BEIS Industrial Fuel Switching Competition

H2Malt

PHASE 1 REPORT

TABLE OF CONTENTS

GLOSSARY

Abbreviation	Description
BAU	Business As Usual
CFD	Computational Fluid Dynamics
CH_4	Methane
CO_2	Carbon Dioxide
GC	Germinative Capacity
GE	Germinative Energy
GHG	Greenhouse Gas
H_2	Hydrogen
H_2O	Water
HAZID	Hazard Identification
MW	Megawatt
NO_x	Nitrous Oxides
RH	Relative Humidity
RR	Risk Register
SWOT	Strengths, Weaknesses, Opportunities, Threats
WP	Work Package

EXECUTIVE SUMMARY

UK Government have made the commitment to transform our energy system and achieve Net Zero by 2050. To reach this goal, businesses across all sectors face the challenge of decarbonisation. For organisations who use industrial processes or have a high energy demand, this is particularly challenging. Alongside this goal, the increase in the cost of fuel, natural gas prices and electricity have created further drivers for change. Some organisations have become first movers in their sector, determined to prioritise their energy transition. One such organisation is Bairds Malt who have committed to reducing their Greenhouse Gas (GHG) emissions by increasing their use of renewable energy and improving process efficiency. Alongside their transition plan, Bairds Malt entered a Climate Change Agreement with the Environment Agency with the soft target of reaching net zero by 2030.

In the past eighteen months, Protium and Bairds Malt have been working in collaboration to identify a route to net zero CO_2 emissions, using green hydrogen at the site in Arbroath. Currently, the Arbroath site generates over 14,000 tCO_2 per year using natural gas alone. It was identified in the previous phase of this project – the pre-feasibility, that the demand for natural gas at the Arbroath site is predominantly due to direct fired Grain Dryers, Buhler Plant kilning and Clova Plant kilning. The purpose of this study was to assess the viability of switching the fuel used for air heaters from natural gas to hydrogen. The fuel composition within the scope of this project was 30 – 100% hydrogen blend with natural gas. This would achieve between 11 – 100% CO_2 emissions reduction in this process.

1. PROJECT OVERVIEW

For the brewing and distillery industries, malt is a constituent product. Grain requires steeping, germinating and drying to be converted into malt. Grain drying utilising a kiln requires the most energy input during the malting process. By typically combusting natural gas in indirect fired air heaters, large volumes of hot air are blown through the grain bed to dry the grain during kilning.

Bairds Malt are a leading British maltster, with almost 200 years of history providing malt to many of the world's leading brewers and distillers. Bairds Malt's site in Arbroath generates over 14,000 tonnes of CO_2 annually through natural gas combustion. Previously, Protium, the UK's leading green hydrogen company, worked with Bairds Malt to conduct a pre-feasibility study to assess methods for decarbonising the thermal processes at Bairds Malt's flagship facility in Arbroath. Green hydrogen was identified as a viable fuel switching option to replace natural gas and create a pathway to net zero carbon dioxide emissions.

However, working closely with air heater manufacturers for the malting industry, Protium identified that hydrogen-ready air heaters are not currently commercially available. The main challenges for the fuel switching lie in the changes in the radiative and convective heat transfer, in the flue gas composition and possible increase in NO_x emissions, of which the impacts on equipment and product quality are not well understood.

In this context, H2Malt was an innovative collaboration between Protium, Bairds Malt, Imperial College London, and The University of Nottingham to assess the feasibility of deploying a hydrogen-fired air heater system. This air heater would be considered for deployment at Baird's Malt flagship site in Arbroath.

The technical approach for H2Malt focused on understanding the parameters of hydrogen-fired heaters, including changes in radiative and convective heat transfer, as well as changes in the flue gas temperature and composition. Further to this, applicable modifications required to successfully incorporate the changes into Bairds Malt's existing processes were considered. This included an assessment of the impact of introducing different hydrogen blends to heater operation, including efficiency, intake air volume, and heat production. This highlighted any challenges to overcome moving towards a 100% hydrogen use case.

The impacts of the changes of flue gas properties on grains during drying were experimentally investigated, as well as alternative configurations to gradually increase the hydrogen content. An analysis of the change in HSE requirements was also undertaken, including a high-level HAZID evaluation.

In order to meet the project requirements, a series of work packages (WP) were proposed:

- **WP1 (Protium). Preparation and site analysis** – Aimed to establish the current configuration and operational parameters of Bairds Malt air heaters at the Arbroath site.
- **WP2.1 (Imperial College London). Feasibility of the hydrogen air heaters solution: Heater Modelling** – Assessed the changes of the air heater performance through numerical modelling of heat distribution.
- **WP2.2 (University of Nottingham). Feasibility of the hydrogen air heaters solution: Impacts on Product Quality**– Investigated the impacts of changes in air temperature and specific humidity due to hydrogen combustion on the germinative capacity of barley.
- **WP3 (Protium)**. **Alternative configurations**– Evaluated alternatives to generate heat with hydrogen for the malting process by integrating different sources of heat and gradually increasing hydrogen content.
- **WP4 (Protium). Health, Safety and Risk Assessment** – A SWOT analysis was undertaken and a HAZID document compiled. A risk register focusing on risks during deployment phase was also compiled.
- **WP5 (Protium). Next stages and dissemination –** Planning of phase 2 of the industrial fuel switching project.
- **WP6 (Protium). Report writing and close out –** Completion of the draft and the final report.

WP5 (Protium) Next stages and dissemination, was not completed in full. In short, gaps in knowledge were established in the course of H2Malt, meaning that Protium did not feel comfortable in meeting the objectives set out for WP5. There is a general lack of knowledge about hydrogen and hydrogen blending in heat producing processes whether direct or in-direct. It is therefore recommended that further detailed full-feasibility and engineering design is carried out before a fuel switch can be made in the kilning process at Bairds Malt.

- However, the aim for this document is to effectively summaries the key findings of each WP undertaken during the H2Malt project and to assess the environmental and social benefits for implementing a hydrogen-fired air heater at Bairds Malt's Arbroath site. **WP1** is discussed in 2.1 Site , **WP2.1** in 2.2.1 Heater Modelling, whilst **WP2.2** is covered in 2.2.2 Impacts on Grains Quality. **WP3** is detailed in 2.3 Alternative Configurations, before the environmental and social benefits are covered in 3 Environmental and Other Benefits. **WP4** is covered in 0 Clearly, implementing green hydrogen systems results in environmental and social benefits. To realise these benefits, analyses identifying risks, hazards and opportunities associated with these projects must be completed. These analyses are discussed in the following section.

- Health, Safety and Risk Assessment and the justification for **WP5** is described in 0

Next Stages.

2. TECHNICAL OUTCOMES

2.1 Site Description

The malting site in Arbroath is situated between the ports of Montrose and Dundee and is known to be Bairds Malt's flagship site. Inaugurated in 1970, the site is also home to Bairds Malt's central laboratory, which carries out malt analysis for all nationwide sites. An aerial view of the Arbroath maltings site identified in red is shown in Figure 1.

Figure 1: Aerial view of Arbroath and Bairds Malt

Bairds Malt have many processes at their site; the focus of the H2Malt project was on the kilning. The kilning process uses indirect natural gas fired heaters that have the potential to be switched to hydrogen, either blended or a full fuel switch to 100% hydrogen – as shown in Figure 2.

The following areas have been considered as part of this study:

- Impacts of burning H_2 on current air heaters (modelling)
- Impacts on barley grains during drying (experimental)
- Suitability and modifications required on current heaters
- Analysis of alternative configurations to gradually increase the hydrogen content
- Influence of changes in radiation and convection mechanisms of heat transfer during design of heat transfer equipment
- How the composition and temperature of flame and flue gas influence the selection of proper material for heat transfer equipment
- High-level health, safety and risk assessment
- Analysis of commercial attractiveness of the hydrogen heater solution

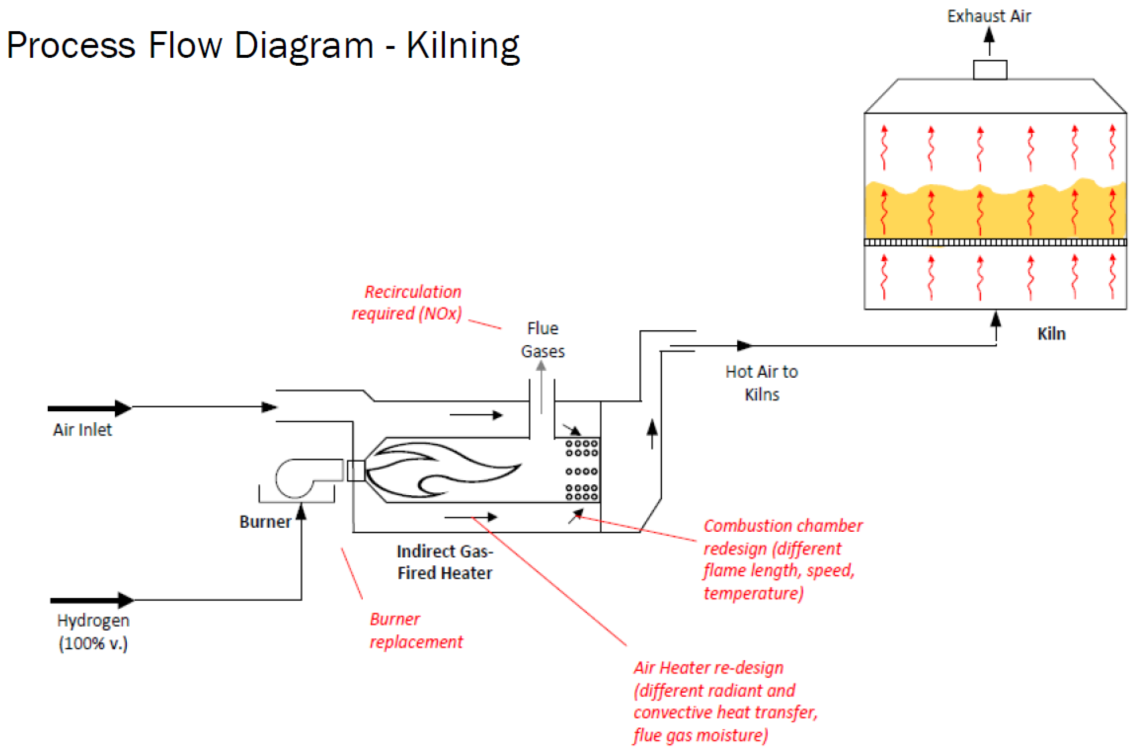

Figure 2: The kilning process at Bairds Malt with proposed hydrogen fuel switch

Figure 2 depicts the hydrogen fuel switch solution that was identified in a previous pre-feasibility study conducted by Protium for Bairds Malt. However, working closely with air heater manufacturers for the malting industry, Protium identified that hydrogen-ready air heaters are not currently commercially available. Imperial College London therefore undertook WP2.1 and conducted computational fluid dynamic (CFD) modelling to assess the feasibility of hydrogen air heaters.

2.2 Feasibility of the Hydrogen Air Heaters Solution

2.2.1 Heater Modelling

Imperial College London have assessed the changes on the air heater performance due to switching to a hydrogen fuel through numerical modelling of heat distribution within the heaters, using inputs from the heater manufacturer. For minimal equipment changes, the current air heaters used by Bairds Malt can be fuelled by hydrogen-methane blends up to 30% v/v, which can lead to 9% CO_2 emission reductions (as specified by burner manufacturer Weishaupt).

Imperial College London have assessed the changes on the air heater performance due to switching to a H2 fuel through numerical modelling of heat distribution within the heaters, using inputs from the heater manufacturer.

To enable higher hydrogen enrichment ratios (up to 100%), the required modifications strongly depend on the temperature levels reached within the mixing chamber upstream of – and at the inlet of – the kiln air / flue gas heat exchanger (see Figure 3). Imperial's study aims to predict the latter for various fuel compositions (i.e., varying hydrogen enrichment ratio, αH2, ranging from 0 to 100%) and burner flowrates, $\dot{m}$b.

<u>Method + Results</u>

The effects of natural gas enrichment with hydrogen on the temperature levels reached in the Bairds Malt air heater used for malting processes were explored using computational tools to perform the necessary simulations.

Three-dimensional (3D) CFD computations were performed in the COMSOL Multiphysics software environment – detailed dimensions of the VARICON FF4-190-109 were used to build a 3-D representation of an air heater (see Figure 4). The small discrepancies obtained between the predictions of the CFD model developed in Imperial's study, and the experimentally verified high-fidelity data found in the literature (less than 5% standard error in outlet temperature) gives confidence in the modelling approach and choice of simplifying assumptions.

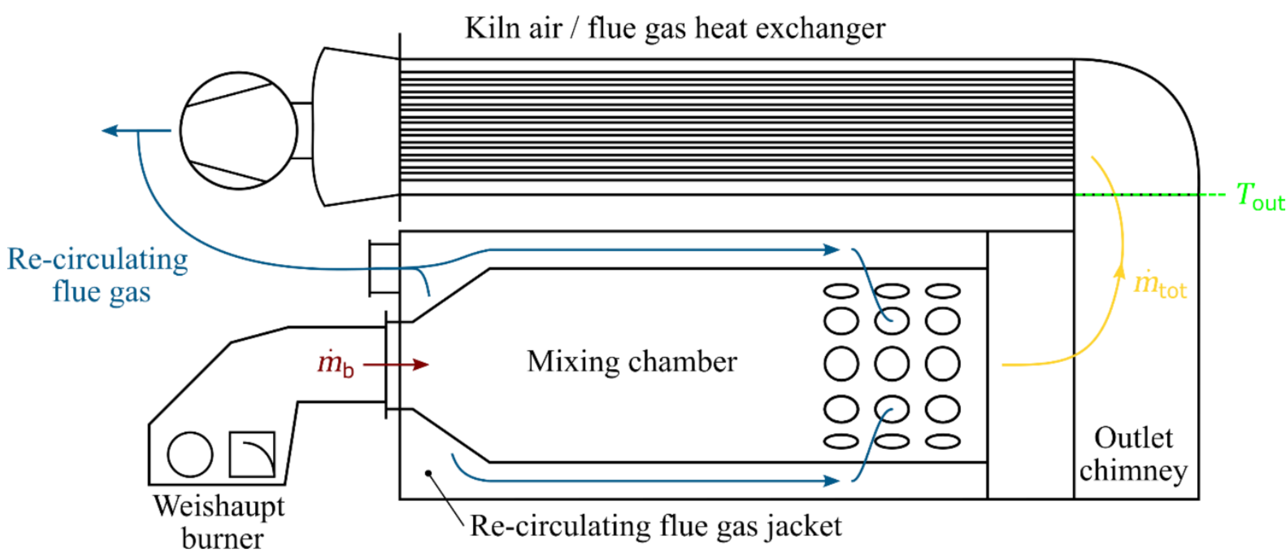

Figure 3: Schematic diagram of a Bairds Malt air heater

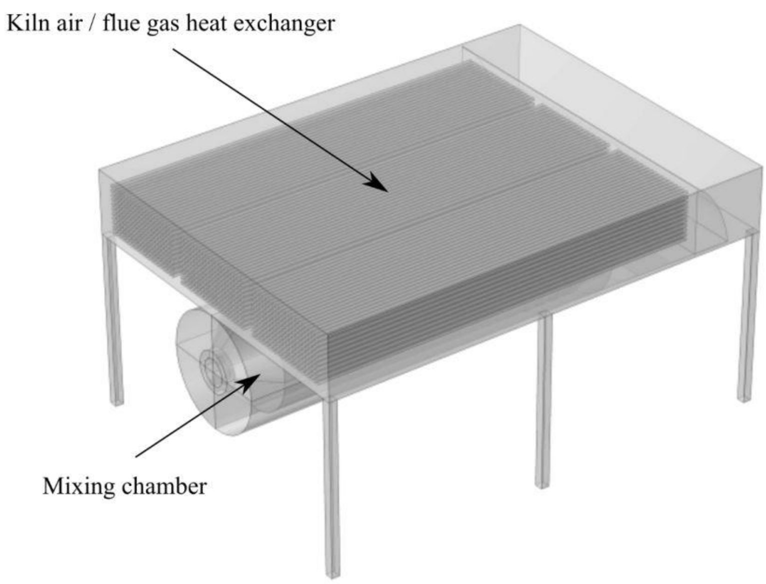

Figure 4: 3-D view of the VARICON FF4-190-109 air heater as modelled in COMSOL

Quantification of the temperature increase due to hydrogen enrichment of the inlet fuel has been performed through a parametric study, whereby the hydrogen mass ratio in the inlet methane-hydrogen mixture was varied from 25% to 100% for burner mass flowrates ranging from ¼ to ¾ of the total flowrate downstream of the mixing chamber. The temperature, pressure and velocity fields in the mixing chamber, outer recirculating flue gas jacket and outlet chimney have been predicted using the 3-D CFD model.

In summary, high temperatures are reached at the burner outlet when using stochiometric air-to-fuel ratios, with flue gas reaching temperatures up to 2,170°C at the mixing chamber inlet for pure hydrogen fuel, against 1,854°C for a 25% H_2 + 75% CH_4 blend. However, although the maximum temperatures reached in the mixing chamber are of importance in determining the feasibility of switching methane to pure hydrogen, the most important increase to quantify is that of the outlet temperature, measured as the surface-averaged temperature at the chimney outlet.

The latter has been reported in the form of operational maps in this report, where the reduction in the burner mass flowrate required to maintain a given flue gas outlet temperature while increasing the ratio of hydrogen in the fuel blend can be graphically determined – see Figure 5 (a) and (b).

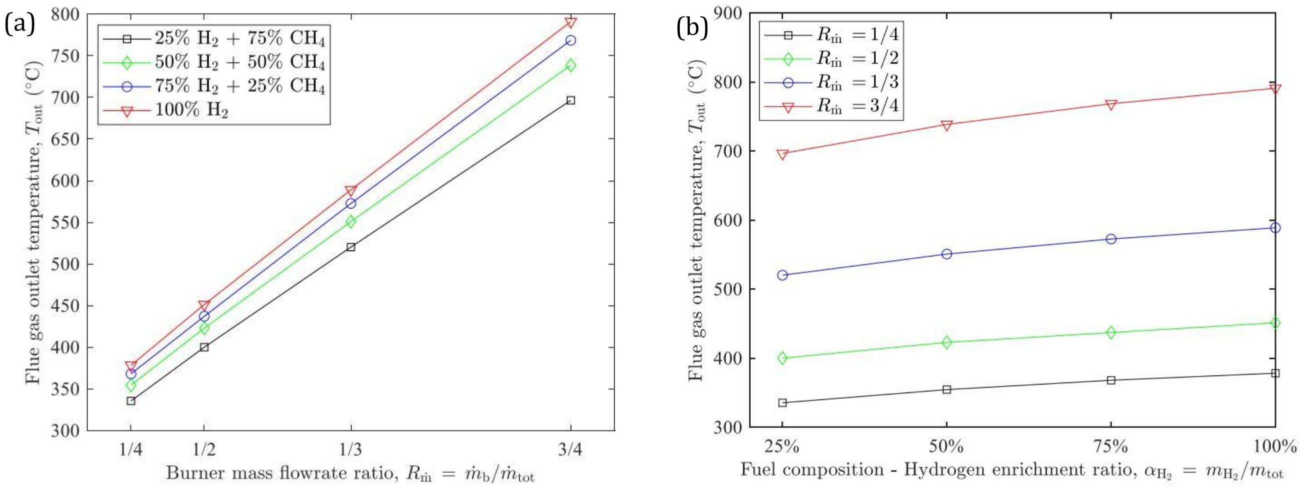

Figure 5 (a): Impact of the burner mass flowrate on the flue gas outlet temperature for various fuel compositions. (b) Impact of the fuel composition on the flue gas outlet temperature for various Weishaupt burner inlet mass flowrates.

<u>Conclusion</u>
As can be seen in Figure 5 (a), a reduction in the burner mass flowrate would counteract the increase in temperature caused by the increase in hydrogen content. Therefore, this allows the current operating temperature to be replicated.

The maximum allowable flue gas outlet temperature of 650°C, as specified by the manufacturer, indicates whether the same equipment may be utilised – therefore the burner mass flow rate must be maintained to avoid exceeding this limit.

In conclusion, equipment re-design would be required to maintain the same burner mass flow rate with 100% hydrogen. The extent of modifications (based on the target hydrogen blends) will require further analysis with the manufacturer if the temperature exceeds 650°C.

Regarding hydrogen air heaters, another issue identified in the previous pre-feasibility study conducted by Protium for Bairds Malt was the uncertainty surrounding changes in air temperature and specific humidity due to hydrogen combustion. WP2.2, conducting by The University of Nottingham, aimed to address this by experimentally assessing the germinative capacity of barley when being dried by direct-fired hydrogen heaters.

2.2.2 Impacts on Grains Quality

The University of Nottingham have investigated the impacts of different drying air temperature and specific humidity (g (H_2O/kg dry air) on the germinative capacity of a selection of commercial UK barley varieties as a result of converting the direct-fired heaters to hydrogen.

<u>Method + Results</u>

Three spring barley varieties (Diabolo, Laureate, Sassy) were supplied by Bairds from the Scottish harvest (2022). Samples were supplied both before and after their conventional existing drying process.

For each non-dried barley variety (n=3), 17 samples (265 g) were dried using a pilot scale toroidal fluidised bed dryer (see Figure 6) under varying conditions of temperature (50 – 60°C) and humidity (10 – 30% RH). The upper limit of humidity investigated in the drying air (30%) was based upon psychrometric calculations and an assumption of 100% hydrogen being used to heat the incoming air at a burner efficiency of 90%.

After drying, the barleys were analysed for Moisture Content, Germinative Energy (4 mL and 8 mL tests) and Germinative Capacity (tetrazolium test). As can be seen in Table 1, these outputs were modelled against drying air temperature and humidity to identify if either were significant factors having an impact on these quality parameters. There were only minor variations across the data sets and no consistent effects of RH or temperature of the drying air across all 3 varieties – in brief, the dried barleys were of good and consistent quality, pretty much irrespective of the drying conditions.

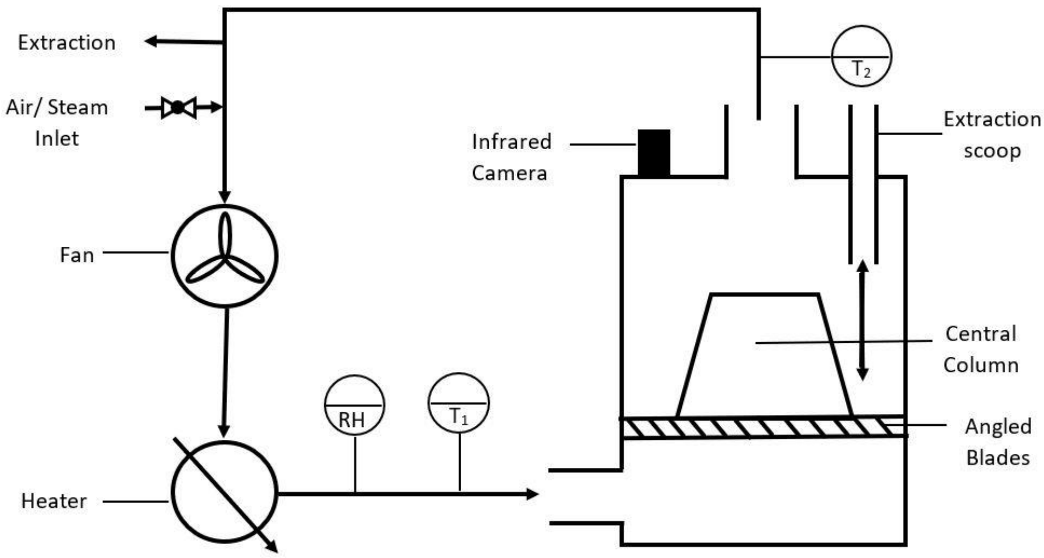

Figure 6: Schematic of Torbed drying system with relative humidity control.

In total, 15 samples of barley (five of each barley variety) were selected for micromalting and subsequent analysis. For each barley variety, three samples were taken from the above pilot scale drying trials (dried at 60 °C and either RH 10, 20 or 30%) and two were taken from the pre-dried barley supplied by Bairds (see Table 2).

Once malted, a series of industry standard malt and wort analyses were conducted, to explore whether barley which had been dried at different air RH values (10-30%) differed with regard to malt quality. There were no indications that this was the case.

The parameters measured were very consistent across the five samples for each variety. In some cases (e.g., wort colour) there were clear impacts of variety. In others (e.g., malt friability, dextrinising units) results varied between conventionally dried samples and the pilot dried samples, but not with the RH of the drying air. There was a small trend, particularly for varieties Diabolo and Laureate, towards increasing friability and related parameters in the pilot dried samples. This was an impact of drying technology differences and not the RH of the drying air.

Table 1: Post-drying analysis of Diabolo barleys dried on the Torbed

Drying Run	Air Temp. (°C)	Air RH (%)	Moisture Content (% w/w)	GE 4mL (%)	GE 8mL (%)	Water Sensitivity (%, 4-8mL)	GC (%)
1	60	30	12.10	95	32	63	100
2	55	20	12.47	93	36	57	100
3	50	10	12.81	95	36	59	99
4	50	30	12.68	94	49	45	99
5	50	30	12.60	93	29	64	99
6	55	10	12.40	95	37	58	98
7	60	10	12.25	95	37	58	100
8	60	10	12.47	96	32	64	100
9	50	10	12.43	97	28	69	99
10	60	20	12.71	96	31	65	98
11	57.5	15	12.31	91	32	59	99
12	55	20	12.80	89	39	50	99
13	60	30	12.00	96	49	47	100
14	55	20	12.44	90	46	44	96
15	55	30	12.14	94	46	48	99
16	52.5	15	12.47	94	36	58	99
17	50	20	12.84	96	41	55	99

GC = Germinative Capacity = percentage of viable grains
GE = Germinative Energy = percentage grains germinating with 72 hrs under specified test conditions in 4 or 8mL water. The difference between 4 mL and 8 mL counts indicates water sensitivity

Table 2: Details of pilot-scale dried barley samples selected for micromalting

Variety	Drying Run Number	Drying Air Temp.	Drying air RH (%)	m.c (%)	GE 4 mL (%)	GC (%)
Diablo	13	60	30	12.0	96	100
Diablo	10	60	20	12.71	96	98
Diablo	8	60	10	12.47	96	100
Sassy	13	60	30	12.29	93	98
Sassy	10	60	20	12.36	87	100
Sassy	8	60	10	12.69	96	99
Laurette	13	60	30	12.29	98	99
Laurette	10	60	20	12.39	97	95

Laurette	8	60	10	12.23	95	95

Conclusion

In conclusion, this preliminary pilot plant and laboratory scale investigation found no impact of drying air RH (in the range 10-30%) on subsequent barley, malt and wort qualities, relative to samples dried using conventional technology at Bairds. This implies that the increased drying air RH resulting from burning hydrogen in the direct-fired drying process would not impact on barley quality for brewing end usage.

Having established the feasibility and identified the requirement for modification to implement hydrogen-fired heaters in WP2.1 and WP2.2, it is important to identify methods for improving the operation of these systems. As kilning is an industrial heat process, it was identified that there is opportunity to utilise alternative methods to supplement the heat requirements during hydrogen generation. This is covered in the next section.

2.3 Alternative Configurations

The objective of WP3 Alternative Configurations was to evaluate alternatives for generating heat with hydrogen for the malting process at Bairds Malt's Arbroath facility. Integration of heat from different sources during the electrolysis process was considered, whilst also increasing hydrogen content from 30% to 100% by volume.

It should be noted that electrolysis must be in close proximity to the kilning process to ensure that the heat may be utilised. Therefore, use of waste heat from electrolysis should only be considered if electrolysis takes place onsite.

<u>Proposed Solution</u>
During a previous pre-feasibility study conducted with Bairds Malt, a solution was proposed to supply a 30:70 split by volume of hydrogen to natural gas for Bairds Malt's kilning process. Minimal alterations would be necessary to utilise the existing air heater and burner with 30% v/v hydrogen. This previous solution was considered the basis for the proposed current alternative configurations.

A liquid closed cooling loop was then identified as the typical method for removing waste heat from large-scale, low-temperature electrolysers. Recouperation of the waste heat from electrolysis to pre-heat incoming air or water in the proposed solution was identified as a method for increasing the efficiency of the hydrogen generation and reducing hydrogen demand.

After review of waste heat reutilisation methods, it was determined that the use of heat exchangers and heat pumps would be the most suitable methods for recuperating the electrolyser heat. This was due to both utilising liquid cooling mediums for operation.

Whilst it is limited for real-world applications, there is a modest amount of literature covering the theoretical utilisation of waste heat utilisation from electrolysers for a range of applications. Low-temperature electrolysers utilising heat pumps as the waste heat integration method were identified as plausible. The average amount of total intrinsic energy of hydrogen that could be recuperated to pre-heat incoming air or water in this method was determined to be 15%.

With this in mind, Figure 7 displays the proposed solution for pre-heating air for the kilning process at Bairds Malt's Arbroath site. As shown, an electrolyser generates hydrogen – to be combusted in the air heater – and waste heat.

Heat is removed from the electrolyser utilising a cooling medium. This cooling medium passes through a heat pump that increases the temperature of the cooling medium before being stored in thermal storage to be utilised at an appropriate time or directed to the heat exchanger, where the incoming air is pre-heated. A separate, similar solution was also provided utilising a steam boiler and pre-heating water.

<u>Modelling</u>
A high-level modelling tool was developed to rapidly determine the impact on air heater capacity, hydrogen demand and hydrogen calorific contribution when changing parameters. These parameters were:

- Total potential energy recoverable as waste heat from the electrolyser (%)
- Hydrogen blend by volume (% - vol)
- Electrolyser capacity (MW)
- Steam boiler capacity (MW)

For the purpose of this alternative configuration exploration, a series of alternative phases were developed – as shown in Table 3. Phase 1 is a baseline system with no heat integration. Phase 1 (a) and Phase 1 (b) recuperate 15% and 20% of the hydrogen potential energy, respectively. This is recuperated as waste heat from the electrolyser. Phase 1 employs a 30:70 blend of hydrogen to natural gas, meaning only 4.13 MW of electrolyser capacity is necessary.

Table 3 – Input parameters for scenarios tested

	Unit	Phase						
		1	1 (a)	1 (b)	2	2 (a)	2 (b)	2 (c)
Steam boiler capacity	MW	0	0	0	0	0	3	6
Total potential energy recoverable as waste heat from electrolyser	%	0	15	20	15	20	15	15
Hydrogen blend by volume	%	30	30	30	100	100	100	100
Electrolyser capacity	MW	4.13	4.13	4.13	36.62	36.62	36.62	36.62

For all of the Phase 2 options, 100% of the heat requirement of the kilning process is provided by hydrogen. Phase 2 has an electrolyser capacity of 36.62 MW and recuperates 15% of the potential energy, whilst 2 (a) pushes the theoretical limit to 20%.

Phases 2 (b) and (c) introduce a steam boiler to supplement the air dryer. A 100% hydrogen supply is still used with 15% recoverable energy from the 36.62 MW. However, the total steam boiler capacity increases from 3 MW for Phase 2 (b) to 6 MW for Phase 2 (c).

<u>Modelling Results and Conclusions</u>
The following is a summary of the key findings from the high-level modelling work:

- It was determined that for Phase 1 scenarios, the reduction in air heater capacity and the calorific hydrogen contribution increase was negligible. As only 30% (by volume) of the fuel mix was supplied by hydrogen for the kilning process, a relatively small electrolyser is required – meaning only an insignificant amount of heat can be recovered.
- For Phase 2 and Phase 2 (a), it was determined that the significantly larger heat generated from the electrolysers could significantly reduce the total hydrogen demand by up to 48%.
- Incorporating a steam boiler in tandem with the air heater and heat integration could reduce the air heater capacity and annual hydrogen demand further – down to an air heater capacity of 6.8MW and reduce hydrogen demand for the air heater by 68% per annum.
- Despite reducing the air heater capacity and hydrogen demand for the air heater, the overall demand for hydrogen is not impacted as the hydrogen that would have otherwise combusted in the air heater is combusted in the steam boiler.
- The most suitable system would reduce the overall hydrogen consumption, improve efficiency, reduce air heater capacity and provide a simplified system that would minimise impact on the system downstream of combustion. An air heater solution that utilises waste heat from an onsite large-scale electrolyser is the most suitable solution, similar to the solution depicted in Figure 7. Integration of a steam boiler would minimise the air heater capacity requirement but adds system complexity.

It is worth reiterating that to utilise the waste heat from the electrolyser, the electrolysis must take place on the same site as where the hydrogen is being combusted. For further information on this section, please see WP3 Alternative configurations.

Increasing the overall hydrogen contribution in a mixed fuel scenario, as in Phase 1 above, decreases the CO_2 emissions produced by the industrial processes at Bairds Malt's facilities. To analyse this and other benefits further, the following section discusses the environmental and other benefits associated with utilising hydrogen as a fuel.

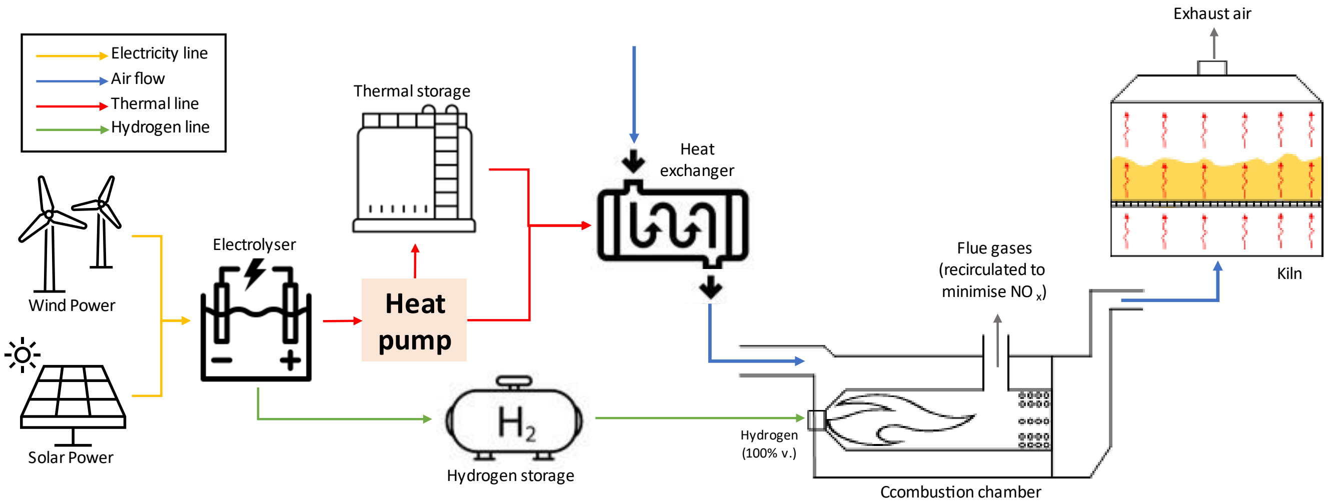

Figure 7: The multi-vector energy system solution utilising waste heat from an electrolyser for air pre-heating, identified in WP3

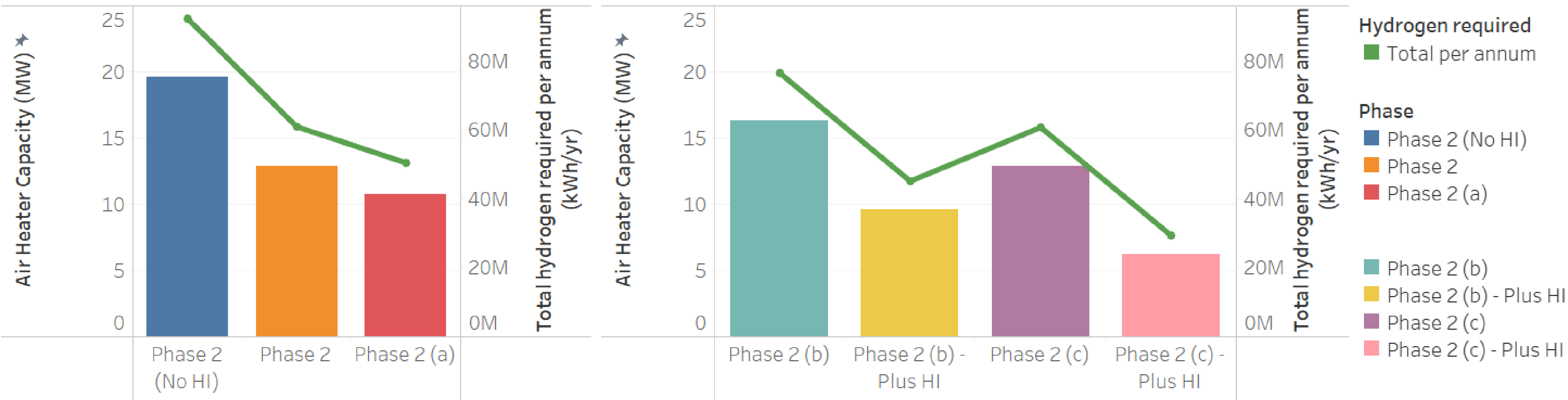

Figure 8: Impact on necessary air heater capacity and total hydrogen required per annum for Phase 2 configurations. Where HI = Heat Integration

3. ENVIRONMENTAL AND OTHER BENEFITS

Conversion of fossil fuel heating technologies to hydrogen has a direct impact on local air quality due to the absence of CO_2, CH_4 emissions and toxic pollutants produced by the combustion of hydrogen. Furthermore, green hydrogen used as fuel for the heating process will be produced from a renewable power source, eliminating upstream emissions associated with the production and processing of natural gas.

3.1 Carbon Emissions Savings

The H2Malt project was designed to contribute towards net zero CO_2 emissions. It is the first study into the use of green hydrogen in the malting process, as no malting-specific demonstrations have yet been conducted. Malting is recognised as an energy intensive process, and green hydrogen has been identified as a viable and efficient alternative to natural gas to fuel air heaters as they have similar behaviours.

This project is an innovative collaboration involving multiple industry leaders and has the potential to save Bairds Malt up to 14,000 tonnes of CO_2 emissions annually when fully implemented in this UK maltster. This will deliver a viable pathway for the maltster to reach its 2030 net zero ambitions, as well as offering a potential framework to reduce emissions across the wider malting industry.

3.2 Potential contributions to Net Zero targets

At Bairds Malt's in Arbroath, the carbon emissions generated by burning natural gas will be reduced as more hydrogen will be added to the fuel mixture. The projected emission scenarios for hydrogen blends ranging from 0% (BAU scenario) to 100% hydrogen considering the forecasted energy demand and it is shown in, Figure 9. The contribution of each plant and each process type to the emissions are illustrated in Figure 10 (a) and (b).

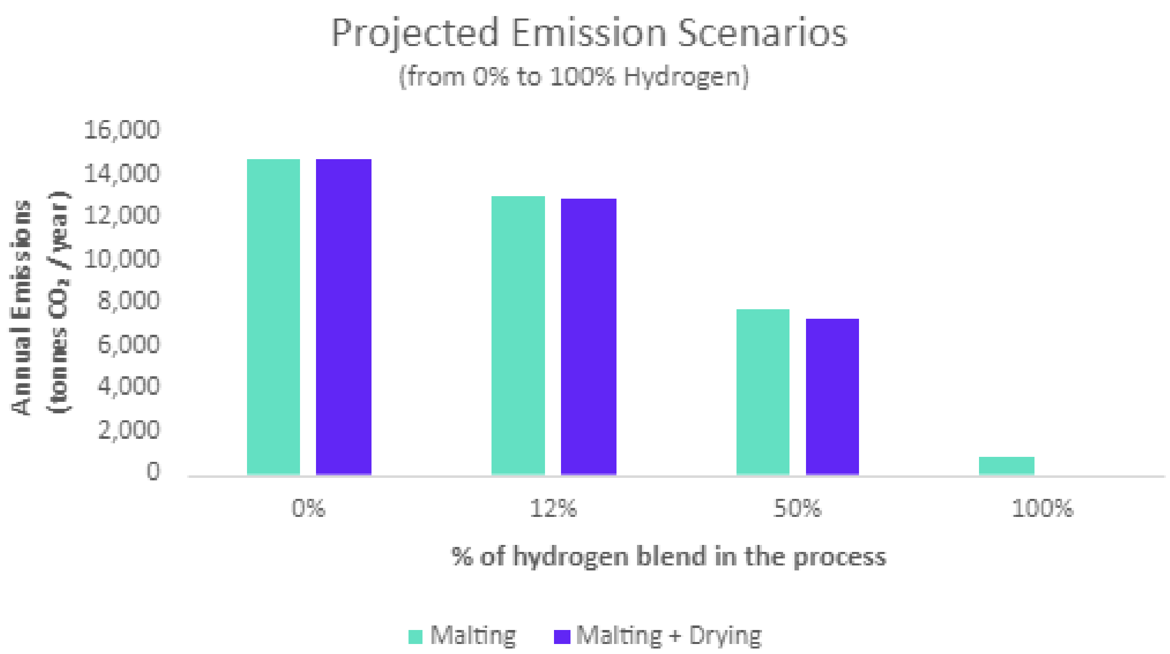

Figure 9: Projected emission scenarios from 0% to 100% hydrogen blend

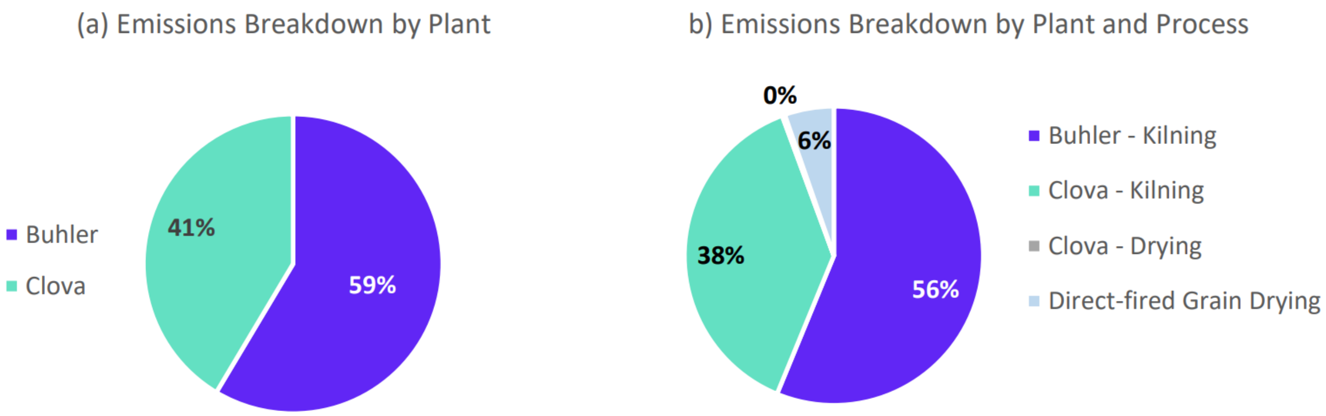

Figure 10: Emission breakdown (a) by plant and (b) by process type

The emission savings from the H2Malt project, should it move to demonstration, will contribute to the UK's 2050 Net Zero targets by directly reducing emissions from heating and industry and offering a future pathway to accelerate those emission reductions. Decarbonising heat is considered one of the toughest challenges facing Net Zero, making the development and delivery of zero carbon technologies crucial. Heating is one of the largest sources of GHG emissions in the UK, representing 37% of total GHG emissions, with industrial processes representing 14% of total emissions. To achieve the UK's Net Zero targets, these emissions must be reduced by more than 95% through the adoption of alternative technologies like hydrogen.

3.3 Social Value Delivered

The food and beverage industry are a crucial aspect of the UK economy, and with the UK malting industry being the third largest in the world it poses an opportunity for job creation as well as promote education by synergising the hydrogen economy with UK maltsters. The successful demonstration of hydrogen ready air heater technology by the malting industry will allow the expansion of UK malting capacity, with additional benefits for the supply chain and the creation of high skilled jobs.

Innovation of the air heaters presents an opportunity to reduce emissions improving local air quality directly. An obstacle to overcome, due to the nature of the technology being in its infancy, is the lack of trained personnel. This will be mitigated by extensive training schemes for, but not limited to, manufacturing, operation, and safety procedures, communications, and finance.

Additionally, with the UK honing down on stimulating the green economy, where low carbon hydrogen is of particular interest, a broad job market in the green hydrogen space will be created. The UK will have a head start and be at the forefront in gaining skills and knowledge for decarbonising the malting industry. Thus, improving the UK malting industry's reputation and increasing engineering exports.

Furthermore, many **thousands** of indirect jobs could be created from the hydrogen supply chain that would need to be developed in the UK to provide hydrogen fuel to air heaters. This would include scaling up green hydrogen production, building and deploying electrolysers, increasing renewable energy capacity, transporting hydrogen, storing hydrogen, and servicing the additional infrastructure required.

Clearly, implementing green hydrogen systems results in environmental and social benefits. To realise these benefits, analyses identifying risks, hazards and opportunities associated with these projects must be completed. These analyses are discussed in the following section.

4. HEALTH, SAFETY AND RISK ASSESSMENT

WP4 of the H2Malt project being carried out as part of the Industrial Fuel Switching grant programme from BEIS included a SWOT analysis, Risk Register and HAZID investigation for the proposed fuel switch at Bairds Malt.

The SWOT analysis presents findings on internal and external influences on the application of hydrogen into the kilning process at Bairds Malt in Arbroath. In Table 4, a SWOT analysis was used to identify strengths, weaknesses, threats, and opportunities associated with the project progress in the near future.

A Risk Register (RR) was used to identify risks and focused on potential setbacks during deployment phase. RR includes information about the priority of the risk, the likelihood of it happening and provides tangible mitigation measures. RR can be found in Appendix III – Risk Register.

The high-level hazard identification assessment (HAZID) study was used to identify hazards associated with the proposed project operations and recommend improvements, modifications and mitigations and safety measures where required.

The HAZID report was carried out using an online survey. Participants included all consortium partners, Protium, Bairds Malt, University of Nottingham and Imperial College. A more detailed onsite HAZID and HAZOP will need to be carried out should the project move to the demonstration phase.

The HAZID produced 3 key areas for further consideration: knowledge, temperature management and fire zoning. Partnership with the burner and kiln equipment manufacturers that a detailed feasibility and prototyping exercise needs to be carried out alongside the wider feasibility studies that a full fire safety philosophy is developed with the new fuel in mind. This should include identification of 3 zones, emergency response and equipment and full training programme for staff and contractors.

Table 4: H2Malt SWOT analysis

Strengths	Weaknesses
Reduced dependence on external factors, natural gas supply and cost	High CAPEX and OPEX (High H_2 production and investment cost)
H_2 heaters are recognised as a future renewable energy heating system	H_2 demand due to size of production will likely require extra safety regulations
Higher combustion efficiency (higher flame temperature and decreased flow)	Efficiency of H_2 supply chain
Possible use with other sources of energy, such as natural gas	Initial premium cost to deliver H_2
Weishaupt burners adaptable for hydrogen supply system (max. 30%)	Limited space for on-site or adjacent construction
No change in the fuelling process for Weishaupt burners (max. 30%)	Requirement for additional equipment and long lead times
Industrial site, easier to secure planning	Lack of skilled labour with knowledge and experience in hydrogen heater systems
New infrastructure does not face objection from residents for visual pollution due to proximity to large industrial structures	High maintenance cost
Sustainability drive as part of Bairds Malt master plan	
Lower CO_2 emissions and sustainable energy	
Opportunities	**Threats**
H_2 heaters becoming important alternative for natural gas	Amount of hydrogen required may bring the site above the Upper Tier COMAH regulations limit
Acts as blueprint for hydrogen heating source at other distilleries across the UK	Application and scope for expansion could be limited by lack of new technology on the market
Potential for future expansion to many destinations across Scotland (140 malts and distilleries in Scotland)	Hydrogen supply not on-site, supply could be disrupted
Significant hydrogen demand beyond heating, such as transport can bring new potential customers	Lack of infrastructure
Decreased use of fossil fuels and reduced emissions and pollutants	Market is relatively new
High carbon taxes	Lack of proven available technology
H_2 heaters becoming important alternative for natural gas	Infrastructure of natural gas can be used for biogas
	Natural gas and H_2 mixture NO_x increased emissions
	Cost of development is larger due to larger scale

5. NEXT STAGES

The purpose of Project H2Malt was to explore further the possibilities of fuel switching from natural gas to hydrogen at Bairds Malt in Arbroath. Within this project exiting processes were considered including the effect on the malt itself and the potential for the indirect dryers in the kiln to switch to hydrogen.

The report from Imperial College provided energy modelling using computational fluid dynamics to analyse and assess behaviour of the indirect air heaters in the kiln following a fuel switch to hydrogen. This report can be found in Appendix 1 – WP2.1: Air heater modelling. This report concluded that a switch to higher blends of hydrogen up to 100% hydrogen will result in higher flue gas outlet temperatures and cooling systems would likely need adapting to manage this. The results of the model gave a good comparison to similar CFD models elsewhere but would need experimental validation.

The Hazard Identification study (Appendix 4 – WP4: H2Malt IFS HAZID Survey) drew similar conclusions about outlet temperatures and cooling processes and when combined these results lead to a continuing knowledge gap.

There is a general lack of knowledge about hydrogen and hydrogen blending in heat producing processes whether direct or in-direct. The knowledge gap is apparent in the responses to many questions in Section 3. It is shown in the limited content of answers, the lack of answers and some contradictions in responses. This does not mean that new applications of hydrogen in burners are not viable, more that to fuel switch in this instance further knowledge is required, in areas such as hydrogen blending versus 100% hydrogen, in the heat management of hydrogen-based systems and in the permitting and planning requirements around fire modelling and zoning.

It is recommended that further detailed full-feasibility and engineering design is carried out before a fuel switch can be made in the kilning process at Bairds Malt.

These outcomes have led to the conclusion that at this time it is not possible for this project to move to the demonstration phase without considerable further investigation into both the site and technical challenges.

One potential area of interest that Bairds Malt could consider for further understanding the potential of fuel switching to hydrogen is to begin the process of validating Imperial College's CFD model. This could be done by making a digital twin of the kilning process, carrying out prototyping activities. Alongside this a much more detailed on site HAZID should be conducted with new fire modelling and hydrogen safety operations initiated. When complete demonstration could be considered.

As such, Protium have made the decision not to continue this project to Phase 2 of the Industrial Fuel Switching Programme.

6. CONCLUSIONS

Work carried out by Imperial College London, The University of Nottingham and Protium, has resulted in an overarching conclusion which is that fuel switching to hydrogen is a viable option for Bairds Malt site in Arbroath, based on the current level of analysis. Modelling studies conducted by Imperial College highlighted the potential to manage the change in temperature caused by the combustion of hydrogen, by manipulating operating conditions. By altering the gas flow rate and thus the pressure, the flue gas outlet temperature can remain within the operating limits of the current system. The use of equipment for 100% hydrogen combustion would require re-design, however the extent of such modifications was not defined within this study.

Analysis undertaken by The University of Nottingham investigated the impact of burning hydrogen on product quality. In comparison to the historical method of drying used at Bairds, all trials indicated that the effect of switching fuel to hydrogen would have minimal impact on the product and would have not impact on the quality of product for brewing purposes.

Finally, alternative configurations were proposed and high-level modelling for each scenario performed. One area which was investigated was the potential to recycle waste heat within the system. Phase 1 scenario adopted a 30:70 H2:NG ratio, and therefore required only a small electrolyser for the lowest volume of hydrogen required in terms of the scenarios evaluated. This option would require the smallest equipment and lowest hydrogen production volume and resulted in a negligible amount of heat available for recovery. For Phase 2 options, hydrogen was used to provide 100% of the heat required for the kilning process with a significantly higher production volume and correspondingly larger electrolyser. In these scenarios, up to 20% of heat was identified as recoverable which could reduce the total hydrogen demand by up to 48%.

One further option investigated was to add a hydrogen fuelled steam boiler, alongside the air heater, to reduce the capacity of the air heater. However, hydrogen would fuel the steam boiler so the demand for hydrogen would not reduce but split demand from the air heater with demand from the boiler.

The optimal solution would utilise waste heat from a large electrolyser collocated with the air heater. While the addition of a hydrogen boiler would minimise the air heater capacity, it would mean integration, operation, and maintenance of new large-scale equipment.

APPENDIX I – MAIN ASSUMPTIONS

Experimental assumptions:

1. The upper limit of humidity investigated in the drying air (30%) was based upon psychrometric calculations and an assumption of 100% Hydrogen being used to heat the incoming air at a burner efficiency of 90%.
2. Drying conditions that fell between experimentally determined drying times were calculated by assuming a linear change in drying time is caused by changes to RH and air temperature.

Modelling assumptions:

The 3-D CFD model developed in-house to predict the impact of injecting hydrogen-enriched methane in the air heater Weishaupt burner is based on the simplifying assumptions below:

3. The combustion of the fuel fully occurs upstream of the mixing chamber, i.e., all fuel is burned within the Weishaupt burner. Hot flue gas is injected within the mixing chamber, where it mixes with cold recirculated flue gas sucked from the flue gas collector at the outlet of the kiln air-flue gas heat exchanger.
4. The thermal energy produced by the complete combustion of the fuel in the Weishaupt burner is predicted using the lower heating value, which considers energy losses due to the vaporisation of produced water. (c) Stochiometric air-to-fuel ratios are used at the inlet of the burner, i.e., the exact amount of dry air required to achieve a complete combustion of the fuel is sucked into the burner (no air excess).
5. Thermo-physical equilibrium and transport properties of the circulating flue gas are estimated as dry air properties – as the maximum deviation on the gas-mixture density across the whole range of temperatures measured in the mixing chamber (500 to 2000 K) is less than 1%, while that on the specific heat capacity does not exceed 11%.

A comparative study against experimentally verified high-fidelity simulations published in the literature has been performed to quantify the deviations and check the validity of these assumptions. Further details of these assumptions can be found in the report delivered by Imperial College London.

APPENDIX II – CURRENT CONFIGURATIONS

PDF

C0017 Project H2Malt - Current Configuration.pdf

APPENDIX III – RISK REGISTER

Risks Register							
Risk Identification		Assessment		Mitigation	Risk/Issue Score		Review
ID	Risk/Issue Description	Impact	Likelihood	Mitigation/ treatment	Risk Score	Risk Rating	Date of update
ID 1	Change in strategic direction for consortium members	Moderate	Unlikely	Stakeholder engagement to the benefit of the project. Letter of engagement for all consortium members.	6	AR	08/05/2022
ID 2	Technical and reliability requirements for insurance of the facility. Insurance companies do not know how to insure as they have no historical insurance knowledge on how to value it. Limited to 1 or 2 options for insurers for the project.	Moderate	Possible	Initiating early engagement with insurers to educate them. This risk is associated with Phase 2 of the Industrial Fuel Switching Competition but is included here for completeness.	9	AR	08/05/2022
ID 3	Conventional natural gas-fired air heaters may appear more attractive than novel hydrogen systems.	Moderate	Unlikely	Ensure that the project aligns with the consortium partners' ESG targets. Develop the financial case for the use of hydrogen over conventional natural gas systems.	6	AR	08/05/2022
ID 4	Potential of limiting commercial and technical competitiveness by having preferred contractors.	Moderate	Very Unlikely	Keeping up to date with the position and capabilities of preferred contractors in the market. Internal reviews to evaluate the performance of contractors.	3	G	08/05/2022
ID 5	Permitting issues for hydrogen within short proximity to housing/residents.	Critical	Likely	Have a good stakeholder engagement process to educate on the benefits of the project & hydrogen safety. Engaging planning and	16	R	08/05/2022

				safety experts early in the project.			
ID 6	Nonstandard permitting process due to unfamiliar equipment and processes for SEPA.	Moderate	Unlikely	Pre-application or variation to the existing permit submitted to SEPA to familiarise them with the project prior to submission of full application.	6	AR	21/10/2022
ID 7	Sensitive receptors and public objection to the project.	Moderate	Possible	Have a good stakeholder engagement process to promote the benefits of the project. Engaging planning and safety experts early in the project.	9	AR	08/07/2022
ID 8	Insufficient development budget.	Negligible	Unlikely	The project scope for Phase 1 has the necessary budget based on direct recent project experience.	2	G	08/05/2022
ID 9	Lack of clear guidelines, regulations, and standards for designing and layout of hydrogen production facilities. Designing to standards that could be updated during the design phase.	Critical	Likely	Agreeing as a consortium the standards and regulations. Research relevant legislation and engage relevant regulatory body throughout the project. Rely on our partner's knowledge of safe & pragmatic hydrogen design.	16	R	08/05/2022
ID 10	Lack of clear guidelines, regulations and standards for designing/modification and drawings of hydrogen indirect gas-fired heater (Especially above 30% H2 mixture).	Critical	Likely	Engaging with direct/indirect gas-fired heaters suppliers and keep them on retainer to understand how the hydrogen regulation space develops over the next few months.	16	R	21/10/2022
ID 11	Impact on change of policy from the devolved/UK governments away from hydrogen.	Critical	Unlikely	Keeping engaged with government policy and remaining politically agnostic	8	AR	08/05/2022

ID 12	Change in government party during the planning phase.	Negligible	Unlikely	Keeping engaged with government policy and remaining politically agnostic	2	G	08/05/2022
ID 13	Lack of clear hydrogen targets due to a misunderstanding of the UK hydrogen strategy.	Negligible	Unlikely	Keeping engaged with government policy and remaining politically agnostic	2	G	08/05/2022
ID 14	Inconsistent project management.	Critical	Unlikely	Protium develops a robust project management process.	8	AR	08/05/2022
ID 15	Unreasonable constraints/mitigations in the planning application e.g., level of local employment or environmental mitigation required making the project commercially unviable.	Moderate	Unlikely	Have a considered stakeholder engagement plan to promote the benefits of the project.	6	AR	08/05/2022
ID 16	Impact on permitting for the boiler configuration and location due to emissions source from the boiler.	Moderate	Unlikely	Pre-application submitted to SEPA to familiarise them with the project prior to submission of full application.	6	AR	21/10/2022
ID 17	Working to incorrect or outdated consortium information. Submitting the project in an incorrect format.	Critical	Unlikely	Clear communication between project partners including an agreed communication policy. Early engagement and feedback from BEIS.	8	AR	08/05/2022
ID 18	Supply chain - global shortage of materials such as steel and wood. The impact from a timing and commercial perspective.	Moderate	Possible	Keep up to date with lead times and prices.	9	AR	08/05/2022
ID 19	Losing internal Bairds Malt champion for the project.	Moderate	Unlikely	Establish and maintain a good relationship within Bairds Malt. Have more than one champion within Bairds Malt. Ensure thorough handover in the event of a champion leaving Bairds Malt.	6	AR	08/05/2022

ID 20	Bairds Malt pursuing other projects which could directly impact the hydrogen project.	Critical	Unlikely	Agreed robust consortium agreement.	8	AR	08/05/2022
ID 21	No additional offtakes identify (undefined amount of H2 required)	Moderate	Possible	Agreeing as a consortium on terms and conditions to which we are designing the project including clear communication between project partners.	9	AR	21/10/2022
ID 22	Failure of consortium partners to deliver on project deliverables.	Negligible	Unlikely	Financial disclosures in this application demonstrate the financial resilience of the partners.	2	G	08/05/2022
ID 23	Not reaching soft targets to achieve Net Zero by 2030 by Bairds Malt.	Marginal	Unlikely	Maintain a good risk and issues escalation strategy.	4	A	21/10/2022
ID 24	Health risks from COVID-19.	Negligible	Possible	Partners all follow preventative measures to mitigate the spread of COVID-19 and have adequate remote work infrastructure in place.	3	G	08/05/2022
ID 25	Equipment and process CE UKCA marking and BSI and KIWA certifications.	Marginal	Unlikely	Engaging with direct/indirect gas-fired heaters suppliers and keep them on retainer to understand about certifications for the equipment.	4	A	21/10/2022
ID 26	Equipment systems not ATEX compliant	Marginal	Unlikely	Engaging with direct/indirect gas-fired heaters suppliers and keep them on retainer to understand about certifications for the equipment.	4	A	21/10/2022
ID 27	Automated control systems interfaces not completely aligned prior to deployment.	Marginal	Unlikely	Bringing system supplier to be brought into the project to review the proficiency of the full system.	4	A	21/10/2022
ID 28	Additional structure and pipelines required to supply	Marginal	Possible	Conducting design assessment and early	6	A	21/10/2022

	H2 to the direct/indirect gas-fired heater.			engagement with the equipment suppliers			
ID 29	Lack of full control over the installation (heaters, gas mixtures and refuelling) could result in equipment damage.	Marginal	Possible	Only authorised and trained personnel can have access to the equipment.	6	A	21/10/2022
ID 30	Construction falls under CDM (Construction, Design and Management) regulations delaying construction process.	Marginal	Possible	Ensuring that construction project aligns with the regulations. Follow RR and project Gantt chart action.	6	A	21/10/2022
ID 31	H2 leak form the pipeline system	Marginal	Possible	Ultraviolet detection equipment installation for H2.	6	A	21/10/2022
ID 32	System integration more complex than estimated.	Marginal	Possible	Engaging suppliers and keep them on retainer to understand how technology develops over the next few months.	6	A	21/10/2022
ID 33	Lack of skilled labour with knowledge and experience in hydrogen heaters systems	Marginal	Possible	All users to complete supplier training on the equipment, process and maintenance.	6	A	21/10/2022
ID 34	Unavailability of key personnel.	Moderate	Unlikely	Partners have sufficient human resources of the requisite skill set to support this project, in case of unplanned absence of key personnel (consultancy workloads demand the operation of multiple project teams).	6	AR	08/05/2022
ID 35	Designing to standards which could be updated during the design phase.	Marginal	Unlikely	Engaging with authorities and keep them on retainer to understand how standards develop over the next few months.	4	A	21/10/2022
ID 36	Hydrogen supply issues.	Negligible	Unlikely	All hydrogen is supplied by Protium,	2	G	08/05/2022

				removing the need to rely on third party suppliers.			
ID 37	Impact on traffic and traffic management during the H2 delivery.	Marginal	Unlikely	Engaging with Bairds Malt logistic team to design robust traffic plan.	4	A	21/10/2022
ID 38	Hydrogen-ready heater not yet developed sufficiently to provide a reliable heating solution.	Moderate	Unlikely	Use steam boiler instead of air heaters. A clear understanding of system requirements by all consortium partners. Effective cooperation and clear communication between consortium partners.	6	AR	08/05/2022
ID 39	Computational modelling does not adequately simulate real-life conditions in the hydrogen-ready air heater.	Moderate	Unlikely	Computational results produced by the university partner are validated by the equipment manufacturer partner, removing the need to rely on third party suppliers.	6	AR	08/05/2022
ID 40	Increased NOx emissions due to the higher hydrogen adiabatic flame temperature.	Marginal	Unlikely	FGR introduction to the system.	4	A	21/10/2022

For further information, please contact:

Kimberley Tweedie,

Project Manager

Protium Green Solutions Limited

kimberley@protium.co.uk