HyNet Industrial Fuel Switching

Phase 1 Public Report

Switching Essity to Hydrogen

HyNet IFS
Industrial Fuel Switching

essity

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 Essity UK Limited ('Essity'). PEL was also awarded Phase 1 funding by BEIS to undertake similar studies in relation to sites operated by Kraft-Heinz, Novelis, Kellogg's and PepsiCo. 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 Essity focuses on the following four main elements:

- A feasibility review in respect of the main issues associated with switching three Essity sites (all located in the North West of England) to hydrogen;
- The process of site selection, scoping and outline design of a programme of work to demonstrate hydrogen fuelling of a selected Essity site;
- A high-level estimate of the cost of converting the three Essity sites to hydrogen; and
- How the findings from the work can be extrapolated across the paper sector in respect of scaling-up, build rate and replicability.

The key messages in respect of the work undertaken in relation to the Essity sites can be summarised as follows:

- There appear to be no insurmountable barriers to switching the core tissue paper manufacturing process to hydrogen from natural gas, albeit this is subject to confirmation during a physical demonstration programme;
- At the time of writing, it appears very likely that a bid will be made by Essity, in partnership with 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 dual-fuel hydrogen and natural gas Yankee burners at Tawd Mill; and
  - Lab-based assessment of the effect of hydrogen on TAD fabric;
- The demonstration would consider impacts upon product quality, efficiency, equipment lifetime, burner suitability and NOx emissions;
- There are four paper machines encompassing two burner types (Yankee and TAD) across the sites under consideration. The demonstration programme will be designed in such a way that the evidence which comes from the work will be relevant to the other burners and machines 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 Essity to maintain the ability to use natural gas and hydrogen interchangeably. The demonstration programme, therefore, will include running burners on hydrogen, natural gas and a blend of both gases;
- In respect of the boilers at each of the Essity sites:
  - The preliminary conclusion based on the Feasibility Study is that the boilers in place are all suitable for switching to 100% hydrogen;
  - The primary modifications required to operate on hydrogen are replacement of the existing burners, and the use of flue gas recirculation (FGR) and/or de-rating to mitigate expected rises in NOx generation. Burners compliant with 2025 MCPD limits will be suitable for operation on a 20% blend of hydrogen; 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 Essity sites to hydrogen and subsequent deployment of the solutions at wider, similar sites largely depends upon the deployment of the wider HyNet hydrogen and (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.

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
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Contents

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, equipment or products;
- Demonstrate that sites can operate in conformance with all safety regulations;
- 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 Essity UK Limited ('Essity'). PEL was also awarded Phase 1 funding by BEIS to undertake similar studies in relation to sites operated by Kraft-Heinz, PepsiCo, Novelis 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 Essity and the wider HyNet IFS2 (and IFS1) programmes 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 Utilisation and Storage (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 carbon dioxide (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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3 Cadent & Progress ve Energy (2018) HyNet Nor h Wes : From V s on to Rea y, June 2018 h ps://hyne co uk/app/up oads/2018/05/14368 CADENT PROJECT REPORT AMENDED v22105.pdf
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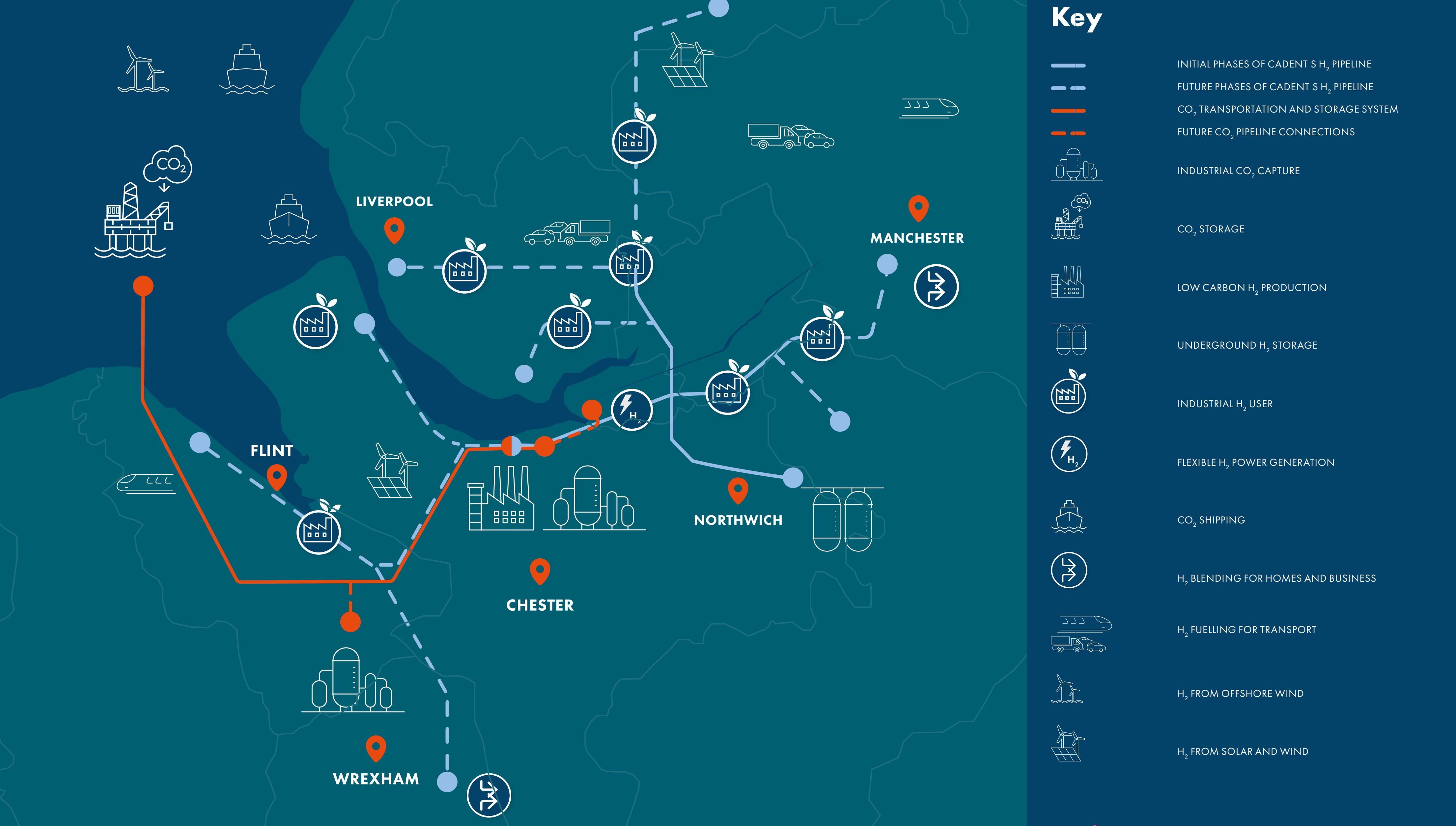
Figure 1 1: Overview of the HyNet Project



1.3 Scope and Objectives of this Report

The programme of work focuses on the following four main elements:

- A feasibility review in respect of the main issues associated with switching three Essity sites (all located in the North West of England) to hydrogen;

- The process of site selection, scoping and outline design of a programme of work to demonstrate hydrogen fuelling of a selected Essity site;

- A high-level estimate of the cost of converting the three Essity sites to hydrogen; and

- How the findings from the work can be extrapolated across the paper sector in respect of scaling-up, build rate and replicability.

2 Essity

Essity's UK and Republic of Ireland Consumer Goods business is made up of personal care and tissue products for use in the home, including leading household brands such as Bodyform and TENA. In the UK, Essity employs 1,000 people across six manufacturing sites, producing branded and own label paper products for the UK market including Cushelle toilet roll, Tork paper products, and Plenty household towel.

2.1 Essity Emissions Reduction Targets

Sustainability has always been a priority at Essity, and major progress has been achieved along with increasing ambitions. To reduce its environmental impact, Essity has committed to reach net-zero greenhouse gas emissions by 2050. In the short term, Essity is also committed to reducing Scope 1 and Scope 2 CO_2 emissions by 35% (from a 2016 baseline) by 2030.

2.2 Tawd Mill

After suspending operations in 2008, Essity's Tawd Mill was recommissioned in 2017 following a £12m investment and now makes premium tissue paper that is converted at other sites into products such as Plenty household towel. Employing 42 people, the site produces ~26,000 tonnes of tissue 'mother-reels' per year from one paper machine. In 2021, gas consumption for the site was 119.4 GWh; in 2020 it was 128.8 GWh.

As described in detail in Section 4.0, Essity's Tawd site has been selected for the Phase 2 demonstration. An aerial view of the site is presented in Figure 2 1.

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Figure 2 1: Aerial view of Essity's Tawd Mill in Skelmersdale

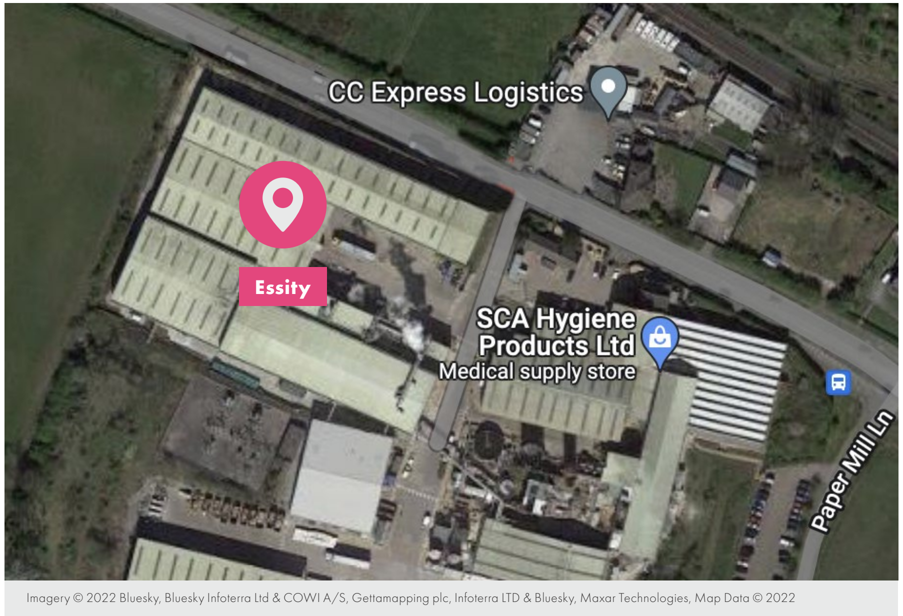


Figure 2 2: Aerial view of Essity's Oakenholt site

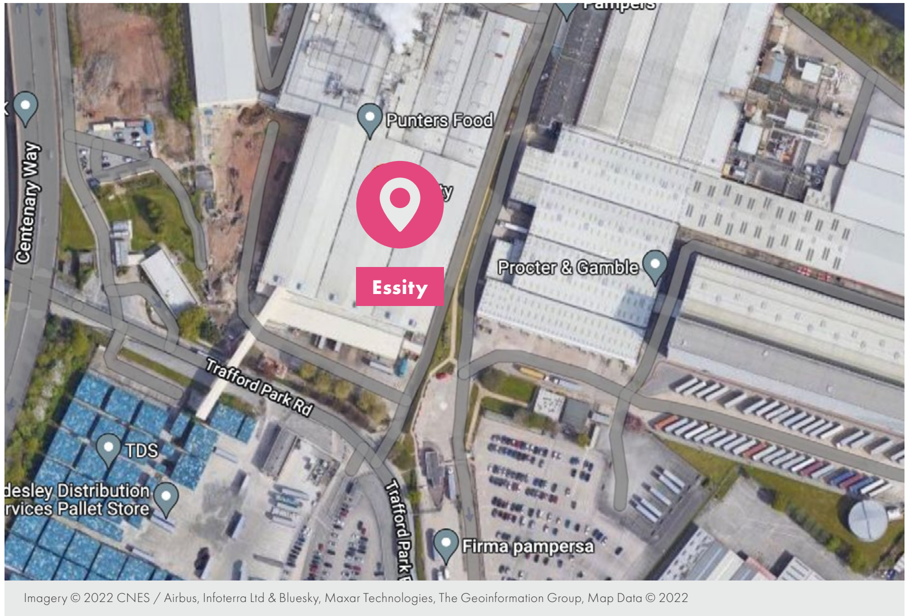


Figure 2 3: Aerial view of Essity's Manchester site

2.3 Oakenholt

The Oakenholt site has been recorded as a paper mill dating back to 1875, and has a production capacity of up to 70,000 tonnes per year from two paper machines. It produces toilet tissue, facial tissue and paper towels for the UK branded and Private Label markets. In 2021, gas consumption for the site was 55 GWh; in 2020 it was 61 GWh.

An aerial view of the site is presented in Figure 2 2.

2.4 Trafford Park

Essity's Manchester Mill is a site capable of producing 44,000 tonnes of tissue mother-reels per year from one paper machine. As the site is integrated, several lines are available to convert the mother-reels into products that are ready to be sent directly to customers. Brands made in Manchester include Plenty and Cushelle, as well as own-brand labels for major retailers. The mill employs approximately 148 people and is situated at Trafford Park, Europe's largest industrial estate. In 2021, gas consumption for the site was 115 GWh; in 2020 it was 127 GWh.

An aerial view of the site is presented in Figure 2 3.

2.5 Overview of the Paper-making Process

At each site, paper production accounts for the majority of thermal energy consumption. This process takes place on a paper machine where a low consistency (>99% water) solution of virgin and/or recycled pulp is formed, pressed and dried to form tissue mother-reels of moisture content <2% or <6%, depending on the process. These mother-reels can be 1-2m in diameter, up to 3.4m wide and 1-2t in weight. Subsequently, the mother-reels are used to make finished goods such as toilet rolls and kitchen towel.

Thermal energy is required to remove water that cannot be removed mechanically through gravity, pressing or vacuum. It is delivered either as steam from the site boiler plant, or high velocity hot air provided by burners integrated to the paper machine's hot air systems.

Essity's three paper-making sites in the North West and North Wales all use a combination of different methods to dry paper. The machines present at all 3 sites can be categorised as either:

- 'Conventional' - Oakenholt machine 1 & 2; or
- 'Through Air Dried' (TAD) - Manchester machine 1 & Tawd machine 1.

The categorisation is made according to the drying processes used in each machine. Illustrations of typical Conventional and TAD machines are shown in Figure 2 4 and Figure 2 5.

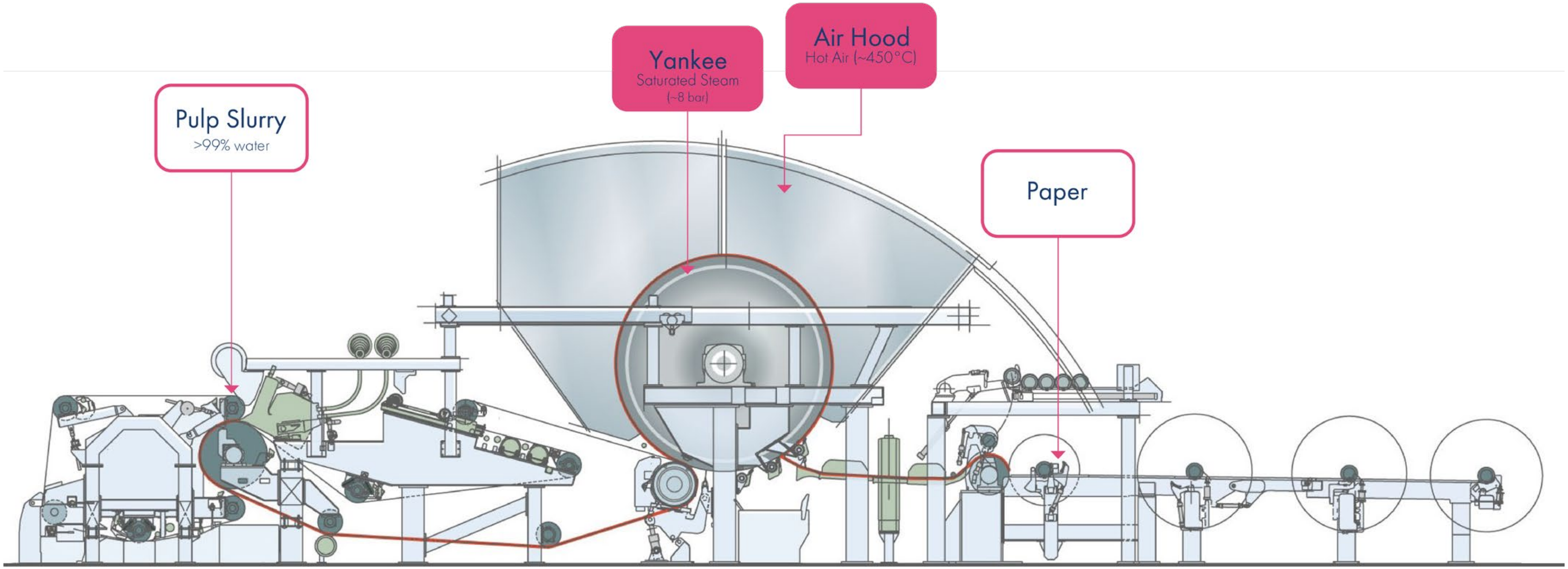


Figure 2 4 Schematic of a Conventional Paper Machine

Note: Product moves left to right through the drying process

Thermal demand in Conventional machines comes from two drivers. First, steam is required to pressurise a rotating drying cylinder (Yankee). The paper is carried on the external surface of the Yankee and steam is condensed on the internal surface. The condensing steam releases heat which is transferred through the Yankee shell to the paper. In addition, two hood caps sit atop the Yankee surface and blow high velocity, high temperature (around 100 m/s, 400°C) air onto the paper surface, causing impingement drying. Moist air is simultaneously removed and partially exhausted to environment via a heat recovery network. The remaining fraction is recirculated back through the system and reheated. On average, three reels of paper per hour are processed through a Yankee burner.

TAD machines do not utilise mechanical drying, because the design of the finished paper relies on high calliper and absorbency while using a lower fibre content. Mechanical pressing of the paper would destroy this effect. To compensate, an additional thermal drying stage is added. The paper is carried, using a porous fabric, over a porous drum through which hot air is driven using two recirculation fans. TAD machines also feature the same Yankee and hood drying configuration that is present in Conventional machines.

Steam is supplied to the paper machine via gas fired boilers, typically of firetube design rated up to 20MW thermal output. Conventional and TAD air systems are heated using gas fired inline burners rated up to 13MW thermal output. Site gas consumption and CO_2 emissions are presented in the Table 2 1.

Site	2020		2021	
	Gas Consumption (GWh)	Scope 1 CO_2 emission (tonnes)	Gas Consumption (GWh)	Scope 1 CO_2 emission (tonnes)
Manchester	127.4	23,200	115.3	21,300
Tawd	128.8	23,800	119.4	22,000
Oakenholt	61.2	11,300	55.0	10,200

Table 2 1 Site Gas Consumption and CO_2 Emissions

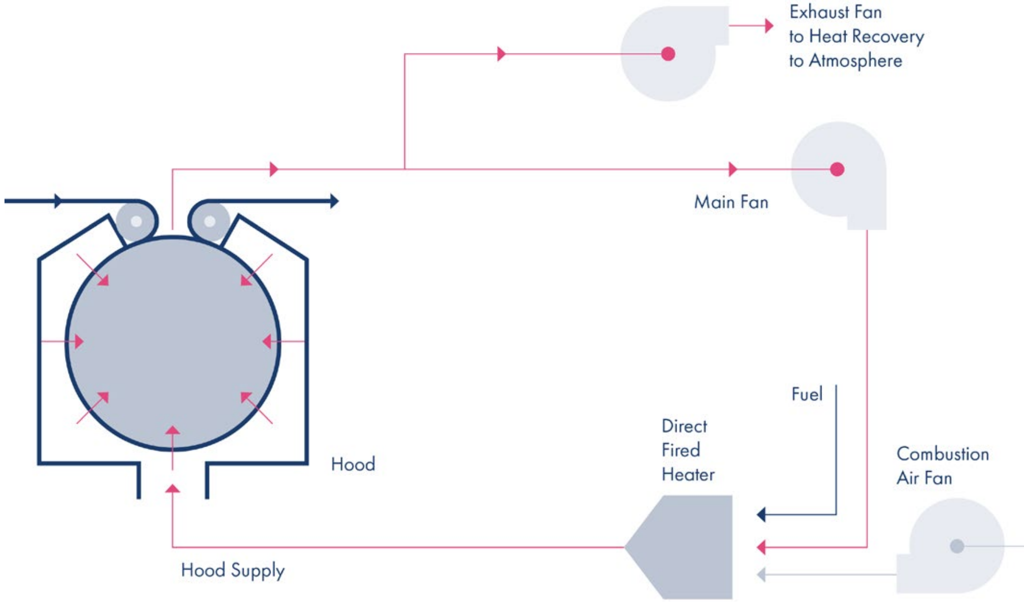
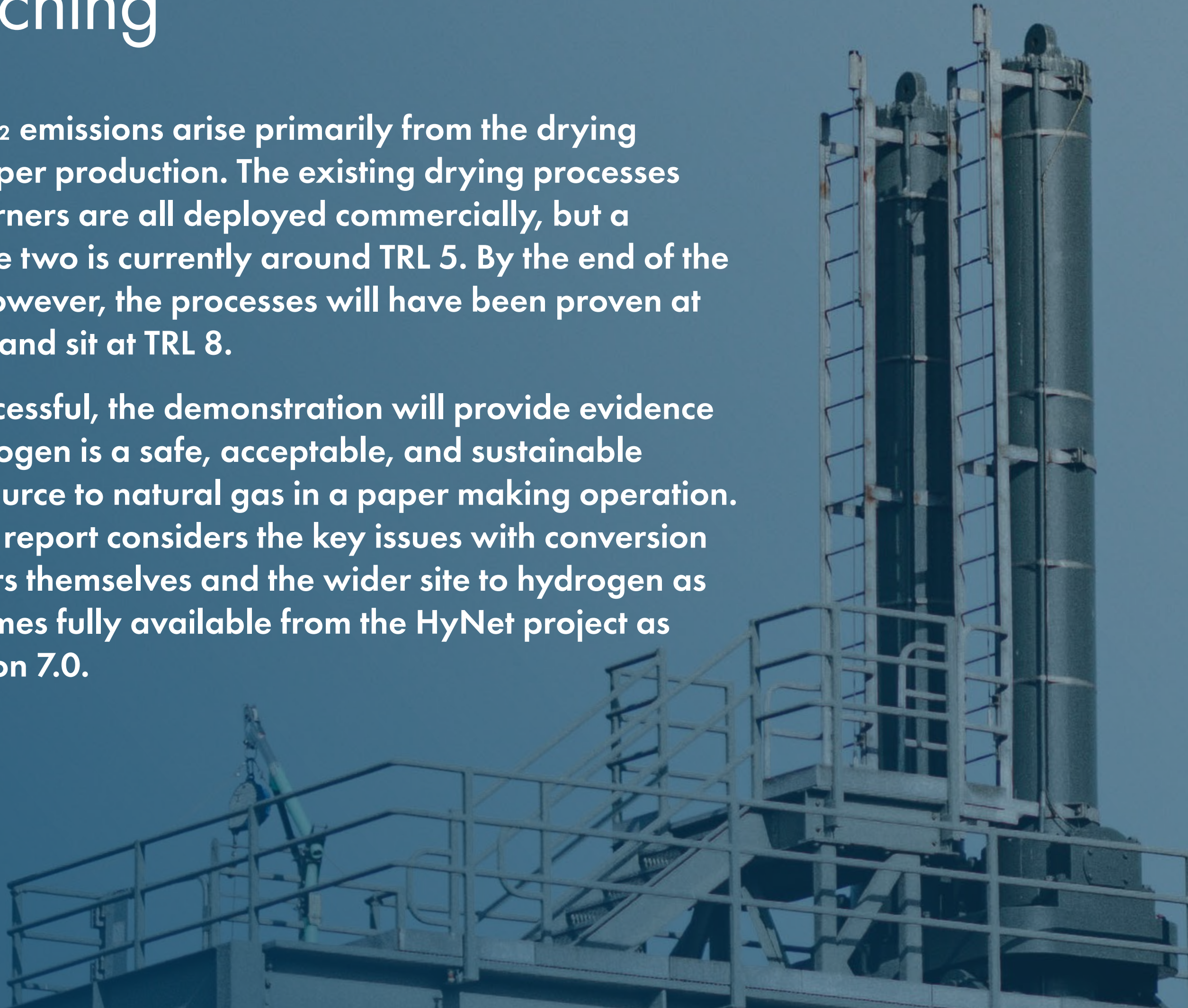


Figure 2 5 Schematic of TAD section of a Through Air Dried (TAD) Paper Machine

3 Essity: Feasibility of Hydrogen Fuel Switching

At Essity sites, CO_2 emissions arise primarily from the drying process within paper production. The existing drying processes and hydrogen burners are all deployed commercially, but a combination of the two is currently around TRL 5. By the end of the demonstration, however, the processes will have been proven at commercial scale and sit at TRL 8.

Assuming it is successful, the demonstration will provide evidence to show that hydrogen is a safe, acceptable, and sustainable alternative fuel source to natural gas in a paper making operation. This section of the report considers the key issues with conversion of both the burners themselves and the wider site to hydrogen as soon as this becomes fully available from the HyNet project as discussed in Section 7.0.



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 Essity sites from the HyNet Phase 2 hydrogen network from 2027, and in the early years of operation it is not inconceivable that supply interruptions will occur.

Given this, 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 Essity 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.

Essity's manufacturing sites consume large quantities of natural gas. For full conversion of the sites to hydrogen, 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.

3.2 Alternative Options for Decarbonisation

TAD and Conventional dryers at Essity's facilities provide the thermal energy that is required to reduce the total moisture content of the paper from 99.7% to 2% (TAD) or 6% (Conventional).

Over the past decade, Essity has considered the following alternative decarbonisation opportunities for the paper-making process:

Biomethane:
Combustion processes can operate by replacing natural gas with biomethane with little to no alteration to the gas train. However, it is challenging to source sufficient biomethane (from anaerobic digestion plants) at an attractive cost. Furthermore, space constraints and the requirement for new consents and permits are such that production on site is not an attractive option.

Electrification:
Essity has one electrified heating system for hot air drying in operation. Relative to the cost of natural gas, however, (even taking into consideration recent significant increases in both natural gas and power costs) electrification of any of the above three sites would be prohibitive. In addition, significant grid infrastructure upgrades would also be required to enable greater supply of electricity to the sites, along with replacement of key equipment.

Pyrolysis of waste to produce syngas or synthetic oil:
The viability of this option depends upon appropriate forms of biowaste being sourced onsite. The only potential feedstock is cellulosic sludge, which has high moisture content and low calorific value and so would require significant treatment and investment. Any pyrolysis unit would also require significant space and so is very unlikely to be attractive.

Combustion of solid biomass:
Secure supplies of biomass for the three sites are not available from third parties in sufficient quantities and, as above for pyrolysis, sludge requires too much processing to be an attractive fuel.

Essity has published a roadmap to achieve net-zero greenhouse gas emissions by 2050. The document includes targets, key action areas, public policy involvement, governance and reporting, and calls for action to policymakers. Essity's journey to net-zero is illustrated in Figure 3 1.

Aside from biomethane, which is not available in sufficient quantities, of the technologies under consideration, hydrogen is the closest to the existing configuration for natural gas, and so has the highest Technology Readiness Level (TRL). Once proven at Essity Tawd Mill, the solution can be rolled out across all Essity sites within the HyNet region by 2030. Wider deployment of the hydrogen solution does depend on local availability of hydrogen, and so pursuit of alternative solutions is important to ensure full decarbonisation of Essity's worldwide operations.

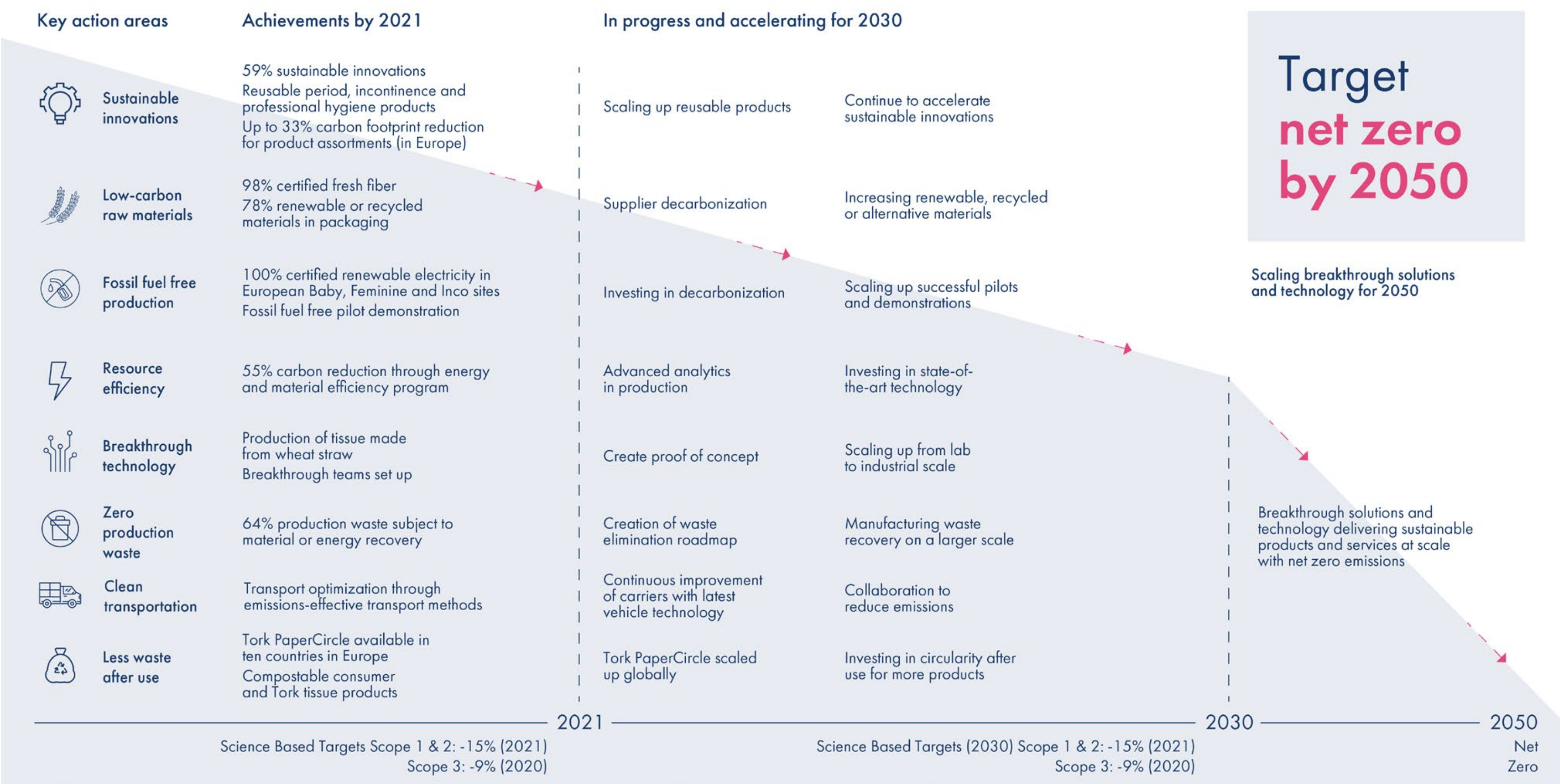


Figure 3 1 Essity's Journey to Net Zero

3.3 Considerations for Proposed Hydrogen Demonstration

This Feasibility Study has concluded that the existing Yankee burners must be upgraded to modern 'hydrogen ready' burners, capable of 100% hydrogen, 100% natural gas, or a blend anywhere in between. The accurate blend ratio will be achieved by a blending station incorporated into the gas train, designed by the burner OEM, utilising servo valve technology, sensors, and a PLC for closed-loop control. The ability to manipulate the blend ratio will allow the trial to be seamlessly incorporated into normal production activities.

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

3.3.1 Transferability of Evidence from Yankee to TAD burners

As the largest consumer of gas in Tawd and Manchester sites, it is important that any impact on the TAD system is fully understood. TAD fabric condition is critical to product quality and at Tawd a typical lifetime of 30 days can be expected for a TAD fabric.

Separate to the Yankee demonstration at Tawd, Essity has asked the TAD fabric supplier to develop a trial to test the impact of various blends of hydrogen and natural gas on the condition of the TAD fabric. Using a test rig located at the supplier's site, it will be possible to replicate humidity, temperature and pressure conditions of a TAD environment. The rig can operate on natural gas, hydrogen or a blend of both. Fabric samples will be exposed to the air flows generated by the rig using different blends of natural gas and hydrogen and key properties will be measured. These properties can then be compared to understand if any change arises from altering the fuel mixture used.

3.3.2 Product Quality

The project must determine if the introduction of hydrogen as an alternative fuel source has any impact on the quality of the product (in comparison to that made using natural gas). The thickness, density and dryness of the paper must also be maintained and could be affected by changes to the moisture content of the combustion gases. As the use of hydrogen does not interfere with the raw materials, pulping, refining, or forming process, and is simply an alternative fuel used to dry the wet sheet, it is anticipated that there will be no effect on the quality of the product produced. Input from the Yankee burner OEM has been obtained and quality will be monitored throughout Phase 2 demonstration.

3.3.3 Efficiency

The amount of available drying capacity is critical to paper manufacturing and can often be the bottleneck to production. Maintaining or improving burner efficiency is therefore critical to a successful full scale demonstration.

Combustion of hydrogen results in an increase in the moisture content in combustion products compared to natural gas, and this increase in moisture content could be expected to hinder drying, reducing process efficiency and drying capacity. However, replacement of the existing combustion system with a more modern system that has better control of combustion air can be expected to have a positive effect on process efficiency.

Execution of the trial will provide valuable insights as to the relative importance of these effects, and the overall impact of hydrogen on process efficiency.

3.3.4 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. Whilst an increase in NOx emissions is anticipated, the quantity of this increase is yet to be understood. Essity will monitor NOx discharge levels before and during any hydrogen trials to quantify and understand the NOx level increase. If NOx emissions rise significantly, work undertaken during the HyNet IFS1 Programme has provided confidence that NOx emissions can be managed via flue gas recirculation (FGR), to operate within existing regulatory limits. FGR would also likely enable tighter limits to be met in the future if required.

3.3.5 Burner Suitability

The existing burners at Essity's Tawd Mill have been installed since the factory first entered production in 1998. Engagement with the burner OEM has revealed the existing Yankee burners are not suitable for use with hydrogen and must be upgraded to suitable alternatives, which are available from the OEM. Burner condition will subsequently be monitored during the trial.

3.3.6 Potential to use Natural Gas and Hydrogen Interchangeably

Essity's Tawd Mill is a 24/7 manufacturing site, and disruptions to production must be kept as low as reasonably practicable to ensure output demands are met. To achieve this, the project must find a solution to enable flexible switching and blending between natural gas and hydrogen, without disrupting the paper making operation.

The existing gas train must also be upgraded to incorporate a 'blending station' to enable 100% of natural gas, 100% of hydrogen, or any blend in between. In collaboration with Essity, the burner OEM is currently designing a suitable solution, which will be tested in its laboratory.

As described in Section 4.0, a range of hydrogen and natural gas blends will be demonstrated should the project secure Phase 2 funding.

3.4 Considerations for Boilers

For both Conventional and TAD production, the drying process relies on provision of saturated steam to the Yankee drum. Accordingly, the boilers at Essity's production sites consume significant quantities of natural gas. Decarbonisation of the sites relies on converting the boilers to use hydrogen.

There are four boilers across the three Essity sites in the HyNet area, each with different boiler shell and burner manufacturers, and installation dates between 1998 and 2017. Accordingly, conversion to hydrogen has different implications for each boiler.

From a preliminary assessment, each of the boilers should be capable of operating on 100% hydrogen. At all of the sites, there will be a need for some relatively straightforward works to be undertaken on the gas system within the boiler houses. Furthermore, DSEAR assessments and boiler house risk assessments will be required in order to ensure the change in fuel gas is implemented safely. For the burners, the key factor is NOx emissions.

There are three relevant considerations relating to the burners and to NOx emissions:

1. Tightening NOx emissions limits in 2025, under the Medium Combustion Plant Directive (MCPD)
2. Impact of introduction of a blend of 20% hydrogen into natural gas
3. Impact of using 100% hydrogen

The primary strategies for reducing NOx emissions are:

1. Installation of low-NOx burners
2. Derating of boilers to a lower steam generation capacity
3. Introduction of Flue Gas Recirculation (FGR)

For each boiler, a new burner will be required in order to fire 100% hydrogen. Depending on the boiler, a combination of FGR and/or de-rating by up to 20% will then be needed in order to comply with NOx limits (a 20% de-rating should not affect the ability of the boilers to meet site steam demand).

However, it is worth noting that some of the installed burners will require replacement simply to meet the new MCPD limits, in advance of the availability of 100% hydrogen. Due consideration must be given as to the merits of installing a hydrogen-ready burner at that point.

Ultimately, it is for Essity to consider its strategy going forward, taking into account the remaining operational life of the boilers, the costs of conversion and the timings and costs of the upgrades required for continued operation of the existing system on natural gas.

4 Site Selection

and Scoping of Phase 2 Programme

The first stage of the Feasibility Study focused on reviewing the feasibility of switching the burners at Essity sites to hydrogen. Subsequently, the objective of the work was to design a programme of work to provide sufficient evidence to support the switching of these (and wider) sites, to low carbon hydrogen fuel.

4.1 Site Selection

At project conception, three potential Essity sites at which the Phase 2 demonstration could take place were considered:

- Oakenholt;
- Tawd; and
- Manchester.

The overarching objective of the demonstration programme is to gather useful data and information that will enable Essity 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 all of its sites in the North West England and North Wales region 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:

- How representative the paper making machinery is of systems and processes used throughout the Essity business in the UK and whether it is reasonable to extrapolate from a particular site to the wider business;
- Ease of modifying existing burner technologies;
- The availability of engineering and management resources to drive and deliver the demonstration programme;
- Physical space and accessibility to enable the construction of a hydrogen 'compound' for the duration of the demonstration programme (which will be using tanker/tube-trailers for hydrogen delivery);
- Wider safety considerations, taking into consideration the possible location of the hydrogen compound, complexity of overall site layout and routing to the paper mill burners, vehicle movements, staff movements and other site-wide safety aspects; and
- The business interruption impact of running a demonstration.

The above criteria were used to consider each of these sites, using a 'red-amber-green' traffic-light approach. 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.

The information presented in Table 4 1 strongly suggests that Tawd is the most attractive site for running a hydrogen fuel switching demonstration.

Under guidance from Essity's internal technology team, it was determined that running a demonstration using Yankee burners would also be representative of TAD burners, and so give confidence to Essity to switch all burners to hydrogen. Consequently, it was agreed that the full scale demonstration at Tawd would focus on Yankee burners only, provided separate assessment of the impact of hydrogen on TAD fabric is performed as per Section 3.3.1.

Criteria	Weighting	Oakenholt	Tawd	Manchester
1. Representativeness	5	No TAD system		
2. Ease of modifying existing burners	4	High mod. costs		
3. Resource availability	3			Competing projects
4. Space & accessibility	5	Limited options for compound		
5. Safety	5			
6. Business interruption cost	3		Higher-value product	Higher-value product

Table 4 1: Site Assessment Matrix

4.2 Summary of Proposed Phase 2 Demonstration Programme

The proposed demonstration will switch the fuel source for the Yankee burners from natural gas to hydrogen, gradually increasing the percentage from 20%v/v hydrogen up to 100%v/v hydrogen. The demonstration plan, at the time of writing, is shown in Table 4 2.

	H_2 v/v%	NG v/v%	Duration
Day 1	20%	80%	1 hr
Day 1	20%	80%	4 hrs
Day 2	50%	50%	1 hr
Day 2	50%	50%	4 hrs
Day 3	75%	25%	1 hr
Day 3	75%	25%	4 hrs
Day 4	100%	0%	1 hr
Day 4	100%	0%	4 hrs

Table 4 2: Planned Test Programme

The hydrogen-firing dates are likely to be split across a two-week period. Key quality metrics will be monitored during the demonstration to assess if there is any impact on product quality as a result of the change in fuel. The metrics to be monitored have been outlined in Table 4 3.

Mother-reel Quality Metric	Unit	Measurement	Current Frequency	Control	Propsed Change to Measurement Strategy
Moisture Content	%	Automatic – scanner linked to QCS	Continuous	Auto – Hood temperature setpoint	None
Basis Weight	g/m^2	Automatic – scanner linked to QCS Manual	Auto-continuous Manual – every 3rd reel	Auto – Basis weight valve	Increase frequency of manual measurement to every reel during trial
Dry Tensile Strength	N/m	Manual	Every 3rd reel	Manual	
Wet Tensile Strength	N/m	Manual	Every 3rd reel	Manual	
Stretch	%	Manual	Every 3rd reel	Manual	
Bulk	μm	Manual	Every 3rd reel	Manual	

Table 4 3: Key Trial Metrics

5 Essity:

Indicative Costs 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 Essity sites to hydrogen as soon as this is available from the HyNet project.

Four main categories of costs are considered:

1. Production equipment conversion:
This relates to modification/replacement of production equipment, and includes design and installation and controls modifications.

2. Boiler conversion:
This relates to modification/replacement of boiler system equipment and associated plant, and includes design and installation and controls modifications.

3. 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.

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 in Table 5 1 provides a preliminary, indicative 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.

Site	Production Euipment	Boilers	Pipework & Ancillaries	Hydrogen Reception	Total
Tawd Mill	£2.0M	£0.2M	£0.4M	£0.4M	£3.0M
Oakenholt	£1.6M	£0.3M[1]	£0.3M	£0.4M	£2.6M
Trafford Park	£2.5M	£0.3M	£0.5M	£0.4M	£3.7M

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

[1] This assumes that the existing boilers at Oakenholt are modified (with new burners), rather than replaced. However, given the age of the existing boilers, Essity may prefer to replace them, in which case the indicative capex budget should be increased by a further estimated £0.5M

6 Extrapolating Findings

across the Paper Sector

This analysis relates to paper-making machines only, as the previous work at Unilever lead by PEL has considered the wider applicability of hydrogen use in boilers.

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 programme of work presented above draws 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 Essity 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 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

Based on the above levels of current direct process emissions from Essity's three sites alone, the solution could deliver abatement of around 78,000 tCO_2/annum. Total emissions from the UK paper sector are estimated to be around 1.6Mtpa.[6] Whilst only a proportion of these emissions are from TAD and Conventional machines (the remainder being from boilers and CHP plant), this gives an idea of the sector-wide emissions reduction potential of the solution.

The information from this study will also be sufficiently diverse to be applicable to the vast majority of Essity's 95 global sites. Sharing this information across the business therefore represents significant opportunity to decarbonise global tissue manufacturing.

Information will be shared outside Essity and so this approach will deliver huge impacts in terms of decarbonising the wider paper sector on a global basis. Total emissions from the European paper sector are estimated to be around 28Mtpa.[7] Again, as in the UK context, whilst only a proportion of these emissions are from TAD and Conventional machines, this gives an idea of the emissions reduction potential of the solution at a European level.

6 CPI (2022) UK Paper Sector Decarbon sation Roadmap Technical Update, February 2022 https://thecpi.org.uk/l brary/PDF/Public/Publications/Position%20Papers/PP 2050RoadmapFeb22.pdf
7 CEPI (2022) Key S atist cs 2021, European pulp & paper industry, June 2022 https://www.cepi.org/wp content/uploads/2022/07/Key Stat stics 2021 Final.pdf
https://www.cepi.org/wp content/uploads/2020/11/Roadmap 2050 Final 2017.pdf

7 HyNet Infrastructure Development

across the Paper Sector

As described in Section 1.2, deployment of the technical solution will not 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 Essity 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.

Figure 7 1: Hydrogen Production Hub Location at Stanlow

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. This presents engineering information relating to the Hub, which will use UK company, Johnson Matthey's Low Carbon Hydrogen (LCH^{TM}) production technology.[8]

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.[9] The ambition of HyNet is to switch around 45% of the region's natural gas consumption to low carbon hydrogen by 2030.

8 HyNet Nor h 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/ government/uploads/sys em/uploads/at achmen data/file/1056041/Phase 2 Repor Progress ve Energy HyNe Low_Carbon Hydrogen 3 .pdf

9 Net Zero Nor h Wes North Wes C uster Plan Interim Findings April 2022 h ps //ne zeronw.co.uk/wp conten /up oads/2022/04/NZNW C uster Plan Interim Findings April 2022 pdf

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 7 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 7 1: Deployment Profile for HyNet Hydrogen Production

7.2 Hydrogen Business Model

As mentioned above, the Vertex Hub has been shortlisted under Phase 2 of the Government's Cluster Sequencing process.[10] 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.[11]

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's in the Government's Hydrogen Strategy.[12]

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.[13] 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.

10 h ps://www gov uk/governmen /publicat ons/c uster sequencing phase 2 eligib e projec s power ccus hydrogen and icc/c uster sequencing phase 2 shor sted projects power ccus hydrogen and icc augus 2022

11 BEIS (2022) Agreement for The Low Carbon Hydrogen Bus ness Mode : Ind ca ve Heads Of Terms, Apr l 2022 h ps //asse s pub sh ng.serv ce.gov uk/governmen / uploads/sys em/uploads/a achment da a/fi e/1067365/ nd ca ve heads of erms for he low carbon hydrogen bus ness mode .pdf

12 HM Governmen , UK Hydrogen S rategy Augus 2021 h ps://asse s publishing service gov uk/governmen /up oads/system/up oads/a tachmen data/fi e/1011283/ UK Hydrogen S ra egy web.pdf

13 BEIS (2022) Hydrogen Bus ness Model and Net Zero Hydrogen Fund: Market Engagement on E ec ro y c A ocat on, Apr l 2022 h ps //asse s.pub sh ng.serv ce gov.uk/ governmen /up oads/sys em/up oads/a achmen data/file/1067159/hydrogen business mode net-zero hydrogen fund market-engagement-e ectro yt c a oca on.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.[14] 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.

14 www.hydeploy.co.uk

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.[15] 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.

At the time of writing, Government is currently consulting upon business models for hydrogen transportation and storage.[16] These are critical enablers and must be progressed rapidly to enable use of hydrogen by industry.

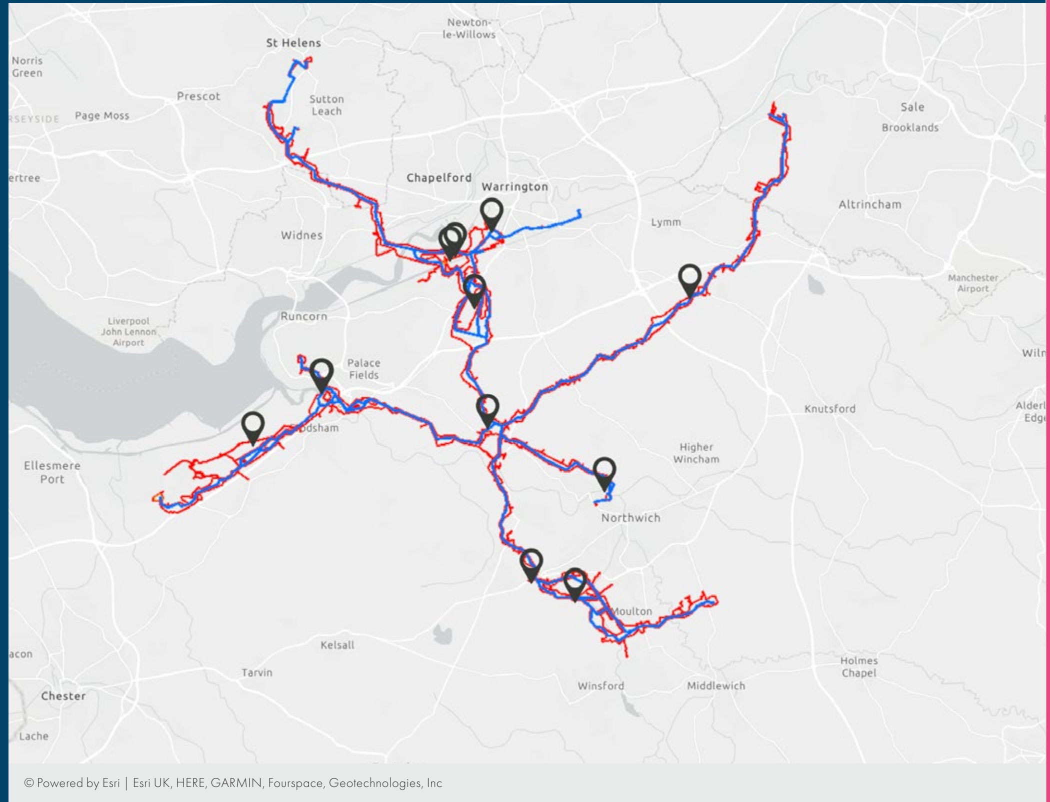


Figure 7 3: Proposed HyNet Hydrogen Network Routing Corridors

15 h ps://www hyne hydrogenpipeline co uk/
16 BEIS (2022) Hydrogen transport and s orage infras ructure: 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

8 Key Messages

The key messages in respect of the work undertaken in relation to the Essity sites can be summarised as follows:

- There appear to be no insurmountable barriers to switching the core tissue paper manufacturing process to hydrogen from natural gas, albeit this is subject to confirmation during a physical demonstration programme;
- At the time of writing, it appears very likely that a bid will be made by Essity, in partnership with 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 dual-fuel hydrogen and natural gas Yankee burners at Tawd Mill; and
  - Lab-based assessment of the effect of hydrogen on TAD fabric;
- The demonstration would consider impacts upon product quality, efficiency, equipment lifetime, burner suitability and NOx emissions;
- There are four paper machines encompassing two burner types (Yankee and TAD) across the sites under consideration. The demonstration programme will be designed in such a way that the evidence which comes from the work will be relevant to the other burners and machines 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 Essity to maintain the ability to use natural gas and hydrogen interchangeably. The demonstration programme, therefore, will include running burners on hydrogen, natural gas and a blend of both gases;
- In respect of the boilers at each of the Essity sites:
  - The preliminary conclusion based on the Feasibility Study is that the boilers in place are all suitable for switching to 100% hydrogen;
  - The primary modifications required to operate on hydrogen are replacement of the existing burners, and the use of flue gas recirculation (FGR) and/or de-rating to mitigate expected rises in NOx generation. Burners compliant with 2025 MCPD limits will be suitable for operation on a 20% blend of hydrogen; and
  - The switch to hydrogen would necessitate wider assessment of operations 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 Essity sites to hydrogen and subsequent deployment of the solutions at wider, similar sites largely depends upon the deployment of the wider HyNet hydrogen and (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.[17] These are critical enablers and must be progressed rapidly to enable use of hydrogen by industry.

17 BEIS (2022) Hydrogen transport and storage infrastructure: A consu tation on business model des gns, regulatory arrangemen s, strategic plann ng and the role of blending. August 2022
https://www.gov.uk/government/consu tations/proposals for hydrogen transport and storage business models

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
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations
EA	Environment Agency
EPC	Engineering, Procurement and Construction

Term	Description
EPCM	Engineering, Procurement and Construction Management
FEED	Front End Engineering Design
FGR	Flue Gas Recirculation
FID	Final Investment Decision
g/m^2	Grams per square metre
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
HSE	Health & Safety Executive
IDC	Industrial Decarbonisation Challenge
IFS	Industrial Fuel Switching
HHV	Higher Heating Value
km	Kilometre
kNm^3/h	Thousands of Normal Cubic Metres per hour
kW	Kilowatt
LCoH	Levelised Cost of Hydrogen

Term	Description
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
NOx	Oxides of Nitrogen
NTS	National Transmission System
NZHF	Net Zero Hydrogen Fund

Term	Description
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
USD	United States Dollars
%v/v	Percentage by Volume
WHRB	Waste Heat Recovery Boilers
XSA	Excess Air
µm	Micron (or micrometre)

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PROGRESSIVE ENERGY