HyNet Industrial Fuel Switching

Phase 1 Public Report

Switching Novelis and Kraft-Heinz to Hydrogen

HyNet IFS
Industrial Fuel Switching

Novelis

KraftHeinz

PROGRESSIVE ENERGY

October 2022

Executive Summary

In March 2022, BEIS awarded Progressive Energy Limited ('PEL'), as lead bidder, funding to deliver a Phase 1 programme of industrial fuel switching (IFS) work, in partnership with Novelis UK Limited ('Novelis's) and Kraft Heinz UK Limited ('Kraft-Heinz's). PEL was also awarded Phase 1 funding by BEIS to undertake similar studies in relation to sites operated by PepsiCo, Essity and Kellogg's.

PEL has previously led Phase 1 and Phase 2 IFS programmes in partnership with Pilkington, Unilever and Essar. At the time of writing, the Phase 2 outputs from this work are shortly due for publication by BEIS.

All sites will be supplied by hydrogen in the future by the HyNet North West project, which comprises CCS-enabled and electrolytic hydrogen production, a pipeline distribution network and large-scale underground hydrogen storage in salt caverns.

This report summarises the work performed during the project. There were two entirely separate workstreams, one addressing the furnaces at Novelis's Latchford Locks Works, the other addressing Combined Heat and Power (CHP) and boiler conversion at Kraft-Heinz's Kitt Green site.

The work undertaken regarding Novelis primarily comprised:

1. A review of the feasibility of switching the furnaces at the Latchford Locks Works to hydrogen;
2. Design of a programme of work, including physical demonstration as required, to address any evidence gaps identified and complete the evidence base to support a future switch to hydrogen fuel;
3. A high-level estimate of the cost of converting Latchford Locks Works to hydrogen; and
4. How the findings from the work can be extrapolated across the aluminium sector in respect of scaling-up, build rate and replicability.

The work undertaken regarding Kraft-Heinz comprised:

1. A review of the readiness of installing CHP generation at Kraft-Heinz's Kitt Green site;
2. A review of the feasibility of switching the boilers at Kitt Green to operate on hydrogen;
3. High-level cost estimates in relation to both of the above; and
4. How the findings from the work can be extrapolated across the food and drink sector in respect of scaling-up, build rate and replicability.

The key messages in respect of the work undertaken in relation to Novelis's Latchford Locks Works site can be summarised as follows:

- At the time of writing, it appears very likely that a bid will be made by Novelis (and PEL) to BEIS's Phase 2 of the IFS Competition for funding of a demonstration to be designed and operated during 2023 and 2024. The demonstration would require:
    - Installation of new burners and regenerators capable of operation on the proposed fuel gases, with the gases blended upstream of the burner and control by a new control panel; and
    - Installation of a refractory suitable for hydrogen.
- There are a range of furnaces across the site, but the focus of the design of Phase 2 demonstration project is upon 'GPP Melter 3', which has regenerative burners of 4 MW_{th} scale and is fully representative of the larger furnaces on site.
- The demonstration would consider impacts upon product quality, furnace efficiency, equipment lifetime, burner readiness, controls and NOx emissions.
- The demonstration will be designed in such a way that the evidence which comes from the work will be relevant to the majority of other furnaces at Latchford Locks Works and those at other locations in the UK and overseas.
- In the early years of operation of the HyNet network, it is likely that supply interruptions will occur and so it will be valuable for Novelis to maintain the ability to use natural gas and hydrogen interchangeably. The demonstration project, therefore, will be designed to include running a furnace on hydrogen, natural gas or a blend of both gases.

The key messages in respect of switching the Kraft-Heinz boilers to hydrogen can be summarised as follows:

- The preliminary conclusion based on the feasibility study is that the boilers in place at Kitt Green are suitable for switching to 100% hydrogen. However, this is conditional on detailed modelling of the condensing economiser to assess the impact of a flue gas with a higher moisture content;
- The primary modifications required to operate on hydrogen is replacement of the existing burners, and the use of FGR to mitigate expected rises in NOx generation. For operation on a 20% blend of hydrogen, the existing burners could be retained; and
- The switch to hydrogen would necessitate wider assessment of operations within the boiler house, including consideration of fuel distribution and DSEAR assessment (the "Dangerous Substances and Explosive Atmospheres Regulations").

The key messages in respect of installing a hydrogen-fired gas engine at Kraft-Heinz's Kitt Green Site can be summarised as follows:

- Bulk pipeline hydrogen will not be available at the Kitt Green site until around 2030, so it is too early (now, in 2022) to start the process of engineering definition and procurement of a CHP scheme.
- It is clear, however, that a number of the major engine and CHP system suppliers that would be a suitable basis for a CHP scheme at Kitt Green have been developing hydrogen-ready products, and some of them have already (or will very soon) be offering such products to market (companies such as 2G, Innio Jennbacher and MTU).
- By the time a procurement process does need to begin for a CHP scheme (perhaps in 2027 or 2028), the sector will have matured further, with newer products being on the market and possibly a wider range of OEMs competing in what is likely to be a burgeoning hydrogen-CHP industry.
- Furthermore, the commercial operating track record of engines running on hydrogen will have grown, providing greater confidence to all of the stakeholders involved in this sector: the OEMs, the CHP system packagers, the energy consumers, and the operating companies that may actually build and operate such schemes under contract.
- This maturing of both technology and the commercial environment in which equipment is bought and operated means that the timing for implementation of such a CHP scheme at Kitt Green – in 2030 or thereabouts – is likely to be favourable.

A fundamental point of note associated with this work is that, whilst the evidence base needs to be expanded and site-specific demonstrations need to be undertaken, hydrogen combustion is not a fundamentally new technology in many industrial applications. Successful deployment will come via demonstration and thus gaining 'user acceptance', but also by bringing in the right skills and 'know-how' from the existing supply chain to deliver incremental change.

Full conversion of the Novelis and Kraft-Heinz sites to hydrogen and subsequent deployment of the solutions at wider, similar sites largely depends upon the deployment of the wider HyNet hydrogen and carbon capture and storage (CCS) infrastructure. However, it is also possible that green (or 'electrolytic') hydrogen production might be deployed at each site in advance of the HyNet network arriving in these locations.

The extent to which the solutions are 'built-out' will also depend largely upon the business models, which are currently under development by Government. Assuming a 'contract for difference' (CfD) model is used under the Hydrogen Business Model, the magnitude of the budget available to support hydrogen production (and indirectly, use) will drive the speed of deployment. Similarly, assuming appropriate knowledge dissemination, hydrogen business models in other countries will determine the build-out rate.

At the time of writing, Government is also currently consulting upon business models for hydrogen transportation and storage.[1] These are critical enablers and must be progressed rapidly to enable use of hydrogen by industry.

1 BEIS (2022) Hydrogen transport and s orage infras ruc ure: A consu a on on bus ness model des gns, regu a ory arrangemen s, s ra eg c p ann ng and the ro e of b end ng. August 2022 h ps://www gov uk/governmen / consu a ons/proposa s for hydrogen ranspor and storage bus ness mode s

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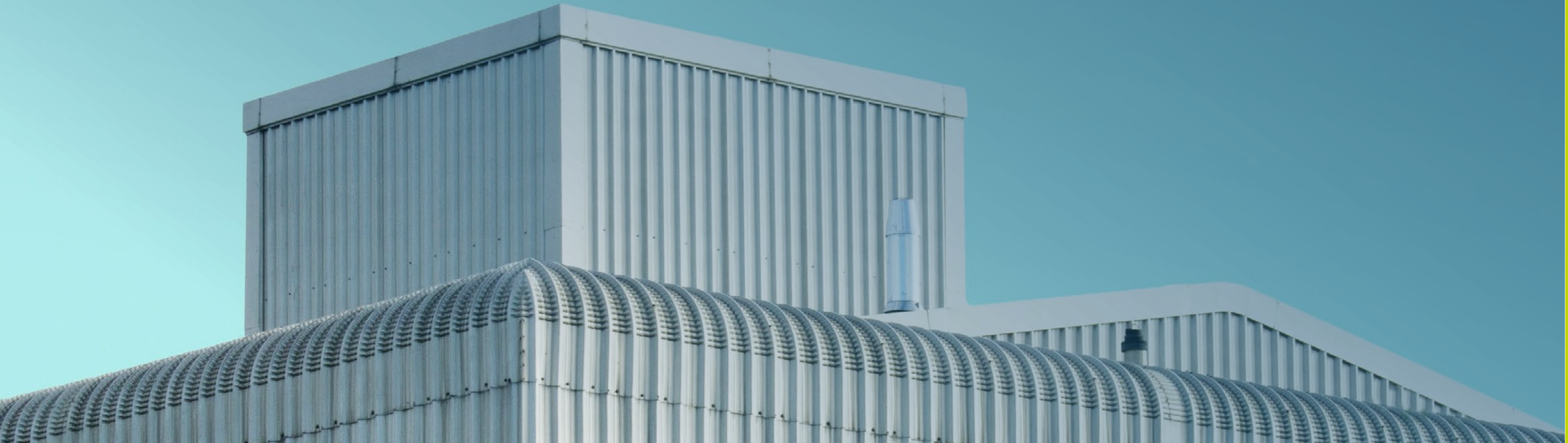
1 Introduction



1.1 Overview of Industrial Fuel Switching (IFS) programme

The main objectives of the Industrial Fuel Switching (IFS) Competition run by the Government's Department of Business, Energy and Industrial Strategy (BEIS) are to:

- Determine the costs of switching industrial sites to hydrogen;
- Prove that there is no detrimental impact upon existing plant and equipment;
- Demonstrate that sites can operate in conformance with all safety regulations;
- Prove that there is no detrimental effect on manufactured products;
- Prove that hydrogen can be fired in compliance with environmental permitting standards; and
- Enable participating and wider sites to switch to hydrogen as soon as it is available.

In March 2022, BEIS awarded Progressive Energy Limited ('PEL'), as lead bidder, funding to deliver a Phase 1 programme of fuel switching work, in partnership with Novelis UK Limited ('Novelis's) and Kraft Heinz UK Limited ('Kraft-Heinz's). PEL was also awarded Phase 1 funding by BEIS to undertake similar studies in relation to sites operated by PepsiCo, Essity and Kellogg's. It is intended that bids for Phase 2 funding for some or all of these sites will be submitted to BEIS. Collectively, work across these sites is referred to as the 'HyNet IFS2 Programme'.

To maximise value to Government and the tax-payer, this programme of work was developed with limited elements that are unique to their settings. Following publication of this report and any associated knowledge sharing activities, this will allow the same approach and evidence developed from the programme to be deployed at other locations around the UK and beyond.

PEL has previously led Phase 1 and Phase 2 IFS programmes in partnership with NSG-Pilkington, Unilever and Essar. At the time of writing, the Phase 2 outputs from this work are shortly due for publication by BEIS.

1.2 Overview of HyNet

This project with Novelis and Kraft-Heinz will support the objectives of the wider HyNet North West ('HyNet') project. It will provide evidence to enable the participating (and wider) sites in the North West (and beyond) to switch to low carbon hydrogen as soon as it is available in bulk from HyNet.

HyNet was conceived by PEL in 2016 via support from National Grid (subsequently Cadent) under the Network Innovation Allowance (NIA) framework. The first phase of work, published in August 2017, considered two core locations within Cadent's regional gas networks (the North West and Humberside) as potential locations for deployment of the UK's first CCUS and hydrogen infrastructure.[2] The North West was chosen as the preferred location due to its close proximity to well-characterised depleted oil and gas fields for offshore storage of CO_2 and the low cost of reusing these assets and existing pipelines, along with equally close proximity to the Cheshire Salt Basin (currently used for storage of natural gas) for underground bulk storage of hydrogen.

This initial study was built upon in a subsequent NIA-funded report published in June 2018.[3] This work defined the project concept for both hydrogen production and distribution, and CCUS.

As presented in Figure 1-1, this included the following key features:

- CCUS-enabled hydrogen production (from refinery off-gas and natural gas) at Essar's Stanlow Manufacturing Complex;
- Hydrogen pipelines from the hydrogen production hub at Stanlow Manufacturing Complex to:
  - Industrial and power generation sites;
  - Injection sites for 'blending' hydrogen into the existing gas network;
  - Major transport hubs; and
  - Underground hydrogen storage caverns in the Cheshire Salt Basin;
- CO_2 pipelines;
- CO_2 storage in the Liverpool Bay oil and gas fields.

It is important to acknowledge that following further engineering and design over the last four years, the current project definition described here has not changed substantially from the above Reference Project.

To reach a final investment decision (FID), HyNet must be successful in the negotiated phase of the Government's 'Cluster Sequencing' process. Under this process it has been selected as a priority Track 1 (Phase 1) cluster in terms of funding of CO_2 transport and storage infrastructure.[4] Furthermore, six of its related CO_2 capture sites, including the hydrogen production plant at Stanlow, have been selected by BEIS under Phase 2 of the process.[5]

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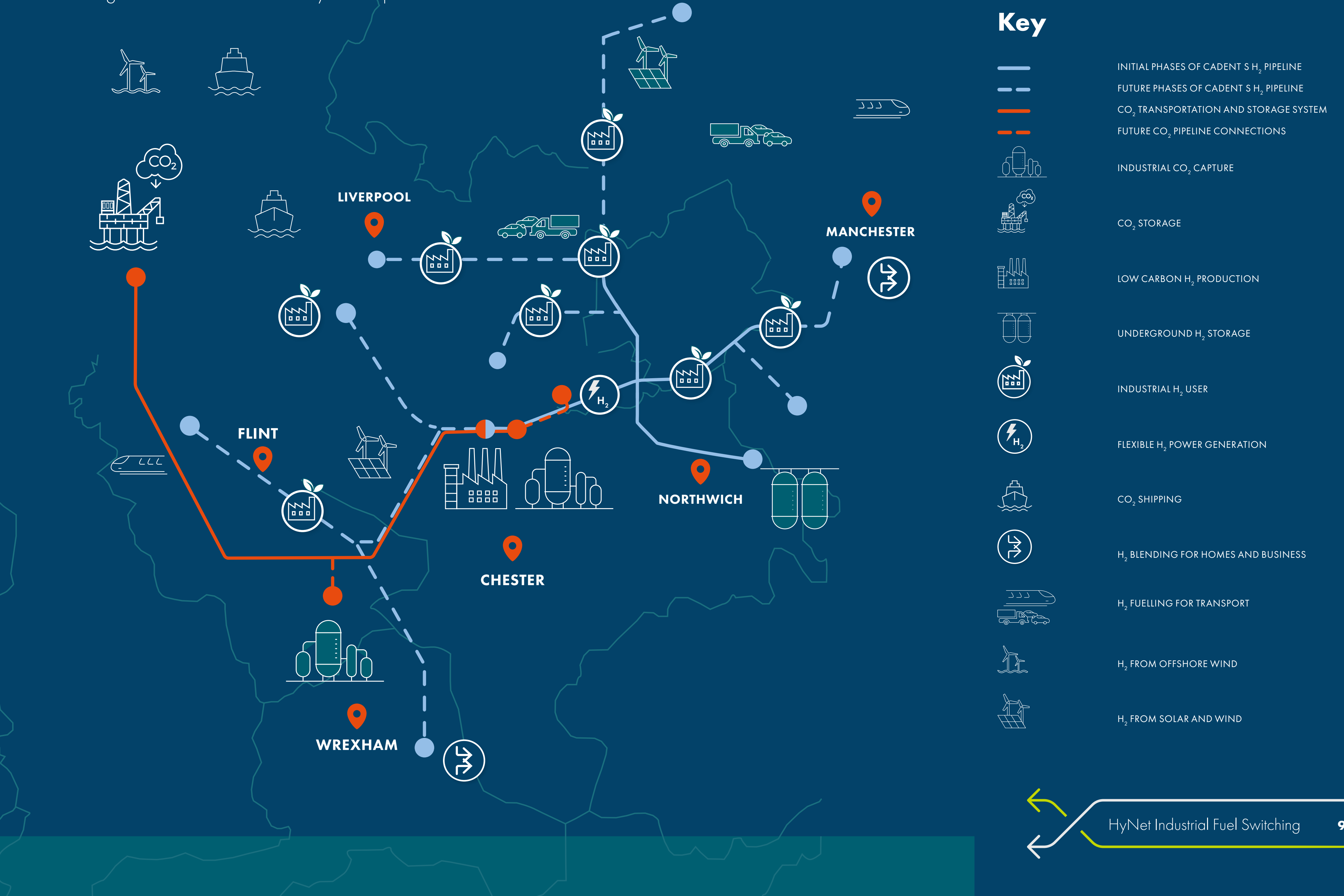
Figure 1 1: Overview of the HyNet Project



1.3 Scope and Objectives of this Report

This report summarises the work performed during the project. There were two entirely separate workstreams, one addressing the furnaces at Novelis's Latchford Locks Works, the other addressing Combined Heat and Power (CHP) at Kraft-Heinz's Kitt Green site.

The work undertaken regarding Novelis primarily comprised:

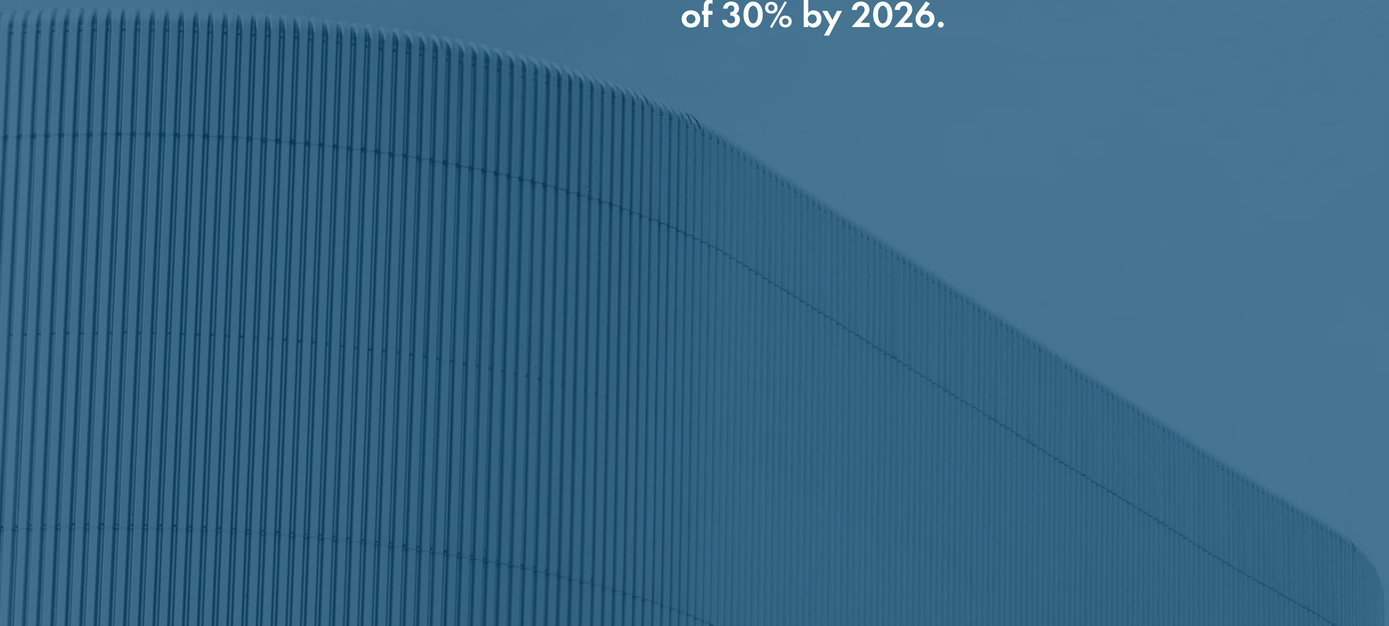
- A review of the feasibility of switching the furnaces at the Latchford Locks Works to hydrogen;
- Design of a programme of work, including physical demonstration as required, to address any evidence gaps identified and complete the evidence base to support a future switch to hydrogen fuel;
- A high-level estimate of the cost of converting Latchford Locks Works to hydrogen; and
- How the findings from the work can be extrapolated across the aluminium sector in respect of scaling-up, build rate and replicability.

The work undertaken regarding Kraft-Heinz comprised:

- A review of the readiness of installing CHP generation at Kraft-Heinz's Kitt Green site;
- A review of the feasibility of switching the boilers at Kitt Green to operate on hydrogen;
- High-level cost estimates in relation to both of the above; and
- How the findings from the work can be extrapolated across the food and drink sector in respect of scaling-up, build rate and replicability.
- Following this, consideration is given to how the development of the technical solutions interface with the development of the wider HyNet Project.

2 Novelis: Latchford Locks Works

As the world's largest recycler of aluminium, Novelis sees tremendous opportunities in continuing to expand the use of lightweight, infinitely recyclable aluminium worldwide, hence Novelis's commitment to net zero carbon emissions by 2050 and an immediate reduction of 30% by 2026.



2.1 Site Location and Layout

Figure 2 1: Novelis, Latchford Locks Works

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Figure 2 2: Aerial view of Novelis's Latchford Locks site

Novelis Latchford Locks Works is one of Europe's largest Used Beverage Can (UBC) recycling plants and Europe's largest closed-loop recycling operation for automotive aluminium rolled products with annual recycling capacity of up to 195,000 tonnes. The dedicated recycling plant at Latchford (shown in Figure 2 1 and Figure 2 2) was opened in 1991, and currently employs 172 people. Site capabilities include remelting, recycling and Sheet Ingot Casting. The large aluminium ingots produced are exported to Germany and Switzerland for further manufacturing into rolled product for can and the automotive sector in Europe or the UK.

Bales of aluminium cans are delivered to and stored on site. The bales of cans are broken up and shredded into small pieces, about the size of a 50p coin. These shredded pieces are pre-treated with hot air (approx. 500°C) which is blown through the shreds to remove the printed decoration. The clean shreds are then loaded into a melting furnace, and heated to 750°C. Once at temperature, the molten metal flows into a deep pit where the casting process takes place. The metal is cooled by direct contact with a curtain of water, solidifies and forms an ingot.

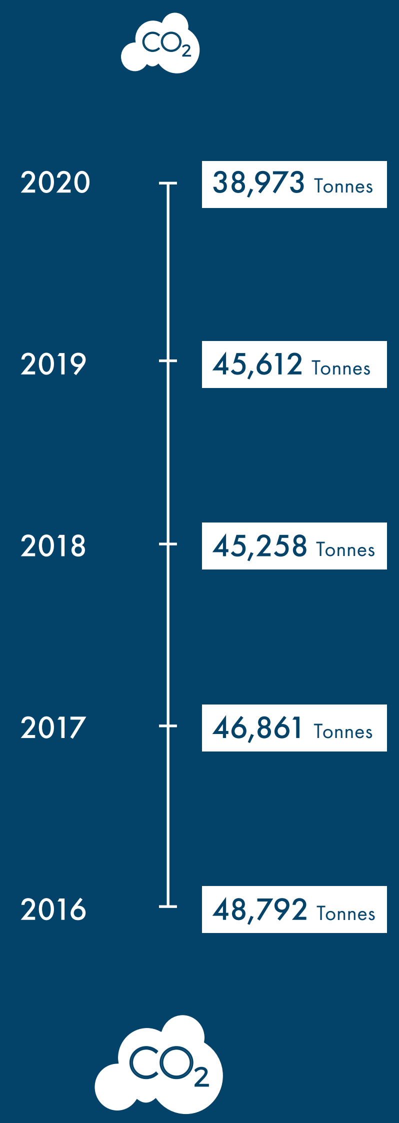
The Novelis Latchford site uses natural gas burners on its furnaces to melt the aluminium for casting into ingots and recycling. These burners are by far the largest source of emissions from the site.

2.2 Existing Environmental Impacts

Switching to hydrogen fuel would enable Novelis to significantly reduce its CO_2 emissions to achieve its net zero emission targets. Site CO_2 emissions between 2016 to 2020 are presented in Table 2 1. In 2019 the site's annual natural gas demand was over 200 GWh, equating to emissions of approximately 45,000 tonnes of CO_2 per annum (tCO_2/annum). Emissions fell to around 40 tCO_2/annum in 2020 due to impact of Covid-19.

Table 2 1: Novelis Latchford Locks Works CO_2 Emissions

Year	2020	2019	2018	2017	2016
Tonnes of CO_2	38,973	45,612	45,258	46,861	48,792



3 Novelis:
Feasibility of Hydrogen Fuel Switching

At Latchford Locks Works, CO_2 emissions arise primarily from the aluminium recycling furnaces. This section of the report considers the key issues with conversion of both the furnaces themselves and the wider site to hydrogen as soon as this becomes fully available from the HyNet project as discussed in Section 12.0.

3.1 General issues for consideration

3.1.1 Approach to hydrogen use

The UK natural gas network has historically operated with extremely high reliability, and it is imperative that security of energy supply to customers is not compromised by a switch to hydrogen.

The HyNet hydrogen distribution network will be progressively rolled out alongside hydrogen production. It is expected that hydrogen will be available to Latchford Locks Works from the HyNet Phase 2 hydrogen network in around 2027.

In the early years of operation of the network, it is likely that supply interruptions will occur and therefore most large hydrogen users will be expected to sign 'interruptible' supply contracts. At this early stage of roll-out, therefore, it will be valuable for Novelis to maintain the ability to use natural gas and hydrogen interchangeably, and so the proposed solution has been designed to be fully flexible between natural gas and hydrogen.

3.1.2 Safety issues

Safe operation of equipment using hydrogen will be considered by the Original Equipment Manufacturers (OEMs) at design stage. However, there are site-wide implications of hydrogen distribution and use.

Latchford Locks Works currently consumes large quantities of natural gas. For full conversion of the site, hydrogen will be delivered by pipeline to the site boundary and distributed around the site in the same way as natural gas is today. Analysis concerning the safe use of hydrogen therefore focusses on the differences between hydrogen and natural gas.

Hydrogen has a greater flammable range than natural gas, and has a greater propensity to leak through joints in pipework. Therefore, it will be necessary to review existing Hazardous Area Classifications for the site, and the suitability of equipment located in any new or extended Hazardous Areas. Dependent on the existing ventilation in different areas of the plant, it may be necessary to install mechanical ventilation, and to consider louvres to aid gas escape. Due to the buoyancy of hydrogen, particular consideration must be given to build-up in elevated areas, which might necessitate the need for oxygen depletion monitoring.

These flammability and leak considerations also need to be considered during material and equipment selection for a distribution system, and at the commissioning stage; purging requirements for hydrogen requirement will be more stringent, and helium should be used in leak testing. Fully welded pipes should be considered where possible.

It is assumed that hydrogen distributed at large scale will be odorized to aid in leak detection, but additional gas detection may also be required. Hydrogen flames are invisible, so flame detection and additional measures such as flange guards to diffuse potential gas jets should be considered.

Notably, existing and upcoming standards will assist in achieving safe design.

3.2 Alternative Options for Decarbonisation

In the melting furnaces at Latchford, shredded, pre-treated aluminium cans are heated to 750°C by generative natural gas burners, to melt them ready for casting into ingots. Figure 3 1 shows a process block diagram for the shredding to casting process.

Novelis has multiple projects across the business to consider alternative technologies for decarbonising the melting process. These projects are closely engaged with the work being performed under the Industrial Fuel Switching programme.

A Novelis-led Net Zero project is underway to identify and implement solutions for carbon neutrality in aluminium manufacturing. The solutions identified will then be implemented at Novelis's manufacturing sites around the world. Technologies being considered involve various electrification and hydrogen-based approaches.

Of these technologies, hydrogen is the closest to the existing natural gas configuration, and once proven as part of the HyNet IFS2 programme, the solution can be rolled out across Latchford Locks Works. Wider deployment of switching to hydrogen depends, however, on local availability of fuel, and so pursuit of low carbon electricity-based solutions is also important to ensure full decarbonisation of Novelis's worldwide operations.

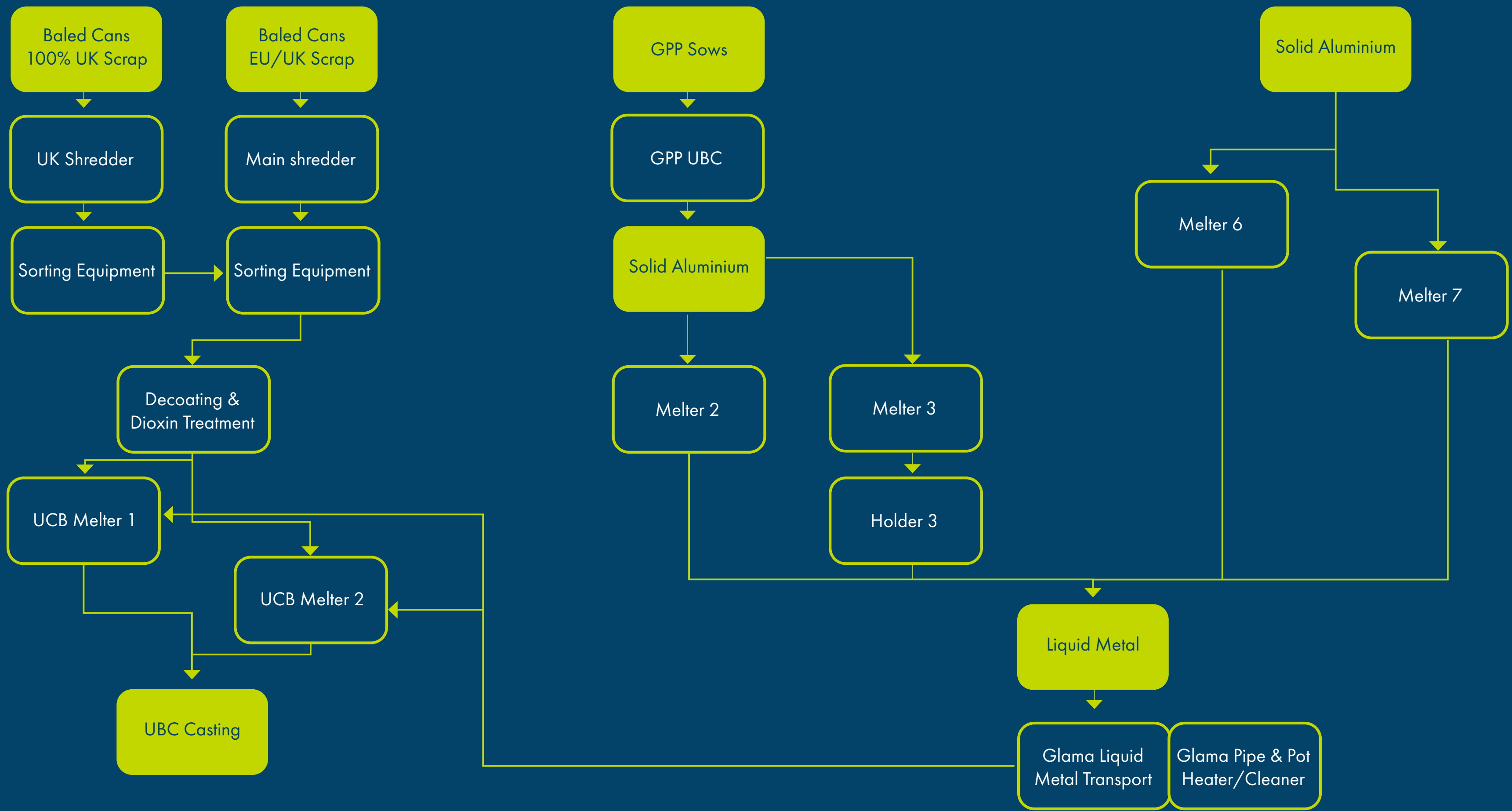


Figure 3 1: High-level diagram for shredding to casting

3.3 Considerations for Proposed Hydrogen Demonstration

It is proposed that furnaces are converted to run on hydrogen, natural gas or a blend of both gases. This will be accomplished by:

- Installation of new burners and regenerators capable of operation on the proposed fuel gases, with the gases blended upstream of the burner and control by a new control panel; and
- Installation of a refractory suitable for hydrogen.

The proposed change raises several questions in terms of feasibility that must be addressed, as described below.

3.3.1 Product quality

One potential consequence of hydrogen use is increased porosity in the product.

Presently, porosity is addressed by injection of chlorine gas (or replacement flux), and argon stirring. It is expected that hydrogen will be 'picked up' by the molten aluminium during melting, increasing the porosity.

The impact of hydrogen on porosity and dross production will be assessed by sampling product from physical demonstration. Novelis has engaged with the University of Sheffield Advanced Manufacturing Research Centre to discuss methods for analysis of samples to assess any deviations of microstructure, chemistry and porosity from the norm.

3.3.2 Efficiency

After the aluminium is melted, the surface is skimmed to remove the impurities known as dross. The dross is collected in pans beneath the furnace door opening and it is taken offsite for recycling, whereby any aluminium is reclaimed and returned to site.

Process efficiency questions relating to hydrogen use encompass both the levels of dross production, and the furnace melting performance. Physical demonstration is required to specifically answer the following questions:

- What is the energy efficiency (kWh/tonne)?
- What is the melting speed (convection/radiation effect, effect of furnace atmosphere: CO_2, N_2, H_2O)?
- What is the general reactivity with aluminium and additives?
- How much dross is produced per batch?

3.3.3 Equipment lifetime

Two areas which may experience long term affects by burning hydrogen gas in the furnace are the refractory and the Local Exhaust Ventilation system (LEV). The key issues are described as follows:

1 Refractory

Through engagement with a refractory supplier, it was established that there are many factors that could impact on the refractory lining. The most important of these were:

a. Increased operating temperature, both directly from the flame and from generally increased operating temperatures and hotspots;

b. Increased levels of water vapour (31% on hydrogen vs 17% when burning natural gas); and

c. Chemical effect of hydrogen and other compounds.

The planned Phase 2 demonstration will involve around 2 weeks operation on hydrogen. Core samples will be taken to capture this valuable data, however 6-12 months' operation is required to give a robust assessment of the issues. In advance of this data, specification of a high-grade refractory will be required, but as operational experience increases, it will be possible to design bespoke, cost-optimal refractory materials.

2 LEV system

The downstream LEV and baghouse system incorporates a hydrated lime dosing system for neutralising the flue gas entering the AAF baghouse. There was an initial concern that increasing the moisture may alter the lime consistency and could lead to filter media blockage and reduced air volume extraction. However, initial research suggests that operating temperatures are sufficiently high that this will not be an issue. Samples will be taken during hydrogen operation to verify this.

3.3.4 Burner readiness

Several burner OEMs claim hydrogen suitability, but Novelis is not aware of hydrogen burners currently in use on aluminium melting furnaces. However, Novelis's burner supplier has declared successful operation of a fuel-flexible natural gas/hydrogen burner in a lab environment. Prior to demonstration at Latchford, Novelis would perform further burner testing at its own facility to further validate the solution.

3.3.5 Controls

Previous hydrogen demonstration work (including that of the HyNet IFS1 programme) has encountered challenges in integrating the tube trailer hydrogen supply into the existing control system. The majority of the issues encountered will not be present with pipeline-supplied hydrogen. For deployment at Novelis, hydrogen and natural gas flow will be controlled by a new control panel.

3.3.6 NOx emissions

Hydrogen use is generally assumed to be associated with higher levels of NOx production than natural gas, due to the higher flame temperatures. Analysis by different parties disagrees on whether NOx emissions from the aluminium furnace will be reduced or slightly increased, hence a demonstration is required to confirm the NOx levels. The flue gas system in place services four furnaces, which could mask changes in NOx production. For this reason, measurements during hydrogen demonstration will be taken directly from the furnace.

4 Novelis:

Scoping of Phase 2 Trials

The first stage of IFS2 Phase 1 focused on reviewing the feasibility of switching the furnaces on site at Latchford Locks Works to hydrogen. Subsequently, the objective of the work was to design a programme of work to provide sufficient evidence to support the switching of the site, and wider sites as part of knowledge sharing, to low carbon hydrogen fuel.

4.1 Furnace Selection for Phase 2 Demonstration

Ranging up to 100 tonnes per day (tpd) in capacity and with a maximum capacity to recycle 30,000 tonnes of aluminium per annum, Novelis has ten furnaces installed at the Latchford Locks Works. Alongside the furnaces, the site has a 14 tonnes per hour (tph) incinerator, responsible for de-coating shredded aluminium used beverage cans. As a result, the site has a total energy demand in excess of 40 MW, including 5 MW from additional small heaters on site.

There are a range of furnaces across the site, but the focus for the potential Phase 2 demonstration project is upon 'GPP Melter 3' (see Figure 4 1). This furnace has regenerative burners of 4 MW_{th} scale and so not only is sufficient supply hydrogen achievable in the context of today's 'merchant' hydrogen market, but it is of sufficient scale as to be fully representative of the larger furnaces on site. Other furnaces considered were either too old or too small and so not representative of the wider fleet.

The demonstration will be designed in such a way that the evidence which comes from the work will be relevant to the majority of other furnaces at Latchford Locks Works and those at other locations.

Figure 4 1: A typical solid aluminium charge for GPP Melter 3

4.2 Summary of Proposed Phase 2 Demonstration Programme

Based on the analysis in Sections 3.3 and 4.1, we have designed a Phase 2 demonstration programme that will provide evidence to enable switching of all Latchford Locks Works furnaces to hydrogen.

Each phase of the demonstration will require one normal working day to complete, as the typical cycle time for melting a 28-tonne charge of aluminium is five hours. The demonstration will run Monday to Friday for two weeks. Prior to commencement, a hydrogen tube trailer will be delivered to site for one week to allow setting up of the hydrogen and natural gas blends, test firing and control loop tuning. Replenishing of the hydrogen trailers will be optimised and depend on the hydrogen consumption for each trial. Nominally, two hydrogen trailers will be required on site each day.

After each day's hydrogen firing, the intention is for Novelis to melt aluminium batches on the nightshift using natural gas only and possibly at the weekend as well, to minimise disruption to production.

As shown in Table 4 1, the first 'run' will be carried out using 100% natural gas to measure all baseline parameters. For subsequent trials, the hydrogen percentage will be increased gradually and blended with the natural gas. When 100% hydrogen fuel is reached, Novelis will continue the trials for repeatability and melt different aluminium grades, then finally switch back to natural gas for handover to normal production.

	Fuel Blend	Aluminium Grade (alloy)
Run 1	100% NG	3,000
Run 2	50% NG / 50% H_2	3,000
Run 3	30% NG / 70% H_2	3,000
Run 4	100% H_2	3,000
Run 5	100% H_2	3,000
Run 6	100% H_2	3,000
Run 7	100% H_2	3,000
Run 8	100% H_2	5,000
Run 9	100% H_2	6,000
Run 10	100% NG	3,000

Table 4 1: Demo Programme showing fuel blends and aluminium grade

5 Novelis:
Indicative Capex for Switching to Hydrogen

In performing the Feasibility Study, and specifically in designing the Phase 2 demonstration programme, understanding has been built in respect of the works and costs associated with switching the entire Novelis site to hydrogen (as soon as this is available from the HyNet project). The focus of this section is therefore upon the Capex associated with switching the whole site to hydrogen, rather than upon the costs of the Phase 2 demonstration programme.

Cost Basket	Cost (£M)
Production Equipment	25.9
Pipework & Ancillaries	1.6
Hydrogen Reception	0.5
Total	28.0

Table 5 1: High-level Capex of whole-site conversion

Three main categories of costs are considered:

1. Equipment conversion in relation to all 10 operating furnaces:

- This relates to modification/replacement of production equipment, and includes design and installation and controls modifications.
- The cost estimate for production equipment conversion assumes the same high-grade refractory used for the demonstration is deployed on all furnaces, however it is intended that as operational experience increases, it will be possible to design bespoke, cost-optimal refractory materials, reducing conversion cost.

2. Pipework and ancillaries:

- This relates to distribution of hydrogen to the relevant processes within the site boundary, and includes engineering and installation costs. It also includes upgrades to ancillary systems such as gas detection, and upgrades to ATEX-rated equipment where required.

3. Hydrogen 'reception':

- This includes the primary meter set and pressure reduction to design pressure.

Costs associated with pipeline connection to the HyNet hydrogen distribution network are excluded, as it is likely that these costs will be recovered via network charges, and will therefore be an ongoing operational cost (subject to confirmation of final regulatory model for hydrogen distribution).

The information presented in Table 5 1 is indicative only and but provides a preliminary view on the overall costs of switching the sites to hydrogen. The proposed demonstration project will provide more detailed information in this respect, should the related bids be successful in the Phase 2 Competition process.

6 Kraft-Heinz:

Kitt Green Site

Kraft-Heinz's Kitt Green site is the largest food processing plant in Europe, making millions of cans of Baked Beans every day. The site began production in 1959, and the last major plant upgrade was in 2004.

Currently, all electricity used at the site is imported from the local network, but steam demand is serviced from a central steam generation plantroom and delivered as saturated steam. Steam is used on-site for all aspects of manufacture of canned goods products including:

- Can and other container manufacturing;
- Food processing;
- Final production including cooking; and
- Clean-in-place (CIP) and other cleaning / finishing processes.

The plant, including the steam generation plant, is shown in Figure 6 1.

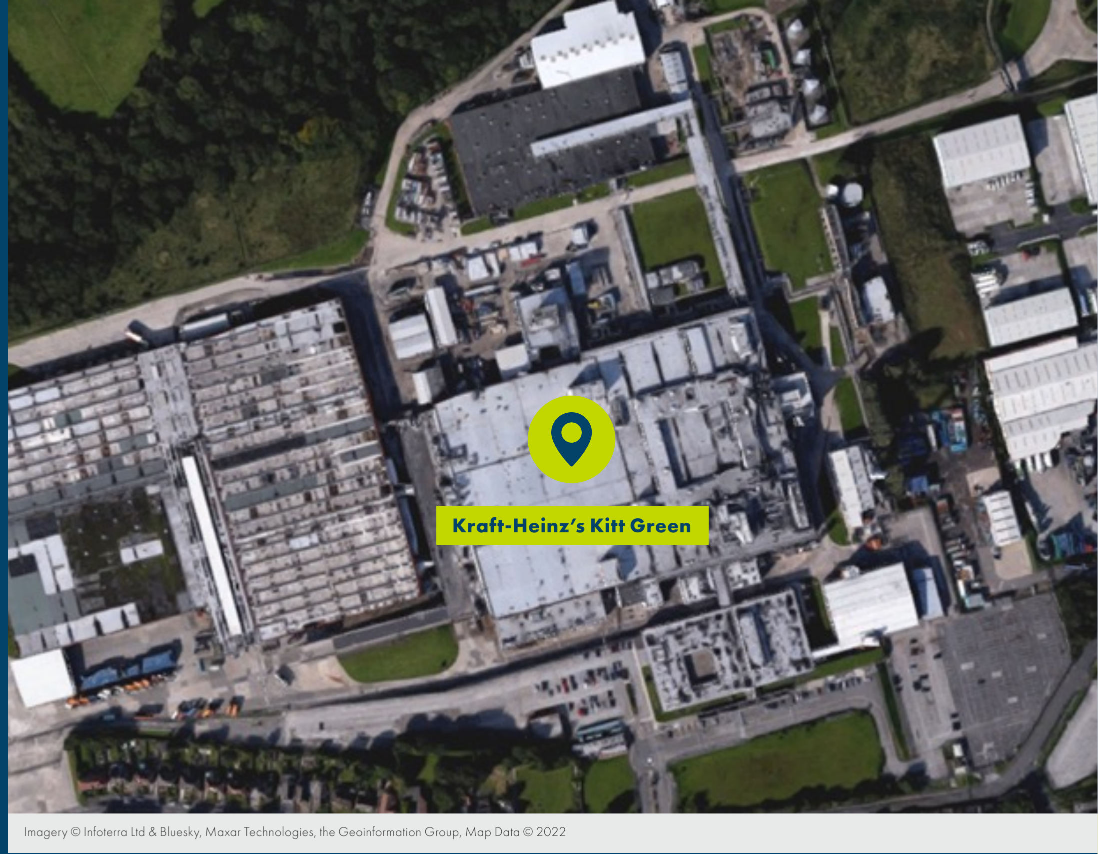


Figure 6 1: Kraft-Heinz's Kitt Green manufacturing plant

6.1 Existing Steam Generation System

The complete steam generation design at the Kitt Green site is a highly complex custom design for this single site. The complete plant design places a priority on operational efficiency and the site requirement that process condensates are not returned to the plantroom to prevent cross contamination. This choice led to the inclusion of a condensing economiser to mitigate the associated energy penalty.

The original design parameter for the steam boiler generation plant was for generation of 90tph, met by 3 duty / assist boiler plant and a standby plant to allow for service and maintenance outages. The boilers were provided by Danstoker, and each have twin Hamworthy burners, capable of firing natural gas or oil.

Figure 6 2: Twin Hamworthy burners firing into Danstoker boiler

The steam boilers are of a steel shell and tube construction. Careful management prevents degradation of the boiler shells, which includes:

- Use of a reverse osmosis water conditioning plant provide the highest grade of soft water available, and storage of the water in a pressurised deaerator;
- Design of the condensing economiser with multiple heat exchange elements to ensure the water is at the correct temperature at all points to achieve the optimum heat recovery whilst then ensuring the flue gases to do not reach dew point and there is enough energy (efflux velocity) to move the gases through the stack; and
- The steam boiler shell package and controls control for the optimum level of water supply, without thermal shocking.

Over the years changes to the production facilities have occurred and the site steam demand has dropped to a level that could be serviced by only two duty boilers, allowing for two standby boilers.

6.2 Existing Environmental impacts

The existing boilers impact the environment through emissions of NOx and CO_2. Annually, around 200 GWh of natural gas is consumed, with associated emissions of around 36,000 tCO_2/annum. 45 GWh of electricity is also imported, with associated emissions around 6,000 tCO_2/annum.

NOx emissions during natural gas-fired operation are limited by the site's permit to 100 mg/Nm^3 at 3% O_2, and the boilers operate well below this level. It is expected that when fully operating on hydrogen, the limit will be uplifted to 200 mg/Nm^3, in line with the requirements of the Medium Combustion Plant Directive (MCPD) albeit this may be reviewed by the Environment Agency.

Limits also apply to carbon monoxide, sulphur and dust, but related analysis is outside the scope of this analysis.

7

Kraft-Heinz:

Feasibility of Hydrogen Fuel Switching

The original intent for Phase 1 work at Kraft-Heinz was for it primarily to comprise the development of a specification and procurement of a FEED study. This was to focus on the installation of a hydrogen-fired combined heat and power (CHP) facility at the Kitt Green site, using one or more reciprocating internal combustion engines as the prime movers for the CHP facility. Subsequently, the undertaking of the FEED study would be subject to a successful funding application to Phase 2 of the IFS2 Competition.

Bulk pipeline supply of hydrogen will not be available at the Kitt Green site from the HyNet infrastructure until around 2030 ('Phase 3' of HyNet's hydrogen network development, as described in Section 12.2). During the intervening period it is likely that the technology landscape for hydrogen-fired reciprocating engines will change significantly, and the site needs are also likely to change over this time. Consequently, discussions with Kraft-Heinz suggested there was limited value of undertaking such a FEED study in the next 12-24 months and that a more appropriate time is likely to be in around 2026/27, as a pre-cursor to an investment decision.

At this point in time therefore it was agreed with Kraft-Heinz and BEIS to undertake:

- A high-level feasibility assessment of using hydrogen in the existing boiler plant at Kitt Green, building on the work performed at Unilever's Port Sunlight facility under the HyNet IFS1 programme; and
- A review of emerging reciprocating engines being offered by OEM for operating on 100% (or high proportions of) hydrogen at an appropriate scale for the Kitt Green CHP project.

The findings from this work are described below.

7.1 General Issues for Consideration

7.1.1 Approach to hydrogen use

The UK natural gas network has historically operated with extremely high reliability, and it is imperative that security of energy supply to customers is not compromised by a switch to hydrogen.

The HyNet distribution network will be progressively rolled out alongside hydrogen production. In the early years of operation of the network, it is likely that supply interruptions will occur and therefore most large hydrogen users will be expected to sign 'interruptible' supply contracts.

By the time hydrogen is available to Kraft-Heinz's Kitt Green site in around 2030, it is expected that hydrogen supply reliability will be more akin to the existing natural gas network. That said, it will still likely be valuable for Kraft-Heinz to maintain the ability to use natural gas and hydrogen interchangeably should any supply constraints still pervade, and so the proposed solution has been designed to be fully flexible between natural gas and hydrogen.

7.2 Safety Issues

Safe operation of equipment using hydrogen will be considered by the Original Equipment Manufacturers (OEMs) at design stage. However, there are site-wide implications of hydrogen distribution and use.

Kitt Green currently consumes large quantities of natural gas. For full conversion of the site, hydrogen will be delivered by pipeline to the site boundary and distributed around the site in the same way as natural gas is today. Analysis concerning the safe use of hydrogen therefore focusses on the differences between hydrogen and natural gas.

Hydrogen has a greater flammable range than natural gas, and has a greater propensity to leak through joints in pipework. Therefore, it will be necessary to review existing Hazardous Area Classifications for the site, and the suitability of equipment located in any new or extended Hazardous Areas. Dependent on the existing ventilation in different areas of the plant, it may be necessary to install mechanical ventilation, and to consider louvres to aid gas escape. Due to the buoyancy of hydrogen, particular consideration must be given to build-up in elevated areas.

These flammability and leak considerations also need to be considered during material and equipment selection for a distribution system, and at the commissioning stage; purging requirements for hydrogen requirement will be more stringent, and helium should be used in leak testing. Fully welded pipes should be considered where possible.

It is assumed that hydrogen distributed at large scale will be odorized to aid in leak detection, but additional gas detection may also be required. Hydrogen flames are invisible, so flame detection and additional measures such as flange guards to diffuse potential gas jets should be considered.

Notably, existing and upcoming standards will assist in achieving safe design.

8 Kraft-Heinz:

Potential for Hydrogen CHP

This Section aims to provide an overview of the readiness of hydrogen-fired reciprocating engines for service in a CHP system at Kitt Green. Specifically, the aims are:

1. To highlight the issues that need to be considered in the use of hydrogen in reciprocating internal-combustion engines;
2. To establish a reasonable understanding of the functional specification of a future CHP system at Kitt Green; and
3. To provide a narrative on the current status of using hydrogen as a fuel for such prime movers, with a focus on the engines from different 'original equipment manufacturers' (OEMs) that would be suitable for use in a CHP scheme at Kitt Green.

Following this analysis of engine readiness, some consideration is given of the potential for heat integration between the engines and the site steam system.

8.1 Key Issues associated with Hydrogen Use

Reciprocating internal combustion engines are designed to operate on a specific fuel that has a number of relatively narrowly defined parameters that can influence the performance and reliability of an engine. Such parameters include:

- Calorific value of the fuel;
- Wobbe Index;
- Propensity to pre-ignite ('knocking');
- Temperature at which it burns in air (which can affect the composition of the exhaust gas emissions);
- Flame speed; and
- Interaction with the materials of an engine's construction (including, for example, the flexible pipelines through which a fuel must flow to reach the engine's combustion chamber).

Such properties are different for hydrogen compared with, for instance, natural gas. Consequently, an engine that was originally designed and controlled to run on natural gas is unlikely to be optimised for running on 100% hydrogen. This section of the report discusses some of the more important characteristics that need to be considered when using hydrogen in reciprocating internal combustion engines.

8.1.1 Calorific Value

The calorific value (CV) of hydrogen (per unit of mass) is higher than that of natural gas. However, because hydrogen has such a low density, the volumetric energy density (units of energy in a certain volume of the gas) of hydrogen is lower than that of natural gas. One cubic metre of natural gas contains about 3.5 time more potential energy than does one cubic metre of hydrogen.

Because of this, the normal volumetric flow of hydrogen into an engine must be about 3.5 times higher than the flow of natural gas into the engine, if it is to provide the same power output. This may affect the design of the fuel delivery systems in an engine, and how it is controlled.

8.1.2 Wobbe Index

The Wobbe Index is a measure of the interchangeability of gaseous fuels – it is calculated by dividing the gross CV of a fuel by the square root of its specific gravity (which is the ratio of the fuel's density to that of air at standard temperature and pressure). Two fuels with the same Wobbe Index will largely release the same amount of energy when burnt in an appliance, without changing any of its control settings.

The Wobbe Index of natural gas does vary a little (this is because the composition of natural gas has some natural variability), but – in the UK – it is currently maintained at between 47.20 MJ/m^3 and 51.41 MJ/m^3 (as defined in the "Gas Safety (Management) Regulations 1996").

The Wobbe Index of pure hydrogen is 45.8 MJ/m^3. Whilst the difference between the Wobbe Index of hydrogen and that of natural gas is a lot less than the difference in the calorific values of the two fuels, this difference may lead to there being a need to make some adjustments to the engine control system when using hydrogen instead of natural gas.

8.1.3 Pre-ignition Propensity (‘knocking’)

‘Knocking’ in an engine is when a fuel combusts prematurely in the engine cycle, leading to inefficiency, higher emissions of potential pollutants, and, potentially, to mechanical damage within the engine. The propensity of a gaseous fuel to pre-ignite in this way can be measured by its ‘methane number’, an index based on the characteristics of methane, which is relatively resistant to such pre-ignition, and which has a ‘methane number’ of 100.

Hydrogen has a ‘methane number’ of 0. Its use significantly increases the propensity for ‘knocking’ to occur in an engine. Because of this, the use of hydrogen as a fuel in a reciprocating internal combustion engine requires the engine designer to consider one or more of the following:

- Operating the engine at a lower compression ratio to reduce the risk of knocking (so having the effect of derating an engine);
- Changing the way in which fuel is introduced into the engine cylinder (possible use of direct injection); and
- Changing the design and geometry of the cylinder head and piston;
- Changes to ignition timing.

Some of these changes are ‘hard-wired’ into the design and operation of an engine, meaning that an engine that is installed and set up to run on hydrogen may not be suitable for operation on natural gas (or – at the least – will not operate optimally if running on natural gas).

8.1.4 Flame Temperature (and NOx formation)

Hydrogen burns with a hotter flame than natural gas. These higher temperatures in the flame can increase the formation of ‘thermal NOx’ (the oxides of nitrogen that are formed from the reaction of oxygen and nitrogen in the combustion air).

Other factors also influence the formation of NOx, such as the air-fuel ratio at which an engine is operating, ignition timing, compression ratio, engine speed, and the physical design of the cylinder head and piston. Furthermore, NOx emissions can be reduced through the use of exhaust gas recovery (EGR) and through ‘end-of-pipe’ treatment such as selective catalytic reduction.

So, whilst the use of hydrogen can cause an increase in NOx emissions from a combustion system, there are features and control systems that can be deployed to limit this impact.

8.1.5 Flame speed

The flame speed is a measure of how quickly the flame is travelling from a fixed reference point. The flame speed of hydrogen is significantly higher than that of natural gas at a given stoichiometry.[6] This can bring both benefit and disbenefit. On the plus side, it can lead to the ability to operate at much 'leaner' mixtures of air and fuel whilst delivering complete combustion, which can bring benefits in terms of lower levels of NOx formation (countering the effect of a higher flame temperature as mentioned in 8.1.4 above). However, the disbenefits can include an increase in the risk of back-firing (depending on the detailed design of the fuel injection system and intake valves), and can lead to higher piston wall temperatures that may require redesign of the engine block cooling system.

8.1.6 Other Properties

Hydrogen reacts differently to the materials in different parts of engine systems, compared with natural gas. For example, some flexible seals used in engines may be unsuitable for use with hydrogen.

Furthermore, the small molecules of hydrogen can increase the risk of unburnt fuel passing the piston rings, and the low ignition energy and wide flammability range of hydrogen can increase the risk of this unburnt fuel igniting within the crankcase, requiring greater levels of crankcase ventilation to minimise risk of damage.

It is also possible for hydrogen to cause cracking in some components or in welds that are in contact with the gas (hydrogen-induced stress corrosion cracking). Avoiding this can involve selecting a different grade of steel, different jointing arrangements, or different welding procedures.

The main combustion product of burning hydrogen in an engine is water vapour. The exhaust gas of a hydrogen-fired CHP system will contain a higher concentration of water vapour than the equivalent system being fired on natural gas. As a consequence, the risk of accelerated corrosion in any heat recovery system installed as part of a CHP scheme needs to be considered when using hydrogen as a fuel, and consideration also given to the risk of visible vapour plumes being emitted from the exhaust stacks of such engines.

8.1.7 Summary

The above short narrative describes a number of the key differences in using hydrogen in reciprocating engines, compared with the use of natural gas. The science of these differences is understood, and engineering solutions can be designed and implemented.

Section 8.3 describes the approach being taken by a number of engine manufacturers in the design and bringing to market of 'hydrogen-ready' engines.

6 Stoichiometry is a measure of the relationship between the quantities of reactants and products before, during, and following chemical reactions.

8.2 CHP Functional Requirements

8.2.1 Energy Demand at Kitt Green

Energy is used at the Kitt Green site in three main forms:

- Electricity, which is currently imported from the local electricity distribution system via a 6.6 kV import connection;
- Steam, which is distributed around the site at a pressure of 8.5 Bar(g). At this pressure, its temperature is approximately 173°C. This steam is currently all generated in the gas-fired boilers at Kitt Green; AND
- Low temperature hot water (LTHW), distributed at 82°C, which is primarily produced using heat recovery from the food manufacturing process.

Detailed analysis was undertaken in respect of the above three sources of demand, but is considered commercially confidential and so not published here.

It should be noted that, in converting other parts of the energy system at Kitt Green to run on hydrogen, there may be some as-yet difficult to predict changes to the energy demand needs at the site. For example, in switching the existing boiler system (which includes a condensing economiser) to run on hydrogen, there may be a benefit in providing some additional low-grade 'waste heat' from the CHP system to increase the temperature of the boiler flue gas before release to atmosphere. This would reduce the risk of a visible vapour plume, which could be a consequence of the higher water vapour content of the flue gas when running on hydrogen. Such details would need to be explored in any future Front End Engineering Design (FEED) study for a CHP scheme.

8.2.2 Resilience

8.2.2.1 Electricity

Back up supply of electricity can be maintained through the grid connection, therefore 100% resilience in the generation of electricity is not a requirement for the CHP project. Redundancy in electricity generating capacity is not needed.

8.2.2.2 Steam

The supply of any steam from the CHP system will simply displace some of the current steam production from the existing boilers. The existing boilers will be retained and will need to continue to operate so that the total site steam demand can be met. Given this scenario, back-up steam supply can be met by the existing steam boilers and there is no requirement for a CHP scheme to have an unusually high level of steam-generation reliability.

8.2.2.3 Low Temperature Hot Water

Similarly, the supply of any LTHW from a CHP system will simply displace the use of steam from the current steam main. The CHP system is not expected to have unusually high reliability with regard to LTHW production, given that the existing system will act as back-up supply.

8.2.3 Summary of Functional Requirements

Based on the above energy demand requirements, and without undertaking more detailed techno-economic analysis, the functional requirements for development of a hydrogen-fired reciprocating-engine based CHP scheme at the Kitt Green site are taken to be:

1. Electricity generating capacity of approximately 6 MW_e, with a turndown capability to 1.5 MW_e. Peak electrical demand will be met from grid-supply.
2. Heat recovery steam generation from the engines to supplement the outputs from the main steam raising boilers. For a 6 MW_e CHP scheme, such a heat recovery steam generation system would be expected to produce approximately 4-5 tph of steam at 8.5 Bar(g) when running at full load, representing approximately 10-15% of the site's steam demand on a weekday;
3. Capability to provide up to approximately 1.5 MW_{th} of top-up heat in the generation of LTHW at 82°C; and
4. A control system that will load-follow based on site electrical demand.

There is one further functional requirement that may need to be considered at the point at which a fuller engineering feasibility or 'Front End Engineering Design' is being undertaken on this possible development. This relates to the reliability of supply from the future hydrogen production, transmission and distribution infrastructure. As noted above, the energy system at Kitt Green has in-built resilience (i.e. it has alternative sources of electricity, hot water and steam), meaning that any CHP scheme would have back-up should it ever be off-line. However, even with this system resilience, it may be the case that Kraft-Heinz would want to continue to run the CHP engines even at times when hydrogen is unavailable. Under these circumstances, there would be an additional functional requirement for the CHP engines – that of fuel flexibility; the ability to switch to natural gas if needed.

8.2.4 Suggested CHP Configuration

The objective here is not to derive a fully cost-optimised CHP solution for the Kitt Green site; rather to identify a sensible and plausible CHP configuration for meeting the above functional requirements. This will then enable focus on the 'hydrogen readiness' of the prime movers that would be suitable for use at Kitt Green.

From the above energy demand data, the following is one plausible concept for a reciprocating-engine based CHP facility (albeit subject to more detailed techno-economic analysis of the options):

- Modular engines to provide an aggregate capacity of approximately 6 MW_e with an aggregate turndown capability to 1.5 MW_e. This could be provided using modular packaged engine-generators in the range 1 to 3 MW_e. Current thinking is that these engine-generators would connect into the Kitt Green electricity system at the main incomer substation at 6.6 kV;
- Heat recovery steam generation from the engine exhausts (all engines) to produce saturated steam at 8.5 Bar(g). Steam from this system would be fed into the main steam header passing out of the existing boiler room. Feedwater to this steam generating system must undergo the same treatment as that currently fed to the existing steam boilers, so as to achieve the same TDS, pH and oxygen content;
- Heat recovery from the cooling system from some of the engines in order to provide up to around 1.5 MW of top up heat for the production of LTHW at 82°C. This heat is to be supplied to the Heat Recovery Room of the Production Building where it will supplement heat recovered from the manufacturing process.

This broad configuration forms the basis for further analysis below.

8.3 OEM Development Status

A number of OEMs are now developing, and planning to bring to market, ‘hydrogen ready’ engines that are able to use 100% hydrogen as a fuel, at the size that might be needed for a CHP project at Kitt Green (i.e. around 1-2 MW_e for each of 3-4 engines). As part of this study, a process of engagement with OEMs was undertaken to discuss their current product offering, and to understand their plans for ongoing development of engines that can run on hydrogen. Engagement was primarily carried out via Microsoft Teams meetings, which gave the opportunity for OEMs to present their hydrogen capabilities, and for discussion of the pathways toward 100% hydrogen-readiness.

The focus of this review is on products for the 50 Hz market (such as in the UK), at the scale required at Kitt Green. A summary of the status of engines offered by the most-advanced OEMs (in this particular respect) is provided below. It should be noted that there are additional players in the market; for example, Wärtsilä is known to be working on developing engines that can run on hydrogen (and, indeed, ammonia), but their focus is on larger engines than would be suitable for use in a Kitt Green CHP.

8.3.1 2G Energy

8.3.1.1 Company Background

2G Energy is based in Germany. It designs, manufactures and supplies CHP systems using reciprocating gas engines between 20 kW_e and 4.5 MW_e. It both manufactures its own engines and it assembles CHP systems using engines from other manufacturers. An example of the latter is a co-operation agreement with Rolls Royce (MTU). [7]

Founded in 1995, the company states that it has over 8,000 customers worldwide, with CHP systems operating in a wide range of applications. It sells engines for operation on a range of different gaseous fuels, including natural gas, biogas, and hydrogen.

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8.3.1.2 Products

2G Energy markets a range of different CHP systems, at different scales of output. It sells CHP systems for operation on a range of different gaseous fuels, including natural gas, biogas, and hydrogen.

Of most relevance to the possible use of CHP at Kitt Green, they include:

The Agenitor range (404, 406, 408 and 412):

- Electrical output of between 75 kW_e and 450 kW_e on natural gas:
- These engine models are probably too small to be considered for the possible CHP scheme at Kitt Green (particularly when considering the likely de-rate for use on hydrogen).

The Aura range (404, 406, 408 and 412):

- Designed with a focus on low-NOx operation on natural gas;
- Electrical output of between 100 kW_e and 420 kW_e on natural gas.[4]

The Avus range:

- Electrical output of between 548 kW_e and 4.5 MW_e on natural gas.

8.3.1.3 Sumary of Hydrogen-readiness

2G Energy has a small number of its 'Agenitor' CHP units that are operating on hydrogen as a fuel in Germany. We understand that the scale of these hydrogen-fired systems has, to date, been limited to around 150 kW_e, but that the company is exploring the bringing to market of CHP systems using larger-scale prime movers.

8.3.2 Innio Jenbacher

8.3.2.1 Company Background

Innio Jenbacher (through Clarke Energy, its distributor in the UK) supplies gas-fired engines and CHP systems up to 10.4 MW_e. It reports to have 23,000 engines in operation around the world.

8.3.2.2 Products

Innio Jenbacher has a wide range of gas engines at different scales, and products for operation on a range of different fuels, including natural gas, biogas, coal-bed methane and 'off-gases' from industrial processes such as steel making. Some of Innio Jenbacher's products have a long history of operation; for example the 'Type 2' engine first came to market in 1976.

Of most relevance to the possible use of CHP at Kitt Green are the following models:

Type 2 – J208 model:
Electrical output of 330 kW_e on natural gas.

Type 3 – the J312, J316 and J320 models:
Electrical output of between approximately 400 kW_e and 1.2 MW_e on natural gas.

Type 4 – the J412, J416 and J420 models:
Electrical output of between approximately 750 kW_e and 1.6 MW_e on natural gas.

Type 6 – the J612, J616, J620 and J624 models:
Electrical output of between approximately 1.6 MW_e and 4.5 MW_e on natural gas.

8.3.2.3 Hydrogen-readiness

Jenbacher has developed its 'Type 4' product range to be 'Ready for H_2' and able to operate on 100% hydrogen or on a blend of natural gas and hydrogen, at a scale of up to 1 MW_e (derated compared with its natural gas equivalent). From the beginning of 2022, Jenbacher has been marketing these 'hydrogen-ready' engines to its customers.

In 2020, Jenbacher demonstrated the operation of one of its J416 megawatt-scale engines natural gas engines on 100% hydrogen (with a derating from 1 MW_e to approximately 600 kW_e), with a claim that the engine will still be able to operate on natural gas or on a blend of natural gas and hydrogen.

8.3.3 MAN

8.3.3.1 Company Background

There are two different companies that operate with the trading name MAN. Both are ultimately owned by the Volkswagen group, but they are distinct and separate, as follows:

MAN Energy Solutions:
A long-established manufacturer of large reciprocating engines, gas turbines, steam turbines, compressors and other process equipment for use in a wide range of industrial sectors and for large marine propulsion.

MAN Engines:
A business unit of MAN Truck and Bus SE, itself a subsidiary of Traton SE, a subsidiary of the Volkswagen group. Its engines are used for – amongst other things –road freight vehicles, buses, and small marine applications.

8.3.3.2 Products

The reciprocating engine products of these two MAN businesses are quite different.

Whilst the gas-fired reciprocating engines produced by MAN Energy Solutions are used in power generation and in CHP applications, its smallest engine has an electrical output of approximately 7 MW_e when in CHP mode on natural gas (the 12 valve V35/44G engine model). This means that the product range on MAN Energy Solutions is unlikely to be suitable for use in the proposed CHP scheme at Kitt Green (albeit, a single V35/44G operating on hydrogen might be a possibility, particularly when considering the de-rating that is likely when operation on hydrogen).

The gas-fired reciprocating engines produced by MAN Engines are designed mainly for use in road vehicles and in small marine applications, but they are also used for small power generation applications and in CHP schemes. The engine range, when operating on natural gas, provides a power output of between about 40 kW_e (the MAN E0834 model) up to about 740 kW_e (the MAN E3872). Consequently, these may be too small for the possible Kitt Green CHP scheme.

8.3.3.3 Hydrogen-readiness

MAN Energy Solutions is working on hydrogen-readiness. It states that its 35/44G, 51/60G and 51/60G TS models are able to operate on a blended fuel with 25% (by volume) hydrogen now, and that it has plans to bring a 100% hydrogen engine to market in 2025. However, as stated above, its models are probably too large for the possible CHP scheme at Kitt Green.

MAN Engines is also considering hydrogen-readiness of its products. It has stated that its E3262 E302 and E3262 LE202 models can already accommodate a blend of 20% (by volume) hydrogen. And it reports the intention to develop its larger E3872 model to also operate on a blend. During the course of this study, however, we were not able to determine whether any plans exist to offer the MWM product range for operation on 100% hydrogen.

8.3.4 MTU

8.3.4.1 Company Background

MTU, owned by Rolls Royce, manufactures and supplies gas-fired engines and power generation units, as well as drive trains for marine and rail propulsion systems, and mechanical drive systems in mining and other industries.

As mentioned in Section 8.3.1.1 above, MTU has a relationship with 2G in terms of sharing prime movers for CHP applications; MTU also works with other CHP system packagers

8.3.4.2 Products

MTU makes a range of reciprocating engines for a range of applications including power generation and CHP. It has engines for operation on both gaseous fuels (such as natural gas and biogas) and liquid fuels (such as diesel).

Of most relevance to the possible use of CHP at Kitt Green, they include:

The 500 series of engines – models 6V, 8V and 12V:
Electrical output of between 250 kW_e and 550 kW_e on natural gas.

The 4000 series of engines – models 8V, 12V, 16V and 20V:
Electrical output of between approximately 1 MW_e and 2.5 MW_e on natural gas.

8.3.4.3 Hydrogen-readiness

MTU has announced plans to make available engines from its 500 series and its 4000 series to run 100% on hydrogen from the end of 2023. The latter series are rated up to 2.5 MW_e on natural gas (the rating when running on hydrogen is unknown, but a derating to perhaps 70% is possible).

8.3.5 MWM

8.3.5.1 Company Background

MWM has a 150-year heritage in the design and manufacture of reciprocating engines. Over its history, it has been through some changes of ownership (including Deutz in 1999) and is now part of Caterpillar Inc. Its products are distributed in the UK through Edina UK Ltd.

8.3.5.2 Products

The company manufactures and supplies gas-fired engines and power generation units of up to 4.5 MW_e, CHP systems based on these engines, and containerised CHP systems (a full CHP system housed in a container) based on some of them.

Of most relevance to the possible use of CHP at Kitt Green, they include:

TCG3016, in V8, V12, or V16 models: Electrical output of between approximately 400 kW_e and 1 MW_e.

TCG3020, in V12, V16 and V20 models: Electrical output of between approximately 1.4 MW_e and 2.3 MW_e on natural gas.

TCG2020, in V12, V16 and V20 models: Electrical output of between approximately 1.0 MW_e and 2.0 MW_e on natural gas.

TCG2032, in V12 and V16 models: Electrical output of between approximately 3.0 MW_e and 4.5 MW_e on natural gas.

Containerised CHP systems are available based on the TCG3016, TCG3020 and TCG2020 engine ranges.

8.3.5.3 Hydrogen-readiness

From the end of 2022, MWM plans to offer engines from (and retrofit kits for) their TCG3016, TCG3020 and TCG 2032 ranges to enable operation on blends of up to 25% hydrogen. During the course of this study, however, we were not able to determine whether any plans exist to offer the MWM product range for operation on 100% hydrogen.

8.3.6 Summary of OEM Engine Hydrogen-Readiness

The plans for bringing 'hydrogen-ready' engines to market are – to some extent – influenced by the way in which demand is developing. Only when hydrogen becomes a widespread fuel for us in such engines will the engine suppliers push hard with making their products available to satisfy that demand. Such companies are unlikely to push hard with the development of such technologies well ahead of there being a clear market for those technologies.

However, as illustrated above, a number of engine OEMs have already launched hydrogen-ready engines, or are planning to do so soon. It is expected that more will follow over the next few years.

As described in Section 8.1, engines that operate on hydrogen need to consider a range of issues, including:

- Risk of 'knocking';
- Calorific value and impact on fuel system design;
- Engine cooling;
- Cylinder head and piston design;
- Engine control system, including air-to-fuel ratio control;
- Fuel injection;
- Materials selection;
- Crack-case ventilation; and
- NOx control.

Some engineering solutions to these issues may simply be to make some changes to the engine management system. But, in order to optimise operation and performance on hydrogen, there may be a need to make fundamental changes to the physical design of an engine designed to run on natural gas (for example, with the use of direct in-cylinder injection of hydrogen, or through changes to the shape of a piston crown to deal with the different combustion characteristics of hydrogen). Such more significant changes in the design of a hydrogen-ready engine (when compared with an engine designed to run on natural gas) may limit the fuel-flexibility of such a hydrogen-ready engine.

However, some of the OEMs appear to be aiming to bring to market engines that do have some level of fuel-flexibility. As noted in Section 8.2.3, one of the functional requirements for a CHP scheme at Kitt Green (and, indeed, other possible energy consumers that are considering a hydrogen-fired CHP system) may be to have some element of fuel flexibility, to manage the risk of shortfall of hydrogen from time to time. The ability of engines to provide that functionality will need to be considered further at the time of undertaking any more detailed engineering design and definition on any specific project, informed by the level of confidence there can be in the reliability of hydrogen supply.

8.4 Opportunities for Heat Integration

There are multiple ways that waste heat from reciprocating engines could be incorporated into the site heat provision at Kitt Green. Some examples include:

- Generation of steam from the exhaust gases for introduction into the site steam delivery network;
- Use of the jacket cooling to provide heat for:
  - Reheating of exhaust from the Condensing Economiser;
  - The heating of the water within the Vacuum Pressurised Deaerator, which holds water within a range of 65-70°C;
  - The preheating of the soft water prior to the introduction to the Reverse Osmosis plant.
- Use of the oil cooler jacket cooling to provide input to the preheating of the soft water prior to the introduction to the Reverse Osmosis plant.

These issues require further analysis in the context of the analysis of the existing boiler plant at Kitt Green in Section 9.0.

9 Kraft-Heinz: Technical Feasibility of Hydrogen Use in Boilers

This section of the report describes the impact of using hydrogen in the various different parts of the boiler/steam-raising system at Kraft-Heinz's Kitt Green site.

9.1 Boiler

Danstoker has confirmed that the use of hydrogen as the primary fuel in the current boiler design is compatible with the existing boiler shell, although the complete burner package would need to be replaced (see Section 9.2.2 below) to allow for a new internal recirculation design. This is consistent with PEL's recent experience at Unilever's Port Sunlight facility (as part of the HyNet IFS1 Programme), where a Danstoker boiler that had been designed for natural gas was fired with hydrogen over a period of several weeks.

It is anticipated the current boiler output of 35tph would need to be derated to around 32tph to achieve NOx emissions below the MCPD limit of 200mg/m^3 when operating on hydrogen. Due to the reduction in site steam demand since the installation of the boiler system, this is understood to be acceptable to Kraft-Heinz.

The boiler has a front refractory plug to protect the radial weld between the furnace and the boiler front tube plate, and this will need to be replaced regardless of the chosen future burner due to the design change of the combustion process. The replacement of this refractory is not unusual during the lifetime of a boiler.

9.2 Burner System

9.2.1 Operation on Hydrogen-Natural Gas Blend

The current burner would operate using a blended gas with a small derating of the combustion process due to the lower calorific content of the fuel gas. Some reduction in the modulation rate may also be required to achieve stable flame and deliver low NOx emissions.

The current burner does not have a low-NOx design, and so it is anticipated that Flue Gas Recirculation (FGR) will be required along with a small reduction in the thermal capacity of the boiler to achieve the current emission permit limits of 100mg/m^3 (consistent with the existing MCPD limit for natural gas, which is not expected to change for the blended gas). Equipment for FGR is already installed at Kitt Green.

9.2.2 Operation on 100% Hydrogen

On a complete change of the primary fuel to 100% hydrogen, there will need to be a wholesale change to the burner and its controls, and use of the FGR installed in the current package design. This is consistent with the approach taken at Unilever's Port Sunlight as part of the HyNet IFS1 Demonstration. The NOx emissions limit for 100% hydrogen is expected to be 200mg/m^3. A new burner would, in principle, be capable of being installed to the current furnace interface plate with limited modification to the boiler.

9.3 Impact on Electrical Controls and Instrumentation

DSEAR and risk assessments are required to determine the extent of any ATEX zones created by use of blended or 100% hydrogen.

For operation on a blended gas, the existing control system is suitable. It is expected that the current 2m distance between the control panels and any hydrogen pipework is sufficient for gas dilution such that the panels will sit outside any ATEX zone, however this is subject to the assessment above.

For 100% hydrogen operation, a new burner and associated control panel will be installed. As per blended gas operation, it is not expected that this panel will need to be ATEX-rated, but again, this is subject to the DSEAR and risk assessments.

9.4 Fuel Distribution

The natural gas distribution into the plantroom is at >150mbar gas pressure and via a single large steel header pipework to the rear of the plantroom. Each boiler is then individually supplied with a single section of steel pipework with its own isolation and meter capability feeding the two burners, each with their own isolation valve for service and maintenance.

This is an out-dated design and does not adhere to modern IGEM standards for testing and purging. Upgrades to the system would need be considered in its current installation if significant changes are made to the boiler system.

For the pipework to be repurposed for hydrogen, it would be anticipated (depending upon pressure supplied within the pipework) that all aspects of valves, gaskets and testing and purging will require upgrading, minimising ATEX zones created.

9.5 Combustion Air System

The introduction of hydrogen to the combustion process reduces the volume of air required for combustion. The current burner design incorporates suitable control for air movement and fan speed such that the combustion air system is suitable for a 20% hydrogen blend can be used without issue. However, the combustion head design has no internal air recirculation, and this will lead to increased NOx generation, even on the blended gas, which would require FGR to bring NOx emissions within the current permit limits. Importantly, each of the eight identical burner designs already includes FGR and so the associated costs would be low.

A change to 100% hydrogen would not be possible with the current burner design due to the overall burner and gas control design and therefore a completely new combustion air system would be needed. The design and location of the new forced draft burner fan would need to be considered given the likely changes to ATEX zones.

9.6 Exhaust Gas Extraction and Condensing Economiser

All aspects of the exhaust gas extraction system is manufactured using mild steel duct, mostly >1000mm diameter and completely insulated and clad for protection. The boiler has a twin outlet section to single distribution that eventually all link together to a single duct though the economiser to the chimney as a single output. A schematic of the system is presented in Figure 9 1.

Given that the boiler does not use condensate return, the condensing economiser is key to the efficiency of the whole plant as this unit increases the operational efficiency of the plant by an estimated 8-9% on a gross basis.

The condensing economiser has been upgraded with suitable controls and tubes to enable the use of hydrogen as the primary 100% fuel and it is currently believed that the change to hydrogen shall have minimal effects on the economiser operation. It is estimated that the higher dewpoint (from 60°C to 73°C) will have a limited effect on the overall operational efficiency (estimated at around 0.3% on a gross basis).

The control of the condensing economiser must be modelled to ensure the heat exchangers are able to maintain the operating conditions as designed, even with the higher flue gas water content, leaving sufficient energy in the flue gases such that they do not reach their dewpoint, which would cause pluming, corrosion and damage to the ID fan assembly. Modelling should therefore be undertaken to assess extract and input of energy and resulting buoyancy / efflux velocity with the exhaust package. This modelling is necessary for both the blended gas and 100% hydrogen cases.

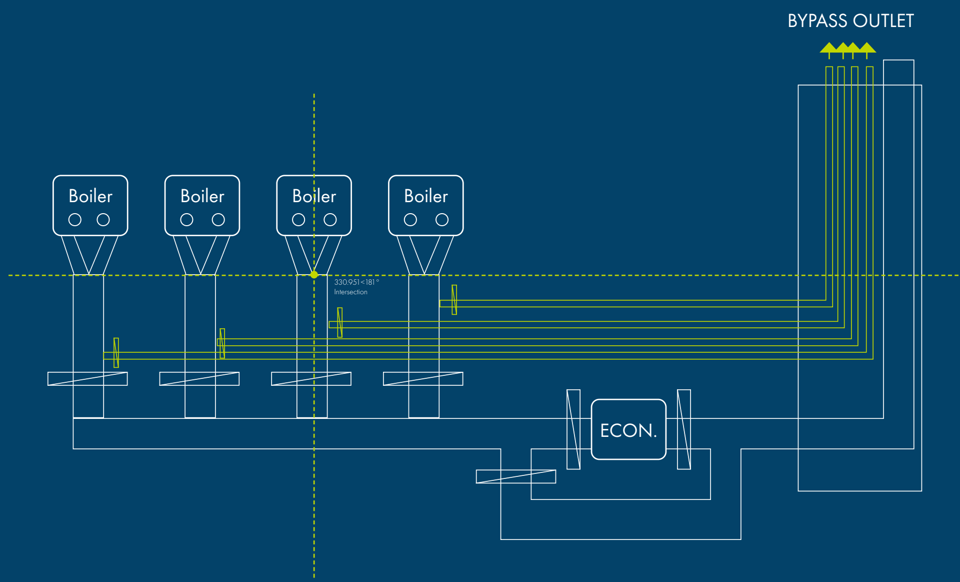


Figure 9 1: Schematic of Exhaust Gas Extraction System

9.7 Safety and Gas Detection/Zoning

The gas flow controls (including the use of flame arrestors in the gas pipework) to each boiler, flame detection, air flow requirements, boiler house risk assessment, and ATEX assessment will all need to be reviewed and / or upgraded under the current fuel change options.

The use of hydrogen will result in new ATEX zone(s). These locations and areas are yet to be defined, although will be predominantly to the front of the boiler shell. Zones associated with the gas distribution pipework will primarily arise from leak points such as flanges, and gas detection may be required.

There are no current IGEM regulations to automatically define ATEX or other gas detection and protection and within this site there are limited supplementary protection devices. Although not defined in any standards it would be anticipated that there shall need to be future considerations for:

- Free air ventilation requirements;
- Gas detection; and
- Thermal detection.

The site should plan to review a DSEAR and their own Risk Assessment to decide upon the changes for considerations such as gas leak detection if / when the blended or 100% hydrogen gas is supplied as part of the UK gas infrastructure. This should be based upon the IGEM regulations for hydrogen and other pipework distribution and control standards.

It is anticipated that any required changes for ATEX and gas distribution pipework can be incorporated into the existing overall package space.

9.8 Maintenance Considerations

The boilers are reviewed annually under the PSSR regulations and the reports of the shell condition to this date are very good with high quality water and no corrosion. The current burner packages are tested and reset to optimum emissions to operation twice per year on both fuels. The change to hydrogen is not expected to change the site’s current two burner service visits per annum regardless of the burner fuel options chosen.

10

Kraft-Heinz:
Costs of Switching to Hydrogen

In performing the Feasibility Study, understanding has been built in respect of the works and costs associated with instituting hydrogen-fired CHP at Kraft-Heinz as soon as low-carbon hydrogen is available from the HyNet project.

Cost Basket	Cost (£M)
Boiler	1.3
Reciprocating engines	6.2
Pipework & Ancillaries	0.4
Hydrogen Reception	0.7
Total	8.6

Table 10 1: High-level costs of whole-site conversion

Four main categories of costs are considered:

1. Boiler conversion:
   This relates to modification/replacement of existing boilers, and includes design and installation.
2. Reciprocating engines:
   This relates to design, purchase and installation of 6 MW_e of hydrogen-fired reciprocating engines for electricity generation.
3. Pipework and ancillaries:
   This relates to distribution of hydrogen to the boilers and engines within the site boundary, and includes engineering and installation costs. It also includes upgrades to ancillary systems such as gas detection, and upgrades to ATEX-rated equipment where required.
4. Hydrogen 'reception':
   This includes the primary meter set and pressure reduction to design pressure.

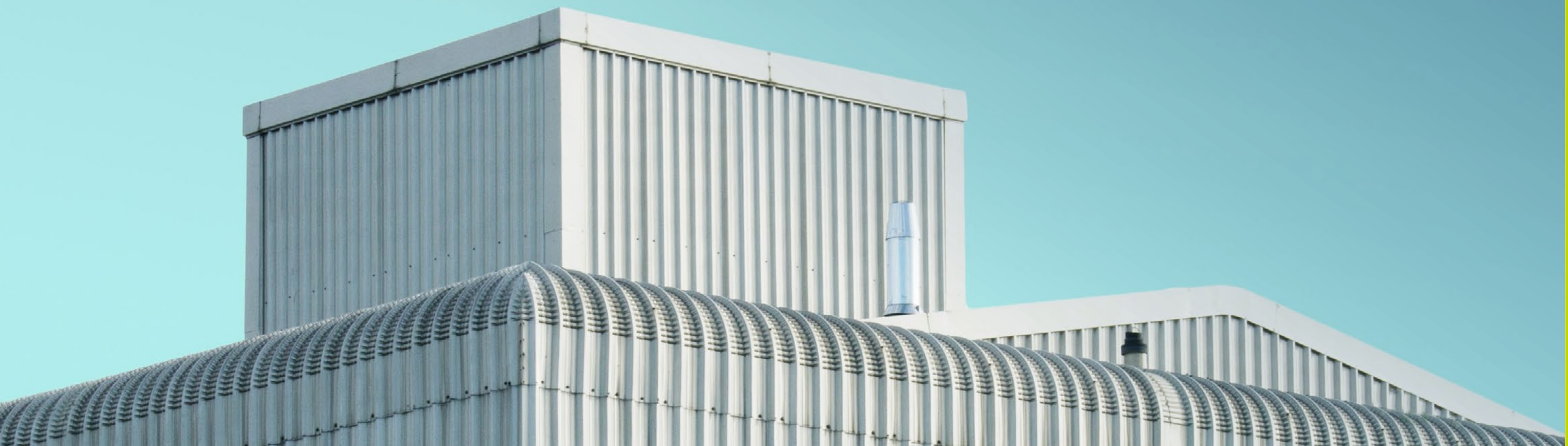
Costs associated with pipeline connection to the HyNet hydrogen distribution network are excluded, as it is likely that these costs will be recovered via network charges, and will therefore be an ongoing operational cost (subject to confirmation of final regulatory model for hydrogen distribution).

The information presented in Table 10 1 is indicative only and but provides a preliminary view on the overall costs of instituting hydrogen-fired CHP at Kraft Heinz.

11

Extrapolating Findings

The analysis presented below relates to aluminium furnaces and engines only, as the previous work at Unilever lead by PEL has considered the wider applicability of hydrogen use in boilers.



11.1 Dependencies

A fundamental point of note here is that, whilst the evidence base needs to be expanded and site-specific demonstrations need to be undertaken, hydrogen combustion is not a fundamentally new technology in many industrial applications. Successful deployment will come via demonstration and thus gaining 'user acceptance', but also by bringing in the right skills and 'know-how' from the existing supply chain to deliver incremental change. The proposed Phase 2 programmes of work presented above draw upon this existing supply chain, particularly in the North West, which provides confidence that deployment will take place as described.

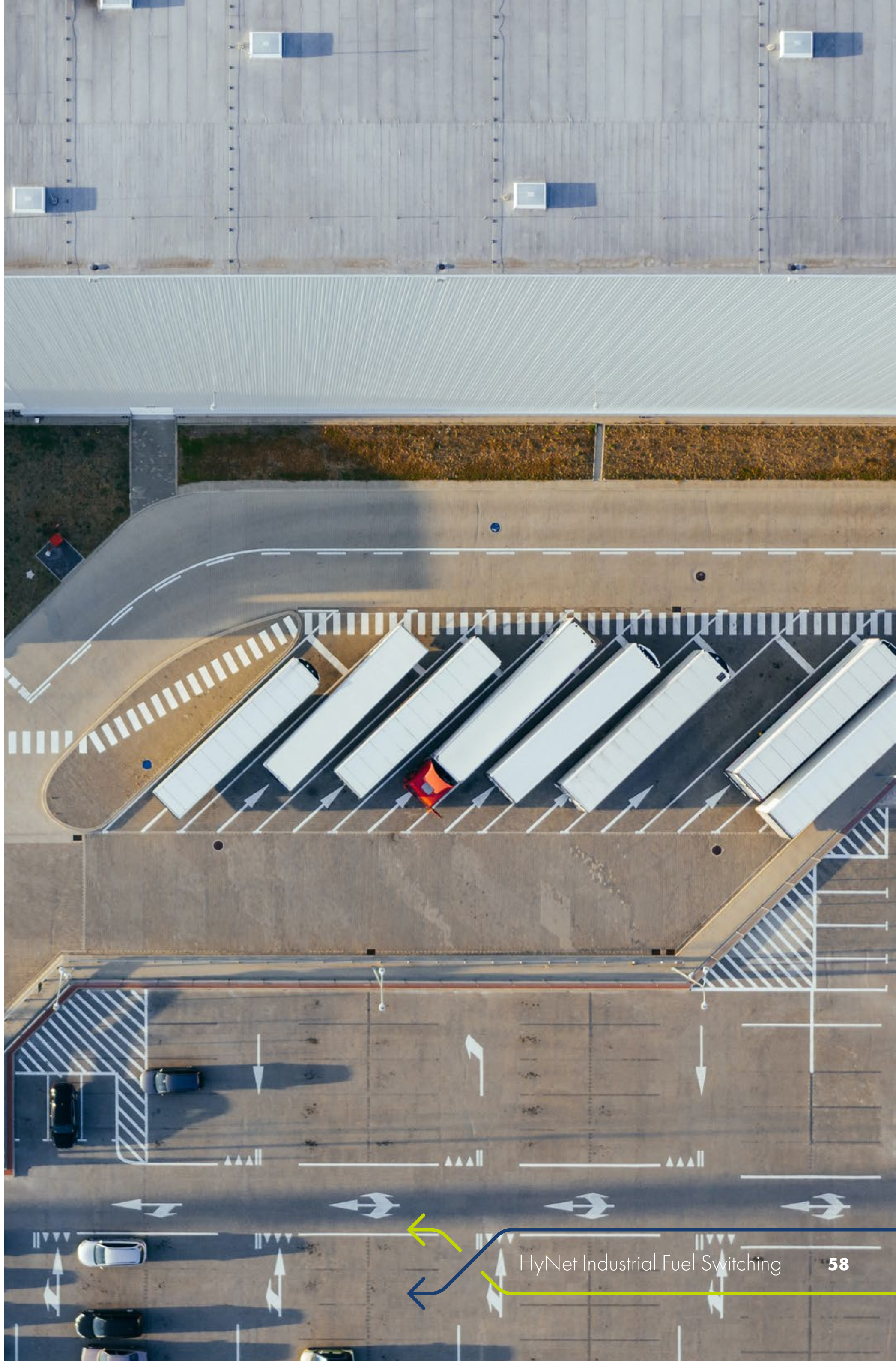
As mentioned above, the full conversion of the Novelis and Kraft-Heinz sites to hydrogen and subsequent deployment of the solutions at wider, similar sites largely depends upon the deployment of the wider HyNet hydrogen and carbon capture and storage (CCS) infrastructure. Ultimately, all elements of this infrastructure are proven at large scale, either in the same or related applications. For example, CCUS projects are commercially operating in the US and both hydrogen and CO_2 pipelines are established technologies with references operating worldwide. The proposed hydrogen production technology described in Section 12.1 has not been deployed at scale for hydrogen production, but the underpinning chemical processes have been deployed in refining and methanol production, giving confidence in the proposed solution, which has been further strengthened by the completed, BEIS-funded FEED study.

Ultimately, therefore, successful deployment of the solutions proposed for the two sites depends not upon other technical innovations, but upon getting all elements of the HyNet project to be 'investment ready' within the same timeframe. To assist this process, BEIS has played a key role in moving forward innovation and development within the sector via provision of grant funding for both fuel switching and hydrogen production. However, it is now both regulatory innovation and confirmation of suitable long-term support mechanisms (both for hydrogen production and for hydrogen transport and storage) that are required to deliver an investment-ready project.

11.2 Build-rate and Scaling-up

The intention of the Feasibility Study is to provide the basis for Phase 2 demonstrations (or 'innovative' FEED studies). During Phase 2, the programme of work will provide all required evidence to enable Novelis to switch to hydrogen as soon as it is available from HyNet (no Phase 2 programme is required at Kraft-Heinz). Therefore, effectively, the solution will be scaled up sufficiently by the end of Phase 2 to enable deployment.

The extent to which the solution is then 'built-out' will depend largely upon the business models, which are currently under development by Government. Assuming a 'contract for difference' (CfD) model is used, the magnitude of the budget available to support hydrogen production (and indirectly, use) will drive the speed of deployment. Similarly, assuming appropriate knowledge dissemination, hydrogen business models in other countries will determine their build-out rate.



11.3 Applicability and Replicability

11.3.1 Novelis

Based on the above levels of current direct emissions, if deployed at from Latchford Locks Works the solution could abate around 46,000 tCO_2/annum, which represents the majority of emissions from the site.

The process operated at Latchford Locks Works is based on melting of recovered aluminium. This process only uses less than 10% of the energy used to produce the metal using raw materials such as bauxite.

Novelis (or its parent company Aditya Birla) operates similar furnaces to those in Warrington around the world. Novelis and Aditya Birla operate both primary and secondary production sites, and given group emissions are expressed as a whole, it is challenging to determine the potential for total emissions reduction across the business. Given the learning from the Feasibility Study will be shared across the business, however, the potential for CO_2 abatement is significant.

It is also important to note that information will be shared outside Novelis, consistent with the HyNet IFS2 Knowledge Dissemination Plan. This approach will deliver huge impacts in terms of decarbonising the aluminium sector on a global basis.

11.3.2 Kraft Heinz

The Kitt Green site has direct emissions of around 36,000 tCO_2/annum, and additional indirect emissions associated with imported electricity of around 6,000 tCO_2/annum. Deployment of hydrogen-fired gas engines represents an opportunity to materially decarbonise the site, particularly if waste heat is leveraged to reduce the energy demand of the boilers. Should the boilers also be converted to hydrogen, then the site would be decarbonised entirely.

The need for low carbon heat and power at Kraft-Heinz's Wigan site is similar across its global network of manufacturing plant. Determining the extent to which the Wigan site can switch to low carbon hydrogen use in gas engines and boilers therefore supports decarbonisation of a broad swathe of the company's manufacturing.

Again, information will be shared outside Kraft-Heinz's, consistent with the HyNet IFS2 Knowledge Dissemination Plan. This approach will deliver huge impacts in terms of decarbonising the food and drink sector on a global basis.

In the UK specifically, a study undertaken on behalf of BEIS under the Hy4Heat programme estimates that the total natural gas consumption using CHP by the UK food and drink sector is around 8 TWh/annum.[8] Using an emissions factor of 0.2 tCO_2/MWh, this equates to around 1.6 $MtCO_2$/annum. However, the BEIS study does not split CHP between gas engines and gas turbines and so a conservative estimate of the emissions which might be abated as a result of the proposed demonstration programme, is around 50% of this total at 0.8 $MtCO_2$/annum.

8 BEIS (2019) H4Heat WP6: Conversion of Industrial Heating Equipment to Hydrogen, November 2019 https://www.hy4heat.info/wp6

12 HyNet Infrastructure Development

As described in Section 1.2, deployment of the technical solution is unlikely to happen without build-out of the HyNet hydrogen production and distribution infrastructure, and consequently further information on these core elements of HyNet is provided below.

12.1 HyNet Hydrogen Production

During the last three years, parallel work has been taking place in respect of the development of a hydrogen production Hub at Stanlow Manufacturing Complex, now led by Vertex Hydrogen. The Novelis and Kraft-Heinz sites, along with all other sites associated with the first three phases of HyNet deployment, will be supplied primarily by the Vertex Hub.

The strategic location of the Hub at Stanlow enables production to be fuelled by both refinery off-gas (ROG) and to supply wider onsite operations, including the CHP plant, to decarbonise the refinery. The location of the Hub within the wider complex is presented in Figure 12 1.

Work funded by BEIS under the Hydrogen Supply Competition included a full FEED study, which was followed by an application for planning consent for the first 1GW of production capacity. The FEED study has been completed and Vertex is currently awaiting the determination of the application for planning consent.

PEL and Essar, as joint venture partners in Vertex, recently published a report on the BEIS-funded FEED study.[9] This presents engineering information relating to the Hub, which will use UK company, Johnson Matthey's Low Carbon Hydrogen (LCH™) production technology.

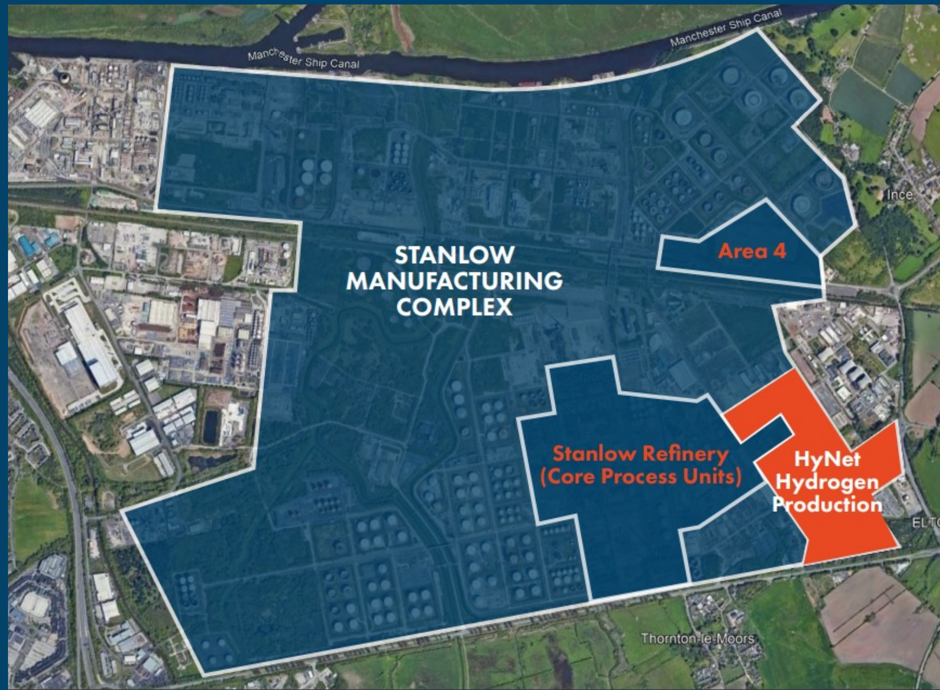


Figure 12 1: Deployment Profile for HyNet Hydrogen Production

9 HyNe North Wes (2022) HyNe Low Carbon Hydrogen P an BEIS Hydrogen Supp y Compe it on November 2021 h ps //asse s pub sh ng.serv ce.gov.uk/governmen /up oads/system/up oads/a achmen da a/fi e/1056041/Phase 2 Repor Progress ve Energy HyNe Low Carbon Hydrogen 3 pdf

As part of the North West Cluster Plan, regional modelling was undertaken, which estimated a total demand for low carbon hydrogen of 30 TWh/annum by 2030, to put the region on the trajectory to achieve Net Zero by 2050.[10] The ambition of HyNet is to switch around 45% of the region's natural gas consumption to low carbon hydrogen by 2030.

To meet the forecasted growth in demand for hydrogen in the region, the Vertex Hub is to be developed and constructed in phases. The planned design throughput of each phase is shown in Table 12 1.

Phase	Hydrogen (kNm^3/h)	Hydrogen (MW_{th} - HHV)	Hydrogen (TWh/annum)	Cumulative (TWh/annum)
1	100	350	3	3
2	200	700	6	9
3	400	1400	12	21
4	400	1400	12	33

Table 12 1: Deployment Profile for HyNet Hydrogen Production

10 Net Zero North West, North West Cluster Plan Interim Findings, April 2022 https://netzeronw.co.uk/wp-content/uploads/2022/04/NZNW-Cluster-Plan-Interim-Findings-April-2022.pdf

12.2 Hydrogen Business Model

As mentioned above, the Vertex Hub has been shortlisted under Phase 2 of the Government's Cluster Sequencing process.[11] At the time of writing, the project is currently in BEIS's due diligence phase and hopes to proceed into the commercial negotiation process associated with Hydrogen Business Model (HBM) support. The HBM will cover the difference between the cost of producing hydrogen and the cost of natural gas, so that Vertex can sell hydrogen to customers at a similar price to that of natural gas.

The HBM is essentially a contract for difference (CfD) similar to that which has been in place to support renewable electricity generation since 2014. The latter is a long-term contract between an electricity generator and a Government Counterparty, for example, the Low Carbon Contracts Company (LCCC). The contract enables the generator to stabilise its revenues at a pre-agreed level (the 'Strike Price') for the duration of the contract. Under the CfD, payments can flow from the Government Counterparty to the generator, and vice versa. In simple terms, when the market price for electricity generated by a CfD Generator (the Reference Price) is below the Strike Price set out in the contract, payments are made by the Government Counterparty to the CfD Generator to make up the difference.

However, when the reference price is above the Strike Price, the CfD Generator pays LCCC the difference. The HBM is likely to function broadly in this manner, albeit there are a number of nuances described in the related 'Indicative' Heads of Terms for the associated contract.[12]

As part of the FEED study for the Hub, a detailed financial model was produced based on the inputs developed through the programme. The output from that assessment showed a Levelised Cost of Hydrogen (LCoH) that is broadly consistent with the range of hydrogen costs developed by BEIS in the Government's Hydrogen Strategy.[13]

Alongside the core hydrogen production from the Vertex Hub, PEL intends to deploy green hydrogen production to supply industry in the area. The first meaningful support for such projects will come via BEIS's 'joint allocation' round for the Net Zero Fund and HBM, which will commence later in 2022, with contracts to be signed by late 2023.[14] These projects will be an order of magnitude smaller than the Vertex plant, but green hydrogen production is expected to ramp up further in the 2030s.

11 https://www.gov.uk/government/publications/cluster-sequencing-phase-2-eligible-projects-power-ccus-hydrogen-and-icc/cluster-sequencing-phase-2-shortlisted-projects-power-ccus-hydrogen-and-icc-august-2022

12 BEIS (2022) Agreement for The Low Carbon Hydrogen Business Model: Indicative Heads Of Terms, April 2022 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067365/indicative-heads-of-terms-for-the-low-carbon-hydrogen-business-model.pdf

13 HM Government, UK Hydrogen Strategy, August 2021 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

14 BEIS (2022) Hydrogen Business Model and Net Zero Hydrogen Fund: Market Engagement on Electrolytic Allocation, April 2022 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067159/hydrogen-business-model-net-zero-hydrogen-fund-market-engagement-electrolytic-allocation.pdf

12.2 HyNet Hydrogen Distribution

The route of the HyNet hydrogen pipeline network will be determined to a large extent by a number of core 'demand' anchors. Largely these anchors are major industrial and power generation sites. However, they also include a small number of 'offtakes' for blending hydrogen into the gas distribution network. These are the locations on the gas network where natural gas is currently injected from the National Transmission System (NTS) into Cadent's local transmission system (LTS). These represent the points at which a blend of hydrogen will initially be injected into the network at up to 20% by volume, as is being demonstrated by the HyDeploy programme.[15] These offtakes also provide the initial locations (along with further locations required to ensure full network coverage) for injection should full conversion of the existing network to 100% hydrogen be undertaken in the future.

At the same time, the network routing must take into consideration the need to connect other suppliers of hydrogen. At the present time, aside from the connection agreement to be negotiated with Vertex, HyNet consortium partner Cadent has only received a limited number of approaches from small producers of green (or 'electrolytic') hydrogen. In the 2030s, connections for green hydrogen production are likely to be larger in scale and so become more of a factor in shaping pipeline development during later phases of deployment.

The HyNet network is being built in phases, but the early 'feeder' lines need to be designed to be sufficiently large to carry enough hydrogen to meet the demand that will connect in later phases of deployment.

15 www hydep oy.co uk
16 h ps //www hyne hydrogenpipeline co uk/

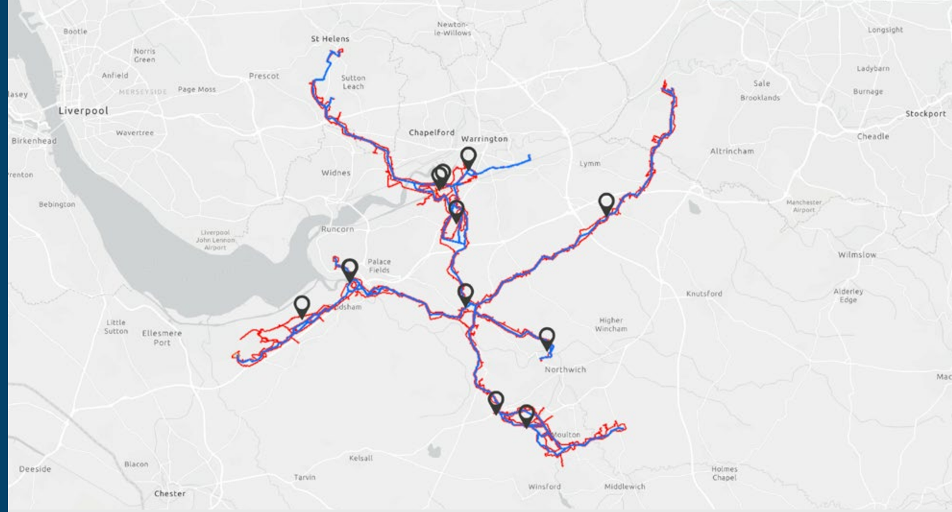


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Figure 12 3: Proposed HyNet Hydrogen Network Routing Corridors

Cadent, is currently engaged in a Development Consent Order (DCO) process to consent the first 125km of hydrogen network.[16] The DCO process is such that Cadent has been required to consult on options prior to selecting a preferred route. At the time of writing, the routes from the statutory DCO consultation are as shown in Figure 12 3.

Ahead of submission of the DCO application, an initial phase of network deployment is planned in 2025, which will connect major hydrogen users (and producers) in close proximity to the Hub at Stanlow – this small network will not require a DCO. There will also be a subsequent DCO process, for a further 350km of pipeline, to connect sites in Liverpool, South Lancashire, North Wales and further into Manchester by 2030. It is likely that this DCO will commence prior to the end of the current DCO process.

12.4 Funding of Hydrogen Distribution Networks

The required changes must include both new pipelines and re-licensing of existing assets, and interactions with end consumers. System operation of the combined hydrogen and gas system will require potentially far-reaching changes. Hence there is a strong case for the existing gas distribution businesses to lead the roll out of hydrogen distribution infrastructure. Given that the aim is widespread change of all regional networks and the reduction of CO_2 emissions represents a universal benefit, there is a clear case for funding being sourced from all gas consumers, not just those in which hydrogen distribution infrastructure is first created.

As described below, Government is relatively advanced in terms of determining business models to support hydrogen production, but is in the very early stages of considering how best to fund distribution and storage. In the HBM consultation, BEIS states that large-scale networks will not be funded under the HBM, but that it has commissioned consultants to undertake research to help it better understand distribution infrastructure requirements. It has also launched a consultation on proposals and announced that a related new working group is to be set up as part of the Hydrogen Advisory Council.[17]

Networks are critical to enabling a range of end-uses of hydrogen, including the manufacturing sector, and to reducing the costs of production and distribution. Business model development to support hydrogen distribution must therefore be accelerated as a critical, strategic priority.

17 BEIS (2022) Hydrogen transport and storage infrastructure: A consultation on business model designs, regulatory arrangements, strategic planning and the role of blending. August 2022 https://www.gov.uk/government/consultations/proposals-for-hydrogen-transport-and-storage-business-models

13 Key messages

The key messages in respect of the work undertaken in relation to Novelis's Latchford Locks Works site can be summarised as follows:

- At the time of writing, it appears very likely that a bid will be made by Novelis (and PEL) to BEIS's Phase 2 of the IFS Competition for funding of a demonstration to be designed and operated during 2023 and 2024. The demonstration would require:
  - Installation of new burners and regenerators capable of operation on the proposed fuel gases, with the gases blended upstream of the burner and control by a new control panel; and
  - Installation of a refractory suitable for hydrogen.
- There are a range of furnaces across the site, but the focus of the design of Phase 2 demonstration project is upon 'GPP Melter 3', which has regenerative burners of 4 MW_{th} scale and is fully representative of the larger furnaces on site.
- The demonstration would consider impacts upon product quality, furnace efficiency, equipment lifetime, burner readiness, controls and NOx emissions.
- The demonstration will be designed in such a way that the evidence which comes from the work will be relevant to the majority of other furnaces at Latchford Locks Works and those at other locations in the UK and overseas.
- In the early years of operation of the HyNet network, it is likely that supply interruptions will occur and so it will be valuable for Novelis to maintain the ability to use natural gas and hydrogen interchangeably. The demonstration project, therefore, will be designed to include running a furnace on hydrogen, natural gas or a blend of both gases.

The key messages in respect of switching the Kraft-Heinz boilers to hydrogen can be summarised as follows:

- The preliminary conclusion based on the feasibility study is that the boilers in place at Kitt Green are suitable for switching to 100% hydrogen. However, this is conditional on detailed modelling of the condensing economiser to assess the impact of a flue gas with a higher moisture content;
- The primary modifications required to operate on hydrogen is replacement of the existing burners, and the use of FGR to mitigate expected rises in NOx generation. For operation on a 20% blend of hydrogen, the existing burners could be retained; and
- The switch to hydrogen would necessitate wider assessment of operations within the boiler house, including consideration of fuel distribution and DSEAR assessment.

The key messages in respect of installing a hydrogen-fired gas engine at Kraft-Heinz's Kitt Green Site can be summarised as follows:

- Bulk pipeline hydrogen will not be available at the Kitt Green site until around 2030, so it is too early (now, in 2022) to start the process of engineering definition and procurement of a CHP scheme.
- It is clear, however, that a number of the major engine and CHP system suppliers that would be a suitable basis for a CHP scheme at Kitt Green have been developing hydrogen-ready products, and some of them have already (or will very soon) be offering such products to market (companies such as 2G, Innio Jennbacher and MTU).
- By the time a procurement process does need to begin for a CHP scheme (perhaps in 2027 or 2028), the sector will have matured further, with newer products being on the market and possibly a wider range of OEMs competing in what is likely to be a burgeoning hydrogen-CHP industry.
- Furthermore, the commercial operating track record of engines running on hydrogen will have grown, providing greater confidence to all of the stakeholders involved in this sector: the OEMs, the CHP system packagers, the energy consumers, and the operating companies that may actually build and operate such schemes under contract.
- This maturing of both technology and the commercial environment in which equipment is bought and operated means that the timing for implementation of such a CHP scheme at Kitt Green – in 2030 or thereabouts – is likely to be favourable.

A fundamental point of note associated with this work is that, whilst the evidence base needs to be expanded and site-specific demonstrations need to be undertaken, hydrogen combustion is not a fundamentally new technology in many industrial applications. Successful deployment will come via demonstration and thus gaining 'user acceptance', but also by bringing in the right skills and 'know-how' from the existing supply chain to deliver incremental change.

Full conversion of the Novelis and Kraft-Heinz sites to hydrogen and subsequent deployment of the solutions at wider, similar sites largely depends upon the deployment of the wider HyNet hydrogen (and CCS) infrastructure. However, it is also possible that green (or 'electrolytic') hydrogen production might be deployed at each site in advance of the HyNet network arriving in these locations.

The extent to which the solutions are 'built-out' will also depend largely upon the business models, which are currently under development by Government. Assuming a 'contract for difference' (CfD) model is used under the Hydrogen Business Model, the magnitude of the budget available to support hydrogen production (and indirectly, use) will drive the speed of deployment. Similarly, assuming appropriate knowledge dissemination, hydrogen business models in other countries will determine the build-out rate.

At the time of writing, Government is also currently consulting upon business models for hydrogen transportation and storage.[18] These are critical enablers and must be progressed rapidly to enable use of hydrogen by industry.

18 BEIS (2022) Hydrogen transport and s orage infras ruc ure: A consu a on on bus ness model des gns, regu a ory arrangemen s, s ra eg c p ann ng and the ro e of b end ng. August 2022 h ps //www.gov.uk/governmen /consu a ons/proposa s for hydrogen ranspor and s orage bus ness mode s

Glossary

Term	Description
ATEX	Equipment for potentially explosive atmospheres (adapted from French)
ALARP	As Low As Reasonably Practicable
BAT	Best Available Technology
BEIS	Department for Business, Energy & Industrial Strategy
°C	Degrees Celsius
CAPEX	Capital Expenditure
CCC	Committee on Climate Change
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Storage
CFD	Computational Fluid Dynamics
CfD	Contract for Difference
CHP	Combined Heat & Power
CO_2	Carbon Dioxide
COMAH	Control of Major Accident Hazards
DCO	Development Consent Order
DNO	Distribution Network Operator

Term	Description
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations
EA	Environment Agency
EPC	Engineering, Procurement and Construction
EPCM	Engineering, Procurement and Construction Management
FEED	Front End Engineering Design
FGR	Flue Gas Recirculation
FID	Final Investment Decision
GDN	Gas Distribution Network
GT	Gas Turbine
GWh	Gigawatt Hour
H_2	Hydrogen
HAZID	Hazard Identification (Study)
HAZOP	Hazard and Operability (Analysis)
HBM	Hydrogen Business Model
HMG	Her Majesty's Government
IDC	Industrial Decarbonisation Challenge
IFS	Industrial Fuel Switching
HHV	Higher Heating Value

Term	Description
km	Kilometre
kNm^3/h	Thousands of Normal Cubic Metres per hour
kW	Kilowatt
LCoH	Levelised Cost of Hydrogen
LHV	Lower Heating Value
LCCC	Low Carbon Contracts Company
LTS	Local Transmission System
m	Metre
MCPD	Medium Combustion Plant Directive
mg	Milligram
MPBH	Medium Pressure Boiler House
m/s	Metres per Second
Mtpa	Million Tonnes per Annum
MW	Megawatt
MWh	Megawatt Hour
MW_{th}	Megawatt (thermal)
NDT	Non-destructive Testing
NG	Natural Gas
NIA	Network Innovation Allowance
Nm^3	Normal Cubic Metres
N/m	Newtons per Metre

Term	Description
NOx	Oxides of Nitrogen
NTS	National Transmission System
NZHF	Net Zero Hydrogen Fund
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
PEL	Progressive Energy Limited
PLC	Programmable Logic Controller
PSMP	Process Safety Management Plan
RDG	Refinery Dry Gas
RAM	Reliability Availability and Maintainability
RAB	Regulated Asset Base
ROG	Refinery Off-Gas
t	Tonne
T&S	Transport and Storage
TAD	Through Air Dried
TRL	Technology Readiness Level
TWh	Terawatt Hour
%v/v	Percentage by Volume
WHRB	Waste Heat Recovery Boilers
XSA	Excess Air
μm	Micron (or micrometre)


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