HyNet Industrial Fuel Switching

Phase 1 Public Report

Switching Kellogg's & PepsiCo to Hydrogen

HyNet IFS
Industrial Fuel Switching

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 PepsiCo International Limited ('PepsiCo') and Kellogg Company of Great Britain Limited ('Kellogg's'). PEL was also awarded Phase 1 funding by BEIS to undertake similar studies in relation to sites operated by Kraft-Heinz, Novelis and Essity. Collectively, work across these sites is referred to as the 'HyNet IFS2 Programme'.

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 CCUS-enabled and electrolytic hydrogen production, a pipeline distribution network and large-scale underground hydrogen storage in salt caverns.

The programme of work for PepsiCo and Kellogg's focuses on the following four main elements:

- A feasibility review in respect of the main issues associated with switching the PepsiCo site located in Skelmersdale (also known as Walkers Snack Food (WSF)), and the Kellogg's sites in Trafford Park and Wrexham, to hydrogen;
- High-level cost estimates in relation to switching the sites to hydrogen once it is available from HyNet;
- The process of site selection, scoping and outline design of a programme of work to demonstrate hydrogen fuelling of cooking ovens at both the selected PepsiCo and Kellogg's sites; 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.

The key messages from the study can be summarised as follows:

- There appear to be no insurmountable barriers to running the cooking ovens at both PepsiCo and Kellogg's on hydrogen, albeit this is subject to confirmation during a physical demonstration programme.
- At the time of writing, it appears very likely that bids will be made by PepsiCo and Kellogg's, in partnership with PEL, to BEIS's Phase 2 of the IFS Competition for funding of demonstrations on cooking ovens to be designed and operated during 2023 and 2024:
  - For PepsiCo, this will be a three-phase programme of work, which will include practical work at HSE science and research park at Buxton, followed by pilot plant hydrogen-firing at PepsiCo's R&D facility at Beaumont Park in Leicester, and then finally a full-scale demonstration at WSF in Skelmersdale, which will demonstrate hydrogen-firing on two manufacturing lines: for Monster Munch and Walkers Baked; and
  - For Kellogg's, this will be a two-phase programme of work, which will include demonstrating hydrogen-firing at the Centre of Excellence pilot oven at Trafford Park, including the four main product groups (rice, corn, Special K, bran), followed by production of corn product at commercial scale.
- The demonstrations with both companies will consider impacts upon product quality, oven efficiency, equipment lifetime, burner readiness, controls and NOx emissions.
- The demonstration programmes will be designed in such a way that the evidence which comes from the work will be relevant to the majority of other ovens at the sites 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 all sites to maintain the ability to use natural gas and hydrogen interchangeably. As much as possible, therefore, the demonstration projects need to include running ovens on hydrogen, natural gas or a blend of both gases.
- In respect of the boilers at both of the Kellogg's sites:
  - The preliminary conclusion based on the Feasibility Study is that the boilers in place are all suitable for switching to 100% hydrogen. The decision on switching rather than installing new boilers requires a techno-economic assessment by Kellogg's;
  - The primary modification required to operate on hydrogen is replacement of the existing burners; 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").

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 PepsiCo and Kellogg's 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.[1] These are critical enablers and must be progressed rapidly to enable use of hydrogen by industry.

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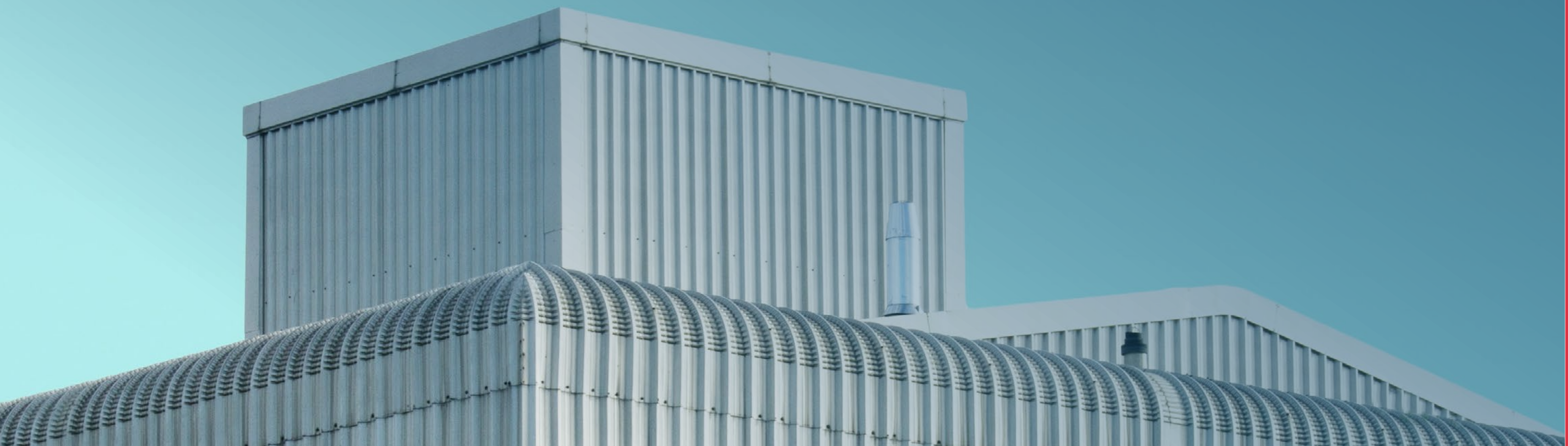
Introduction



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:[2]

- To determine the costs of switching industrial sites to hydrogen;
- To prove that there is no detrimental impact upon existing plant and equipment;
- To demonstrate that sites can operate in conformance with all safety regulations;
- To prove that there is no detrimental effect on manufactured products;
- To prove that hydrogen can be fired in compliance with environmental permitting standards; and
- To 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 PepsiCo International Limited ('PepsiCo') and Kellogg Company of Great Britain Limited ('Kellogg's'). PEL was also awarded Phase 1 funding by BEIS to undertake similar studies in relation to sites operated by Kraft-Heinz, Novelis and Essity. 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.

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1.2 Overview of HyNet

This project with Kellogg's and PepsiCo 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 Carbon Capture and Storage (CCS) and hydrogen infrastructure.[3] 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.

The initial HyNet study was built upon in a subsequent NIA-funded report published in June 2018.[4] This work defined the project concept for both hydrogen production and distribution, and CCUS.

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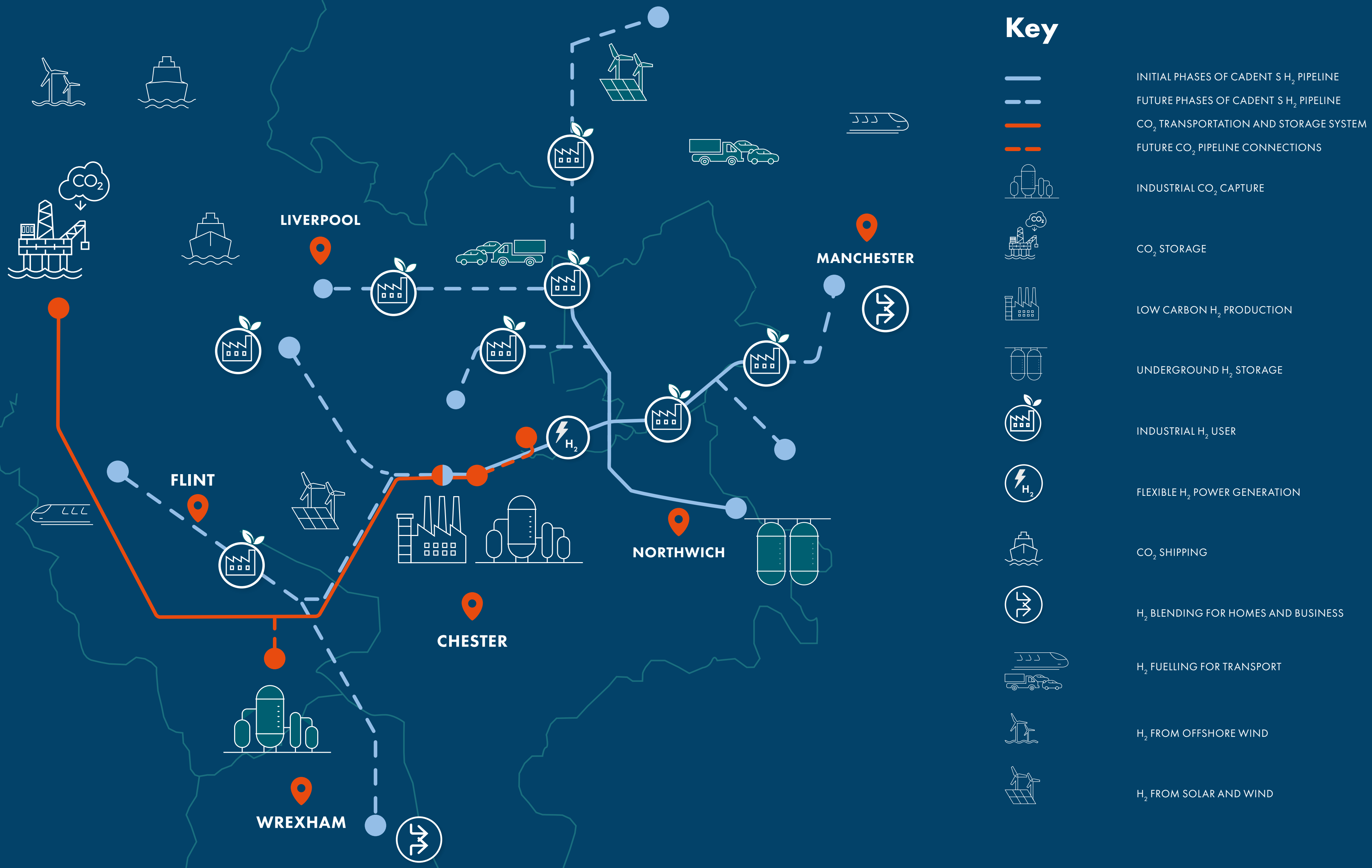
As presented in Figure 1 1, this included the following key features:

- 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.[5] 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.[6]

Figure 1 1: Overview of the HyNet Project



1.3 Scope and Objectives of this Report

The programme of work for PepsiCo and Kellogg's focuses on the following four main elements:

- A feasibility review in respect of the main issues associated with switching the PepsiCo site located in Skelmersdale (also known as Walkers Snack Food (WSF)), and the Kellogg's sites in Trafford Park and Wrexham, to hydrogen;
- The process of site selection, scoping and outline design of a programme of work to demonstrate hydrogen fuelling of cooking ovens at both the selected PepsiCo and Kellogg's sites; and
- High-level cost estimates in relation to switching the sites to hydrogen once it is available from HyNet;
- How the findings from the work can be extrapolated across the food and drink sector in respect of scaling-up, build rate and replicability.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 Description of Sites

2.1 PepsiCo

PepsiCo is a USD $81bn global food and drink business responsible for leading brands including Walkers, Quaker Oats and Pepsi. In the UK and Ireland, PepsiCo employs 4,500 people across six manufacturing sites, including a Quaker Oats mill in Cupar and in addition to the Skelmersdale site, further Walkers factories in Leicester, Coventry and Lincoln.

2.1.1 PepsiCo Emissions Reduction Targets

PepsiCo recognises that the global food system is currently responsible for 30% of total annual greenhouse gas (GHG) emissions and has continuously transformed the way it works to set new targets to get to zero emissions.

By 2030, PepsiCo is planning to reduce absolute GHG emissions across its direct operations (Scope 1 and 2) by 75% and its indirect value chain (Scope 3) by 40% against its 2015 baseline. This action is expected to result in the reduction of more than 26 million tonnes of GHG emissions.

PepsiCo is also seeking to achieve net-zero emissions by 2040, one decade earlier than called for in the Paris Agreement.

To meet these targets, PepsiCo is looking to take part in a demonstration with the long-term aim of switching an entire site to 100% clean energy through the use of low-carbon hydrogen. The proposed demonstration at Skelmersdale will support this goal.

2.1.2 Site Overview and Current Technologies

The full-scale Phase 2 demonstration will be situated at WSF, Skelmersdale. The site was selected not only due to its location within the HyNet industry cluster, but also due to the variety of snack foods produced with a range of different baking and drying technologies.

The Skelmersdale site produces a range of snacks critical to its portfolio, including popular snacks such as Snack-a-Jacks and Walkers crisps. The site is the UK's only manufacturer of Monster Munch and Walkers Baked crisps. Acquired by PepsiCo in 2004, first production was started in 2006. The plant is operated 365 days per year by 630 employees. An aerial view of the site is presented in Figure 2 1.

PepsiCo uses a range of direct-fired drying and baking ovens in food manufacture, including impingement ovens, rotary ovens and conveyor dryers. Methods such as air recirculation are used to maximise efficiency, however even fully optimised equipment requires substantial heat input from natural gas.

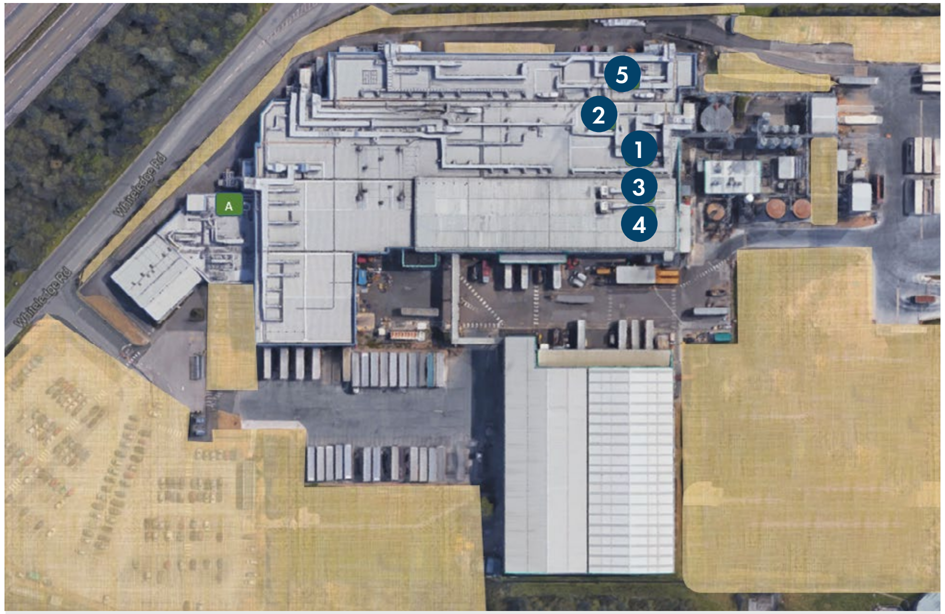


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Figure 2 1: Aerial View of PepsiCo's Skelmersdale Site

The site consists of 62 bag-makers, 210 stock keeping units and 5 production lines using ovens and fryers:

- 1 **Line 1** produces Monster Munch;
- 2 **Line 2** produces Walkers Baked crisps;
- 3 4 **Line 3 and 4** produce Snack a Jacks; and
- 5 **Line 5** produces Walkers Crisps.

2.1.2.1
Line 1 - Monster Munch

This process produces an extruded product using maize as the key ingredient. A wet mix of maize feeds continuously into an extruder which forms the Monster Munch shapes (called 'feet') on a continuous basis. Following this, the shapes are then fed into an oven for drying and baking, before application of seasoning and then transfer into packaging. The oven is a natural gas fired Buhler Aeroglide dryer.

2.1.2.2
Line 2 - Line Walkers Baked

Walkers Baked is a dough-based, better for you, product that is produced from potato starch. The dough is sheeted through a number of rollers, cut and then baked through a gas-fired Wolverine Proctor impingement oven prior to shaping and then further drying.

2.1.2.3
Line 3 - Mini Snack a Jacks

This is a compression popping process in which rice and maize granules are pre-treated and fed into a compression machine to form the shapes. From here, the chips are fed into seasoning and then into a drier before transfer into the packaging.

2.1.2.4
Line 4 - Snack a Jacks

This is very similar to the Mini Snack a Jacks but produces a larger cake and uses a Aeroglide drier.

2.1.2.5
Line 5 - Walkers Crisps

This is a continuous process of washing, peeling, slicing potatoes before entering a continuous fryer to form a potato chip. The fryer runs with vegetable oil heated indirectly with a gas fired burner. The chips are then seasoned and packaged.

2.2 Kellogg's

Kellogg's is an American multinational fast moving consumer goods manufacturing company, producing cereal and convenience foods. Kellogg's most well-known brands include Corn Flakes, Rice Krispies, Frosted Flakes and Pringles.

2.2.1 Emissions Reduction Targets

As part of Kellogg's 'Better Days Promise' goal to create better days for 3 billion people by the end of 2030, the company set a target to reduce Scope 1 and Scope 2 GHG emissions by 65% by 2050 (from a 2015 baseline) and to reduce absolute value chain emissions (Scope 3) by 50% from by 2050. Table 2 1 summarises Kellogg's proposed timeline for emission reduction and progress made by 2021. In the short term, Kellogg's is committed to reducing Scope 1 and Scope 2 GHG emissions by 45% by 2030.

Goal Year	Commitment	2021 Progress
2015	Baseline Science-based targets established	
2020	15% normalised energy use reduction 15% normalised GHG reduction	15% (manufacturing) 25% (manufacturing)
2030	45% absolute reduction in Scope 1 and 2 emissions 15% absolute reduction of Scope 3 emissions	29.2% absolute reduction of Scope 1 and 2 emissions Scope 3 results in progress
2050	66% absolute reduction of Scope 1 and 2 emissions 50% absolute reduction of Scope 3 emissions	29.2% absolute reduction of Scope 1 and 2 emissions Scope 3 results in progress

Table 2 1: Kellogg's emission reduction targets and progress to date

2.2.2 Site Overviews and Current Technologies

Kellogg's cereals were first introduced to the UK back in 1922 and Kellogg's opened its first British factory in Trafford Park, Manchester in 1938. The factory now covers 130,000 square feet. Kellogg's second UK factory opened in Wrexham, North Wales in 1978. An aerial view of the sites is shown in Figure 2 2 and Figure 2 3.

All products begin with the cooking of the raw product (Corn or Bran) in ovens where steam generated from the boiler house is injected directly into the product to both cook and add moisture to the food. Following the cooking stages, the product goes through several stages before final packaging. The main steps along this process include drying, shredding, pelletizing and flaking where the product is shaped, followed by several drying, tempering, coating and toasting stages. Following toasting, the products are then packaged and stored before distributed to relevant distribution centres and other sites.

At both sites, ovens are used to toast and dry Cornflakes, Rice Krispies, Special K, Bran Flakes and Wheats, reducing the finished food moisture to below 3%. A significant portion of the sites' total natural gas consumption is used in these toasting and drying stages.

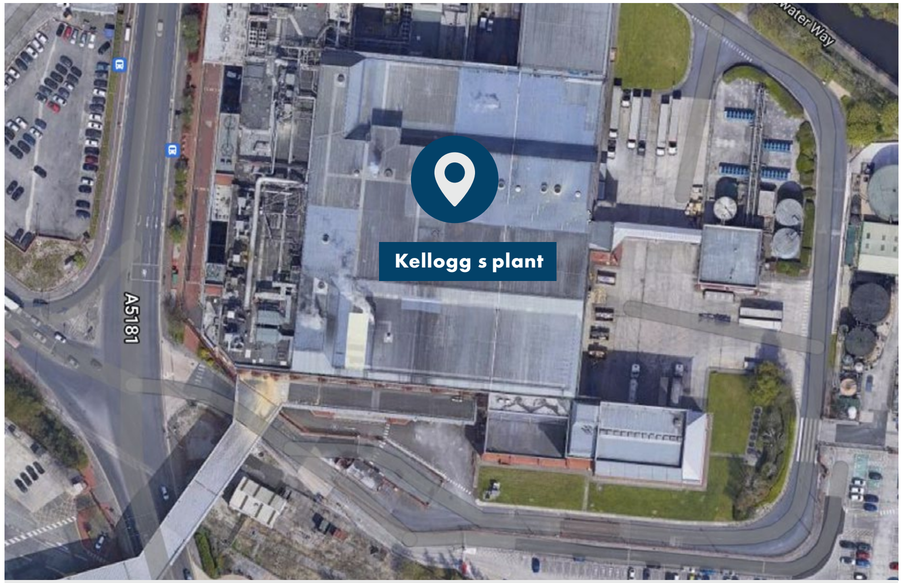

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Figure 2 2: Aerial view of Kellogg's Plant in Trafford Park, Manchester

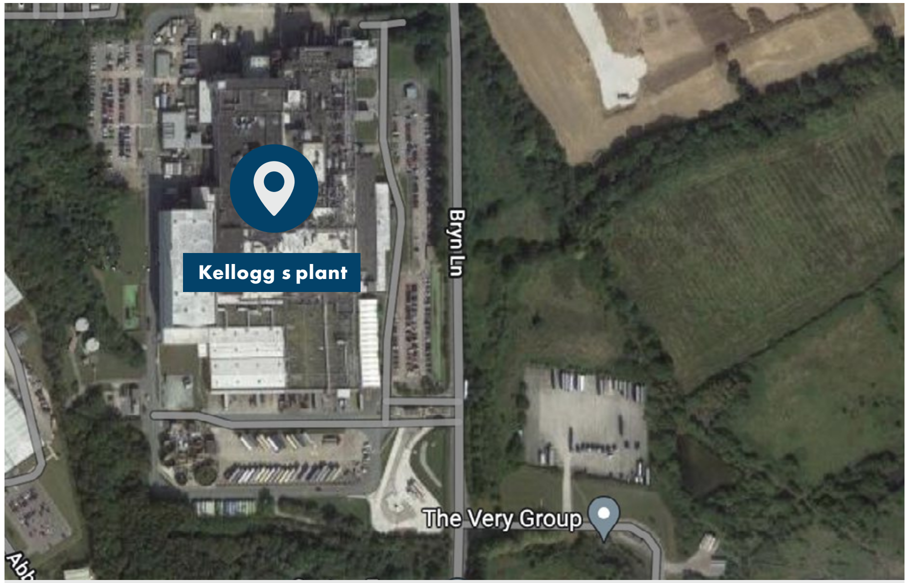

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Figure 2 3: Aerial view of Kellogg's Plant in Wrexham

2.2.2.1 Trafford Park

Kellogg's Trafford Park is the largest cereal factory in Europe and Cornflakes factory in the world, now producing one million boxes of cereal a day and employing just under 1,000 people. To achieve this, the factory uses 200 tonnes of corn each day, half of which is used to create Cornflakes, whilst the remaining half is used to manufacture Crunchy Nut and Frosties. Historic natural gas use is around 170 GWh/annum, which resulted in CO_2 emissions of around 30,000 tpa, albeit this number is likely to fall due to reengineering energy supply to the plant. The Trafford Park plant consists of a number of direct fired toasting ovens which utilise the hot combustion gases and air to toast and dry the raw material into corn, rice and wheat products. The site also houses Kellogg's European R&D and Pilot Plant centre.

2.2.2.2 Wrexham

Cereals produced at the Wrexham factory include Special K, Fruit and Fibre, Bran Flake and All Bran. Employing 400 people, Wrexham produces 81 million kilograms of cereals per year, giving the site an annual natural gas consumption of 82 GWh, resulting in 16,000 tonnes of CO_2 emissions per year.

Four out of the five manufacturing lines at Wrexham execute similar production processes to Trafford Park. The exception is that of the Krave cereal extrusion line.

3 Feasibility of Hydrogen Fuel Switching

Emissions from Kellogg's and PepsiCo arise from ovens and dryers, from oil heating (PepsiCo) and from boilers (Kellogg's). Outputs from the feasibility study in respect of the feasibility of conversion of ovens, dryers and oil heating is provided below.

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 Kellogg's and PepsiCo sites from the HyNet Phase 2 hydrogen network in around 2030.

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 all sites to maintain the ability to use natural gas and hydrogen interchangeably, and so the proposed solutions have 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, which were determined during Hazard Studies conducted at each site as part of this Phase 1 Feasibility Study. Key outcomes from these studies are summarised below.

The Kellogg's and PepsiCo sites under consideration all consume 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 sites, 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, including IGEM TD 13 Ed 2 Supplement 1 and IGEM SR/25 and BCGA CP33, will assist in achieving safe design.

3.1.3 Alternative Decarbonisation Options

Both Kellogg's and PepsiCo operate a range of sites in diverse locations worldwide. In pursuit of effective decarbonisation across their portfolios, both companies are pursuing a range of potential decarbonisation and energy efficiency technologies, from increased use of LED lights to heat recovery and reuse from process exhausts. Those which could potentially decarbonise the processes considered in this study include:

- Electrification of heat in boilers and ovens;
- Procurement of low carbon fuels and electricity from the grid;
- Heat pumps; and
- Introduction of renewable fuels.

All equipment under consideration in this study is currently fired by natural gas. Hydrogen is attractive against the above solutions both because, like natural gas, it is able to deliver large quantities of high-grade heat, and also because it represents close to a 'drop-in' replacement fuel.

It is likely feasible that existing equipment can be switched from natural gas to hydrogen by replacement of burners, avoiding the capital expenditure associated with the complete replacement of equipment (and upgrades to infrastructure) that would be required with a switch to electricity.

That said, hydrogen conversion can only be implemented where there is a source of hydrogen available. It is therefore important that alternatives continue to be pursued for implementation in areas where hydrogen is not available.

Current rises in both gas and electricity prices, driven by the war in Ukraine, are such that it is difficult to determine the relative fuel costs associated with electrification and hydrogen, and this cannot be done within the scope of this study.

3.2 Cooking Ovens and Driers

The feasibility questions raised are largely common to both ovens and driers which are operated by both PepsiCo and Kellogg's at the three sites.

3.2.1 Product quality

The ovens and driers considered in this study are direct-fired, and so the combustion gases come into direct contact with the product. Two potential product quality issues arise:

1. The effect of increased moisture content in the combustion gases on the drying process; and
2. The potential for chemical reactions between the 'new' combustion gases and the food, leading to adverse flavour.

The former has been addressed in two ways. At Kellogg's, a competent third-party consultant has carried out a modelling review of the impact of the new process conditions on the drying process, and has specified equipment modifications accordingly. At PepsiCo, OEMs have been engaged directly to advise on the required modifications to their equipment. Throughout any demonstration work, moisture content will be measured.

Although flavour issues with the finished product are thought to be unlikely, the only way to assess the impact of hydrogen is to run physical testing. Both Kellogg's and PepsiCo have well-established rigorous processes to test product and ensure that the switch to hydrogen has had no adverse effect.

3.2.2 Efficiency

It was expected that operational efficiency of ovens on hydrogen would be reduced due to the higher moisture content of the combustion gases. Following engagement with OEMs, it is expected that efficiency will be lower, but that the effect will be small. Fuel use will be carefully quantified during future demonstration work to evaluate the efficiency change.

3.2.3 Equipment lifetime

Hydrogen flames differ from natural gas flames both in shape and temperature. Any change in heat profile within equipment could have the potential to compromise equipment lifetime. This has been addressed in different ways for different processes. Strategies employed include:

- Inclusion of a make-up air blower and ducting to provide additional cooling to the heat chamber box;
- Modifying nozzles to achieve similar flame length; and
- Replacing the combustion chamber with one sized specifically for hydrogen flame length and temperature.

No further adverse interactions between combustion gases and construction materials are expected, but inspections after hydrogen firing will be used to confirm this.

3.2.4 Equipment Functionality

Hydrogen-fired equipment should produce product at the same quality and throughput as the original natural gas-fired equipment, and this will be verified through physical demonstration.

During the early years of hydrogen roll-out, burners should be able to switch between natural gas and hydrogen. During engagement with OEMs for this study, it was not possible to source single burners that were capable of seamless switching between the two fuels for food applications (where high levels of modulation are required), and so fuel switching can be accomplished either through nozzle changes on a suitable burner (incurring hours of downtime) or through installation of natural gas and hydrogen burners in parallel. The specific design will be determined during Phase 2.

3.2.5 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. OEM estimates of NOx production from the new hydrogen burners, based in part on representative testing, were for levels to be approximately double those observed for the natural gas equivalents. This is consistent with expectations. NOx levels will be monitored during any hydrogen demonstration work.

3.2.6 Safety

Hazard study workshops were held during the feasibility studies to inform design of Phase 2 demonstration work, and further Hazard study work has been performed at PepsiCo. Preliminary equipment design by OEMs has considered the need to ensure safe operation, and designs therefore incorporate appropriate flame detection, purging and emergency shut-off measures.

Further industry-standard design reviews and risk assessment will be completed during detailed design, construction, and acceptance testing phases. A controlled commissioning, qualification and verification process will be followed at installation.

Hydrogen use in areas of high occupancy is an area of limited experience, and for this reason the demonstration programme to be pursued by PepsiCo includes off-site verification of equipment, with the intent of generating safe ways of working that can be shared across the industry.

Site-wide risks associated with hydrogen use are described in Section 3.1.2.

3.3 PepsiCo Fryers

PepsiCo uses an oil fryer in the production of potato chips. Oil is heated in a heat exchanger and then piped to the frying unit. This means that there is no contact between the fuel used for heating and the end product; the oil heater functions analogously to a boiler and so evidence in relation to hydrogen-firing can be taken from the HyNet IFS1 demonstration at Unilever's Port Sunlight plant.[7] Therefore, the only product quality issue is whether oil can be heated to the required conditions.

Following discussions with the current equipment supplier it is apparent that they are already able to commit to supplying a dual fuel natural gas/ hydrogen oil heater on a commercial basis. As there is no product quality question, there was no need to progress feasibility work further and it can be concluded that it is possible to use hydrogen in this application without any need for demonstration.

3.4 Kellogg's Boilers

There are no industrial-scale boilers at PepsiCo's Skelmersdale plant. However, both the Trafford Park and Wrexham Kellogg's plants have such units.

Kellogg's has already undertaken design and procurement for the conversion of its Trafford Park boilers to dual-fuel natural gas/hydrogen, and so the assessment of feasibility of conversion has already been made. Therefore, assessment under this study is limited to the four boilers at Wrexham.

From a preliminary assessment, it is believed that there will be a need to undertake some works on the gas system within the plant room. It is also believed that it may be feasible to replace the burners and retain the existing boiler shells, which is a relatively simple upgrade, although – given the age of the existing boilers (40+ years in some cases) – there may be a rational argument to consider some boiler replacement (with hydrogen-ready boilers) to provide long-term optimisation of the plant room.

However, in the scenario in which just the burners are replaced:

- It is likely that the boilers would have to be derated by around 20% to ensure that NOx limits are met;
- Existing control panels are fitted close together, and so ATEX Zoning requirements arising from a hydrogen-fuelled system would likely add cost to the equipment.

Historic steam demand at Wrexham greatly exceeds current demand, and steam-generating capacity on-site reflects this. Therefore, derating to meet NOx limits is thought to be feasible without impacting plant operations.

While conversion to dual-fuel hydrogen/natural gas is believed to be feasible, ultimately Kellogg's must perform its own techno-economic assessment of the best way forward in terms of plant room optimisation. This assessment will need to consider the fact that 'business-as-usual' upgrade works will be required in the boiler plant room to enable ongoing compliance with the Medium Combustion Plant Directive even when running on natural gas (for example, installation of new burners to achieve lower NOx emissions). These upgrade works may – potentially – include replacement of the existing and aged boilers with new boilers to provide asset longevity (as mentioned above). Given the drivers for these works regardless of conversion to hydrogen, the additional cost of being hydrogen-ready may be relatively small, as indicated in Section 5.0 below.

4 Site Selection & Scoping

of Phase 2 Demonstrations

The first stage of the IFS2 Phase 1 work focused on reviewing the feasibility of switching PepsiCo and Kellogg's ovens, boilers and fryers 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 sites to hydrogen.

A relevant boiler demonstration at Unilever's Port Sunlight site was already funded by BEIS under the first IFS Competition, and so the related evidence can be used by Kellogg's in respect of the boilers at Trafford Park and Wrexham.[8] As mentioned in Section 3.3, the Unilever work is equally relevant to the PepsiCo fryer, as there is no contact between the fuel used for heating and the end product. Consequently, the focus of the demonstration design is upon the ovens only.

8 Progress ve Energy (2022) HyNet Indus r al Fuel Sw ch ng, May 2022

4.1 PepsiCo

The PepsiCo Skelmersdale site is within the HyNet North West area and the hydrogen distribution pipework will reach PepsiCo in 2030 (Pipeline Construction Phase 3).

4.1.1 PepsiCo Oven Selection

PepsiCo uses a range of direct-fired drying and baking ovens in food manufacture, including impingement ovens, rotary ovens and conveyor dryers. The objective of the demonstration programme is to enable PepsiCo to assess the impact of hydrogen-firing on plant performance and product quality. This will enable PepsiCo to undertake a risk-managed transition to operating on hydrogen in the long-term at all of its Skelmersdale site once pipeline-distributed low-carbon hydrogen becomes available from HyNet. In this context, the site selection criteria that were considered at a high level, using a 'semi-quantitative' assessment method, were:

1. How representative the oven is of systems and processes used throughout the PepsiCo business in the UK and beyond, and therefore how widely applicable the results will be;
2. Whether fuel use is low enough that it is feasible to supply sufficient hydrogen for a Phase 2 demonstration;
3. Whether fuel use is material enough to support construction of hydrogen supply to the site in the long term;
4. Whether commercial guarantees are already available from burner OEMs; if they are available, then a demonstration is not required.

The above criteria were used to consider each of these sites, using a 'red-amber-green' traffic-light approach, where green indicates that a trial is feasible and/or useful, and red indicates that a trial is unfeasible or not required. The different criteria were also given a weighting of 5 (high priority) to 1 (low priority). The findings are presented in Table 4 1. Where clarification is helpful as to why a particular rating has been given, relevant notes are added to the assessment matrix.

Lines 1 and 2 scored most strongly on the assessment. Taking these two lines forward will provide experimental data on two very different technologies (direct drying and impingement cooking), providing PepsiCo confidence in the effect of hydrogen across their portfolio of products, in particular addressing the strong base of extruded products (Line 1). Line 2 consumes material quantities of fuel, such that positive trial results can underpin a decision to bring hydrogen to site once the HyNet hydrogen distribution pipework is available in 2030 (Pipeline Construction Phase 3), enabling future trial and conversion of the remaining processes. As discussed in Section 3.3, PepsiCo has confidence line 5 can be switched to hydrogen without a full-scale demonstration.

Criteria	Weighting	Line 1	Line 2	Line 3	Line 4	Line 5
1. Wider applicability of results	5	Extruded products	Baked Products	Expanded products	Expanded products	Potato Chip frying
2. Feasibility of hydrogen supply for trial	5					
3. Materiality of fuel consumption	4					
4. Necessity of trial to facilitate OEM guarantees	3					As per Section 3.3

Table 4 1: PepsiCo oven selection matrix

4.1.2 Summary of Proposed Phase 2 PepsiCo Demonstration Programme

The demonstration programme is made up of the following three distinct stages:

1

Offsite trials at HSE science and research park at Buxton, which will:

- Leverage HSE expertise in safety aspects of burning hydrogen in a food and drink production environment.
- Allow OEMs to confirm design assumptions and undertake an equipment lifetime assessment.

2

Small scale pilot plant trials at PepsiCo's R&D facility at Beaumont Park in Leicester, which will:

- Generate early insights to potential impacts on product quality and build confidence for Stage 3 live burning trials.
- Allow hydrogen-firing in an environment which does not run a risk of downtime for production at the Skelmersdale site.

3

Full-scale demonstration at WSF in Skelmersdale, which will:

- Demonstrate hydrogen firing on two manufacturing lines:
  - Line 1 Monster Munch. Conversion of Aeroglide ovens to have dual fuel switching capability. The objective of the trial is to prove drying capabilities without impact to product.
  - Line 2 Walkers Baked. Conversion of Wolverine Proctor impingement oven to dual fuel switching capability. The objective of the trial is to prove oven capability of matching the impingement drying curve.

The demonstration plans for each of the above three stages are provided in Table 4 2.

Location	Offsite, HSE Buxton	Beaumont Park, PepsiCo	Skelmersdale, PepsiCo	Skelmersdale, PepsiCo
Scale	Buhler C12 Unit	Buhler C12 Unit	Buhler Aeroglide Dryer	8 zone Wolverine Proctor Impingement Oven
Objective	Evaluate equipment capability to burn hydrogen. Complete safety assessment.	Identify potential impacts on product quality. Build confidence for Stage 3 live burning trials.	Conversion of Line 1 Monster Munch to have dual fuel switching capability. Prove drying capabilities without impact to product.	Conversion of Line 2 Walkers Baked to dual fuel switching capability. Prove oven capability of matching the impingement drying curve.
Equipment conversion trials and safety assessments				
Equipment Capability	Ability to burn hydrogen and achieve setpoint control.	Ensure infeed flow can be maintained at a constant flow and achieve a moisture reduction target.	Ensure infeed flow maintained at a constant flow and achieve a moisture reduction target.	Ensure infeed flow maintained at a constant flow and achieve a moisture reduction target.
Trial Timing	10 days over 3 weeks	56 hours over 4 days	56 hours over 4 days	56 hours over 4 days
Analytical	N/A	Moisture volatile headspace - Colour analysis - Contaminants		
Sensory	N/A	Tetrad assessment Descriptive assessment	Tetrad assessment - Descriptive assessment - Hybrid Technical Match Consumer Test	

Table 4 2 PepsiCo Demonstration Plan

4.2 Kellogg's

4.2.1 Site Selection

The overarching objective of the demonstration programme is to gather useful data and information that will enable Kellogg's to assess the impact on plant performance and product quality. This will enable it to undertake a risk-managed transition to operating on hydrogen in the long-term at both sites in the North West England and North Wales region once pipeline-distributed low-carbon hydrogen becomes available from HyNet.

During the Project Inception phase, both the Trafford Park and Wrexham sites were considered as potential locations for the Phase 2 demonstration. Under guidance from Kellogg's team, it was determined that the pilot-scale demonstration will be located at Trafford Park, due to the existing onsite pilot plant. The small-scale pilot trial will enable product quality assessments to take place across all Kellogg's products produced at the two sites, without the production downtime associated with full-scale demonstrations. It was determined the full-scale demonstration should also be located at Trafford Park, in order to utilise the hydrogen supply infrastructure that will already be installed for the pilot trials.

4.2.2 Kellogg's Oven Selection

A range of potential ovens were considered for use in the Phase 2 demonstration. The oven selection criteria which were considered can be summarised as follows:

- The degree to which results from the trials would provide confidence for conversion of systems and processes used throughout the Kellogg's business in the UK to hydrogen;
- The level of risk to the business associated with hydrogen demonstrations on the oven; and
- Accessibility of the oven in respect of hydrogen piping from the hydrogen 'compound'.

Based on the above criteria, the following ovens were selected for demonstration design and potential inclusion in a Phase 2 bid:

1. The pilot-scale oven (for 2 kg/min of product) located in the 'Centre of Excellence' (CoE); and
2. Commercial scale oven, used for production of Corn products (50-60 kg/min of product).

The CoE oven has been selected for use in an initial trial to understand impact on product quality and process performance on Rice, Corn, Special K and Bran products. This is a low-risk route to providing confidence on multiple product streams, satisfying the first two criteria.

If successful, the programme will proceed to full-scale demonstration on the full-size oven. This oven is well-placed within the plant, is of a technology type that cannot be replicated in the pilot plant, and is the unit most likely to be impacted by the presence of additional moisture resulting from the use of hydrogen, with the result that a positive trial would provide a high degree of confidence in the use of hydrogen in Kellogg's wider fleet of existing ovens. Additionally, the oven has a new burner that is representative of future burner installations on-site. The oven therefore performed well against the first and third criteria.

4.2.3 Summary of Proposed Phase 2 Demonstration Programme

Stage 1 of the programme will test production of the four main product groups at pilot scale in the CoE oven. Following achievement of production at the required quality, Stage 2 will demonstrate hydrogen-fired production on live manufacturing equipment at Trafford Park.

The programme will be planned such that the wider plant operations can continue as normal, and downtime for the equipment used in the trial is minimised.

4.2.3.1 Stage 1

This involves production of the four main product groups (rice, corn, Special K, bran) to the required quality, at pilot scale. This is intended to:

- Validate the predictions of the feasibility and modelling work carried out at Feasibility Stage;
- Highlight any differences between operation on hydrogen compared to natural gas;
- Facilitate development of operating methodologies and setpoints suitable for full-scale hydrogen-fired production; and
- Provide sufficient confidence in the process such that the programme can proceed to Stage 2.

The programme will commence with one week running on natural gas, to produce reference products. Subsequently, the oven will fire hydrogen for one week for each of the four product groups. The programme will commence with rice, as this can be produced as an extended run, giving more time to understand the impact of hydrogen and to make adjustments to the oven setpoints. The Stage 1 programme is presented in Table 4 3.

Measurements will be taken relating both to product quality and technical performance. Prior to completion of tetrad tests, finished food must mature for 2 weeks.

Week	Test	Duration		Hydrogen use		
		Days	h/day	Mean (kW)	Mean (kg/h)	Total (kg)
1	Reference production on natural gas, 1 day per product	4	2	–	–	–
2	Rice production	5	2	439.5	11.0	109.9
3	Corn production	5	0.5	439.5	11.0	27.5
4	Special K production	5	0.5	439.5	11.0	27.5
5	Bran production	5	0.5	439.5	11.0	27.5

Table 4 3: Stage 1 Test Programme

4.2.3.2 Stage 2

Stage 2 focuses on the production of corn product at commercial scale. This is intended to:

- Verify that the results of the pilot scale testing translate to the commercial production equipment and are applicable to full-scale ovens; and
- Provide sufficient confidence for Kellogg's to commit to using hydrogen in its commercial ovens once available from HyNet.

The programme is summarised in Table 4 4 and consists of 4 hours per day of hydrogen-firing, for 5 days. Whilst saleable quality product may be produced this will not be sold, as shelf-life tests will not be completed in time.

Measurements will be taken relating both to product quality and technical performance. Prior to completion of tetrad tests, finished food must mature for 2 weeks.

	Test	Duration	Product throughput	Hydrogen use		
		Hours	kg/h	Mean (kW)	Mean (kg/h)	Total (kg)
Day 1	Corn production	4		–	–	–
Day 2	Corn production	4		263	7	26
Day 3	Corn production	4		263	7	26
Day 4	Corn production	4		263	7	26
Day 5	Corn production	4		263	7	26

Table 4 4: Stage 2 Test Programme

5 Indicative Capital Cost Estimates

of Switching To Hydrogen Indicative Costs

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 Kellogg's and PepsiCo sites to hydrogen as soon as this is available from the HyNet project.

Site	Production Equipment	Pipework & Ancillaries	Hydrogen Reception	Total
Kellogg's Trafford Park[1]	£4.3	£1.3	£0.4	**£6.0**
Kellogg's Wrexham[2]	£4.8	£1.4	£0.5	**£6.7**
PepsiCo Skelmersdale[3]	£3.2	£0.9	£0.2	**£4.3**

Table 5 1: High-level costs of whole-site conversion (£M)

Notes:

1. Does not include boilers as hydrogen ready boilers currently being procured ahead of installation
2. These figures include for works to enable fuel switching of the ovens and for the additional works needed within the boiler plant room to enable hydrogen readiness (over and above the cost of the works that are expected to be needed anyway, as discussed in Section 3.4 above).
3. Switching of existing ovens only

Three main categories of costs are considered:

1. Equipment conversion:
   - This relates to modification/replacement of production equipment, and includes design and installation and controls modifications.
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, upgrades to ATEX-rated equipment where required, and (in the case of Kellogg's Wrexham) boiler plant modifications that may be needed over and above any upgrade work that may be required in any case.
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 based upon estimates provided by both OEMs and by the engineering design contractors, which supported the work at both sites. It should be noted that it is indicative only but provides a preliminary view on the overall costs of switching the sites to hydrogen. The proposed demonstration projects will provide more detailed information in this respect, should the related bids be successful in the Phase 2 Competition process.

6 Extrapolating Findings Across Industry

6.1 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 Kellogg's and PepsiCo 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 7.1 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.

6.2 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 the sites to switch to hydrogen as soon as it is available from HyNet. 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.

6.3 Applicability and Replicability

The need for low carbon heat and power at the sites is similar across any of both companies’ global network of manufacturing plants. Determining the extent to which the three sites in the North West of England and North Wales can switch to low carbon hydrogen will therefore support decarbonisation of a broad swathe of both companies’ global manufacturing.

Information from this Feasibility Study and the subsequent demonstration programmes (should these be funded by BEIS) will be shared outside PepsiCo and Kellogg’s, consistent with the HyNet IFS2 Knowledge Dissemination Plan.

The Hy4Heat Work Package 6 study commissioned by BEIS did not include any quantification of the emissions from ovens in the UK food and drink sector.[9] During the scope of this study it has therefore not been possible to quantify the emissions reduction which might be delivered in the UK should the technical solutions be deployed by all other sites which operate similar ovens.

However, it is reasonable to state that the solutions would deliver meaningful impact in terms of decarbonising the food and drink sector should they be deployed on a global basis.

9 BEIS (2019) H4Heat WP6: Convers on of Indus r al Hea ng Equ pment to Hydrogen, November 2019
h ps //www hy4heat.info/wp6

7 HyNet Infrastructure
& Related Business Models

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.

7.1 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 Kellogg's and PepsiCo 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 7 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.[10] This presents engineering information relating to the Hub, which will use UK company, Johnson Matthey's Low Carbon Hydrogen (LCH™) production technology.

10 HyNet North West (2022) HyNet Low Carbon Hydrogen P an : BEIS Hydrogen Supp y Compe on, November 2021 h ps //asse s pub sh ng.serv ce.gov.uk/ governmen /uploads/sys em/uploads/at achment data/file/1056041/Phase 2 Repor Progress ve Energy HyNe Low_Carbon Hydrogen 3 pdf

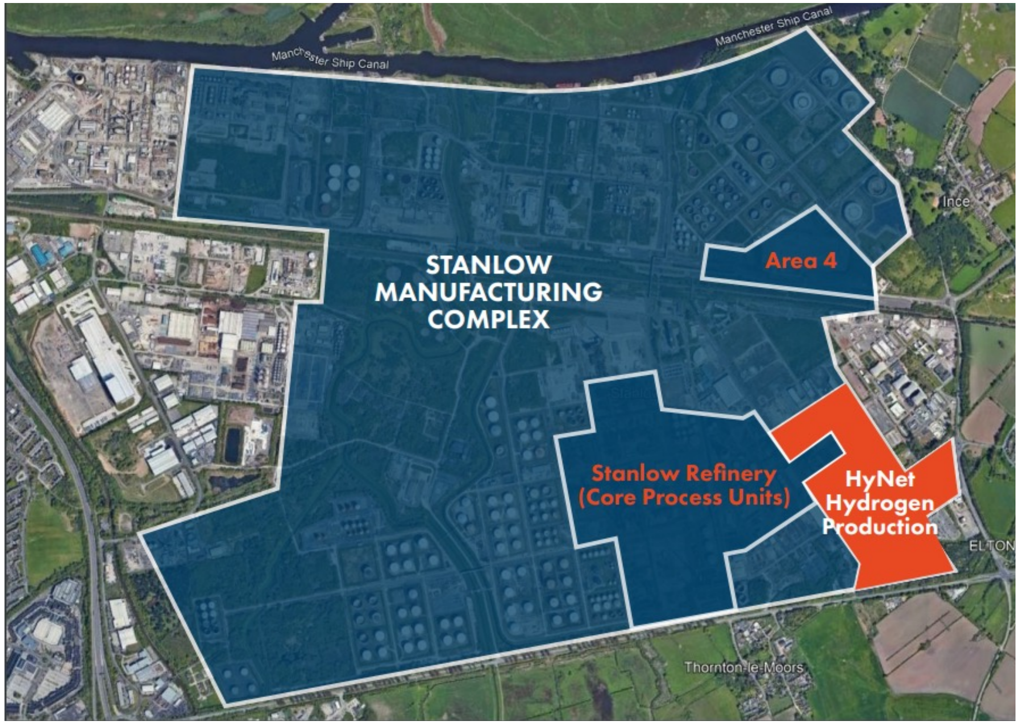

Figure 7 1: Hydrogen Production Hub location at Stanlow

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.[11] 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 Figure 7 2.

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

Figure 7 2: Deployment Profile for HyNet Hydrogen Production

11 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

7.2 Hydrogen Business Model

As mentioned above, the Vertex Hub has been shortlisted under Phase 2 of the Government's Cluster Sequencing process.[12] 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 CF D 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.[13]

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.[14]

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. 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.[15]

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.

12 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

13 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

14 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

15 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

7.3 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.[16] 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.

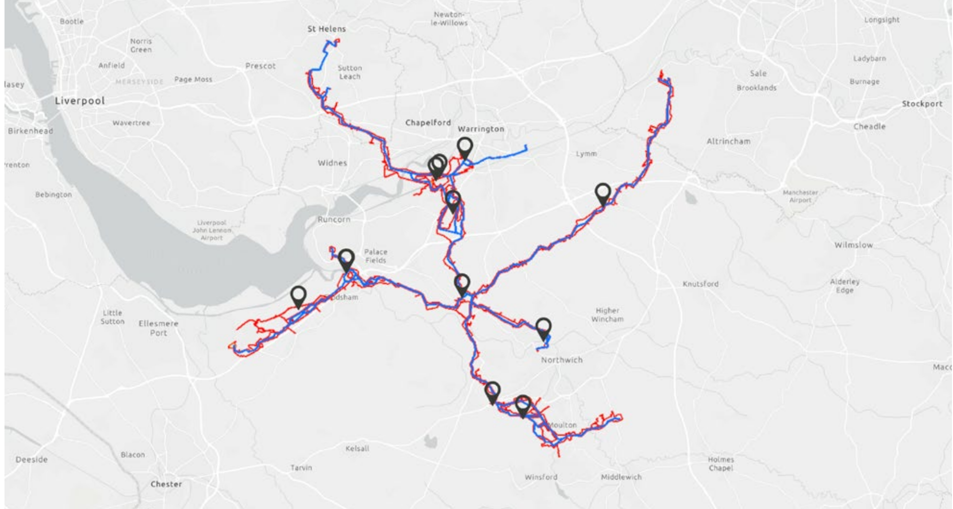

Figure 7 3: Proposed HyNet Hydrogen Network Routing Corridors

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.

Cadent, is currently engaged in a Development Consent Order (DCO) process to consent the first 125km of hydrogen network.[17] 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 7 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.

16 www.hydeploy.co.uk
17 https://www.hynethydrogenpipeline.co.uk/

7.4 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.[18]

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.

18 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

8 Key messages

The key messages in respect of the work undertaken in relation to PepsiCo's Skelmersdale and Kellogg's Trafford Park and Wrexham sites can be summarised as follows:

- There appear to be no insurmountable barriers to running the cooking ovens at both PepsiCo and Kellogg's on hydrogen, albeit this is subject to confirmation during a physical demonstration programme.
- At the time of writing, it appears very likely that bids will be made by PepsiCo and Kellogg's, in partnership with PEL, to BEIS's Phase 2 of the IFS Competition for funding of demonstrations on cooking ovens to be designed and operated during 2023 and 2024:
  - For PepsiCo, this will be a three-phase programme of work, which will include practical work at HSE science and research park at Buxton, followed by pilot plant hydrogen-firing at PepsiCo's R&D facility at Beaumont Park in Leicester, and then finally a full-scale demonstration at WSF in Skelmersdale, which will demonstrate hydrogen-firing on two manufacturing lines: for Monster Munch and Walkers Baked; and
  - For Kellogg's, this will be a two-phase programme of work, which will include demonstrating hydrogen-firing at the Centre of Excellence pilot oven at Trafford Park, including the four main product groups (rice, corn, Special K, bran), followed by production of corn product at commercial scale.
- The demonstrations with both companies will consider impacts upon product quality, oven efficiency, equipment lifetime, burner readiness, controls and NOx emissions.

- The demonstration programmes will be designed in such a way that the evidence which comes from the work will be relevant to the majority of other ovens at the sites 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 all sites to maintain the ability to use natural gas and hydrogen interchangeably. As much as possible, therefore, the demonstration projects need to include running ovens on hydrogen, natural gas or a blend of both gases.
- In respect of the boilers at both of the Kellogg's sites:
    - The preliminary conclusion based on the Feasibility Study is that the boilers in place are all suitable for switching to 100% hydrogen. The decision on switching rather than installing new boilers requires a techno-economic assessment by Kellogg's;
    - The primary modification required to operate on hydrogen is replacement of the existing burners; and
    - The switch to hydrogen would necessitate wider assessment of operation within the boiler house, including consideration of fuel distribution and DSEAR assessment.

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 PepsiCo and Kellogg's 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. These are critical enablers and must be progressed rapidly to enable use of hydrogen by industry.

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
CoE	Centre of Excellence
COMAH	Control of Major Accident Hazards
DCO	Development Consent Order
DNO	Distribution Network Operator
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations
EA	Environment Agency

Term	Description
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
GHG	Greenhouse Gas
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
HSE	Health & Safety Executive
IDC	Industrial Decarbonisation Challenge
IFS	Industrial Fuel Switching
HHV	Higher Heating Value
kg	Kilogram
kg/min	Kilogram per Minute
kg/h	Kilograme per Hour

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
LED	Light Emitting Diode
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
tph	Tonnes per Hour
TRL	Technology Readiness Level
TWh	Terawatt Hour
USD	United States Dollars
%v/v	Percentage by Volume
WHRB	Waste Heat Recovery Boilers
WSF	Walkers Snack Food
XSA	Excess Air

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Industrial Fuel Switching

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