a batch operation and this may lead to problems as a gasifier is not easy to turn off, once a batch of feedstock is being gasified. To avoid this problem a second heater will be used to divert the gas to when the distillery is being changed to a new batch. Finally, as most refineries are steam heated the project will be based at new experimental facilities at the Livingston Development Centre, where a steam boiler, from a manufacturer with large sales in the distillery market, will be based close to the gasifier test rig. This site will then be used for demonstrations of the technology to the whole distillery market.

Currently a modern distillery uses 14.4 MJ of fossil fuel energy to produce one litre of whisky (John Fergus, InchDairnie). There is sufficient waste Draff and PAS to replace about 23% of this energy with low CV gasified biomass, which is the basis of this proposal. The proposed novel gasifier will use a more reactive fuel to heat the gasification furnace, which will be ethanol, with additional waste biomass and bio-oils in the gasifier for complete decarbonisation. Initial work will be carried out with NG as the more reactive fuel, so that the optimisation of the gasifier can be undertaken prior to using ethanol. When hydrogen is available in the gas grid it could be used as the reactive fuel and this will also be demonstrated in the proposed work programme.

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

OTHER TECHNOLOGIES THAT WERE CONSIDERED AND HOW WE CAME TO OUR CHOSEN TECHNOLOGY

We consider that 100% hydrogen and biomass or bio-oils 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, with bio-ethanol as the more reactive fuel to heat the gasifier, is the best route to decarbonise distillery heat now.

The CCC (Biomass in Low Carbon Economy, Nov. 2018) advocates that biomass should only be used with BECCS 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. There are no BECCS plants and no biomass to hydrogen plants in operation, so this type of advanced technology would result in no immediate decarbonisation in the near future, so would prevent zero carbon targets from being achieved in the timescales required. 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 and AD.

1. Domestic and commercial gasification boilers are currently on the market by several manufacturers with >90% thermal efficiency for hot water and the present work has achieved for a 280kW pine wood gasifier >75% gasifier efficiency. In a smaller laboratory scale gasifier an optimised gasifier thermal efficiency of 78% was achieved and this was the equipment used to demonstrated that draff and PAS could be gasified. 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%. This proposal is essentially a scale up of these <50 kW gasification boilers to a larger 350 kW scale and applied to steam generation as well as hot water. The gasification boilers are much more tolerant of the type of biofuel and this would give the distillery the options of sourcing local biomass such as barley straw that AD and combustion biomass boilers cannot use.

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 size 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 [https://theenergyst.com/whisky-distillery-toasts-15-energy-bill-savings-from-lpg/].

2. Biomass combustion in direct fired boilers have good thermal efficiencies comparable to those for gasification boilers. The [Sustainable and optimal use of biomass for energy in the EU beyond 2020] 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)]. However, combustion biomass heat plant are much less tolerant to the fuel type than gasification boilers. Typically, they need a premium processed biomass in pellet format, which costs more to operate. 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.

3. Both the gasification and combustion biomass boilers have 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%.

The use of gasification of waste biomass and bio-oils using gasifier fast heating with a reactive gas fuel such as ethanol, as in this proposal, will help the transition to zero carbon in the distillery industry. However, it is a much larger change to a distillery to install a gasifier and biofuel handling plant, compared with a hydrogen burner from grid supplied hydrogen. However, if

https://ec.europa.eu/energy/sites/ener/files/documents/biosustain_report_final.pdf zero carbon is required on a timescale that grid hydrogen cannot be delivered, then a dual fuel ethanol/bio-oil approach is feasible. However, distilleries only have PAS as a waste bio-oil and this is not easy to burn. Currently, the type of burner used with steam boilers is not available for high boiling point viscous bio-oils.

The present biofuel gasification route to zero carbon is probably the next best option to a 100% hydrogen solution and is more practical, as green hydrogen is not available to a distillery now through the gas grid. A local supply of green hydrogen from wind farms and electrolysers could be set up to use as the reactive fuel in the gasifier, but this will never be cost competitive with crude ethanol without financial incentives to use hydrogen. Crude ethanol is likely to be lower in price in the future as the transition to electric vehicles for road transport means that the current infrastructure for producing bio-ethanol for addition to gasoline at 5% will be looking for new customers.

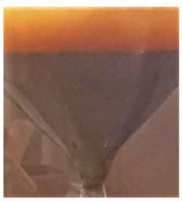
3 Experimental/ modelling results and conclusions

Draff and PAS samples have been obtained from John Fergus & Co Ltd, InchDairnie Distillery and their properties determined and small scale tests carried out to show that they could be gasified. Also, chemical equilibrium software has been used to show that the presence of water in the solid or oil samples could with fast flame heating produce additional hydrogen in the LCV gas.

There is a problem of the water content of biofuels, especially PAS. However, it is possible that steam produced from rapid flame heated water will combine with C and CO to yield additional hydrogen. In conventional gasifiers steam is injected to increase hydrogen yield and if this can be achieved in this flame heated batch biomass gasifier then that would improve the thermal efficiency. The hydrogen yield will be determined in the development of the full scale gasifier.

Fig 5. Draff and PAS used in small scale gasification.

Dried draff
Prior to small
Scale gasification



Gravity separation of PAS
from pot ale.

PAS
Prior to small scale
gasification

Contaminated water after PAS separation. Oxygen treatment is proposed using the oxygen from the electrolyser for hydrogen production. This will be followed by char absorption of VOCs to leave clean water that can be discharged to drain.

Draff and PAS used in small scale gasification (Appendix 6)

4 Description of the Demonstration Project

Fuel switching for distillery heat is proposed from fossil fuels to a combination of green/blue hydrogen or crude ethanol as the gasifier reactive fuel which heats the gasifier furnace. The gasifier burner uses very lean operating to generation about 800 – 900K in the gasifier.

Very lean burner operation requires a specific burner design and the Leeds University design that will be used has been shown to have the required lean flame operation. Distillery draff and pot ale will be gasified, together with other biofuels, such as barley straw and crude glycerol.

The BGG will be burnt in an LCV Jet Mix burner developed by Leeds University, for heating a steam boiler for distillery operation. Difficult to burn renewable biomass and bio-oils will be used and this Phase 1 work has shown that draff and PAS can be gasified, as well as crude glycerol which is a waste product of little value from biodiesel manufacture (10% of biodiesel is waste crude glycerol). Raw vegetable oils can also be gasified together with any waste farming residue.

This novel form of mixed biomass gasification will enable complete decarbonisation of distilleries, if the gasifier flame heater uses green/blue hydrogen or crude ethanol from gasoline ethanol supplies. However, initial work on the development of the gasifier will be carried out with NG, as the Wobbe Index of NG and hydrogen are within 7%, the same burner used for NG can be used for hydrogen.

This proposal 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 for the burner that heats the gasifier. As most distilleries use steam boilers for indirect heating of the distillery, the work will be carried out on a new dedicated burner, gasifier and steam boiler test facility at the Colorado HQ in Livingston. This will enable a working package of burner/gasifier/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.

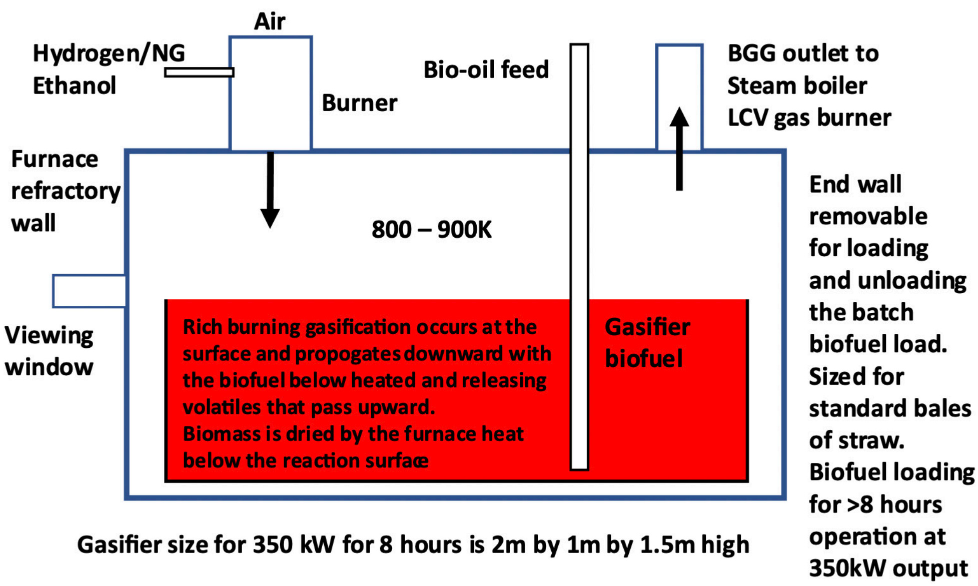
For direct fired distilleries the heating space will be fired with LCV Grid Mix burners, sized to fit the combustion flow passages around the existing distillery burner passages. The demonstrator rig for this will also be built at Livingston.

How this demonstration 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 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 now. 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 to decarbonisation of industrial processes.

5 Design of Demonstration

The heat release from all fuels is close to 3.0 MJ/kgair. So for 350 kW of output 0.12 kg/s of air is required. It is desired to have a temperature of the gasifier NG heater of about 835K which using adiabatic flame temperature predictions is a Ø of 0.20, which has 16.4% oxygen in the flame gases for consumption in the gasifier. This is an A/F of 82.5/1 and a fuel flow rate of 1.45 g/s which is a 72.7 kW preheater burner. The is 20.8% of the overall thermal input to the steam boiler, the rest coming from the biomass, which would be 277 kW from the gasified gas released at the LCV burner in the steam boiler. The design would have the gasifier close to the steam boiler burner to minimise thermal losses in the transfer of the hot gasified gases to the steam boiler.



Gasifier size for 350 kW for 8 hours is 2m by 1m by 1.5m high

6 Benefits and Barriers

6.1 An assessment of the benefits for the solution

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 could switch to hydrogen when it is available. This proposal enables a start to be made on significant decarbonisation of the industry, even if NG is used for the gasifier heater, there will still be a substantial decarbonisation, as 79% of the steam boiler energy will come from the gasified biomass. This proposal is deliberately targeted at the use of biofuels and waste biofuel products, such as crude glycerol, which are low cost and have little other use other then 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.

The main reactive biofuel, ethanol, that will be used has a current price of 1.85p/MJ, this is more expensive than the estimated future cost for hydrogen and if this is the real delivered price, then the industry will switch to hydrogen. Draff and PA are waste products from the distillery and PA currently costs the refinery to dispose of it. Straw or Hay can be purchased at about 0.3p – 2p/MJ, depending on the water content and on the time of year and the gasifier will be sized to be able to take standard bales of hay or straw. Wood chips are available at 0.7p/MJ and wood pellets at 1.1 p/MJ (Perthshire Biofuels). 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 gasified biomass could reduce energy costs as well as decarbonising the distillery industry. With the draff and PA waste being free and sufficient to displace 23% of NG energy, the fuel switching to biomass for the remaining 77% of energy to give 100% decarbonisation, is likely to reduce the operating costs of a distillery. However, the more reactive fuel for heating the gasifier will be a higher operating cost item, as for complete decarbonisation this has to be either bio-ethanol or hydrogen and both are a higher cost than NG or any of the biomass supplies. However, the gasifier heater was shown above to be only 21% of the energy input and so the overall energy costs should be lower than current NG costs.

6.2 An Assessment of the 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 and cost reduction. Also, the gasification of PAS requires its separation from PA which is currently done using evaporation using fossil fuels. To use the energy in PAS it is proposed that gravity separation of PAS from PA is used with a combination of oxygen gas bubble treatment and char absorption of VOCs in the residual liquid, with the aim of meeting water disposal quality standards without using evaporation.

A further interesting issue is that the current demonstrations of the technology have been on the basis of a batch of biomass in the furnace which is gasified over a period of a few hours, we will introduce a system for addition of new biomass. Hopper feed will have to be developed

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 £200k per gasification unit per distillery.

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

- Gasifier,
- Gasifier burner,
- LCV burner (separate burners for steam boiler and direct fired distilleries)
- Steam boiler burner conversion
- Water heater and LCV burner
- Bio-oil storage
- Biomass storage
- Gasifier control system

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 draff and PA from the process which has 23% of the required energy and the low cost of biomass that can be purchased locally or from biodiesel manufacturers who produce waste crude glycerol with a low price (0.5p/MJ).

6.5 Assessment of the Process Risks

A key process risk is the optimisation of the thermal efficiency of the gasifier and the development of control systems to operate the gasifier at the optimum equivalence ratio, but the demonstrated pilot scale optimum efficiencies of 70% look reliable.

A further risk is that the gasifier heater burner has only been operated on NG, kerosene and diesel and not on ethanol. However, as the burner operates very lean at 0.2Ø we do not anticipate any problems.

6.6 How the process could be scaled, against a counterfactual.

The design of a 350kW thermal output gasifier has been outlined and the same principles can be used to design for any thermal output. A larger gasifier will be required for higher thermal outputs if the same operational time on a single biomass load is required. 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.

Scale up if ethanol was used would also be relatively simple. As the steam boiler in the larger distilleries would not be changed, the new burners are the main change. Conventional biomass heat could require 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. 64% 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 (31% 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. Scotland produced 778M litres of whisky in 2020 (down 14% from 2019) and this released 655,742 tonnes of CO_2 in 2020 (SWA for 2018, 528,792 tonnes). This proposal could eliminate all this CO_2 with no increase in operational costs, but with higher capital costs.

**31 per cent of w
in Scotland is not connected to
the National Grid and uses fuel oil.**

6.8 If possible, please estimate the 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 biofuels will be lower cost than NG or fuel oil, but the more reactive gasifier flame heated by 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 draff and PAS are zero cost process waste fuels and have 23% of the required energy, it is likely that overall cost will be reduced. In addition, the cost of disposal of PA may be avoided further reducing 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.

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 gasifier burner and the LCV steam boiler burner. 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) Gasifier furnace development.
- (c) Integration of the gasifier to the steam boiler with minimum BGG transfer dis tance.
- (d) Integration of the BGG LCV burners into the direct fired distillery heater (Items 7 and 8 in project delivery plan).

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

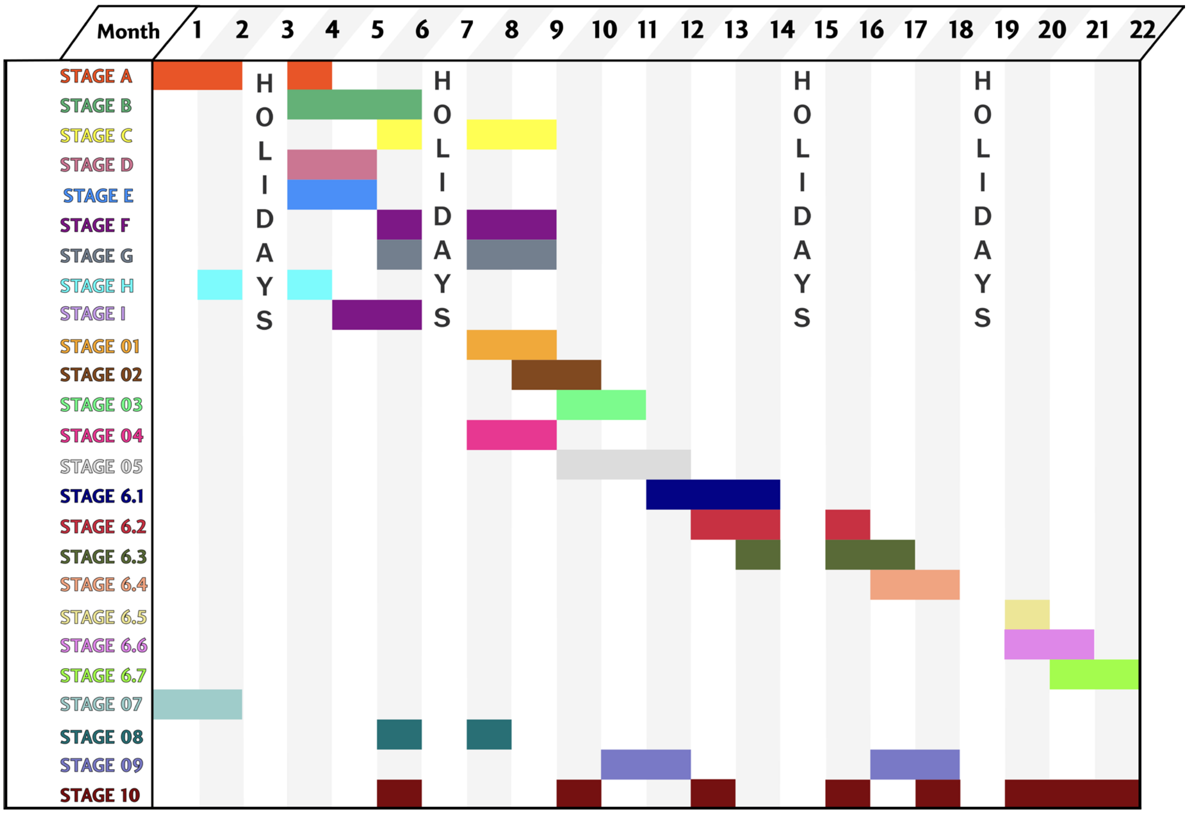
In addition to the above processes the following components will be developed:

- (e) Biomass store and loading system for the batch gasifier.
- (f) Bio-oil store and process flow system into the gasifier (which can be continuous).
- (g) Gasifier peak seeking control system for optimisation of the thermal efficiency which will include the installation of a heating FTIR to analyse the gasifier gas composition and a hydrogen analyser.
- (h) Hot BGG transfer from the gasifier to the steam boiler with the minimum of heat losses.
- (i) Burner flame detection and flame management system for the gasifier burner and the LCV BGG burner.

A project delivery plan.

1. Commission the burner test rig for the gasification burner using NG, ethanol and hydrogen.
2. Commission the gasification furnace and air supply and burner system.
3. Commission the BGG LCV gas burner.
4. Commission the steam boiler and gasifier integration.
5. Optimisation of the gasifier for peak thermal efficiency.
6. Operation of the gasification furnace on different biomass:
    - 6.1 Draff.
    - 6.2 Draff and PAS.
    - 6.3 Crude Glycerol.
    - 6.4 Barley Straw.
    - 6.5 UCO.
    - 6.6 UCOME.
    - 6.7 Mixed biofuels.
7. Development of the direct fired distillery BGG LCV burner test rig.
8. Commissioning of the direct fired BGG LCV distillery burner test rig.
9. Operation of the direct fired distillery burner test rig on Draff and Glycerol BGG.
10. Report and data analysis.

TIMESCALES



- **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 at the end of this programme the BGG route to decarbonisation will have completed its development and will be ready to take orders from distilleries that wish to decarbonise using biofuel gasification in 2023. The product development could thus be self funding from sales.

The product also has applications in other areas such as BGG fuelling of diesels and micro-gas turbines for green power generation, gasification of plastic waste for power or heat would also be possible.

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 be a complete pilot line, leading to an early transition of distillery heat using bio fuel produced from distillery waste, feeding a low CV gas burner, connected to a steam boiler, providing energy to the distillation process.

As the energy needs will be diverse across a range of distilleries, the Module concept will help to match the process to the individual distillery need.

In working up the potential of the Livingston Development Centre, we have benefited from a close working relationship with Glen Turner for large scale energy needs and with InchDairnie for more typical distillery energy needs.

The pilot line will also take into account the diverse range of distillery and local waste that can be gasified, ranging from distillery Draff to bales of Barley straw sourced from local farmers. The significant effect of this will be the size of gasifier feed that can accommodate such materials, but this will be valuable in helping a distillery partner decide what will best suit their plans.

The fuel to the gasifier whether it be ethanol or hydrogen will be discussed with the distillery as to local availability and cost.

The key fuel components and primary challenges are:

- Green Hydrogen use will need to answer the questions of source, including on site electrolysis, and the energy required to run the process, availability from the grid, and the costs to the distillation process.
- Ethanol availability, the cost and logistics.
- Biomass local availability, cost and logistics, including the on site storage for just in time demand.

MODULE 1.

The first step in the planning for a distillery requirement will be a burner design that is related to the distillery waste available.

The novel burner design feeding the gasifier unit will be scaled to support a 350kW steam boiler.

This burner will be designed to run on NG or ethanol, giving options to the local distillery on both availability and carbon reduction.

This Module will demonstrate both scale in burner output and use of different feed gases.

MODULE 2.

The gasifier unit typical of a size needed to feed the 350 KW steam boiler, complete with auto feed.

We will show in Module 2 a range of scale that will enable the particular distillery to confirm its footprint, output size, including the waste material be it distillery draff or bales from local farmers.

MODULE 3.

The novel burner and gasifier will be linked to 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.

All the necessary instrumentation and safety requirements will be incorporated and showcased for all the modules and the complete working system, will be controlled from a separate control room.

MODULE 4.

A self-contained control room will be designed and built to run the complete pilot line and housed in a container unit that can be replicated on site in a distillery.

MODULE 5.

Direct fired distilleries with axially staged dual fuel burners will also be demonstrated on a separate test rig.

There are only three distilleries in Scotland using direct fired burners in the distillation process, but we will show in Livingston that our novel biomass burners will operate as direct fired.

It is intended that we work closely with a distillery in setting up the pilot, and this is being pursued.

THE BIG PICTURE.

Livingston will be the demonstration centre that relates to individual distillery requirements in that we open the doors to all distilleries, rather than a select few at the start, but it demonstrates the earliest possible route to carbon zero through the gasification of distillery and other waste.

The novel gasifier burners will be designed to operate as Dual Fuel NG/Ethanol so immediately reducing the carbon foot print of the distillery operation.

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.

As most distilleries use steam heating, the project does not need to be based at a distillery where it would interrupt production and raise Health and Safety issues.

The decarbonisation of steam production will also be available for any steam boiler process industry application, and we will work with our steam boiler suppliers to exploit this wider market, from brewing to food processing to hotels and public buildings to name but a few of our customer industries.

9 Route to Market

Livingston will be unique in demonstrating a route to carbon zero for distilleries and for many other energy using industries, giving a well promoted route to market.

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. There are about 130 (SWA) whisky distilleries currently operational, with more planned.

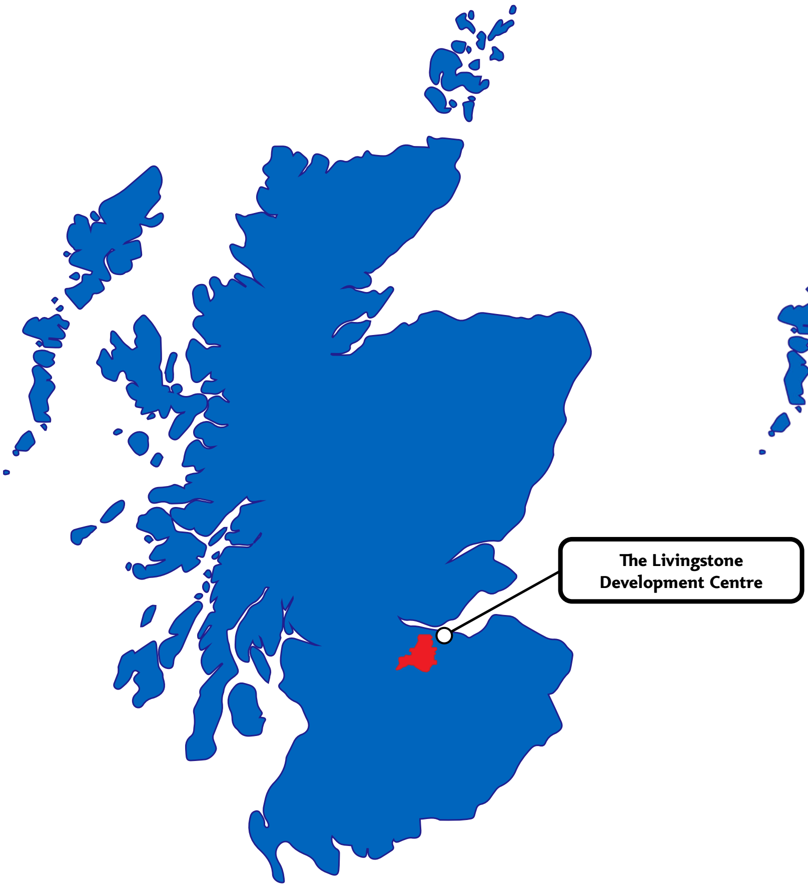
Livingston will showcase the technology of biofuel gasification, novel gas burners, and show that the process involved can be moved out to individual distillery operations as a scaled package.

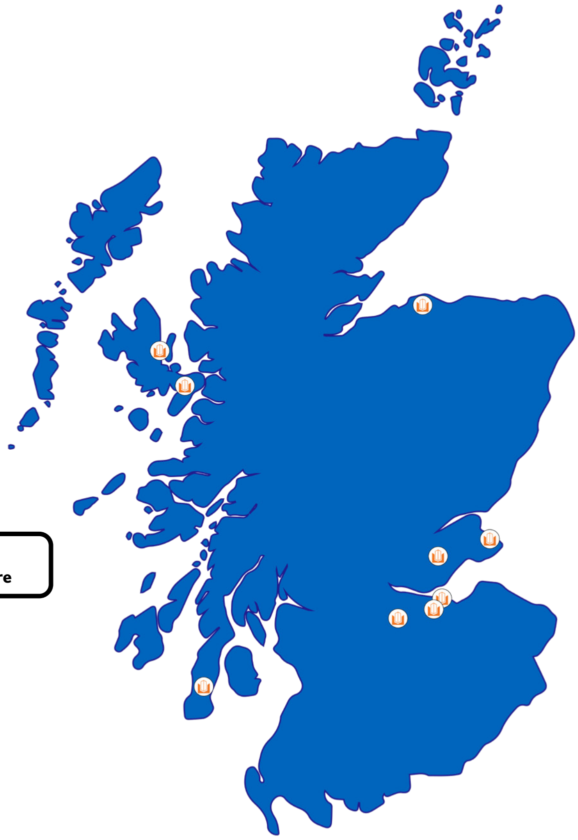
So we will work with all, rather than with a selected one or two distilleries.
The majority of distilleries use indirect firing gas burners into steam boilers, and this will be replicated with a pilot plant in the Livingston facility.

Direct firing burners are also used in the industry where a direct flame plays against the distillation vessel walls and novel gasification burners will be developed for this application. Direct firing is promoted as a product benefit by Suntory of Japan, and the belief is that it will continue to be a requirement, particularly for international business development. We intend to talk to the three direct fired distilleries with a view to agree 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.

Colorado Construction and Engineering, in partnership with CBS and Leeds University is a unique combination, bringing together strategic operators in building distilleries and developing gas burners for use with hydrogen, ethanol, and with Biofuels.

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 Andrew, Torabhaig on Skye being examples, and the connection with both distillery engineers and with specialist resources like Frilli and Robertsons has helped in planning what Livingston will offer.





Colorado Distilleries

CBS are the largest independent gas burner designer and manufacturer in the UK, already experienced in the development of hydrogen burners with product currently going through certification prior to going to market, and established technologies in Biofuel with the University of Leeds.

These contacts and market awareness will be key in promoting the Livingston development Centre to potential customers.

The corporate contact base extends into the Japanese and US markets through current ownership structures in the distillery industry, and as we are seeing already, the keen worldwide interest in decarbonisation opening up opportunities for Colorado / CBS in international markets.

The Scotch Whisky Association will be a valuable voice, sitting as it does between the distillery and the consumer, in 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 Colorado Livingston Development Centre will be a significant response to the issue.

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 lecturers on the CPD course. The structure of this course will include lectures on lesson learnt in decarbonisation and the challenges in delivering the hydrogen, bio-oil and biomass 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

Phase 1 experimental work has measured the GCV of dry draff from InchDairnie distillery at 20.5 MJ/kg and this was used in estimating that 23% of the distillery energy that could be derived from draff and PAS (15 MJ/kg). The remaining energy for complete decarbonisation would be sourced from other low cost waste biofuels. As road vehicles transition to electric over the next 15 years the current infrastructure for biodiesel and ethanol production for automotive fuels will require alternative use and could be used for renewable heat in distilleries.

Currently a modern distillery uses 14.4 MJ of fossil fuel energy to produce one litre of whisky (John Fergus, InchDairnie), which for NG is 0.80 kgCO_2/L. The aim of this proposal is to reduce this CO_2/L to zero for distilleries that install the technology.