H2JUICE FEASIBILITY STUDY (IHA STREAM 2A)

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COSTAIN

PRINCES GROUP

Dŵr Cymru Welsh Water

WALES&WEST UTILITIES

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AACE	Association for the Advancement of Cost Engineering
ABP	Associated British Ports
AD	Anaerobic Digestion
AGI	Above-Ground Installation
AI	Artificial Intelligence
ALARP	As Low As Reasonably Practicable
Am^3/h	Actual cubic metres per hour
ATJ	Alcohol-to-Jet
ASME	American Society of Mechanical Engineers
barg	bar gauge
BEIS	Department for Business, Energy & Industrial Strategy
BIM	Building Information Modelling
BS	British Standard
CAPEX	Capital Expenditure
CCUS	Carbon Capture, Utilisation and Storage
CE	Conformité Europèene
CIP	Cleaning In Place
CMS	Combustion Management System
CO_2	Carbon Dioxide
COMAH	Control of Major Accident Hazards
COP	Coefficient of Performance
CP	Cathodic Protection
CTR	Cost Time Resource
d	day
DCWW	Dŵr Cymru Welsh Water
DEFRA	Department for Environment, Food & Rural Affairs
DESNZ	Department for Energy Security and Net Zero
DMZ	De-militarized Zone
DN	Diameter Nominal
DNO	Distribution Network Operator
DSEAR	Dangerous Substances and Explosive Atmosphere Regulations
DUKES	Digest of UK Energy Statistics
ECV	Emergency Control Valve
EMC	Electromagnetic Compatibility
EPCM	Engineering, Procurement and Construction Management
ESD	Emergency Shutdown
FEED	Front-End Engineering Design
FGR	Flue Gas Recirculation
F&G	Fire & Gas
GDN	Gas Distribution Network
GEU	Grid Entry Unit
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GRP	Glass-Reinforced Plastic
GS(M)R	Gas Safety (Management) Regulations
GVA	Gross Value Added
GW	Gigawatts
h	hour

HART	Highway Addressable Remote Transducer
HASEMP	Health, Safety and Environmental Management Plan
HAZID	Hazard Identification
HBM	Hydrogen (Production) Business Model
HGV	Heavy Goods Vehicle
HMI	Human-Machine Interface
HP	High Pressure
HSE	Health & Safety Executive
HSW	Hydrogen South West
H2	Hydrogen
IED	Industrial Emissions Directive
IGEM	Institution of Gas Engineers & Managers
IHA	Industrial Hydrogen Accelerator
IP	Intermediate Pressure
IRENA	International Renewable Energy Agency
I/O	Input/Output
kg	kilogram
kW	kilowatt
kWh	kilowatt hour
LAN	Local Area Network
LCOA	Levelised Costs of Abatement
LCOH	Levelised Costs of Hydrogen
LCHS	Low Carbon Hydrogen Standard
LCA	Life Cycle Analysis
LHV	Lower Heating Value
LP	Low Pressure
mA	milliamp
MAM	Meter Asset Manager
mbarg	millibar gauge
MEA	Monoethanolamine
mg	milligram
MM	million
MoU	Memorandum of Understanding
$MtCO_2e$	Millions of tonnes of Carbon Dioxide equivalent
MVA	megavolt amperes
MWh	Megawatt hour
m^3	cubic metres
NB	Nominal Bore
ND	Nominal Diameter
NG	Natural Gas
NGM	National Grid Metering
Nm^3/h	Normal cubic metres per hour
NPS	Nominal Pipe Size
NOx	nitrous oxide
NTS	National Transmission System
NWHA	Northwest Hydrogen Alliance
OGA	Oil & Gas Authority
OPEX	Operating Expenditure
PCV	Pressure Control Valve
PE	Polyethylene

PLC	Programmable Logic Controller
PRI	Pressure Regulating Installation
PRV	Pressure Relief Valve
PSA	Pressure Swing Adsorption
PSR	Pipeline Safety Regulations
R&D	Research & Development
RSR	Pipeline Safety Regulations
RIIO	Revenue = Incentives + Innovation + Outputs
s	second
SIF	Safety Instrumented Function
SME	Small to Medium-sized Enterprise
SMR	Steam-Methane Reforming
Sm^3	standard cubic metres
STEM	Science, Technology, Engineering and Mathematics
SWIC	South Wales Industrial Cluster
t	tonne
TBM	t-butyl mercaptan
tCO_2eq	tonnes of Carbon Dioxide equivalent
TIC	Total Installed Costs
TRL	Technology Readiness Level
UNC	Uniform Network Code
WGS	Water-Gas Shift
WP	Workpack
wt	weight
WwTW	Wastewater Treatment Works
WWU	Wales & West Utilities
yr	year
°C	degrees Celsius
£	UK Pound Sterling
€	Euro
$	US Dollar

EXECUTIVE SUMMARY

The H2Juice project, set in a key industrial Welsh heartland provides a replicable and scalable end-to-end fuel switching solution. The scheme entails a novel approach to hydrogen production, repurposing gas distribution pipelines and industrial fuel switching and will abate 2,113 tCO_2eq / year without CCUS. With the addition of carbon capture and storage the project has the potential to displace 8,270 tCO_2eq / year. The project also explores the potential industrial decarbonisation opportunities in deblending hydrogen from a future blended distribution network.

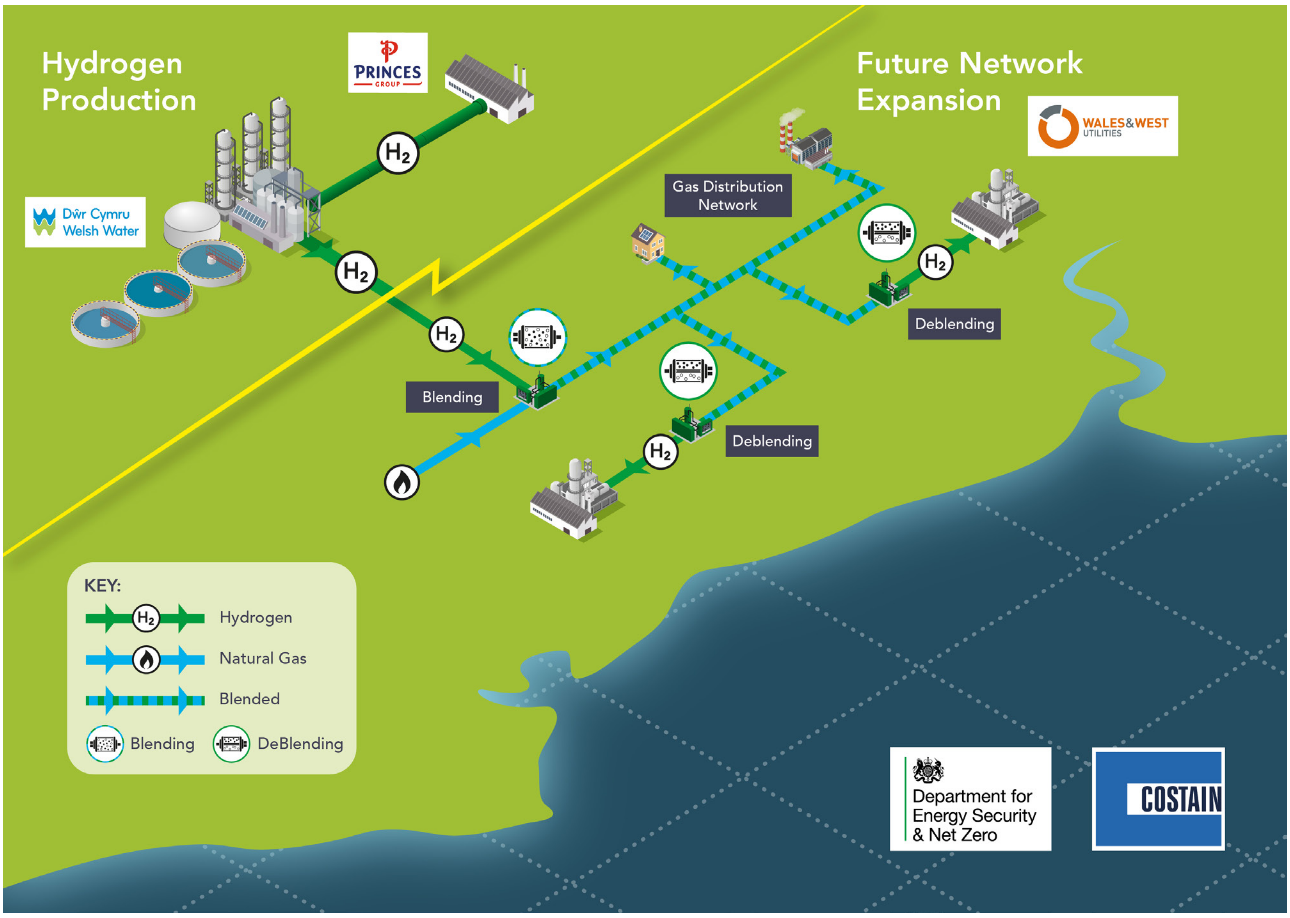


Figure 1 - H2Juice concept and future network expansion

This study has been produced by Costain Ltd (Costain) in partnership with Dŵr Cymru Cyfyngedig (Welsh Water), Wales & West Utilities (WWU), CR Plus and Princes Ltd for the Department for Energy Security and Net Zero (formerly Department for Business, Energy & Industrial Strategy) Industrial Hydrogen Accelerator (IHA) programme Stream 2A competition.

The objectives of the study were to:

- Develop the H2Juice concept and define the design requirements for FEED and demonstration in IHA programme Stream 2B competition (Stream 2B).
- Calculate the Levelised Cost of Hydrogen (LCOH) and Levelised Cost of Abatement (LCOA).

- Deliver a Class 4 Association for the Advancement of Cost Engineering (AACE) cost estimate for the IHA programme Stream 2B competition (Stream 2B) demonstration project.
- Calculate the emissions abatement of the H2Juice project.
- Assess the replicability and scalability of the concept.

Our chosen end user partner for the H2Juice project, Princes Ltd, has committed to decarbonise its operations and group activities, commencing with carbon neutrality for operations ahead of science-based targets for Net Zero being set during 2023-2024.

The Princes Ltd Cardiff soft drinks facility is located approximately 2 km from the Welsh Water Cardiff East Wastewater Treatment Works. The facility utilises high temperature steam in its operations, supplied by two industrial package boilers currently operating on Natural Gas, with a mean natural gas usage of 12,130,056 kWh per year. Demand is highly variable, increasing from base to peak demand in approximately 4 minutes. The site operates 24/7, 365 days a year. Any disruption to the site steam supply is expensive, shutting down operations for 24 hours to allow the pasteurisation process to be reestablished.

In this study we assessed the technology options currently available for fuel switching at the Princes Ltd facility. The key considerations for the technology assessment were:

- Levelised Cost of Hydrogen
- Emissions Abatement
- CAPEX / OPEX
- Availability / Reliability

The assessment concluded that fuel switching to hydrogen was the optimum solution, providing the lowest CAPEX, highest emissions abatement (with the addition of CCUS), and highest level of steam availability through deployment of dual-fuel burner technology, meaning the boilers could switch back to Natural Gas should there be any interruption to the supply of hydrogen.

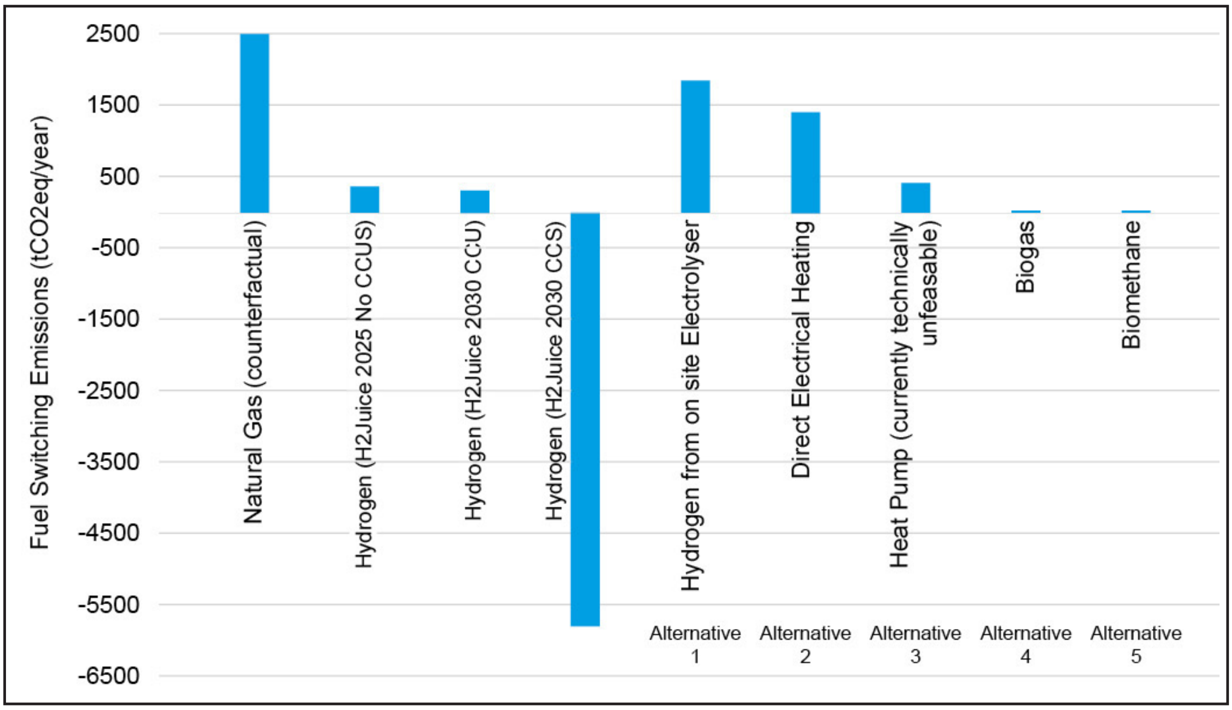


Figure 2 - Emissions Comparison for Fuel switching Technologies (incl.CCUS)

[1] *BEIS Industrial Strategy 2019*

The graphic values for the H2Juice project in Figure 2 represents the carbon intensity of the hydrogen produced by the H2Juice project for the following cases:

- Scenario 1 (2025): no CCUS i.e. CO2 from hydrogen production process vented to atmosphere
- Scenario 2 (2030): carbon capture facilities added to hydrogen production process. All captured CO2 utilised in end-use applications (e.g. food and drink sector), displacing fossil-fuel derived CO2.
- Scenario 3 (2030): carbon capture facilities added to hydrogen production process. All captured CO2 sequestered in a permanent underground store. (Assumed location: HyNet injection facility, Connah's Quay, north Wales).

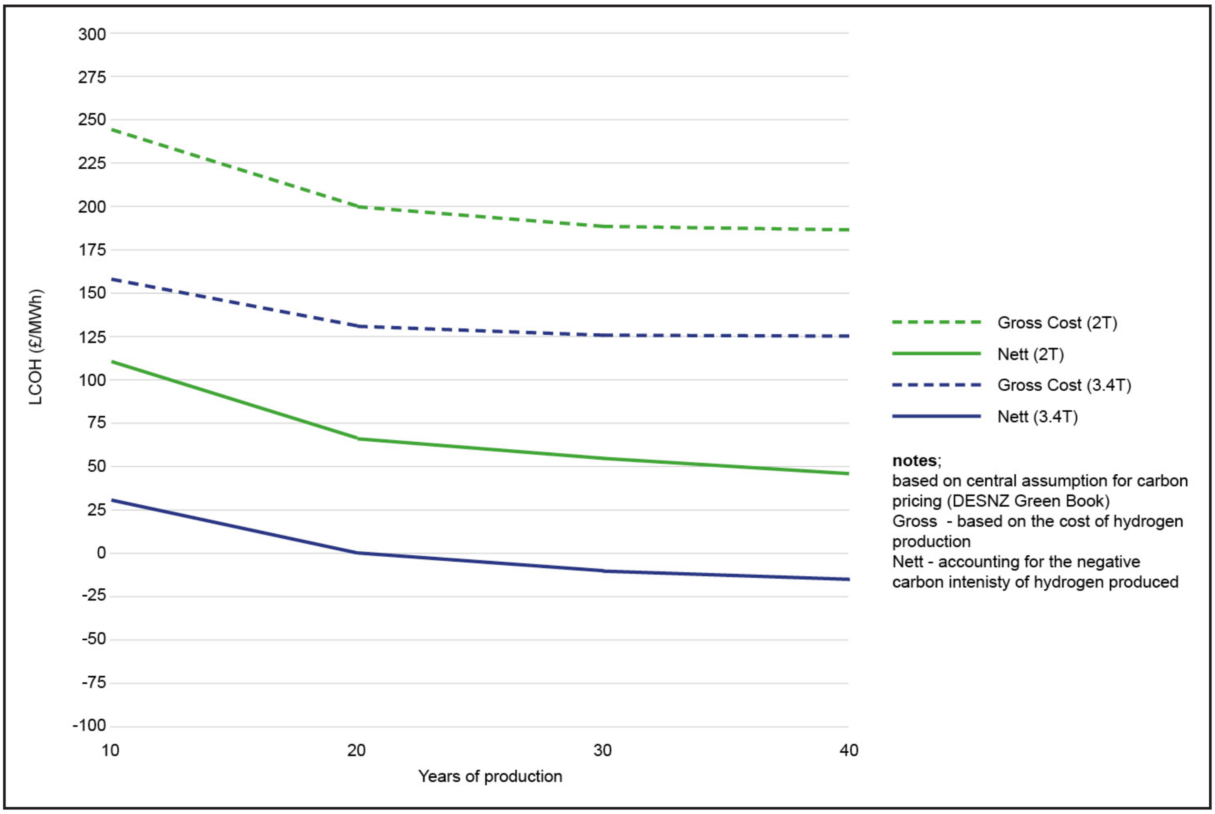


Figure 3 - Forecast LCOH

Figure 3 shows the calculated levelised cost of hydrogen for both the 2T and 3.4T production rates over the design life of the scheme. The gross values demonstrate the LCOH without accounting for the negative carbon intensity of the hydrogen produced, while the nett values include for this. This demonstrates that, when considering the negative intensity of the hydrogen produced, and the forecast cost of carbon, the H2Juice project can ultimately supply hydrogen with a forecast negative LCOH. All of these forecasts are based on Scenario 3, where the CO_2 is permanently sequestered.

The key components of the H2Juice concept developed in this feasibility study are:

- Hydrogen generation from sewage-derived biogas at the Welsh Water Cardiff East Wastewater Treatment Works (WwTW).
- High Pressure (HP) buffer storage of hydrogen to balance supply and demand.
- A pipeline connecting supply and demand, consisting of a section of new Medium Density Polyethylene pipeline (MDPE) and the repurposing of an existing Natural Gas pipeline to hydrogen duty.

- Industrial boiler modifications at the Princes Ltd facility to demonstrate how their industrial package boilers could switch to enriched hydrogen blends and a 100% hydrogen supply to accommodate fuel switching, resulting in decarbonising the facilities operations.

The feasibility study has demonstrated that the H2Juice concept is feasible and has established the end-to-end design for further development in future phases of the project. Furthermore, the feasibility study demonstrates that the H2Juice concept provides a cost effective and reliable fuel switching solution for the Princes Ltd juicing operations.

Hydrogen Generation

Biogas is currently generated at the Welsh Water site, through Anaerobic Digestion (AD) from sewage. The biogas is currently used to generate electricity to provide some of the power demand for the treatment plant.

In the H2Juice concept, the biogas is used as feedstock for the reforming process. Biogas from this renewable source produces biogenic emissions, this means that any emissions from their combustion are theoretically carbon-neutral, since a proportional amount of the greenhouse gas will be consumed by the organic matter which replaces them.

Unlike reforming fossil fuels, H2Juice can deliver low carbon hydrogen without the need for carbon capture. Using biogas as feedstock and with the addition of CCUS the concept delivers a much greater level of emissions abatement due to the negative carbon intensity of the hydrogen produced.

Hydrogen produced by reforming fossil fuels such as Natural Gas requires CCUS to produce low carbon hydrogen that meets the Low Carbon Hydrogen Standard (LCHS). The hydrogen delivered in the H2Juice demonstration project, utilising the LCHS calculation methodology will have a carbon intensity of 7.9gCO2e/MJ, well below the LCHS threshold of 20gCO2e/MJ. By 2030, CO2 produced from the process will be removed through the addition of Carbon Capture, Utilisation and Storage (CCUS) facilities. At this point the carbon intensity of the hydrogen produced through the H2Juice concept will have a carbon intensity of -133.3 gCO2e/MJ.

In the H2Juice scheme, biogas will be upgraded; gas pre-treatment upgrades the quality of biogas to biomethane by removing carbon dioxide (CO2), water, hydrogen sulphide and trace components. The biomethane will be converted in Steam-Methane Reformers (SMRs) and Water-Gas Shift (WGS) reactors to produce heating grade hydrogen (>98% purity). This feasibility study has determined the H2Juice process can produce 2 tonnes of hydrogen per day (2.75 MW), with potential for future expansion to 3.4 tonnes per day (4.675 MW).

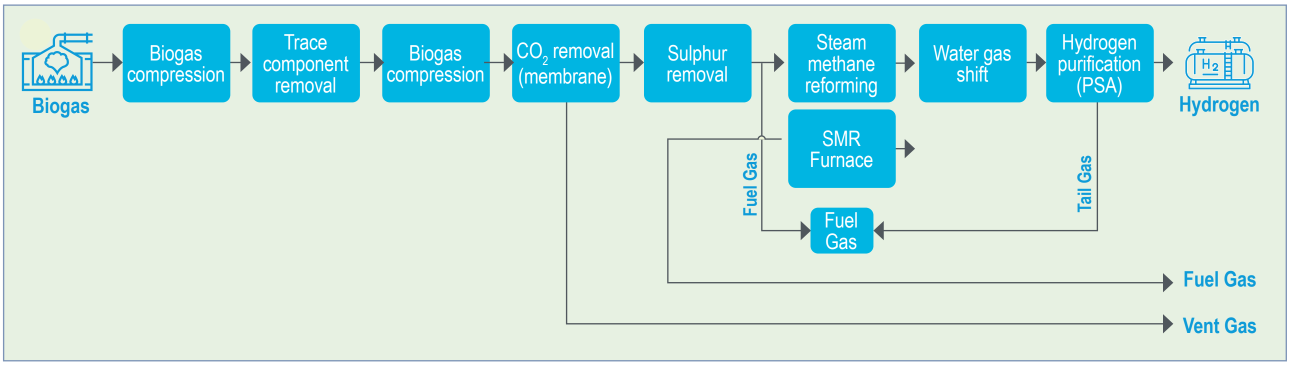


Figure 4 - Hydrogen Production

Hydrogen Pipeline

The Welsh Water and Princes Ltd sites are approximately 2 km apart across an industrial area. The project has assessed the options for linking hydrogen production with the Princes Ltd soft drinks facility and concluded that a connecting pipeline is the optimum solution.

The study has assessed the options for either construction of a new pipeline or repurposing an existing gas distribution main. The study identified the existence of an existing NPS (Nominal Pipe Size) 8" (DN200) Intermediate Pressure (IP) main that could be repurposed to hydrogen duty, negating the need for a difficult crossing of the nearby railway lines and need for obtaining easements for a new pipeline through the congested industrial landscape. This would be the first project to demonstrate that an existing IP network could be segregated and partially repurposed for hydrogen, answering the R&D needs of the gas networks. Given the number of industrial customers supported by similar infrastructure across the UK, this represents a realistic scenario in the development of net zero energy networks.

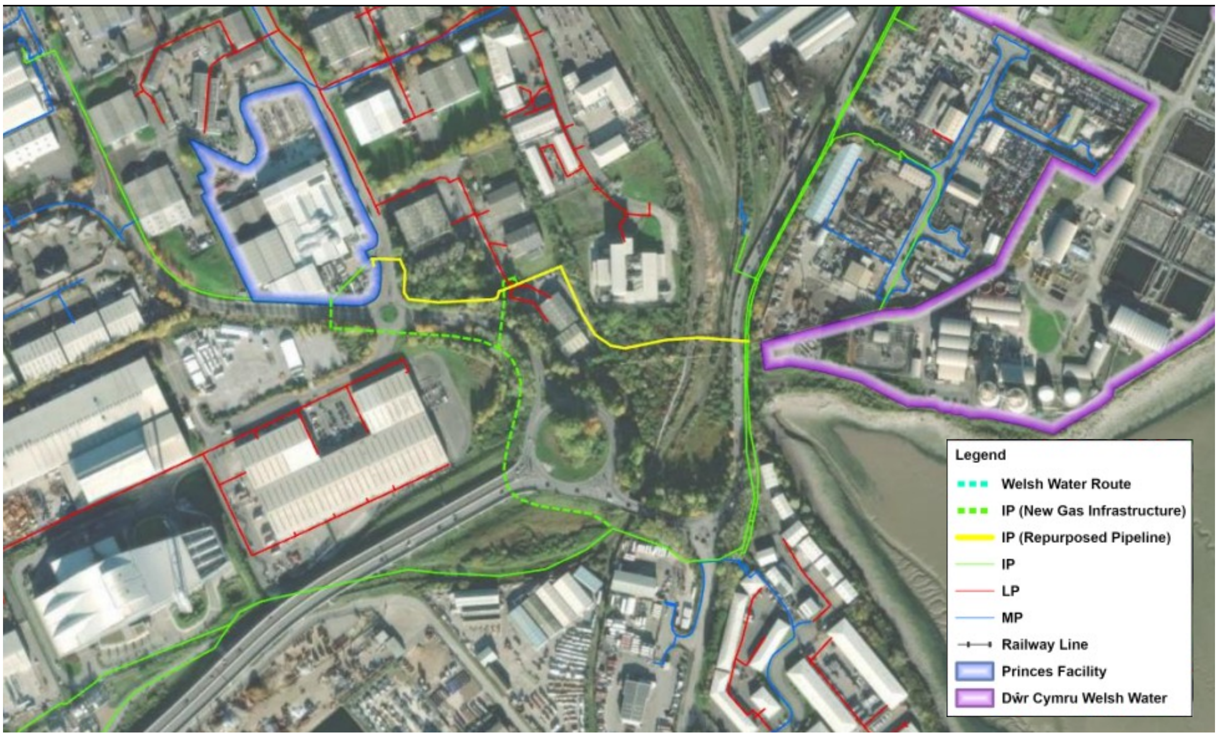


Figure 5 - WWU IP Distribution Network, re-purpose option (yellow)

End User Fuel Switching

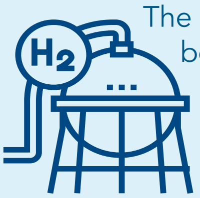
The study has developed a scope of modifications for fuel switching at Princes Ltd. The innovative solution developed by this study allows both boilers to operate on new dual-fuel burners, allowing them to use natural gas or hydrogen. Both boiler chambers can remain unchanged although a 10% de-rating of steam output as well as additional temperature monitoring are recommended. A new burner control system will enable dual-fuel operation including multiple hydrogen blends.

Scalability and Replicability

The learning generated by this project could be replicated across many industrial sectors, helping accelerate industrial decarbonisation in the UK with potential to provide exportable skills and technology, helping position the UK as a global leader.

The H2Juice concept provides a replicable, circular economy, end-to-end solution for deployment at Wastewater treatment Works / biogas generation facilities across the UK and beyond, providing a supply of low carbon hydrogen to industrial consumers in the locality.

The H2Juice project produces low carbon hydrogen without the need for CCUS, providing an attractive and replicable Levelised Cost of Hydrogen (LCOH). As this is a "First of a Kind" demonstrator the Levelised Cost of Abatement (LCOA) are relatively high, the cost of abatement will reduce dramatically once the concept is scaled up in wide scale deployment.



The dual-fuel burner technology is replicable in most types of industrial package boilers. The Hy4Heat programme estimated there are over 1,400 similar type units generating high temperature steam currently in operation around the UK.

The developed Stream 2B scope will also demonstrate the operation of industrial boilers on different blends of hydrogen, **from 20% through to 100% hydrogen supply (by volume) providing invaluable information on the tolerance of industrial combustion equipment to hydrogen blends >20%.**

Following completion of the demonstration project, it is intended that the end-to-end scheme will move to commercial operation. Welsh Water and Princes Ltd will enter into a commercial agreement for the supply of hydrogen. This will support both organisations' commitments to decarbonise their operations. It is intended that the re-purposed pipeline will be adopted by WWU to form part of their regulated asset base.

1. INTRODUCTION

1.1 Background: DESNZ (formerly BEIS) IHA Programme

In 2022, the Department for Energy Security and Net Zero (DESNZ) launched the NZIP Industrial Hydrogen Accelerator (IHA) programme offering a total of £26 million "for innovation projects that can demonstrate end-to-end industrial fuel switching to hydrogen" [Ref 1]. Costain Ltd (Costain) submitted their H2Juice proposal in partnership with Dŵr Cymru Cyfyngedig (Welsh Water), Wales & West Utilities (WWU), CR Plus and Princes Ltd. In September 2022, DESNZ announced that H2Juice was one of nine projects successful in receiving IHA funding to undertake Stream 2A feasibility studies [Ref 2]. The follow-on Stream 2B competition will provide funding, up to a £7M grant intensity cap for successful projects, to progress through to either detailed FEED or demonstration.

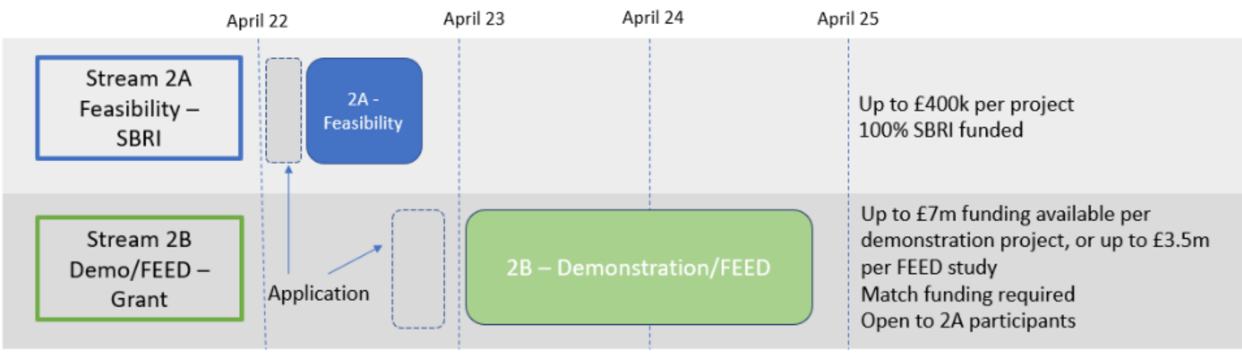


Figure 6 - IHA Stream 2 Timeline (2022-23)

1.2 Concept: H2Juice

The H2Juice concept provides end-to-end fuel switching from natural gas to hydrogen in a key industrial Welsh heartland. This is achieved through an integrated engineering solution consisting of the production, storage, transportation and end-use of low-carbon hydrogen. Renewable hydrogen is produced from sewage-derived biogas at the Welsh Water Cardiff East Wastewater Treatment Works (WwTW) and supplied by pipeline to an industrial heat end-user approximately 2 km away, the Princes Ltd soft drinks facility. The H2Juice concept also proposed to investigate the potential for blending and de-blending facilities to demonstrate how the grid can supply end-users with a range of hydrogen blends.

Of all the decarbonisation concepts considered for the Princes Ltd site, H2Juice offers the largest reduction in greenhouse gas emissions (GHGs) and also offers low fuel switching costs. The H2Juice concept and the rationale for its selection are discussed in the report:

- **Sections 2-5:** technical description (overall concept, hydrogen production, hydrogen transportation, hydrogen fuel switching)
- **Section 6:** technology assessment (including counterfactual, alternatives)
- **Section 7:** levelised costs

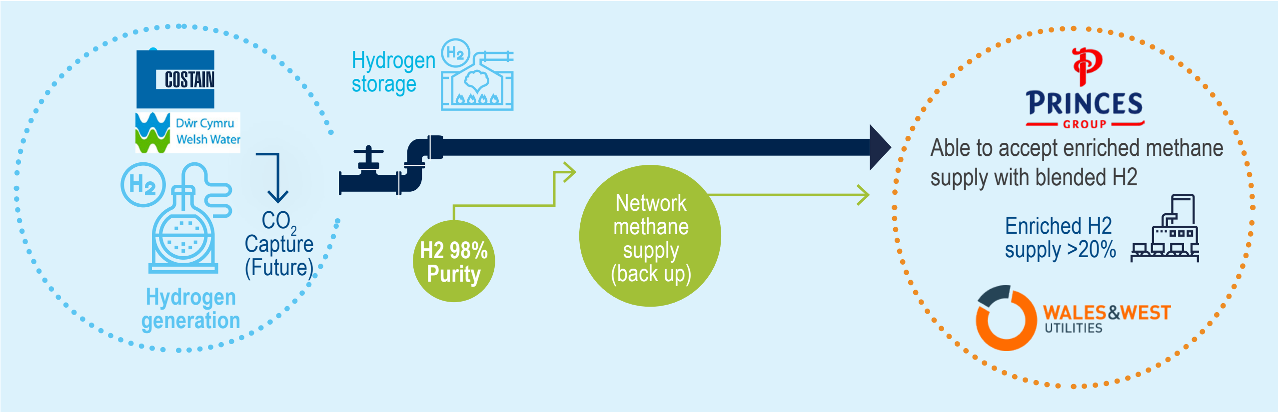


Figure 7 - H2Juice Concept

1.3 Objectives

1.3.1 End-to-End Fuel Switching Demonstration

The UK government DESNZ Industrial Decarbonisation Strategy promotes fuel switching to low carbon hydrogen [Ref. 3]. The Institution of Gas Engineers & Managers (IGEM) [Ref. 4] has highlighted the strengths of hydrogen fuel switching: high temperature heat provision, minimal retrofit scope, minimisation of end user interruption. This has been further supported by DESNZ through the Industrial Fuel Switching Phase 1 [Ref. 5] and 2 [Ref. 6] programmes.

The study demonstrates that, in the H2Juice concept, fuel switching is well suited to the industrial end-user partner.

The Princes Ltd soft drinks facility requires high temperature heat and Princes Ltd is keen to minimise retrofit scope and interruption. H2Juice uniquely demonstrates integrated, end-to-end fuel switching via:

- **Hydrogen production:** from sewage-derived biogas at Welsh Water
- **Hydrogen processing:** storage, blending, de-blending and buffer storage at Welsh Water
- **Hydrogen transport:** pipeline from Welsh Water to Princes Ltd end-user
- **Hydrogen fuel switching:** substitution of natural gas with hydrogen at Princes Ltd.

1.3.2 Blending & De-blending Demonstration

Total UK GHG emissions in 2021 were 424.5 MtCO2e, a decrease of 47.3% since 1990 [Ref. 7]. Heating from industrial processes account for 14% of UK emissions [Ref. 8]. As heat is mostly supplied through natural gas, decarbonisation of the gas supply is critical to meeting the UK government's commitment to achieve Net Zero by 2050 [Ref. 9]. To reduce emissions, natural gas can be substituted with either pure hydrogen or with a blend of natural gas and hydrogen. From the National Grid report "Hydrogen Deblending in the GB Gas Network" (2021) [Ref. 10]:

> "if hydrogen is blended into natural gas at up to 20 mol%, decarbonisation is viable with minimal modifications and/or avoiding significantly increasing risks associated with utilisation of the gas blend in end-use devices (such as household appliances), overall public safety, or the durability and integrity of the existing natural gas pipeline network."

Should the distribution network remain limited to 20 vol% hydrogen, industrial end-users can decarbonise further by de-blending the gas stream at their site to produce then consume higher concentrations of hydrogen. The National Grid report [Ref. 10] identified de-blending technologies including membrane separation and pressure swing adsorption (PSA) at pressures over 70 barg. The H2Juice concept demonstrates a 'real world' deployment of blending and de-blending technologies.

1.3.3 Emissions Reduction

The H2Juice Stream 2A study considers the heat requirement of the industrial end user, the Princes Ltd Cardiff soft drinks facility. It considers emissions from the counterfactual (natural gas), from H2Juice and from alternative concepts considered for supplying heat to the site:

- Hydrogen from on-site electrolysis
- Direct Electric Heating
- Heat Pumps
- Biogas
- Biomethane

1.3.4 Expansion Potential

The H2Juice concept demonstrates expansion potential on the following basis:

- **Geographic:** potential for increased hydrogen production and additional end-users in the Cardiff area
- **Production:** potential for hydrogen production at other Welsh Water sites and across the UK sewage industry
- **End-Use:** potential for hydrogen deployment at other Princes Ltd sites and across the UK food & drink industry.

Section 9 of the study shows that wider deployment of the H2Juice concept would reduce industrial heat emissions in support of the UK Net Zero target.

1.4 Concept Selection

Upon launch of the IHA programme, Costain began to identify fuel switching options via internal workshops and idea generation sessions across the North-West Hydrogen Alliance (NWHA), Hydrogen South-West (HSW) and the South Wales Industrial Cluster (SWIC).

From discussions amongst SWIC participants, Costain recognised that low-carbon hydrogen could be produced by Welsh Water from sewage-derived biogas. The hydrogen produced could then be transmitted via a pipeline to an industrial heat end-user seeking to reduce emissions. Referring to the proposed hydrogen production rate and the location of the Welsh Water Cardiff East WwTW, the Princes Ltd soft drinks facility in Cardiff was identified as a suitable candidate. Refer to Section 6.0 for alternatives considered.

1.5 Project Partners

With Costain as project leader, the partnership agreed that due to the capital intensity of the H2Juice concept, a Stream 2A application would be most appropriate. With project partners keen to engage, a professional alliance was formed, later supported by a Memorandum of Understanding (MoU). The project is already being promoted via corporate media outlets [Ref. 11].

"Our purpose is to improve people's lives by creating connected, sustainable infrastructure that enables people and the planet to thrive. Through our smart contracting and consultancy solutions we help our clients across the UK's transportation, water, energy and defence sectors to improve their business performance by enabling their infrastructure programmes to be safer, better, greener, faster and more efficient. The success of this project ratifies these goals as we demonstrate our commitment to the Energy Transition and look to become the go-to Contractor helping deliver Net Zero."

"Welsh Water has ambitious plans to achieve Net-Zero by 2040 and advocates collaborative projects to help the Country transition toward greater environmental sustainability. Welsh Water is excited by the innovative prospect of converting biogas from its Advanced Digestion facility in Cardiff, into renewable Hydrogen for use in Industry. Reducing carbon emissions from industrial process is critical to achieving a more environmentally sustainable future. Welsh Water already generates 24% of its energy needs from its own renewable energy assets and is investing toward achieving 35% self-sufficiency in 2025. Welsh Water is proud to be a partner in this innovative Hydrogen project, and is excited at the opportunity to deliver wider environmental benefits from our Advanced Digestion facility in Cardiff."

"The use of deblending (or gas separation) technology has previously been explored for application at transmission system pressures, but not before been applied at distribution (<7 barg) pressures associated with supplying the vast majority of I&C consumers. This project will address this gap and generate new evidence to support uses for distributed deblending systems which could enable greater and earlier decarbonisation potential for existing natural gas users. Furthermore, in cases where I&C customers are able to accept hydrogen blends in excess of 20%vol, the hydrogen off-gas can be used for re-injection into the gas grid where this can be used to balance the levels of hydrogen within the grid and increase the operational capability of a future smart grid. Ultimately this will increase the decarbonisation potential of a repurposed gas network, whilst delivering value for money by minimising new infrastructure."

"Princes Ltd is committed to becoming carbon neutral across its manufacturing sites by 2030. The H2 Juice project will provide real world, at scale, application of Hydrogen conversion routes for existing site equipment to enable the Cardiff site to reduce its carbon footprint and ultimately become carbon neutral. There is potential for replicability of the project within Princes Ltd sister sites, and throughout UK industry as whole. Challenges that will be addressed via undertaking this project will include the contractual agreements between supplier and end user, identifying and dealing with issues between these parties (uptime of H2 supply, capabilities, storage of H2, back up options, costs), H&S considerations of such a project will also be addressed. Princes Ltd also have a requirement for food grade CO2 at sister sites, therefore the opportunity for Carbon Capture and reuse is attractive."

1.6 Project Delivery

1.6.1 Deliverables

Stream 2A was undertaken between September 2022 and January 2023. Activities were split into workpacks (WP)::

Workpack No.	Description	Lead Party
WP1	Hydrogen Generation	COSTAIN
WP2	Gas Network – Transportation & Blending	COSTAIN
WP3	Hydrogen Use – Fuel Switching	CR+
WP4	Operational Integration	COSTAIN
WP5	Project Management	COSTAIN

Table 1 - Workpack Summary

WPs were executed under the following organisational structure:

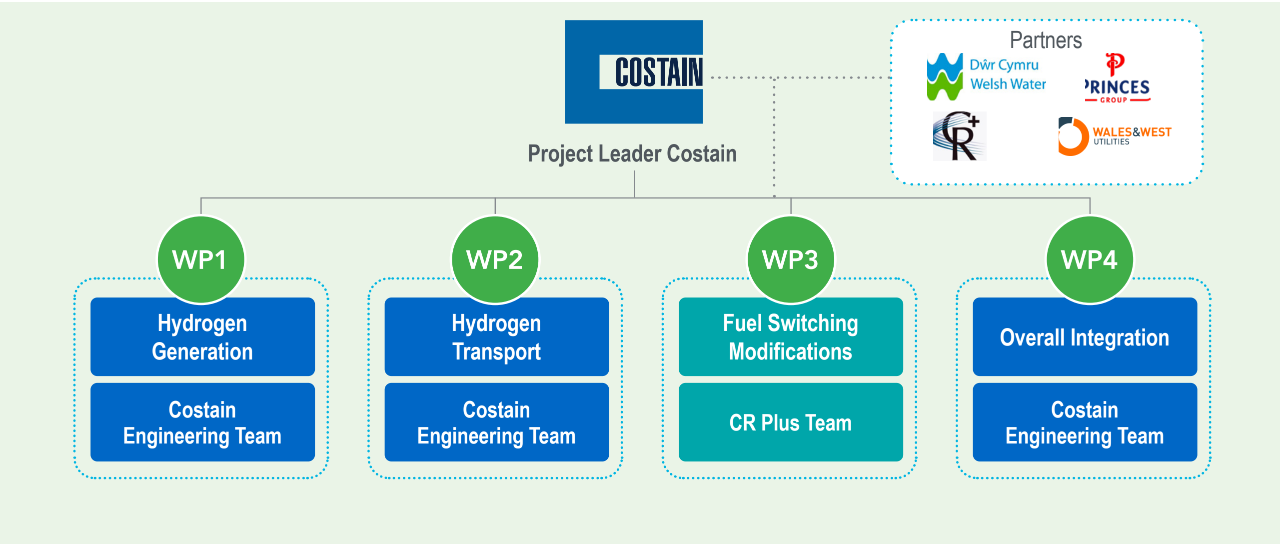


Figure 8 - Organisational Structure

Deliverables produced during Stream 2A are listed in Appendix - H2Juice Phase Stream 2A Feasibility Study Deliverables.

1.6.2 Final Report Scope

The scope of this final report is as per BEIS report guidance [Ref. 9]:

- Stream 2A, sections 2-7 and 9: feasibility study main outputs and findings
- Stream 2B, section 8: project delivery plan, Front-End Engineering Design (FEED)

1.6.3 Standards

Applicable standards are listed in full in Appendix - Standards.

2. END-TO-END FUEL SWITCHING

2.1 Overview

The H2Juice process is summarised as:

- Biogas is generated from sewage in the existing Welsh Water anaerobic digestion (AD) process. In the H2Juice concept, biogas is upgraded to biomethane by the removal of Carbon Dioxide (CO2) via a membrane removal process.
- Biomethane is converted to hydrogen in two reaction stages: Steam-Methane Reforming (SMR) and Water-Gas Shift (WGS).
- The hydrogen is routed to blending and de-blending facilities where natural gas is added or removed before distribution to the end user as a stream containing 20 to 98 vol% hydrogen.
- CO2 from the process is removed in the Carbon Capture, Utilisation and Storage (CCUS) facilities. This CO2 will be re-used in the food & drink sector.

Three heat & mass balances were generated, all at a production rate of 2 tonnes per day (t/d) hydrogen [Ref. 13]. The three cases consider 20, 80 and 98 vol% hydrogen output to end-users from the blending and de-blending facilities. Please see sheets excerpts in Appendix - Heat and Mass Balance.

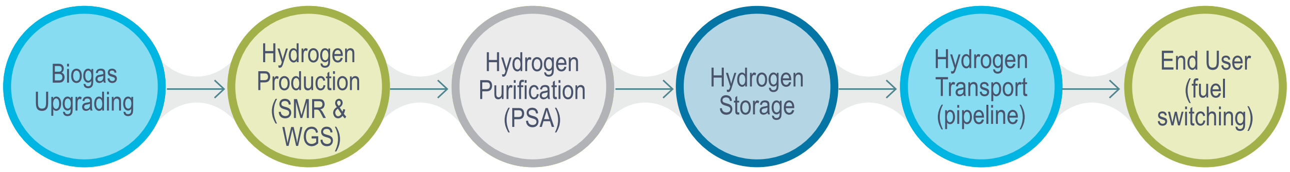


Figure 9 – End-to-End Fuel Switching

2.2 H2Juice Development

The diagrams below show the anticipated development progression of the H2Juice scheme through to 2050.

2.2.1 Demonstration (2025)

The demonstration phase (commencing 2025) is summarised as:

- Hydrogen production, storage and buffer storage established at Welsh Water
- Existing intermediate pressure (IP) WWU pipeline segregated and re-purposed for hydrogen service to connect Welsh Water and Princes Ltd sites. New pipeline sections added as required to complete the connection.
- Fuel switching modifications (essentially replacement burners, control system, additional monitoring, associated pipework) established at Princes Ltd site ensure hydrogen operation on both site boilers. (Natural gas supply retained to ensure instantaneous back up through the dual-fuel burner technology.)

2025 Phase 2B Demonstration Project, producing hydrogen meeting low carbon hydrogen standard

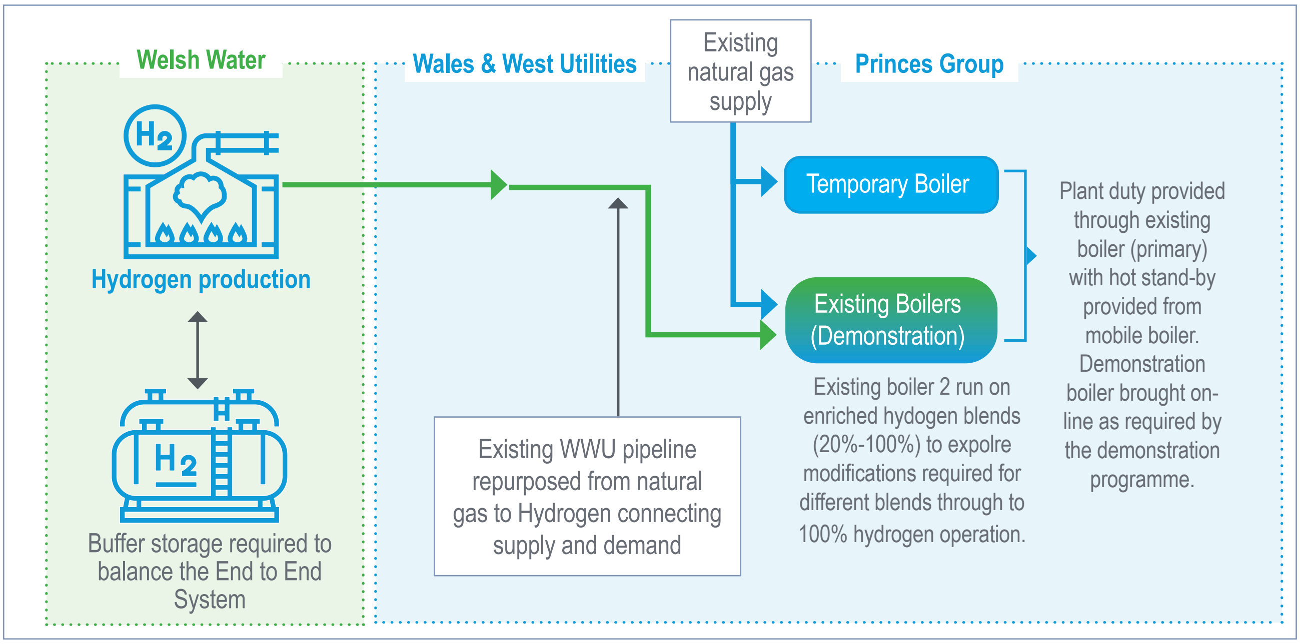


Figure 10 - Demonstration (2025)

2.2.2 CCUS Addition (2028)

In 2028, CCUS will be added to ensure the hydrogen produced will meet the DESNZ (formerly BEIS) Low Carbon Hydrogen Standard [Ref. 14] by generating GHG emissions below 20 $gCO_2e/MJLHVH_2$.

Natural gas supply is retained to ensure instantaneous back up through the dual-fuel burner technology should there be a loss of hydrogen supply.

2028 - Addition of CCUS producing hydrogen with a negative carbon intensity

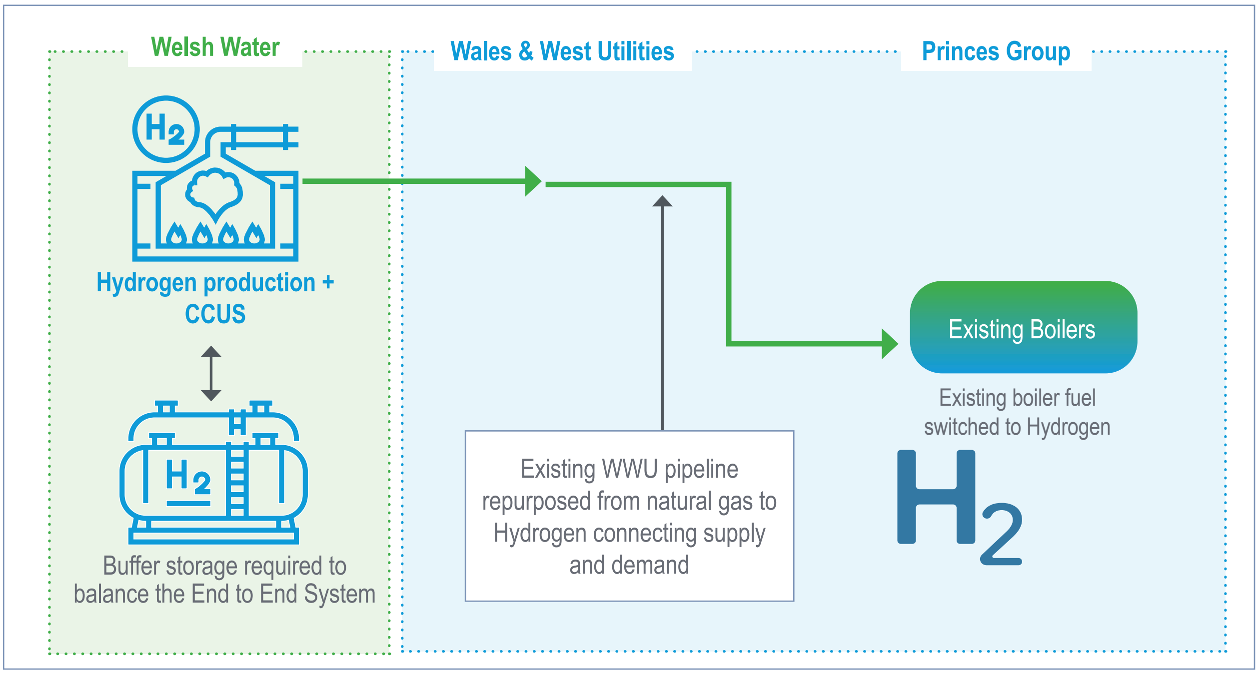


Figure 11 - CCUS Addition (2028)

2.2.3 Surplus Hydrogen Exported into Gas Distribution Network (2030)

In 2030, surplus hydrogen will be added to the Gas Distribution Network (GDN):

- Hydrogen pipeline from Welsh Water to Princes Ltd creates a network to supply heat grade hydrogen to additional users along the pipeline route, accelerating local industrial decarbonisation.
- Addition of Above-Ground Installation (AGI) blending unit to combine hydrogen with natural gas. Local GDN to be converted to operation on 20 vol% hydrogen.

2030 - Surplus Hydrogen blended into Gas Distribution Network

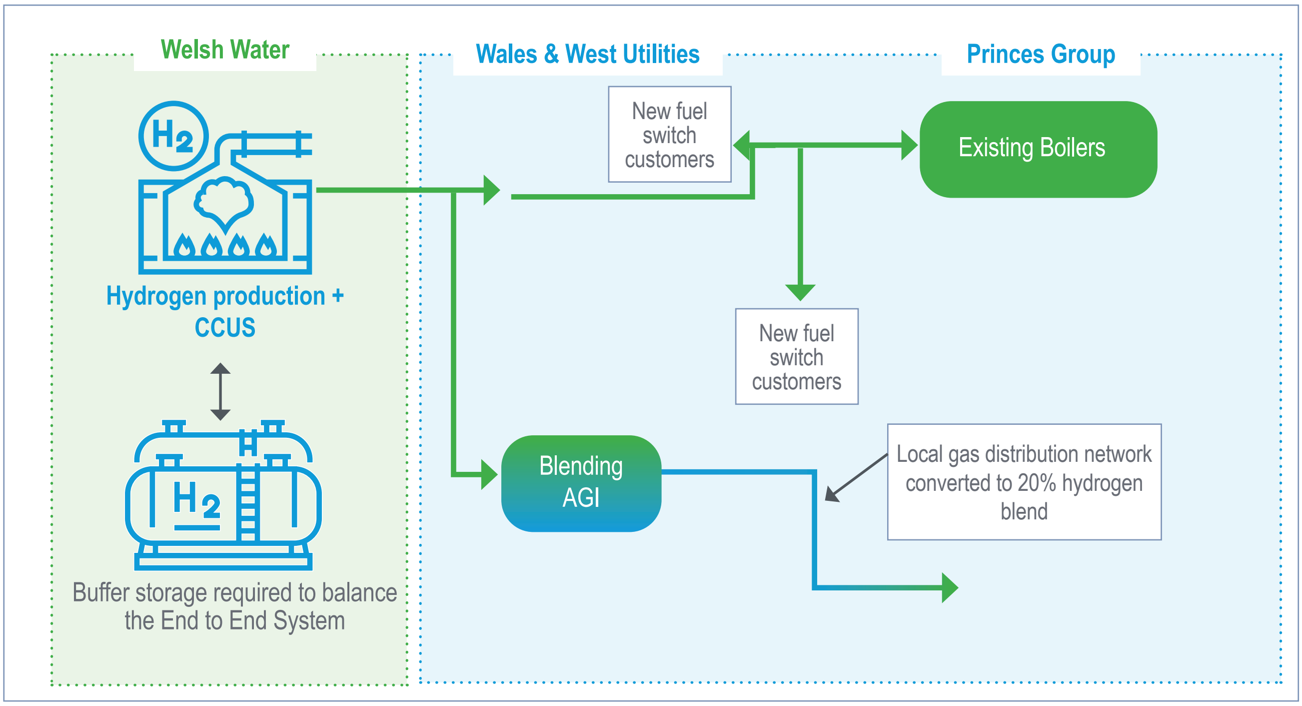


Figure 12 - Surplus Hydrogen to GDN (2030)

2.2.4 Fuel Switching via De-Blending (2030 onwards)

Beyond 2030, subject to the policy decision to move the gas network to a 20% hydrogen blend, users supplied with 20 vol% hydrogen from the Gas Distribution network could install de-blending facilities at their sites. This will allow them to use hydrogen at higher blends, through to a 100% hydrogen supply. This could accelerate industrial decarbonisation across the wider network footprint.

2030 to 2050 customers connected to GDN fuel switched through deblending

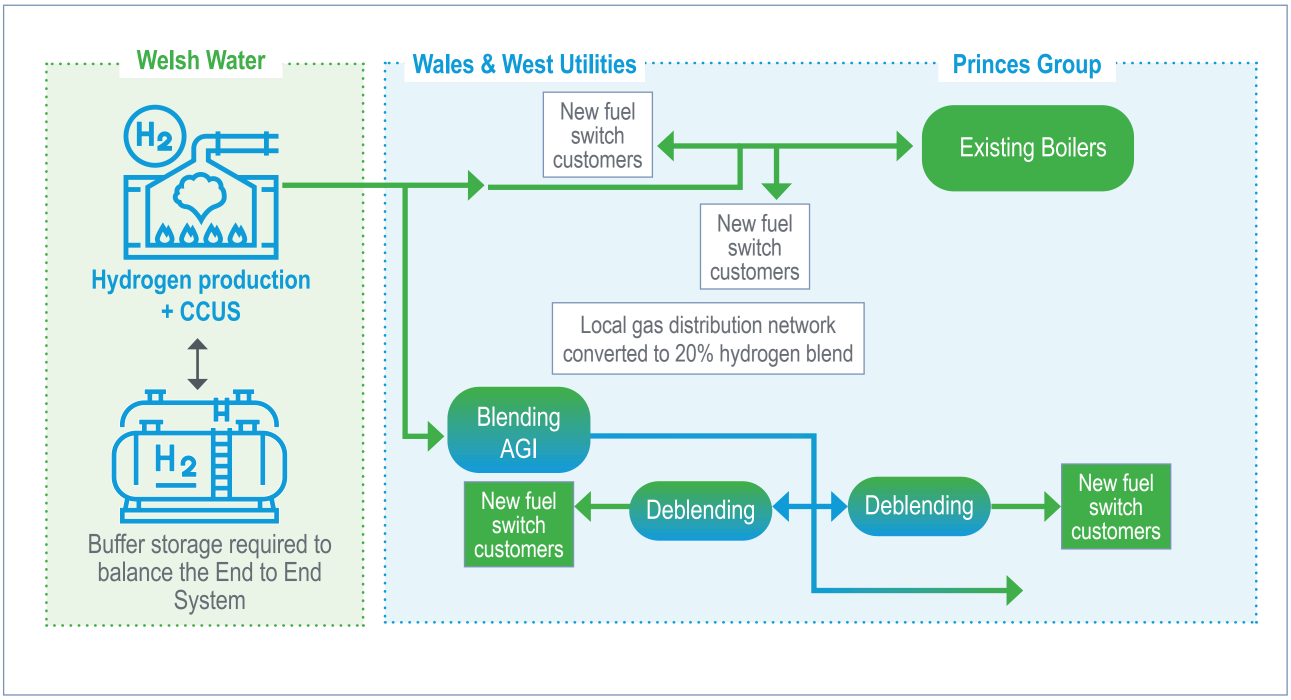


Figure 13 - Fuel Switching via De-Blending (2030 onwards)

3. HYDROGEN PRODUCTION, CCUS, BLENDING & DE-BLENDING

3.1 Hydrogen Production

3.1.1 Overview

In the H2Juice concept, biogas produced from sewage at the Welsh Water Cardiff East WwTW is upgraded to biomethane by the removal of CO2. The biomethane is converted to hydrogen in the SMR and WGS stages. The hydrogen is purified to heat grade ready for direct use.

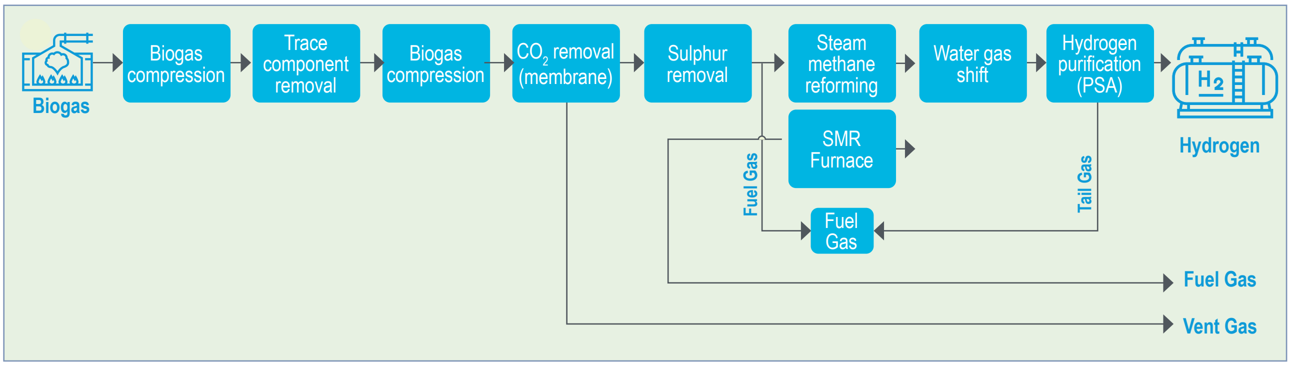


Figure 14 - Hydrogen Production Overview

3.1.2 Biogas Upgrading

Figure 15 shows the biogas upgrading process. Biogas (approximately 62 vol% methane, 38 vol% CO2) is generated at the Welsh Water site from sewage. In the H2Juice concept, this is upgraded to biomethane (approximately 87 vol% methane, 9.5 vol % propane, 3.5% vol CO2) by the membrane removal of CO2, water, hydrogen sulphide and trace components.

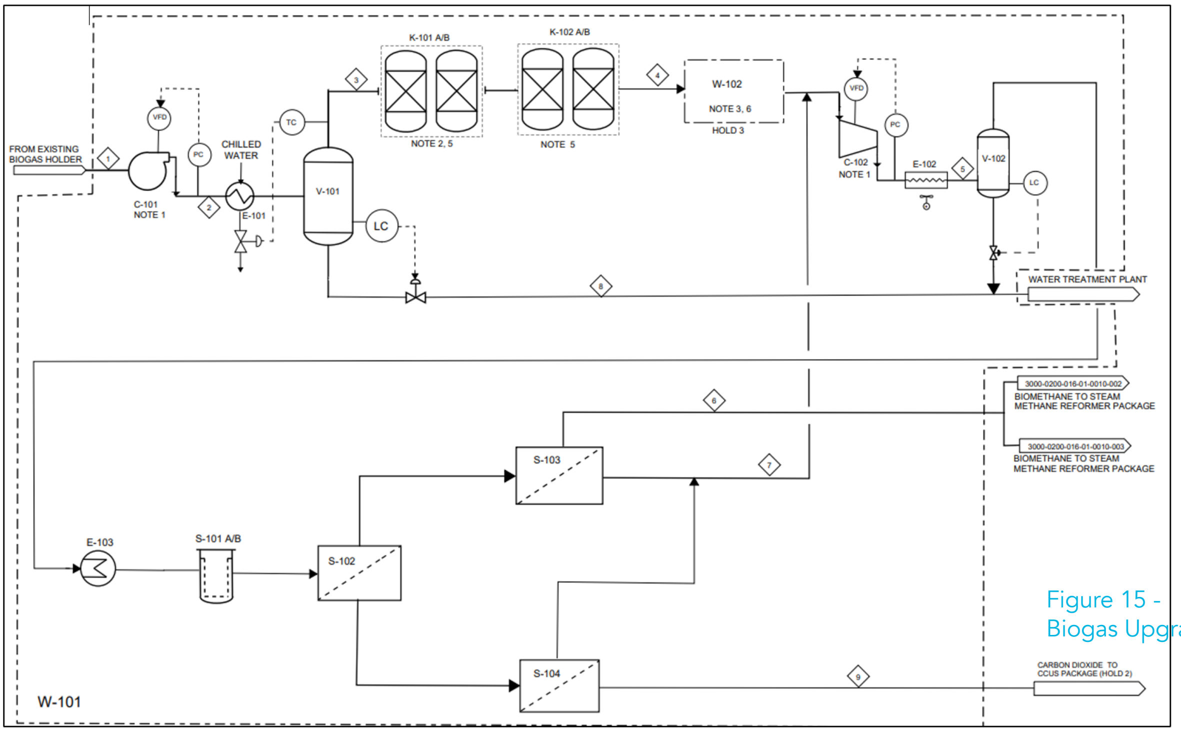


Figure 15 - Biogas Upgrading

3.1.3 Hydrogen Production and Purification

Figure 16 shows the two parallel production trains and associated purification units, producing a total of 2 t/d hydrogen (i.e. 2 x 1 t/d), with potential to increase hydrogen production to 3.4 t/d (i.e. 2 x 1.7 t/d). Each train consists of SMR which converts biomethane into hydrogen followed by WGS which reduces the stream carbon monoxide content. Purification of the WGS outlet stream is primarily via PSA.

The hydrogen produced will be of heat grade (typically >98% purity hydrogen) and will meet the gas quality specifications in standard IGEM/H/1 (2021) [Ref. 15]. Hydrogen produced from this H2Juice process is at 7 barg, 38 °C (maximum).

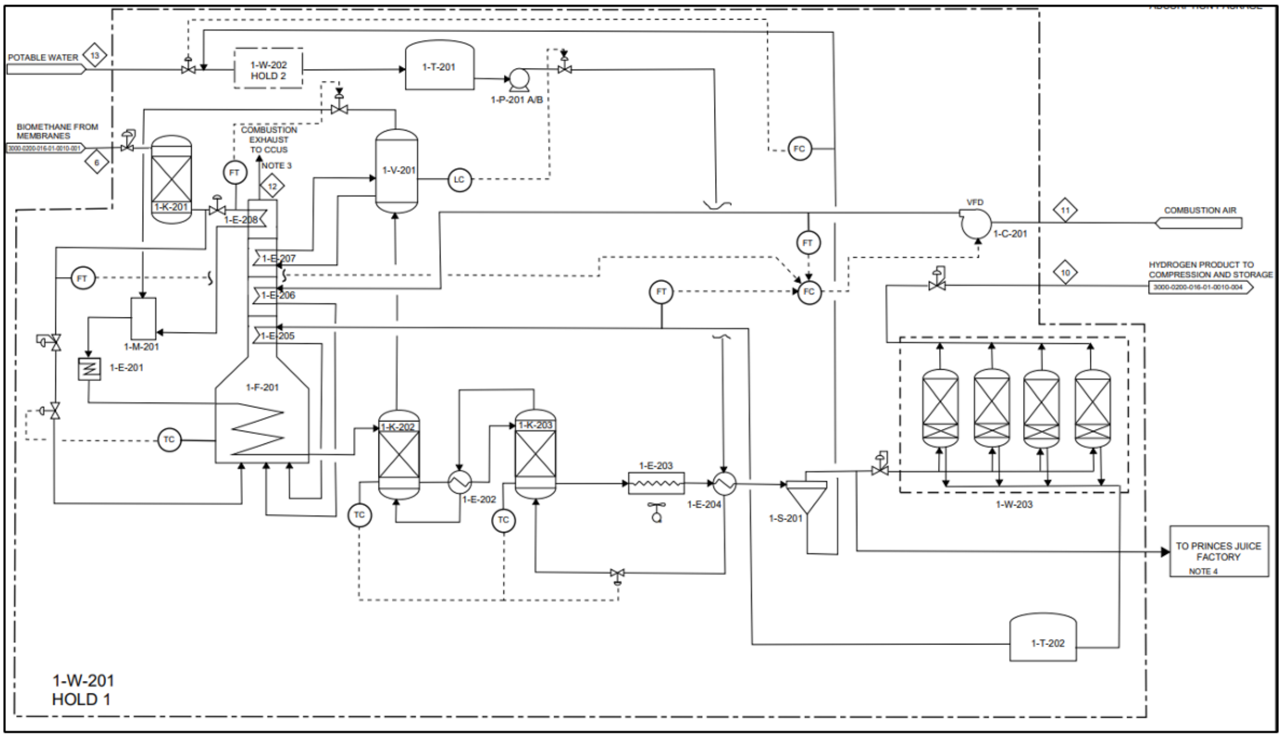


Figure 16 - Hydrogen Production & Purification

3.2 CCUS

CO_2 is currently released when biogas is consumed as on-site fuel at the Welsh Water site. CO_2 will also be generated via the H2Juice concept as the biogas is used for hydrogen production, however CO_2 emissions from biogas are classed as biogenic. As per Section 2.0, CCUS will be installed on H2Juice facilities by 2030 to capture this CO_2. Captured CO_2 will either be permanently sequestrated or utilised to displace CO_2 produced from fossil fuels. CO_2 will be produced from three locations in the hydrogen production process and will be captured:

Location	CO_2 Emissions Rate (kg/h)
Biogas upgrading stage, removed in membrane	485
SMR and WGS reactions, removed as tail gas in PSA	516
Fuel gas combustion in SMR direct fired heater	303

Table 2 – CO_2 Production from Hydrogen Production

The emissions from the second and third sources above are routed to the CO2 capture process. This is a proven chemical absorption process using an amine aqueous solution (30% wt. Monoethanolamine, MEA) as a liquid solvent. The solvent is thermally regenerated in a stripper column with the released CO2 purified and, if required, liquefied for storage and export. As the stream from the biogas upgrading stage is already high in CO2 content (97.5 vol%), this is combined with the capture process outlet stream.

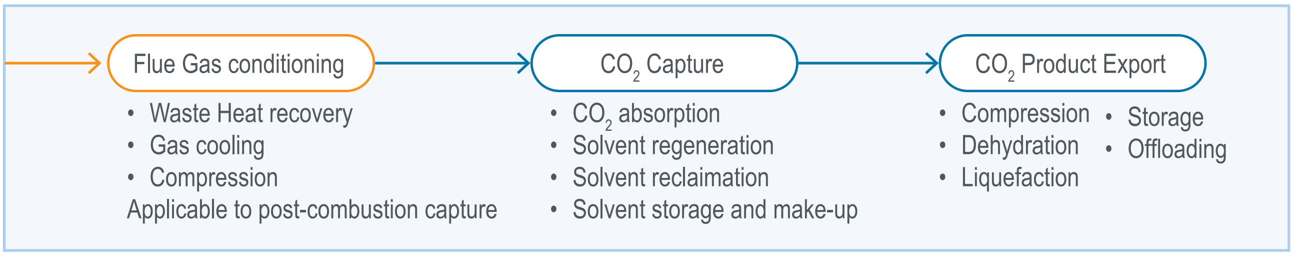


Figure 17 - CO_2 Capture Process

3.3 Storage

High pressure storage of up to 600 kg of hydrogen is located downstream of the hydrogen production process. As per Section 5.3, this provides sufficient hydrogen to meet half a day of average Princes Ltd heat demand when hydrogen production is not available. The size (and location) of this inventory has been assessed from a safety perspective [Ref. 17] and ensures the site remains below the threshold for lower-tier Control of Major Accident Hazards (COMAH) classification.

3.4 De-Blending

Deblending technology could be utilised in the future to allow industrial consumers to partially decarbonise their operations, or fully fuel switch to hydrogen once the local gas distribution network converts to a 20% hydrogen blend (as graphically depicted in section 2.2.4).

A number of gas separation technologies were assessed. The study determined that polymer membrane and Pressure Swing Absorption (PSA) technologies could be combined into a configuration to deliver the Princes Ltd duty requirements described in the Function Specifications [Ref. 18].

The deblending concept was assessed during Stream 2A but it was decided not to take the concept through to the demonstration phase due to the low Technology Readiness Level (TRL) of de-blending. However, the intention is to further develop the deblending concept in the H2Juice stream 2B submission, where the deblending concept would be further developed in a detailed FEED study to move the TRL from 2 to 5.

3.5 Blending

Blends of hydrogen, from 20% to 100% are required to deliver the blending trials of the dual-fuel burners, which is a key objective in the stream 2B demonstration project.

The feasibility study assessed the options to deliver hydrogen blends for the dual-fuel burner trials to meet the Princes Ltd duty requirements described in the Function Specifications [Ref. 18]. The feasibility study determined that the blends required for the dual-fuel burner demonstration could be achieved via simple volumetric blending utilising flow control valves at the outlet from the hydrogen production facility.

3.6 Buffer Storage

Buffer storage of up to 25 kg of hydrogen at a pressure of 16 barg will be located at the Welsh Water site, upstream of the export pipeline inlet. As per Section 5.3, this provides sufficient hydrogen to support peak heat demands at Princes Ltd.

3.7 Site Utilities

The utilities provided at the WwTW (electrical power, potable water, instrument air, nitrogen) are detailed in Appendix –– Welsh Water Utilities. The natural gas supply is shown in the extract (Figure 18) from the Plot Plan [Ref. 19].

Electrical power will be supplied via the existing site network 7.5 megavolt amperes (MVA) connection. Natural gas for blending will be supplied from the WWU Intermediate Pressure (IP) distribution network at up to 7 barg. Existing site connection capacity is 1,600 Sm3/h with composition data at the nearby Dowlais offtake supplied by WWU. Supply conditions are as per Appendix - Gas Safety (Management) Regulations 1996 (GS(M)R). Compared to electrolytic hydrogen production routes, H2Juice water requirements (and discharges) are low.

3.8 Layout

Process units are containerised wherever possible. Spacing was determined in the Preliminary Safety Study [Ref. 17]. This considered operational, access and maintenance requirements. As shown in the extract (Figure 18) from the Plot Plan [Ref. 19], equipment is located in an area on the east of the site:

- Production facilities in the south of the area
- High pressure storage facilities are segregated to the north of the area

Natural gas for blending and hydrogen for supply to Princes Ltd are routed to and from this area in a shared route to the south-west. Whilst an alternative location for process units exists adjacent to the west boundary fence of the plot, the selected location minimises crossings (roads and piping).

The proposed location does not create significant congestion. The prevailing wind is from the south-west, resulting in rapid dispersion towards an open area (Bristol Channel) in the event of a release. The biogas treatment and upgrade which present low operating pressures are to be kept in close proximity to the biogas holders.

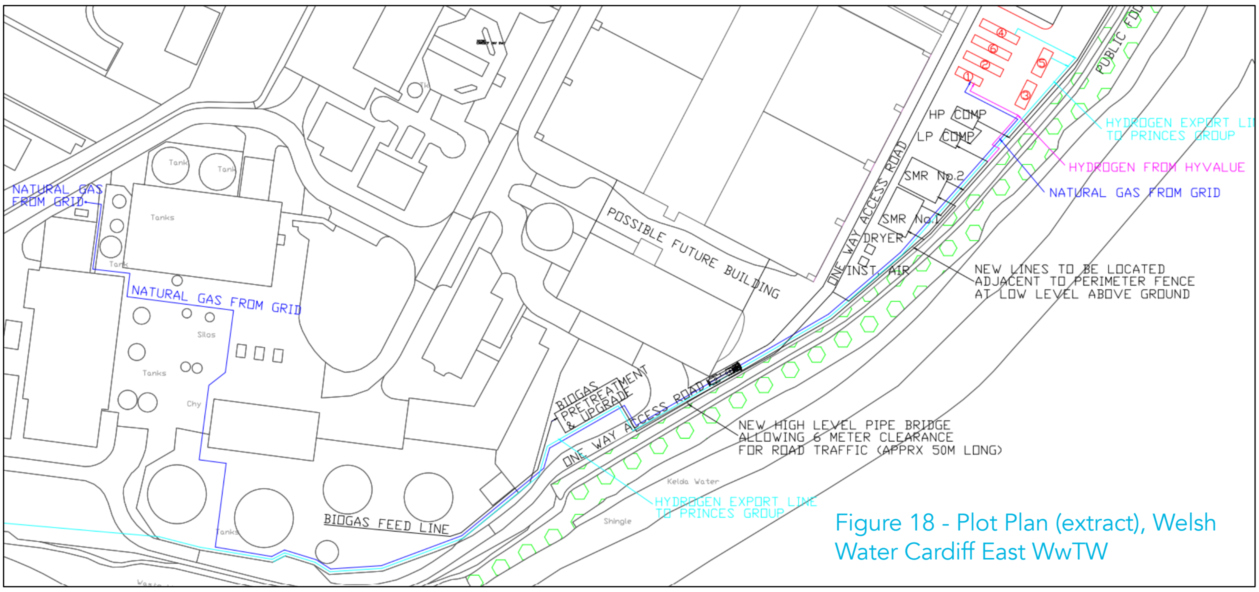


Figure 18 - Plot Plan (extract), Welsh Water Cardiff East WwTW

3.9 Control & Instrumentation

3.9.1 Philosophy

A constant production rate of 2 t/d hydrogen can be maintained with any excess to storage or to any alternative users. As demand from the end user, Princes Ltd, is highly variable, supply will be regulated by the Pressure Control Valve (PCV) in the export line, with the balance exported to hydrogen storage facilities for other uses.

3.9.2 Design

Control requirements are described in Appendix - Control & Instrumentation. Key considerations:

- Control and safety functions including Emergency Shutdown (ESD) shall be controlled by the package vendor Programmable Logic Controller (PLC). The package will trip and stop safely without the need to interact with other equipment or act on instruments and valves outside the vendor package.
- Vendor package human-machine interface (HMI) screens shall reside in the Welsh Water control room. The HMI screens shall display alarms, controller data, modes, status, diagnostics, logs, and reports.
- Vendor package safety shutdown trips performed within the package shall be in accordance with the requirements of BS EN 61511 and BS EN 61508.
- All Safety Instrumented Functions (SIFs) and safety systems shall be in accordance with the requirements of BS EN 61511 and BS EN 61508.
- To protect against cyber threats, a de-militarized zone (DMZ) consisting of two firewalls will segregate the local enterprise network from the PLC operations LAN.
- Fiscal metering shall be provided at three points across the Welsh Water site: natural gas from grid at the inlet site battery limit, hydrogen from on-site production process and hydrogen export at the site battery limit to Princes Ltd.
- In general, process control instrumentation shall be conventional 4-20 mA Highway Addressable Remote Transducer (HART) transmitters. NAMUR NE43 compliant transmitters will be used for SIFs. Valve position switches will be proximity types in accordance with EN 60947-5-6:2001. All field instrumentation will be appropriately certified for use in a hazardous area. Instrumentation forming part of a Safety Instrumented Function shall comply with IEC 61511 and IEC 61508.
- Building fire detection and alarm systems shall be supplied for occupied buildings to meet the requirements of BS 5839 Part 1.

3.9.3 Digital Twin

A digital twin, built from Building Information Modelling (BIM) and engineering data, would deliver key benefits:

- End-user demand prediction
- Optimisation of AD plant operation to maximise biogas production
- GHG emissions savings quantification via real-time consumption data

A secure web-based portal would offer remote access to plant data from off-site.

Costain has developed a deep-learning Artificial Intelligence (AI) system for the smart infrastructure needs of its clients. Case Studies, including St Fergus gas terminal and National Grid, are described in Appendix – Digital Case Studies.

3.10 Electrical

Electrical requirements are described on Appendix - Electrical. H2Juice power requirement (approximately 1 MW to produce 2 t/d hydrogen) is low compared to an electrolysis-based hydrogen application (approximately 2 MW to produce less than 1 t/d) [Ref. 20]. It will be supplied via the existing site network 7.5 MVA connection. All loads are anticipated to be low voltage.

3.11 Safety

The Preliminary Safety Study [Ref. 17] considered:

- Identification of main process health and safety hazards
- Preliminary dispersion modelling
- Review of applicable guidelines and regulatory standards
- Over-pressure Protection
- ESD and Depressurisation
- Safety Instrumented Systems
- Dangerous Substances and Explosive Atmosphere Regulations (DSEAR) requirements
- Fire & Gas (F&G) Detection
- Passive and Active Fire Protection
- COMAH requirements

Following a desktop HAZID, the Preliminary Safety Study [Ref.17] identified the main process health and safety hazards:

Hazard	Source
Flammable materials	Biogas Biomethane Hydrogen Natural gas Carbon monoxide
Toxic materials	Hydrogen sulphide Carbon monoxide Carbon dioxide
Asphyxiating gases	Biogas Biomethane Hydrogen CO_2
Stored energy	High pressure storage High-speed rotating equipment (compressors)
High temperature fluids and equipment	Steam SMR Compressor discharges

Table 3- Main Health & Safety Hazards

The most significant risks associated with these hazards relate to loss of containment that could lead to fire (e.g. flange leak) or over-pressure events (e.g. explosion).

The main environmental hazards anticipated are:

- Emissions to air from equipment Pressure Relief Valves (PRVs)
- Noise from compressors and other equipment
- Fugitive emissions from equipment.

4. HYDROGEN TRANSPORTATION

4.1 Overview

The Welsh Water and Princes Ltd sites are approximately 2 km apart across an industrial area. Via a Pipeline Desktop Route Assessment [Ref. 21] and site visit, Stream 2A considered two options:

- Re-purposing an existing pipeline: requires re-enforcement of existing network
- Construction of new pipeline

For either option, the pipeline would be operated by WWU, initially as a stand-alone facility with the potential to integrate into the local network in the future.

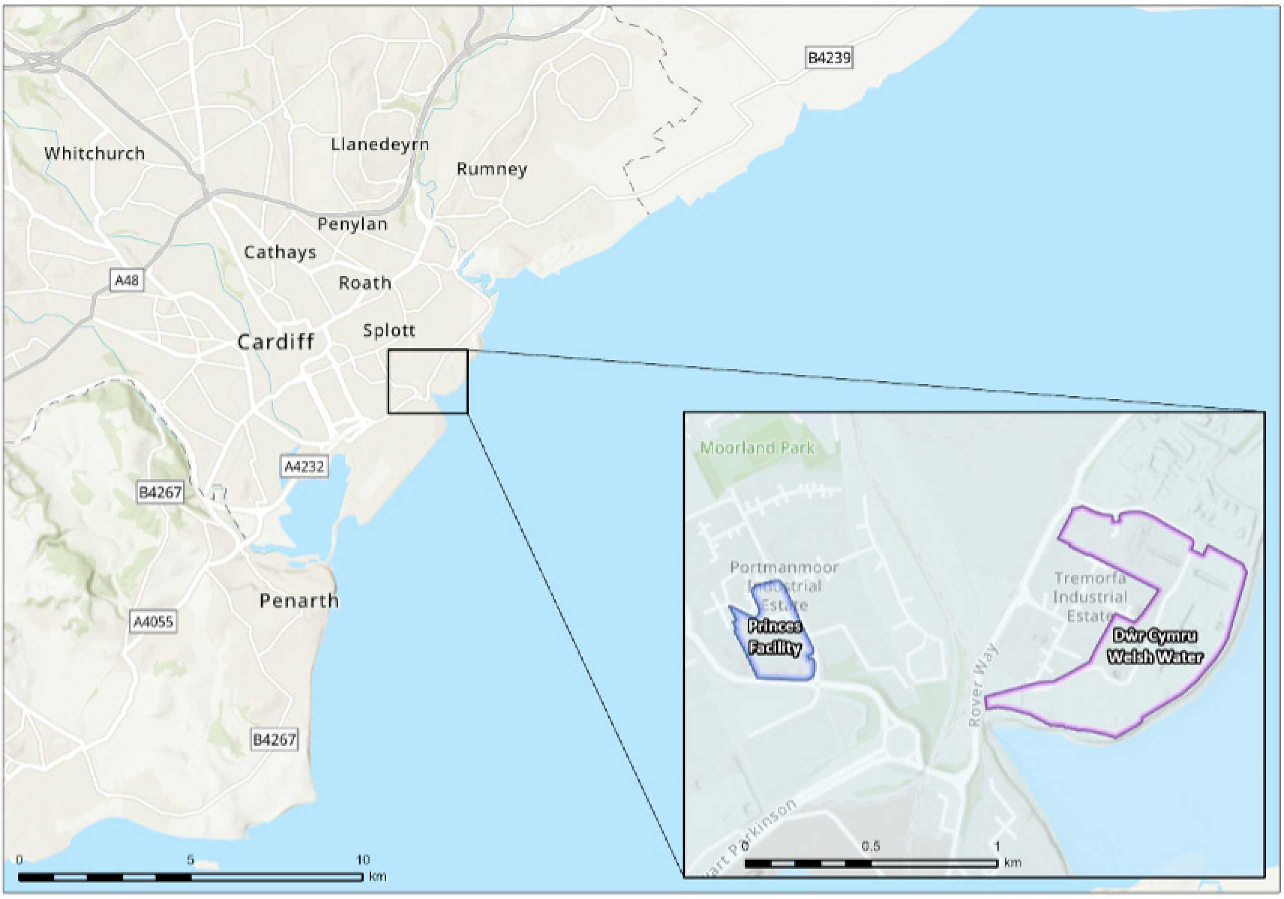


Figure 19 - Key Location: Welsh Water, Princes

4.2 Operating Conditions

As advised by WWU, the operating range of the existing IP natural gas distribution network is 2 to 7 barg. Operating pressures typically range from 5.5 to 6 barg [Ref. 22]. The future hydrogen pipeline will operate at similar pressures. Connections to the repurposed IP pipeline would be with steel pipe to maintain the existing pipeline cathodic protection (CP) system. While a new pipeline could be constructed from either plastic (MDPE 100 grade) or carbon steel (ISO 3183 grade L245).

4.3 Sizing

The Pipeline Sizing Study [Ref. 23] considered criteria for:

- Maximum allowable pressure drop: 0.05 barg per 100 m (2 to 5 barg), 0.07 bar per 100 m (5 to 8 barg)
- Maximum velocity: 60 m/s (diameter nominal, DN, up to 75 mm), 30 m/s (DN75 to DN300)
- Erosional velocity (ASME B31.12: 2019 - Hydrogen Piping and Pipelines)

Considering cases at the lowest (2 barg) and highest operating pressures (7 barg), the Pipeline Sizing Study [Ref. 23] concluded:

- DN90 (3" equivalent) will address all current Princes Ltd requirements (mean, peak)
- The next size up, DN125 (4" equivalent), will cover potential future expansion to 4 t/d hydrogen production at Welsh Water.

4.4 Re-Purposing Existing Pipeline (preferred option)

The Pipeline Desktop Route Assessment [Ref. 21] identified an existing NPS 8" (DN200 equivalent) natural gas pipeline close to the Welsh Water and Princes Ltd sites, shown in yellow in Figure 20.

The Pipeline Design Package [Ref. 24] assessed the suitability of this pipeline for repurposing from Natural Gas to hydrogen duty. The study found that repurposing the pipeline would be feasible, however it would need an integrity assessment, Quantative Risk Assessment, and revalidation in-line with the requirements of IGEM/TD13 [Ref. 25].

In addition to the revalidation of the existing pipeline the local distribution network would need to be reinforced to maintain gas supplies to customers connected to the local network. The Pipeline Design Report identifies the reinforcement requirements, totalling approximately 700 m in total, as shown in green (dashed) in Figure 20.

Repurposing the existing pipeline is the preferred option, as it would remove the requirement for construction of a difficult rail crossing and mitigate the need to obtain easements for a new pipeline.

This concept could be further assessed to support the creation of a segregated hydrogen network in the Cardiff area. WWU indicated such a network would be subject to an exemption from the Gas Safety (Management) Regulations (GS(M)R) [Ref. 26].

The study also identified a further mitigation option, should it not be possible to revalidate by using the existing pipeline as a "carrier sleeve" for slip lining with a new 125mm NB Medium Density Polyethylene pipe.

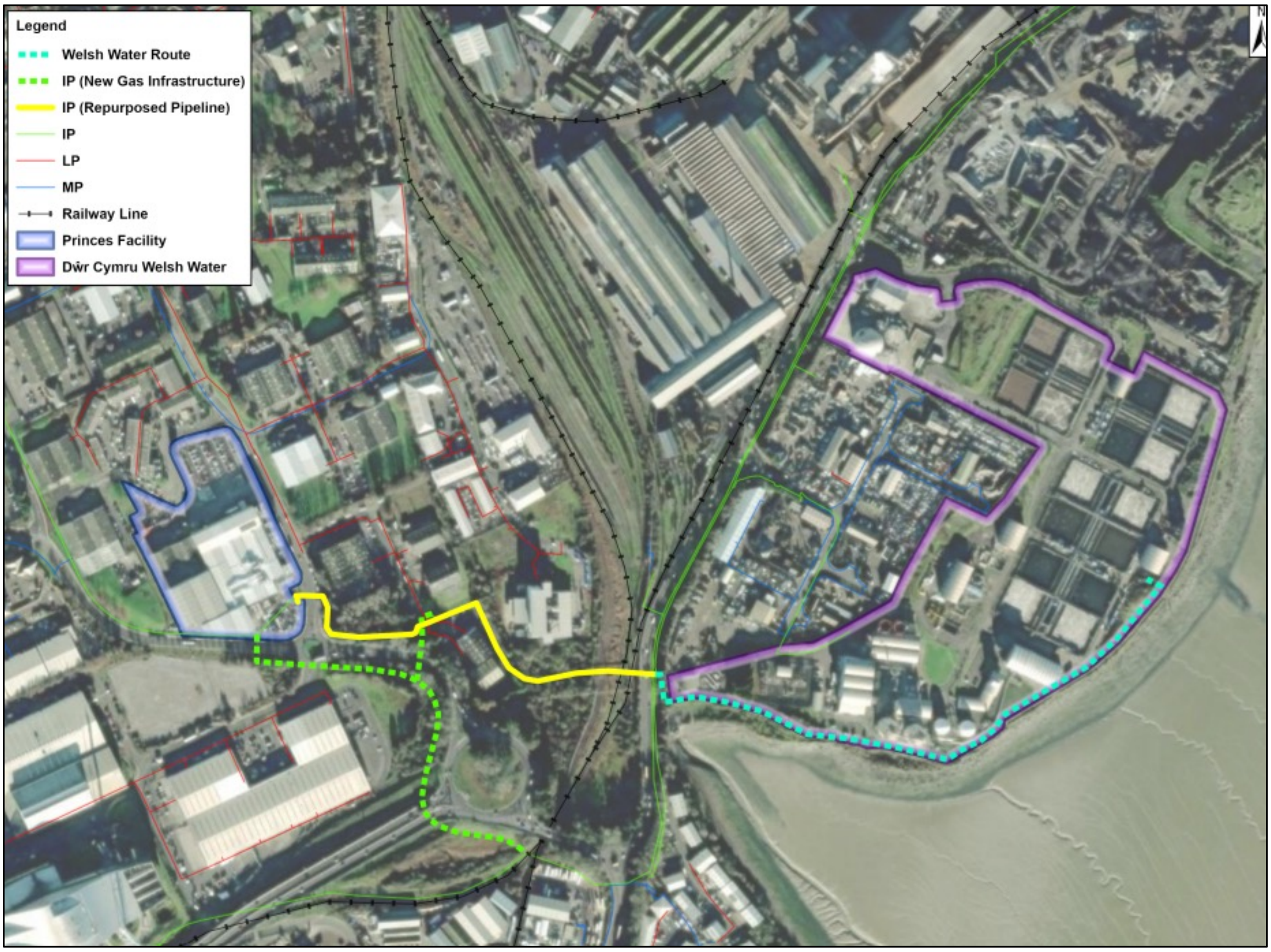


Figure 20 – Pipeline Re-use Options, Welsh Water to Princes Ltd.

4.5 New Pipeline Option

The Pipeline Desktop Route Assessment [Ref. 21] considered options for a new, DN125 (4" equivalent) non-inserted polyethylene (MDPE) pipe. With a maximum design pressure of 7 barg, a minimum proximity distance of 6 m is required. Costain in-house software, U-Route, generated heatmaps indicating route difficulty by weighting construction costs, biodiversity, environmental impacts and land ownership. Two routes (including sub-options) were identified (Figure 21):

- **North Route (blue):** 1.4 km, based on initial corridor produced by U-Route. Avoids an environmentally designated area and runs through predominantly private land. In the purple sub-option (+0.6 km), a greater proportion of the route follows the public highway, potentially allowing for permitted development.
- **South Route (green):** 1.2 km, follows Rover Way south before running through scrubland adjacent to Adventure Travel bus depot. Crosses the railway south of the Ocean Way road bridge before running through designated land, re-joining Ocean Way as street works after the roundabout. Red sub-option (-0.3km) crosses the railway 'as the crow flies', running through designated land before re-joining the highway at the roundabout. Orange sub-option (-0.2 km) crosses the railway adjacent to the existing BOC high pressure oxygen pipeline before re-joining the highway at the roundabout. Yellow sub-option (+ 0.1km) parallels the existing BOC high pressure oxygen pipeline, crossing under Ocean way, then re-joining the Green Route to Princes Ltd.

However, as noted in the section above construction of a new pipeline is considered the "back up" option.

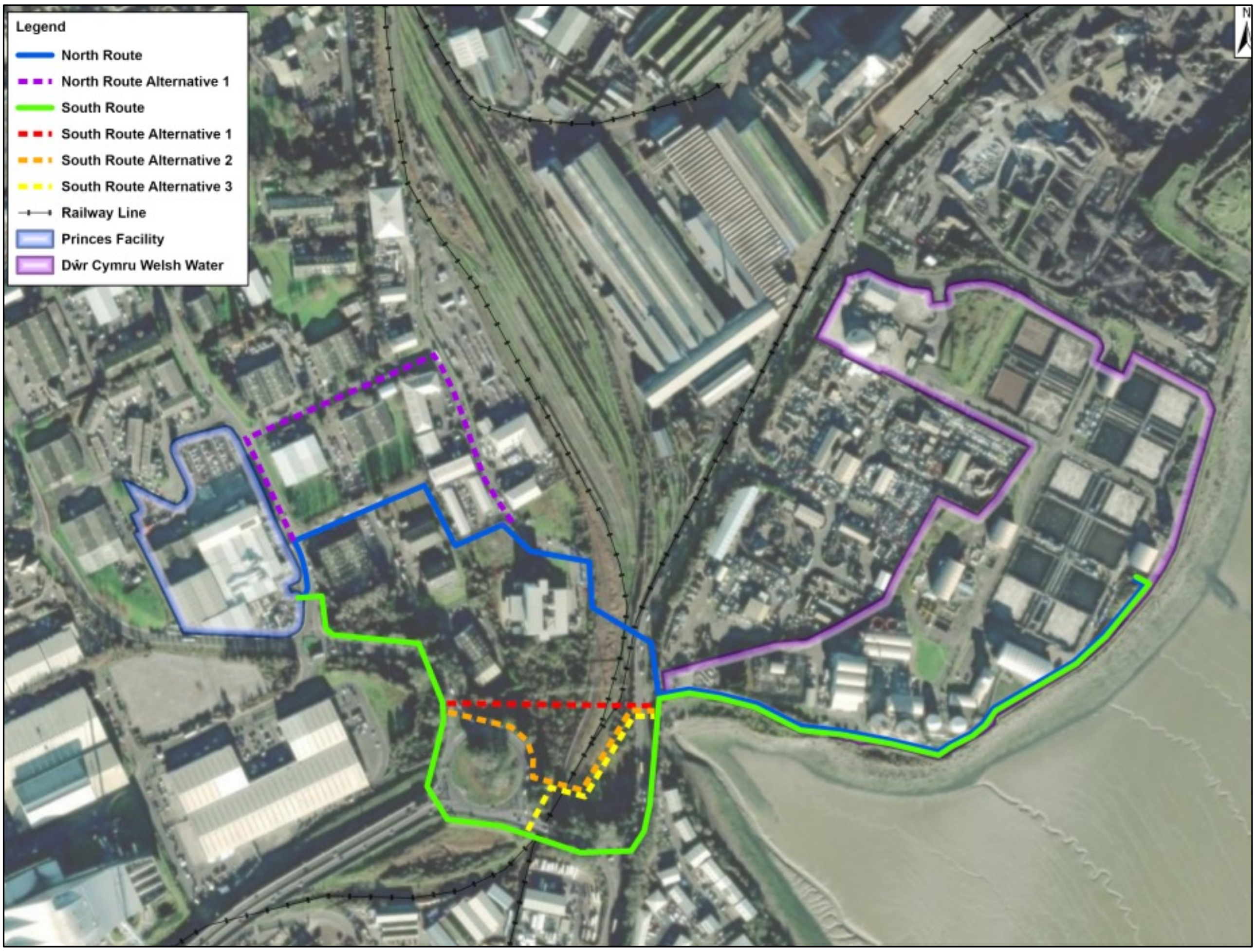


Figure 21 - New Pipeline Routing Options, Welsh Water to Princes Ltd.

Key route observations for all new pipeline options:

- **Rail crossing:** to meet Network Rail standard NR/L2/CIV/044, Planning, Design and Construction of Undertrack Crossings. It is recommended that early contact be made with owners (Network Rail or Associated British Ports, ABP) to understand requirements and to complete a Basic Asset Protection Agreement.
- Various utility and 3rd party pipeline crossings, including a buried oxygen pipeline within Celsa Castle Works

4.6 Constructability

The Pipeline Desktop Route Assessment [Ref. 21] identified that for both options, constructability is impacted by the limited space between the WwTW and railway sidings. Near the proposed exit from the WwTW, there are two large (circa 3 m diameter) sewers. Depending on sewer depth, should the new pipeline be unable to transverse over the top while maintaining a satisfactory depth of cover, the pipeline and any subsequent excavations will be approximately 5 m deep. As the WwTW is located in the vicinity of the Severn Estuary, any excavation may require significant de watering during construction activities..

4.7 Stream 2B Demonstration

The stream 2B demonstration project will build on the Pipeline Design Report, developed in the feasibility study.

Key activities required include:

- Revalidation of the existing 8" (200mm NB) pipeline to the requirements of IGEM/TD13
- All works required for construction of the new section of pipeline within the WwTW boundary.

4.8 Odorisation

The export stream from Welsh Water to Princes Ltd will be odorised to support leak detection. As the odorant type for hydrogen has not yet been defined in standards, Stream 2A assumed that the odorant already present in natural gas used for blending will be sufficient. This in line with the Hy4Heat WP2 Hydrogen Odorant study [Ref. 27]. This odorant is a blend of t-butyl mercaptan (TBM) and dimethyl sulphide [Ref. 28]). Odorisation requirements will be confirmed via gas network test programmes and will be implemented in subsequent project streams.

4.9 Legal and Regulatory Implications

The Pipeline Design Package [Ref. 24] considered the legislative overview, Gas Safety (Management) Regulations (GS(M)R), Pipeline Safety Regulations (PSR) and Associated Standards associated with hydrogen pipelines such as the recently published IGEM/TD/3 supplement for the repurposing of sub-7 barg natural gas pipelines for hydrogen duty. No major issues were identified: for details, refer to the Pipeline Design Package [Ref. 21].

5. HYDROGEN FUEL SWITCHING

5.1 Overview

Fuel switching refers to the use of an alternative fuel in existing combustion equipment. It offers a highly cost-effective means of emissions reduction as the capital expenditure (CAPEX), operating expenditure (OPEX), timescale and disruption associated with fuel switching can be low compared to alternatives. Boilers have been successfully converted to hydrogen e.g. Dunphy Combustion demonstration at Unilever Port Sunlight [Ref. 29].

For H2Juice, CR Plus generated an Existing Combustion Infrastructure Report [Ref. 30], Retrofit Philosophy [Ref. 31] and a Testing Scope of Work [Ref. 32]. The estimated scope and CAPEX of the required modifications (essentially replacement burners, control system, additional monitoring, associated pipework) are low: £911k.

5.2 End User Requirements

At the Princes Ltd Cardiff soft drinks facility, steam is raised in two boilers which currently operate on natural gas. These two boilers are the sole users of natural gas on the site [Ref. 33]. Steam is supplied to users including [Ref. 34]:

- Pasteuriser circuits (x8)
- Sterile tanks
- Filling machines
- Clean In Place (CIP) activities
- Desiccant dryer (for removal of moisture from compressed air circuit)
- Powder processes
- Smaller users e.g. warm water circuits

The steam system operates at 7.5 barg [Ref. 34], equating to a saturation temperature of 173°C [Ref. 35]. Whilst certain pasteurisation processes in the juice industry are operated at lower temperatures [Ref. 36], Princes Ltd confirmed that their current temperatures are required at the Cardiff soft drinks facility, not only for pasteurisation but also for sterilisation and CIP [Ref. 37]. The H2Juice concept is therefore to deliver heat to Princes Ltd at the current grade i.e. 173 °C.

5.3 Heat Demand

5.3.1 Annual Demand

The feasability study has calculated that a supply of 1t/d of hydrogen is required to meet the Princes Ltd demand.

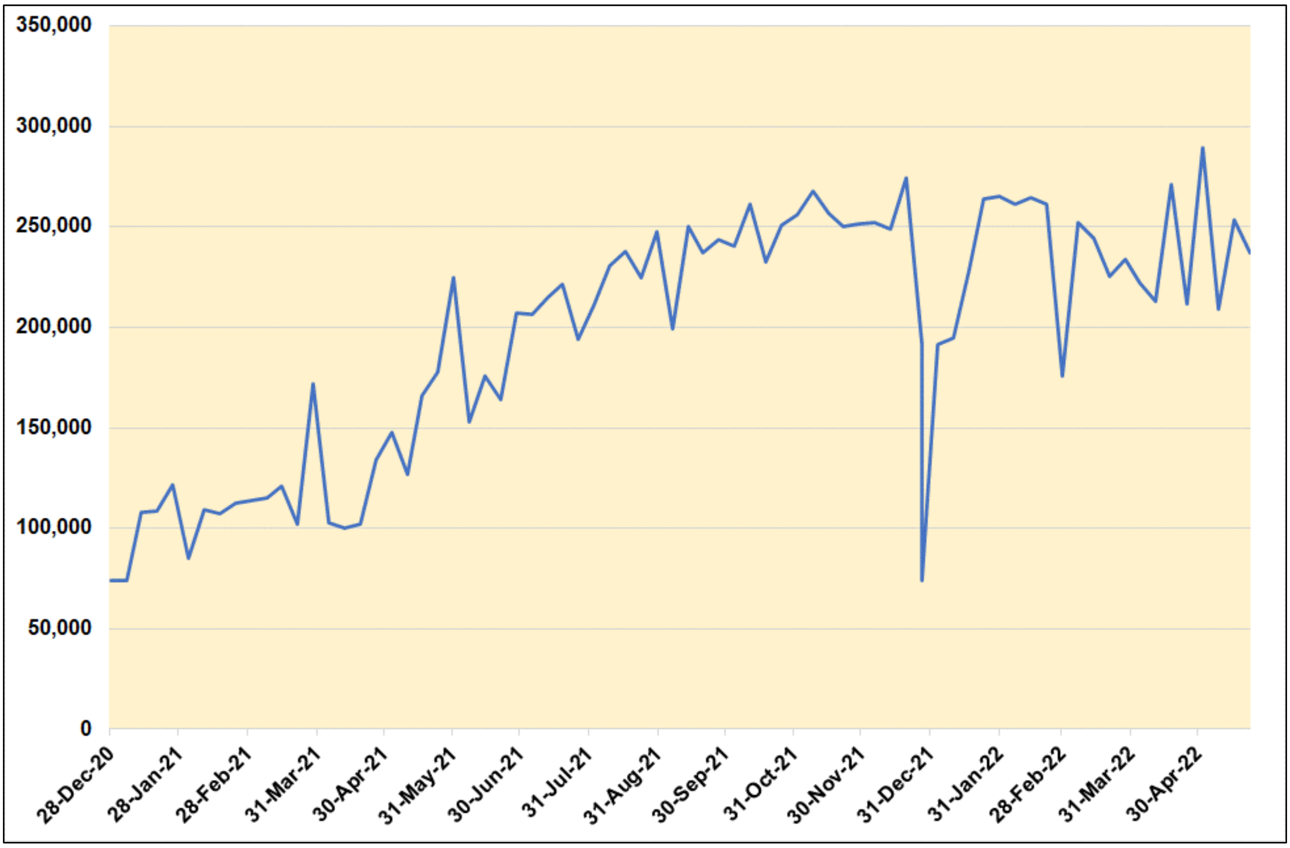


Figure 22 - Heat Demand (kWh per week) - Princes Ltd. Soft Drinks Facility, Cardiff

5.3.2 Weekly Demand

Referring to the week of highest demand (02 May 2022, Figure 22) [Ref. 38]. For 24/7 plant operation [Ref. 39], the hydrogen requirement is 1.24 t/d i.e. 1.7 MW.

5.3.3 Peak Demand

Heat demand is highly variable due to the parallel batch process that take place. Steam demand can change rapidly, increasing from base to peak in approximately 4 minutes.

This equates to a peak heat demand of 2.9 MW, requiring a hydrogen supply rate of 2.1 t/d, just exceeding the production rate of 2 t/d. Buffer storage (up 25 kg) upstream of the export pipeline can supplement hydrogen production for a conservatively long period of extended peak demand (up to 6 hours).

5.4 Reliability & Sparing

The Princes Ltd Cardiff soft drinks facility operates 24/7, stopping only for 15 hours on Christmas day [Ref. 39]. The two site boilers are subject to annual shutdowns when a hire boiler is brought to site: refer to Section 5.8.

Site steam supply is typically lost twice a year. This results in a loss of sterility on all eight pasteurization plants, requiring contents to be discarded, cleaning in place (CIP) and repeated high temperature sterilization.

To ensure best available uptime at Princes Ltd, the natural gas supply is retained, allowing boilers to switch back immediately upon loss of hydrogen. The hydrogen supply itself delivers a high level of availability via:

- Feedstock: WwTW generates sufficient biogas for hydrogen production. Output is 60 GWh/yr of which 35 GWh/yr is required for hydrogen. Refer to Section 9.5.
- Plant capacity: hydrogen facilities (production, blending, de-blending) are sized for 2 t/d hydrogen, exceeding mean demand of 1.0 t/d. A single production train can meet Princes Ltd requirements. Refer to Section 5.3.1.
- Storage: sufficient hydrogen is stored at Welsh Water to meet half a day of mean demand when hydrogen production is not available i.e. up to 0.6 t storage vs. 1.0 t/d demand. Refer to Section 5.3.3.
- Buffer storage: provides sufficient hydrogen (in addition to hydrogen production) to support peak demand for up to 6 hours. Refer to Section 3.6.

5.5 Fuel Switching Philosophy

The Princes Ltd facility will be switched to hydrogen operation on the following basis:

- Both boilers will be modified for operation on hydrogen (or hydrogen blend). The hire boiler will not be modified for operation on hydrogen.
- Boilers will be converted and switched over one at a time to develop experience and confidence.
- Natural gas supply and facilities to be retained to ensure the site can revert should hydrogen be unavailable. Simultaneous co-firing on hydrogen and natural gas is not required.
- Wherever possible, hydrogen facilities will be located adjacent to the equivalent existing natural gas facilities.
- The scope of modifications will be such that costs and disruption are minimised.

5.6 Gas Reception

The existing natural gas supply arrives at the south-east corner of the Princes Ltd site via the WWU IP distribution network (Figure 23). Arriving at the gas meter house at 2 to 7 barg, its flow rate is measured, and pressure reduced to 140 mbarg. From the gas meter house, a DN150 (6") pipeline supplies the boiler house, passing under the goods yard entrance road. Inside the boiler house, the pipeline splits into two DN100 (4") pipelines to feed each boiler.

Ownership and responsibilities are summarised as:

- WWU: IP distribution network, offtakes, Pressure Regulating Installations (PRIs) and district governors
- Meter Asset Manager (MAM): from downstream of the Emergency Control Valve (ECV) to upstream of the meter isolation valve. In this instance, the MAM is National Grid Metering (NGM) [Ref. 42].
- Princes Ltd: meter isolation valve and downstream

In future, hydrogen will arrive at the south-east corner of the Princes Ltd site via the re-purposed or new, dedicated pipeline from Welsh Water. Arriving at the new hydrogen gas meter house located adjacent to the existing natural gas meter house at 2 to 7 barg, its flow rate and composition are measured, and its pressure is reduced to 160 mbarg.

The exact location of the hydrogen gas meter house is subject to survey. It will be constructed to a standard glass reinforced plastic (GRP) specification. A master lock will allow site access and

Distribution Network Operator (DNO) grid network access. Equipment will include (at a minimum)::

- Isolation equipment (valves)
- Metering equipment
- Pressure let down equipment
- Bypass pipework for meter change

From the hydrogen gas meter house, a new pipeline supplies hydrogen to the boiler house, passing under the goods yard entrance road, following a similar route to the existing natural gas pipeline. Inside the boiler house, the pipeline splits into two to feed each boiler. Due to the change in fuel, the boiler house will require a new Dangerous Substances and Explosive Atmosphere Regulations (DSEAR) assessment.

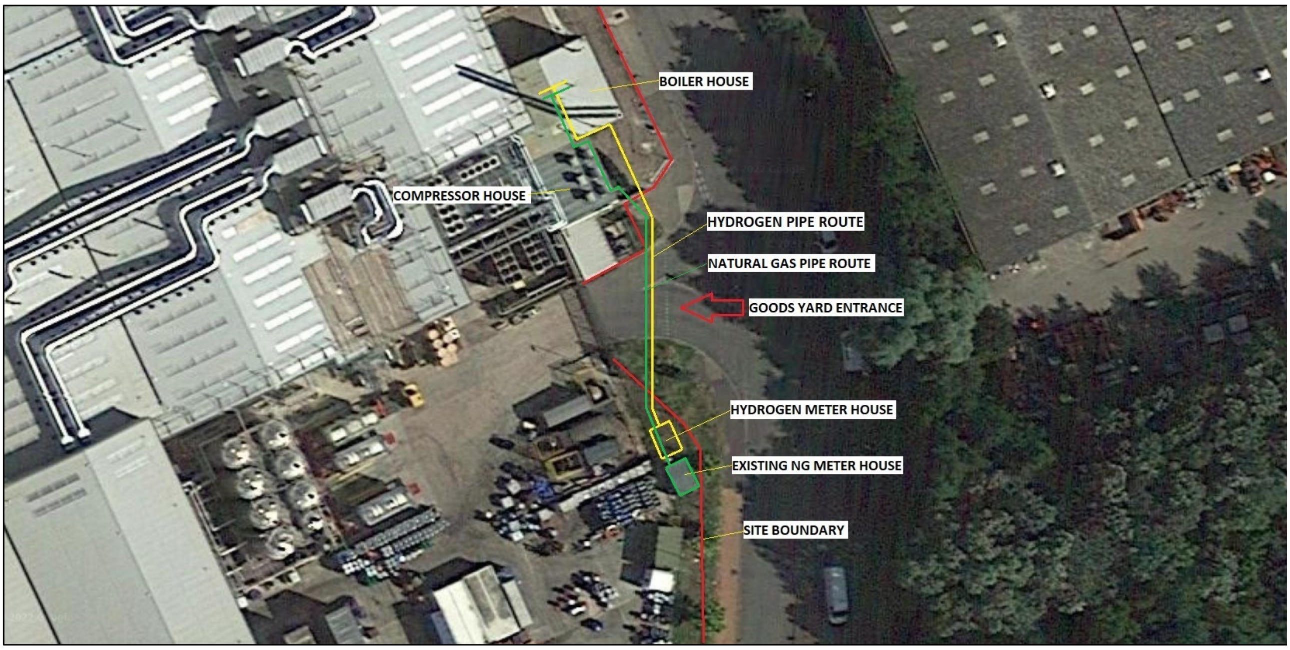


Figure 23 - Gas Reception and Site Pipework, Princes Ltd Cardiff Soft Drinks Facility

5.7 Metering & Instrumentation

Existing natural gas metering facilities at the Princes Ltd site consist of:

- Site main gas meter located in the gas meter house. Meter data, as used for billing, can be viewed via the online portal of the supplier, Engie.
- Gas meters on each boiler. Linked to the eSight online portal, these meters are also manually read weekly by site personnel and recorded in a utilities database.

In future, hydrogen metering facilities at Princes Ltd after gas letdown will include:

- Flow meter to record supply to Princes Ltd Located in the hydrogen meter house, the meter shall be of a recognised standard, classed as suitable for use with hydrogen gas. Such meters are readily available on the market. The meter shall have smart monitoring capability to provide communication back to a data portal for analysis.
- Composition meter
- Pressure transmitter
- Temperature transmitter

5.8 Boilers

The Princes Ltd soft drinks facility has two existing boilers, both of 6,000 kg/h steam capacity: Dennis Baldwin (2006), and Byworth (2019): details in Appendix - Boiler Data, Princes Ltd. The boilers operate in a lead-lag configuration set via the local area ABB HMI screen. A lead-lag changeover is initiated automatically each week.

Each boiler is subject to a scheduled annual shutdown of approximately 7 days [Ref. 39]. During this period, a hire boiler is brought to site to maintain the steam supply. Every 5 years (or upon failure of an annual inspection), a boiler is shut down for 4 weeks, again requiring use of the hire boiler. Hydrogen conversion of the hire boiler is excluded from the study.

Both boiler chambers can remain unchanged for hydrogen operation, although the CR Plus Existing Combustion Infrastructure Report [Ref. 30] identifies a potential de-rating of steam output of up to 10% due to the reconfiguration of the burners and differences in flame length and speed between hydrogen and Natural Gas. No materials incompatibility was identified from the study. To prevent boiler damage due to higher heat flux during hydrogen operation, additional temperature monitoring was recommended:

- Furnace back-end temperature, mounted through access door
- First-pass cha mber temperature
- Second-pass chamber temperature
- Flue temperature

Oxy trim, not currently installed on either boiler, will be added for dual-fuel firing and to act as a safety device should incorrect gas-air ratios develop inside the boiler.

5.9 Burners

On both existing boilers, the burners (supplied by Dunphy) require a minimum natural gas supply pressure of 76 mbarg: details in Appendix - Boiler Data, Princes Ltd. The CR Plus Existing Combustion Infrastructure Report [Ref. 30] advised that the existing burner system is not suitable for hydrogen service until the following modifications are carried out:

- **Uni-bloc valves:** replacement required as current items are cast iron. This is incompatible with hydrogen service due to potential for early failure via embrittlement [Ref. 43].
- **Burners:** replacement required with dual-fuel burners to allow use of natural gas or hydrogen. Such burners are already available on the market. Manufacturers, including Dunphy, advised burner replacement and upgrade costs to be near-identical. Replacement allows fuel switching to commence with ‘as new’ burners with no age-related deterioration [Ref. 43].

The proposed hydrogen burner requires min inlet pressure of 110mBarG whereas the existing NG boilers have a min inlet pressure of 76mBarGHydrogen has a lower energy content and lower density than NG.A higher quantity of H2 to match the same energy as natural gas. Due to higher volume requirement a larger bore pipeline is required and also larger valves. To overcome the pressure drops and provide the required pressure at the burner head (avoiding flame back) the higher pressure is required.

5.10 Control System

A new burner control system on each boiler will enable dual-fuel operation. The LAMTEC CAN bus combustion management system (CMS), similar to the current Ratiotronic 6000, is proposed. Oxygen trim will be added to the new Ratiotronic 6009 control system. Alternative firing profiles can be loaded to allow operation on multiple hydrogen blends. A local HMI at each boiler will provide control and visibility of data and trends.

6. TECHNOLOGY ASSESSMENT

6.1 Overview

In the Technology Assessment Technical Note [Ref. 46], heating options for the Princes Ltd Cardiff soft drinks facility were assessed in terms of GHG emissions, technical feasibility and conversion cost. Current operation on natural gas (i.e. counterfactual) was compared with the H2Juice concept and five alternative technologies:

- Alternative #1: Hydrogen from on-Site Electrolysis
- Alternative #2: Direct Electric Heating
- Alternative #3: Heat Pumps
- Alternative #4: Biogas
- Alternative #5: Biomethane

For Alternatives 1 to 3 (electricity-based solutions), the Grid Average, Consumption-Based, Industrial value of 0.127 kgCO2eq/kWh (2025) was obtained from the DESNZ (formerly BEIS) Green Book [Ref. 47]. Whilst emissions could be reduced by use of a dedicated renewable electricity supply, such a solution would entail further significant CAPEX.

6.2 End User

During the recent plant expansion (2019), steam was identified as the preferred source of process heating due to the existing site infrastructure, site knowledge and requirements for system capability and reliability to meet the 'peaky' demand profile [Ref. 48].

6.3 Counterfactual

Princes Ltd current GHG emissions basis:

- Annual natural gas consumption
- GHG conversion factor, natural gas, net (DESNZ (formerly BEIS)): 0.20297 kgCO2eq/kWh [Ref. 49]

6.4 H2Juice

The H2Juice concept refers to fuel switching from natural gas to hydrogen in the currently-installed combustion equipment at Princes. As per Section 5.0, the CR Plus Retrofit Philosophy [Ref. 29] identified that the scope and costs of the required modifications (essentially replacement burners, control system, additional monitoring, associated pipework) are low: £911k.

Three H2Juice carbon intensity scenarios were considered:

- Scenario 1 (2025): no CCUS i.e. CO2 from hydrogen production process vented to atmosphere
- Scenario 2 (2030): carbon capture facilities added to hydrogen production process. All captured CO2 utilised in end-use applications (e.g. food and drink sector), displacing fossil-fuel derived CO2.
- Scenario 3 (2030): carbon capture facilities added to hydrogen production process. All captured CO2 sequestered in a permanent underground store. (Assumed location: HyNet injection facility, Connah's Quay, north Wales).

Carbon intensity was obtained via the UK Low Carbon Hydrogen Standard methodology [Ref. 14]. Carbon intensity and corresponding Princes emissions for each scenario are summarised as:

Scenario	Carbon Intensity ($gCO_2e/MJH2$)	Main Contributors ($gCO_2e/MJH2$)	Princes Emissions ($tCO_2eq/year$)
1	7.9	**Biogas feed:**1.2 **Biogas upgrading and Reforming:** 5.7 **Compression to 30 barg:** 1	349
2	6.3	**Biogas feed:** 1.4 **Biogas upgrading and Reforming:** 2.6 **CCS process and infrastructure:** 2.0 **Compression to 30 barg:** 0.4	279
3	-133.3	**Biogas feed:** 1.4 **Biogas upgrading and Reforming:** 2.6 **CCS process, infrastructure and road transport:** 6.3 **Compression to 30 barg:** 0.4	-5,808

Table 4 - H2Juice Carbon Intensity and Princes Emissions

Refer to Appendix – Carbon Intensities for detailed calculation

6.5 Alternatives

6.5.1 Alternative #1: Hydrogen From On-Site Electrolysis

An electrolyser at the Princes Ltd site could use mains water and grid electricity to produce hydrogen for heating. Based on the mean hydrogen demand of 1.0 t/d identified in Section 5.3.1 and using a typical electrolyser stack efficiency of 50 kWh/kg [Ref. 50], the required installed capacity is:

(50 kWh/kg x 996 kg/d / 24 h/d) / 1000 kW/MW i.e. 2.1 MWe

The International Renewable Energy Agency (IRENA) identified a high electrolyser CAPEX range: $0.7 to 1.4 million per MWe [Ref. 51]. Using the UK government annual exchange rate of £0.8003 per $ [Ref. 52], the CAPEX of the required installed capacity at Princes Ltd would cost £1.2 million to £2.4 million.

CR Plus advised electricity-based solutions (Alternatives 1 to 3) could be prohibitive due to the scope of modifications and space limitations [Ref. 53]. A high-level TIC estimate (Q3 2022) of £9 million included heat pumps, power supply upgrade and integration but excluded any civil and structural works required. OPEX is also high, especially during periods of high electricity prices, in addition to routine maintenance and utilities costs (£30,000 per year).

6.5.2 Alternative #2: Direct Electric Heating

Direct electric heating converts electricity to heat via the principle of Joule heating. Using a resistor, the typical conversion efficiency, as quoted by vendors, is effectively 100% [Ref. 54].

6.5.3 Alternative #3: Heat Pumps

Heat pumps extract heat from their surroundings (air or ground) via a four-stage system of compression and evaporation (as illustrated in Figure 24). The boiling point of the refrigerant is selected to be sufficiently low to extract latent heat from the source and to provide the temperature driving force to provide the heat for vaporisation. Heat pump systems can deliver a typical efficiency as quoted by vendors, of 300 to 400%, i.e. for every kW of electricity consumed, 3 to 4 kW of heat can be obtained [Ref. 55].

The 2020 SINTEF white paper, Strengthening Industrial Heat Pump Innovation [Ref. 56] divides heat pumps into two categories:

- Applications up to 100 °C which can be covered by mature heat pump technologies
- Applications in the range of 100 °C to 200 °C for which heat pump suppliers and technical developments are required to meet the market needs

As per Section 5.2, a high temperature is required at the Princes Ltd soft drinks facility: 173°C. This exceeds the 150 °C that commercially available high temperature heat pumps can currently deliver [Ref. 57]. As there is not a suitable heat source readily available to start with (e.g. waste heat) for upgrade [Ref. 48], so until higher temperature units become available, heat pumps are technically unfeasible for this application. In addition to technical limitations, central and distributed heat pumps have previously been deemed unviable in this application due to CAPEX, OPEX and site uptime considerations [Ref. 48].

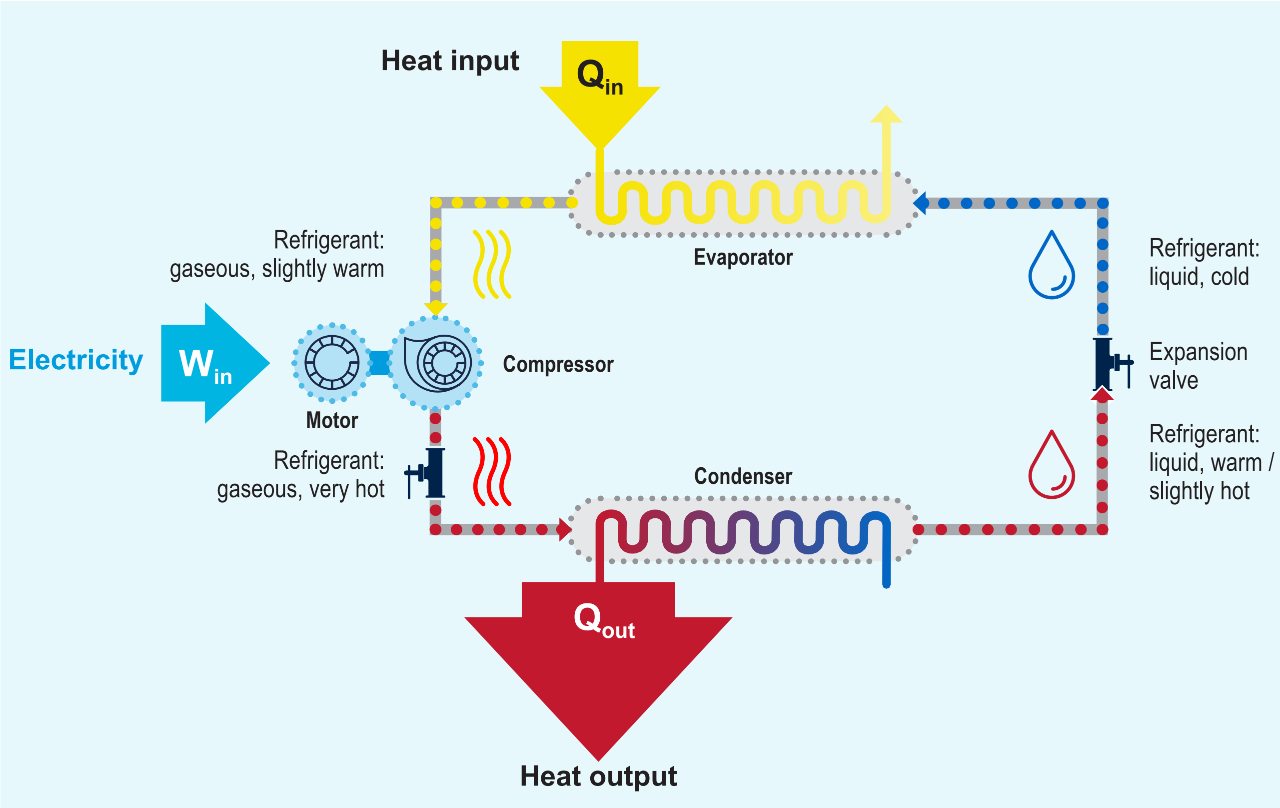


Figure 24 - Heat Pump Operation

6.5.4 Alternative #4: Biogas

Biogas is generated from sewage at the Welsh Water Cardiff East WwTW. As discussed in the Technology Assessment Technical Note [Ref. 46], Welsh Water advised the biogas composition is approximately 62 vol% methane, 38% vol CO2. From the UK Low Carbon Hydrogen Standard [Ref. 14], biogas carbon intensity is 0.00022 kgCO2eq/kWh.

Biogas was confirmed by CR Plus to be suitable for use at the Princes juice facility subject to:

- Installation of a larger diameter gas train and nozzles
- Replacement of the Unibloc valves which are made from an incompatible material

6.5.5 Alternative #5: Biomethane

Biomethane is not produced at the Welsh Water Cardiff East WwTW. As discussed in the Technology Assessment Technical Note [Ref. 46], Welsh Water advised the biomethane composition at their Five Fords WwTW (near Wrexham) is approximately 87 vol% methane, 9.5 vol % propane and 3.5% vol CO2. From the UK Low Carbon Hydrogen Standard [Ref. 14], biomethane carbon intensity is 0.10625 gCO2eq/MJ.

As Biomethane is produced to meet the gas composition standard in the Gas Safety (management) Regulations 1996 it was confirmed by CR Plus to be suitable for use at the Princes juice facility without modification.

6.6 GHG Emissions

From a comparison between the counterfactual, H2Juice and the five alternatives identified:

- The H2Juice concept (in combination with CCUS) offers the largest reduction, generating negative emissions of -5,808 tCO2eq/year. As per Section 5.0, the fuel switching CAPEX is low:

£911k.

- Currently available heat pumps would require Princes to operate at lower process temperatures; this was confirmed as unfeasible [Ref. 36]. As per Section 6.2, the required TIC is prohibitive: £9 million.
- The other alternatives considered were all confirmed to be technically feasible but deliver greater emissions than H2Juice.

Case	Technical Feasibility	Plant Modification CAPEX	Annual Emissions (tCO_2eq / year)	Emissions Reduction vs. Counterfactual (tCO_2eq / year)
Counterfactual: Natural Gas	YES (proven in this application)	N/A	2,462	N/A
H2Juice: Hydrogen	YES	LOW	Scenario 1: 349 Scenario 2: 279 Scenario 3: -5,808	2,113 2,183 8,270
Alternative 1: Hydrogen from on-site Electrolyser	YES	HIGH	3,091	-629
Alternative 2: Direct Electric Heating	YES	HIGH	2,060	402
Alternative 3: Heat Pump	NO NOTE 1	VERY HIGH	687 (at lower process temperatures)	1775
Alternative 4: Biogas	YES	LOW	2.7	2,459
Alternative 5: Biomethane	YES	LOW	4.6	2,457

Table 5 - Emissions Summary

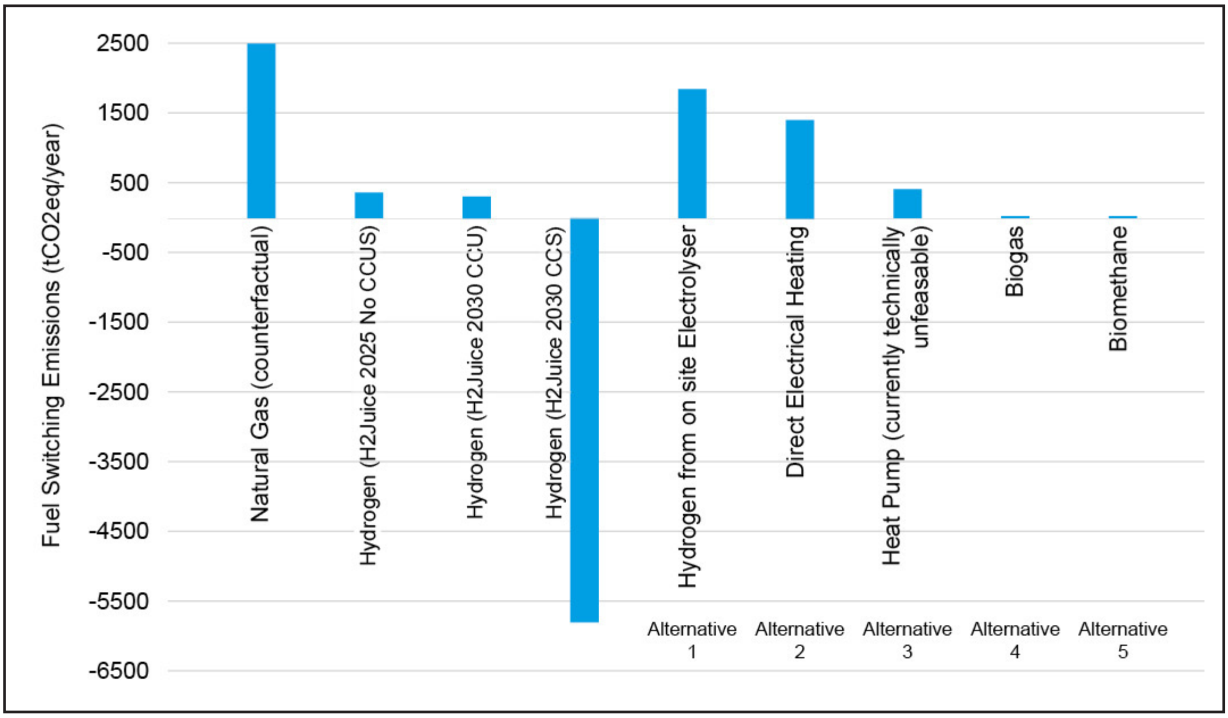


Figure 25 - Emissions Comparison

NOTE 1. Princes process temperature requirements exceed current heat pump capabilities

6.7 NOx Emissions

Princes Ltd site emissions of NOx (2021) ranged from 49 to 54 mg/m3 against a limit of 100 mg/m3 [Ref. 58]. Switching to hydrogen increases both the volume of gas burned and the combustion temperature thus raising potential NOx emissions. Reducing the oxygen level in the combustion air and the addition of flue gas recirculation (FGR) can maintain NOx emissions on hydrogen service to 70 to 80 mg/m3 [Ref. 59]. NOX emissions will be closely monitored during the demonstration phase.

7. LEVELISED COSTS

7.1 Overview

Project economics are considered in terms of:

- Gross Levelised Cost of Hydrogen (LCOH): including CCUS with carbon captured and utilised (no allowance made for the negative carbon intensity of the captured carbon)
- Nett Levelised Cost of Hydrogen (LCOH): including carbon captured and permanently sequestrated (benefits derived from the negative carbon intensity of the hydrogen accounted for in the calculation)
- Levelised Cost of Abatement (LCOA): carbon capture only (based on the incremental benefits of adding CCUS to the hydrogen production)
- Levelised Cost of Abatement: H2Juice demonstration project (based on PIC for the whole project)

The costs to deliver the whole project in Stream 2B are presented in Section 8.3.

7.2 Levelised Cost of Hydrogen

LCOH was obtained via the methodology in the DESNZ (formerly BEIS) Hydrogen Production Costs 2021 report [Ref. 60].

7.2.1 CAPEX

As detailed in the LCOH report [Ref. 61], CAPEX estimates were obtained via vendor quotes for major plant items. As per the DESNZ (formerly BEIS) guidance [Ref. 60], LCOH addresses hydrogen production only, covering biogas upgrading, hydrogen production (SMR and WGS) and purification (PSA). These were converted into total installed costs (TICs), including Bulks and Site Costs, via the Costain in-house software, Genie

Plant Section	CAPEX (£MM)	TIC (£MM)
Hydrogen Production only	12.4	26.2

Table 6 – Hydrogen Production only, CAPEX & TIC

7.2.2 OPEX

LCOH OPEX data source and values are summarised as:

Category	Scope	Source
Fixed OPEX	Maintenance cost Maintenance labour cost Operating labour cost Administration Support labour	Costain costing norms
Variable OPEX	Electricity Natural gas	DESNZ (formerly BEIS) Green Book [Ref. 47]

Table 7 – LCOH OPEX Data Source and Values

7.2.3 Cases

From the cases considered in the project LCOH report [Ref. 61]:

H2 Production rate (t per/day)	CCUS Accounting	Case Description	LCOH 10 years (£/MWh)	LCOH 20 years (£/MWh)	LCOH 30 years (£/MWh)	LCOH 40 years (£/MWh)
2T	Gross Cost	2 t/d hydrogen production incl. CCUS	240	200	189	186
	Nett	2 t/d hydrogen production incl. CCUS	112	67	53	48
3.4T	Gross Cost	3.4 t/d hydrogen production incl. CCUS	157	133	127	125
	Nett	3.4 t/d hydrogen production incl. CCUS	29	0	-10	-13

Table 8 - LCOH Results

Gross and Nett Costs represent the total cost for producing hydrogen with and without the benefits derived from the negative carbon intensity of the hydrogen produced. Calculation spreadsheets are attached in Appendix – Carbon Intensities for detailed calculation.

Due to economies of scale, the lowest LCOH is obtained for the higher hydrogen generation capacity of 3.4 t/d versus the base 2 t/d.

Compared to large-scale Natural Gas reforming projects the CAPEX and OPEX for the H2Juice concept is relatively high, but the value associated with the negative emissions generated by utilising biogas as feedstock results in declining and even negative costs over the 40 year design life of the plant.

Furthermore, there is much less volatility in H2Juice LCOH as it is less exposed to the recent electricity price escalation compared to electrolysis-based hydrogen production routes.

7.3 Levelised Cost of Abatement

Levelised Cost of Abatement were calculated for the following cases:

- Levelised Cost of Abatement (LCOA): carbon capture only.
- Levelised Cost of Abatement: H2Juice demonstration project.

7.3.1 CAPEX

CAPEX estimates were obtained via vendor quotes for major CCUS plant items, including compression, dehydration and purification. These were converted into total installed costs (TICs), including Bulks and Site Costs, via the Costain in-house software, Genie.

Plant Section	TIC (£MM)
CCUS only	5.4
H2Juice Demonstration Project	36.9

Table 9 – TIC

7.3.2 OPEX

LCOA OPEX data source and values are summarised as:

Category	Scope	Source
Fixed OPEX	Maintenance cost Maintenance labour cost Operating labour cost Administration Support labour	Costain costing norms
Variable OPEX	Electricity	DESNZ (formerly BEIS) Green Book [Ref. 47]
Variable OPEX	CO_2 Transport & Storage	Costs: €10/t CO_2 Exchange rate: £/€0.8489 i.e. £8.5/t CO_2. [Ref. 52]
Variable OPEX	Uncaptured CO_2 Cost	Range: £260/t CO_2 (2025) to £378/t CO_2 (2050).

Table 10 – LCOA OPEX Data Source and Values

7.3.3 Results

From the cases considered:

H2 Production rate (t per/day)	CCUS Accounting	Case Description	LCOA 10 years (£/tCO_2e)	LCOA 20 years (£/tCO_2e)	LCOA 30 years (£/tCO_2e)	LCOA 40 years (£/tCO_2e)
2T	CCUS Only	2 t/d hydrogen production incl. CCUS	133	117	113	112
	H2Juice Demonstration Project	2 t/d hydrogen production incl. CCUS	476	381	356	348
3.4T	CCUS Only	3.4 t/d hydrogen production incl. CCUS	103	92	90	89
	H2Juice Demonstration Project	3.4 t/d hydrogen production incl. CCUS	291	234	219	214

Table 11 - LCOA Results

The lowest LCOA is obtained with economies of scale for the higher hydrogen generation capacity of 3.4 t/d versus the base 2 t/d.

The LCOA for the H2Juice demonstration project are considerably higher than for the LCOA achieved through the addition of CCUS only. This can be explained due to the scale of the H2Juice demonstration and the LCOA would dramatically reduce once the H2Juice concept is deployed at commercial scale.

8. STREAM 2B: PROJECT DELIVERY PLAN

8.1 Project Description

The Stream 2B project will consist of three separate components, combined into an end-to-end scheme that will demonstrate the viability of the following:

1. Hydrogen production from biogas derived from effluent waste at the Welsh Water Cardiff East WwTW
2. Repurposing an existing NPS 8" (DN200) WWU IP main from natural gas to hydrogen to link production with demand
3. Conversion of industrial boilers to operate on blends of natural gas and hydrogen from **20 to 100 vol% hydrogen**

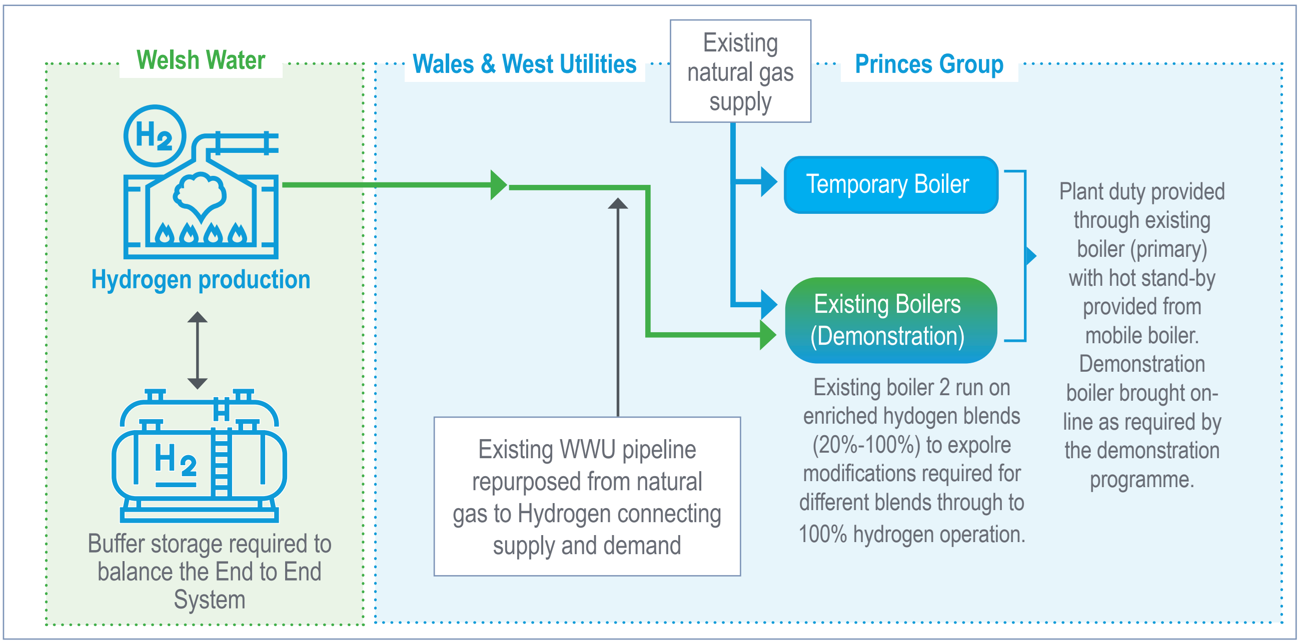


Figure 26 - Stream 2B Schematic

The project will demonstrate how the hydrogen can be produced from biogas derived from sewage and how this can be used to enable fuel switching at the Princes Ltd facility.

The Welsh Water Cardiff East WwTW has an existing AD plant which converts effluent waste into biogas. The biogas is currently used to fuel gas engines, generating electricity to meet part of the electricity demand for the treatment works. The estimated 1,800 GWh per year of biogas produced from effluent in the UK water sector could produce almost 40,000 tonnes per year of hydrogen [Ref. 62]. **Once successfully demonstrated, the technology could be replicated across Welsh Water sites and more widely across the UK, providing a source of low carbon hydrogen to support industrial decarbonisation.**

The conversion of the existing WWU IP pipeline would be the first UK project to convert an existing network pipeline from natural gas to hydrogen duty. There are thousands of km's of IP steel pipeline in the UK gas distribution network. Demonstrating the suitability of carbon steel IP gas mains for conversion to hydrogen would provide a credible conversion option for this type of pipeline, potentially negating the need for new pipelines to connect hydrogen production to industrial customers. A monitoring regime will be agreed with the Health & Safety Executive (HSE) to assess the impact of converting the pipeline to hydrogen duty and will be implemented during the demonstration phase and subsequent operations.

The Stream 2B scheme will also undertake a FEED study to develop a de-blending solution which could be deployed in all UK gas distribution networks. Once hydrogen blends are introduced in the UK's gas system, de-blending technology could allow network operators to provide blends to meet industrial customers specific requirements through to a **100% hydrogen supply, therefore accelerating industrial decarbonisation.**

The Stream 2B scheme will demonstrate that existing industrial boilers can be modified to operate on a range of blends of hydrogen through to full fuel switching whilst also retaining the ability to revert to the natural gas supply. As discussed in Hy4Heat WP6 [Ref. 27], there are over 1,400 high temperature steam boilers of a similar type to the Princes Ltd boilers in operation around the UK where this technology could be deployed. There are also many more package type boilers in operation across other industry sectors which would be suitable for the dual-fuel burner technology developed in the H2Juice project.

8.2 Engineering Design

The Stream 2B scheme will generally be a continuation of the scheme developed through the feasibility study (Stream 2A). It will demonstrate end-to-end industrial fuel-switching where hydrogen is generated, transported and used for fuel switching, managed via a three-phase, gated process:

- **Phase 1:** undertake FEED, producing sufficient technical detail and deliverables to mature the cost estimate to Association for the Advancement of Cost Engineering (AACE) Class 2, establish long lead delivery items alongside a level 2 delivery schedule. In parallel, undertake planning and consenting activities to enable investment decision at the end of phase 1 to build the demonstrator.
- **Phase 2:** having passed through the investment gate review after phase 1, phase 2 will entail detailed design and procurement of equipment, materials and necessary construction contractors for the end-to-end solution. Project construction will conclude with mechanical completion, cold commissioning and hot commissioning of the three project elements before an end-to-end proving test.
- **Phase 3:** the final phase of operational trials will commence once phase 2 is complete and the gate for operation has been signed off. This gate will include the satisfactory certification of end-to-end systems, permitting, consenting and regulatory and safety approvals. Operational trials will include hydrogen generation, distribution and storage to the boilers. It will enable the project team to conclude that project benefits have been realised and that operations can be safely undertaken within the desired economic requirements.

The technical scope of the H2Juice project will entail full FEEDs across the existing Stream 2A scheme: hydrogen production, distribution, storage, de-blending and fuel switching on industrial boilers.

A consortium agreement will be developed between the partners Costain, Welsh Water, WWU and Princes Ltd to apply for Stream 2B funding from DESNZ (formerly BEIS). Costain will act as the overall Project Management Organisation (PMO), co-ordinating the overall project and managing all interfaces.

As per the indicative Stream 2B programme, hydrogen generation will be on-line by January 2025: refer to Appendix – Stream 2B Programme. .

8.3 Cost Estimates

Preliminary cost estimates have been developed for the Stream 2B submission.

8.4 Plan

Following completion of the demonstration of hydrogen production at the Welsh Water Cardiff East WwTW and blending trials at Princes Ltd, the end-to-end scheme will move to commercial operation.

It is intended that Welsh Water and Princes Ltd will enter into a commercial agreement for the supply of hydrogen with boilers converted to 100% hydrogen operation. This will support both organisations' commitments to decarbonise their operations. As per Section 6.6, switching Princes Ltd from natural gas to Welsh Water hydrogen reduces site emissions from 2,462 to 782 tCO2eq / year.

The re-purposed pipeline will be adopted by WWU to form part of their regulated asset base. WWU intend to apply for funding at a later date to develop the FEED study undertaken as part of the Stream 2B scheme. This is to demonstrate de-blending technology within a network setting in a future phase of the scheme outside of Stream 2B funding.

8.5 Permissions

The following sections detail the consenting requirements for each component, however, this could vary during the execution of the demonstration project should legislation change.

8.5.1 Hydrogen Production

At the Welsh Water Cardiff East WwTW site, modifications to the existing biogas facilities and the construction of new hydrogen production facilities will be consented under the permitted development provisions of the 2008 Planning Act. Equipment less than 10 m high will most likely be considered under permitted development allowances, allowing for construction with the associated Health & Safety Executive (HSE) notifications e.g. F10 for Construction Design and Management compliance [Ref. 63].

The site already has an Industrial Emissions Directive (IED) permit which covers all point source emissions and their emission limit values. Welsh Water would produce a technical variation for additional plant and equipment following an H1 Assessment to determine air quality impacts and to ensure emission limit values can be permitted by the regulator, Natural Resources Wales (NRW). Welsh Water have an internal Competent Operator Scheme and Competency Management System to ensure operational compliance with permits across all its AD assets.

As a Statutory Undertaker Welsh Water's provision for undertaking essential water and sewerage activities also provide extensive Permitted Development rights within the operational boundary of its assets, where there is not significant visual or other intrusion on external receptors. Welsh Water work with planning consultants to ensure that the Town & Country Planning (General Permitted Development) Order 1995 is adhered to and that necessary applications are submitted in good time to the Authority and Statutory Consultees.

H2Juice project incorporates additional technology into the existing Anaerobic Digestion facility owned and operated by Welsh Water in Cardiff. This is already permitted under the Industrial Emissions Directive for digestion activities and associated steam boilers, combined heat and power engines and waste gas burners. Welsh Water already has an understanding of its obligations under this Permit and would work with the regulator, Natural Resources Wales, on any amendments to ensure continued compliance for the site during and after project construction. Welsh Water has an 'in-house' permitting team which works alongside a suite of consultancies for specific environmental assessments as part of the permitting and consenting process.

8.5.2 Hydrogen Pipeline

As per Section 4.0, the pipeline connecting the hydrogen production at the Welsh Water Cardiff East WwTW and Princes Ltd will consist of a section of new DN125 Medium Density Polyethylene pipeline within the Welsh Water site boundary and the repurposing of an existing DN200 (8") IP main.

Both pipeline sections will be constructed to recognised industry standards and will be consented under the statutory rights of the gas distribution networks as set out in the Gas Safety (Management) Regulations GS(M)R and the Pipeline Safety Regulations (PSR). Both sets of legislation and their associated subsidiary regulations are currently under review to accommodate natural gas / hydrogen blends and 100% hydrogen. There are several network-led projects currently "in-flight" that will provide the technical evidence required to modify this legislation, allowing the hydrogen pipeline to be incorporated into the WWU Regulatory Asset Base following the demonstration project.

Wales & West Utilities have permitted development rights which are set out in Part 17 of the General Permitted Development Order 1995. Class F (a) allows for the laying underground of mains, pipes or other apparatus without the need for planning permission unless the pipe would be considered a 'notifiable pipeline'. Within this scheme, the proposed sections of new and repurposed network would not be classified as a notifiable pipeline, meaning the permitted development class applies.

WWU will obtain all necessary landowner consent and permanent agreement for the construction of new methane and hydrogen network sections within WP2.1. This will involve approaching landowners at an early stage to understand timescales, and appointing a land agent to lead negotiations if necessary. Work will also include a review of existing Deeds of Easement for sections of network to be repurposed for hydrogen, there could be a need to approach landowners for new easements where existing agreements are currently not appropriately documented. A review of existing easement agreements will begin before April 2023, with landowner negotiations set to start at the project outset in April 2023. A firm view will be taken on route options and eligibility to meet project timescales at the first BEIS stage gate in November 2023.

WWU will obtain all necessary HSE consents for the repurposing of existing network infrastructure and new hydrogen infrastructure within WP2.4. This will involve early liaison with the HSE to understand evidence required to satisfy the proposed safety case. A review of similar schemes, such as those initiated by Kiwa Gastec and Northern Gas Networks will also be undertaken to build on the existing evidence base which has been developed by the UK Gas Distribution Networks under the BEIS Hydrogen R&D programme.

WWU propose a regulatory model which will see ownership and operation of the hydrogen pipeline as part of its transportation business. All Gas Act and licence obligations will apply as for a natural gas pipeline; the Uniform Network Code (UNC) does not apply to hydrogen pipelines, however. This will therefore require a separate transportation agreement to be written with the user (and/or producer) as part of the operating model.

8.5.3 Boiler Modifications

No required consents have been identified to accommodate the boiler modifications to be undertaken in the Stream 2B demonstration project. An update of the site environmental permit will be required in line with the proposed change.

Some areas of existing regulations could need to be amended to accommodate the commercial operation of the Princes Ltd boilers following completion of the demonstration project however it is expected that any changes required would be implemented before the end of the demonstration phase. These may include minor changes to:

- Gas (Calculation of Thermal Energy) Regulations
- Boiler Efficiency Directive (92/42/EEC)
- Measuring Instruments Directive (2014/32/EU)
- Gas Appliances Directive (2019/142/EC)
- UK Building Regulations

8.6 Safety

8.6.1 Plan

In delivering the 2B project Costain will develop a Health, Safety and Environmental Management Plan (HASEMP). The plan will detail all the roles of expert staff and their roles and responsibilities. During the physical demonstration works, site and task specific Risk Assessments and Method Statements (RAMS) will be developed to manage the risks associated with the demonstration trials.

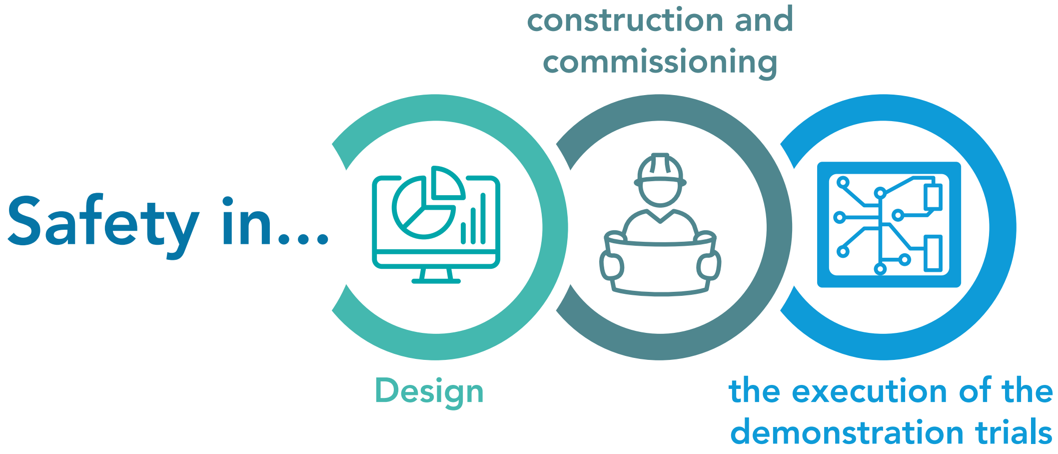
HASEMP contents are summarised in Appendix - HASEMP

8.6.2 Capability

Costain are an experienced design and construction contractor and will be responsible for delivering the FEED, design and construction elements of hydrogen production and de-blending. The hydrogen pipeline design, repurposing of the IP main and construction activities will be managed by WWU who deliver such projects as part of their day-to-day operations. The boiler modifications and blending trials will be managed by the sub-contract partner, CR Plus, who have extensive experience in this type of project.

Costain has a proud safety record with well-established processes and procedures. Costain are currently delivering the design and construction of major UK infrastructure including HS2 and will act as the overall design lead for the 2B scheme. Costain has also delivered numerous hydrogen design and development schemes, including the design of a "first of a kind" hydrogen blending facility at Northern Gas Networks Winlaton site.

The Costain safety plan and approach will be developed to cover:



9. VALUE, FUTURE PLANS & DISSEMINATION

9.1 Project Description

Due to its scalability, the learning derived from H2Juice, including its social value, is potentially wide-reaching. Its expansion potential to additional end-users and the collaboration between partners provide an opportunity for wider social, environmental and economic benefits.

9.2 Social Value

9.2.1 Social Value Model

As demonstrated, the key benefit that can be realised by H2Juice is the lowering of emissions. This has great benefits for the community in the immediate vicinity of Princes Cardiff. As this scheme can be replicated nationally and applied to similar boiler / heat users, it has the potential to greatly reduce emissions across the UK.

The skills and related jobs that can be generated in the area are important; the construction phase will require skilled construction personnel as well as the wider up-take in to the partners' project teams and organisations. Welsh Water have identified at least 4 other potential plants where they can apply the same bio-gas to hydrogen H2Juice scheme, confirming that this project can have a very positive, lasting impact going forward.

H2Juice also provides opportunities in line with the themes outlined in the PPN 06/20 Social Value Model [Ref. 64]. This is primarily in terms of Theme 3: Fighting Climate Change. Another theme, Theme 2: Tackling Economic Inequality, see Appendix – Social Value.

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19. Doc. Ref.: 1176-0330-019-30-0001-001, H2JUICE FEASIBILITY STUDY Plot Plan

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Appendix STREAM 2A FEASIBILITY STUDY DELIVERABLES

The following deliverables were produced by Costain during the H2Juice Stream 2A feasibility study:

Document No.	Industry
1176-0200-016-01-0001-001	Block Diagram
1176-0200-075-07-0001-001	Technology Assessment Technical Note
1176-0200-027-01-0001-001	Utilities Schedule
1176-0200-015-01-0001-001	Heat & Mass Balance
1176-0200-064-01-0001-001	Basis of Design, WP1: Hydrogen Generation
1176-0200-079-07-0001-001	High Level Reliability & Sparing Study
1176-0200-062-03-0001-001	Levelised Cost of Hydrogen Report
1176-0230-021-30-0001-001	Pipeline Desktop Route Assessment
1176-0200-064-01-0002-001	Basis of Design, WP2: Gas Network – Transportation & Blending
1176-0230-021-32-0001-001	Pipeline Sizing Study
1176-0230-064-36-0001-001	Functional Specification
1176-0330-019-30-0001-001	Plot Plan
1176-0230-064-36-0002-001	Pipeline Design Package

The following deliverables were produced by CR Plus during the H2Juice Stream 2A feasibility study:

Document No.	Industry
1176-0220-075-23-0001	Existing Combustion Infrastructure Report
117636-0200-064-01-0003-001	Basis of Design, WP3: Hydrogen Use – Fuel Switching
117636-0200-064-01-0003-001	Retrofit Philosophy
117636-0200-064-01-0003-001	Preliminary Testing Scope of Works

Appendix STANDARDS

All equipment shall be Conformité Européene (CE) marked in accordance with relevant European Union (EU) directives.

DESNZ (formerly BEIS) Standards

1. UK Low Carbon Hydrogen Standard: Guidance on the greenhouse gas emissions and sustainability criteria
2. Annexes: Guidance on the greenhouse gas emissions and sustainability criteria under the low carbon hydrogen standard

British / International Codes & Standards

1. BS 7671 (Latest edition) – Requirement for Electrical Installations
2. BS EN 60079 – Explosive Atmospheres
3. BS EN 61439-1 – Low Voltage Switchgear and Controlgear Assemblies
4. BS EN 12186 – Gas Infrastructure – Gas Pressure Regulating Stations for Transmission and Distribution
5. BS EN ISO 6976 – Natural Gas – Calculation of CV, Density, RD and Wobbe Index from Composition
6. BS EN ISO 10715 – Natural Gas – Sampling Guidelines
7. BS EN ISO 10723 – Natural Gas – Performance Evaluation for On-line Analytical Systems
8. BS EN ISO 14111– Natural Gas – Guidelines to Traceability in Analysis
9. BS EN ISO 12213-2– Natural Gas – Calculation of Compression Factors
10. BS4800 – Schedule of Paint Colours for Building Purposes

EU Directives and UK HSE Regulations

1. 2006/42/EC – Machinery Directive
2. 2014/30/EU – Electromagnetic Compatibility Directive
3. 2014/35/EU – Low Voltage Directive
4. 2014/68/EU – Pressure Equipment Directive
5. Energy Institute 15 – Area Classification Code for Installations Handling Flammable Fluids
6. Electricity at Work Regulations 1989
7. Controls of Substance Hazardous to Healthy (COSHH) Regulation 2002
8. Dangerous Substances and Explosive Atmospheres Regulation (DSEAR) 2002

IGEM Standards

1. IGEM/GM/8 – Non-domestic Meters installations
2. IGEM/TD/13 Edition 2 – Pressure Regulating Installations for Transmission and Distribution Systems
3. IGEM/TD/16 – Communication No.1768 Biomethane Injection
4. IGEM/TD/17 – Communication No.1769 Steel and PE Pipelines for Biogas Distribution
5. IGEM/SR/25 Edition 2 – Hazardous Areas Classification of Natural Gas Installation
6. IGEM/TD/3 Edition 5 – Steel and PE Pipelines for gas distribution

Network Standards

1. NGN/PM/EL/1 – The Selection, Installation and Maintenance of Luminaires and Lamps
2. NGN/PM/EL/2 – The Standards that are used for the Certification of Electrical Apparatus for Potentially Explosive Atmospheres
3. NGN/PM/EL/4 – Inspection and Testing of Fixed Electrical Equipment and Systems
4. NGN/PM/EL/5 – Installation of Cables
5. NGN/PM/EL/7 – Electricity at Work Regulations 1989
6. NGN/PM/G/17 – The Management of New Works, Modifications and Repairs Incorporating Commissioning, Operational and Asset Acceptance
7. NGN/PM/INS/2 Part 2 – Maintaining the Integrity of Instrument Systems and Equipment
8. NGN/PM/RE/9 – Instrumentation and Electrical Records Associated with T Plant
9. NGN/PM/MAINT/8 – Maintenance of Local Gas Treatment Equipment
10. NGN/PM/MAINT/12 Part 1 – Maintenance of Instrumentation Systems and Equipment
11. NGN/PM/MAINT/12 Part 3 – Maintenance of Instrumentation Systems on Offtake Sites
12. NGN/PM/NDT/1 – Carrying out Non-Destructive Testing of Plant and Equipment
13. NGN/PM/NDT/2 – Non-Destructive Testing of Welded Joints on Construction and Fabrication Projects
14. NGN/PM/PT/1 – Pressure Testing Pipework, Pipelines, Small Bore Pipework and Above Ground Austenitic Stainless-Steel Pipework
15. NGN/SP/CDO/1 Part 1 – Piping, Piping Features & Control Symbology
16. NGN/SP/E/28 – The Design of Pressure Regulating Installations with Inlet Pressures Not Exceeding 100 bar
17. NGN/SP/EL/13 – Earthing
18. NGN/SP/EL/23 – Cable & Equipment Marking: Part 1 – Electrical
19. NGN/SP/INE/3 – Selection of Telemetry Signals to Operate the T Gas Supply System
20. NGN/SP/P/1 – Welding of Steel Pipe Operating at Pressures Not Greater Than 7 bar
21. NGN/SP/P/9 – The Welding of Fittings to Pipelines Operating Under Pressure (Supplementary to BS 6990)
22. NGN/SP/PA/9 – Paint Systems – Properties and Performance Requirements
23. NGN/SP/PA/10 – New and Maintenance Painting at Works and Site for Above Ground Pipeline and Plant Installations
24. NGN/SP/V/6 Part 1 – Steel Valves for Use with Natural Gas at Normal Operating Pressure Above 7 bar

25. NGN/SP/V/8 – Valves (25 mm Nominal Size and Below) for Instrumentation and Control Purposes
26. NGN/SP/VA/1 - Fluid Powered Actuators for Two Position Quarter Turn Valves
27. NGN/SP/VENT/1 - Procurement of Weatherproof Vent Caps for Use at Pressure up to 100 bar gauge

Gas Industry Standard

1. GIS/PRS/35: 2011 – GRP Housing for Gas Regulator Installations and Associated Operation Equipment
2. GIS/F7 – Steel Welding Pipe Fittings, Nominal Size 15mm to 450mm Inclusive, for Operating Pressures Not Greater than 7 bar
3. GIS/VA1 – Fluid Powered Actuators for Two Position Quarter Turn Valves
4. GIS/V6 Part 1 (2019) – Steel Valves for Use with Natural Gas at Normal Operating Pressure Above 7 bar
5. GIS/V8 – Valves (25 mm Nominal Size and Below) for Instrumentation and Control Purposes
6. GIS/V7 Part 1 – Metal-bodied Line Valves for Use at Pressure up to 16 bar and Construction Valves for Use at Pressures up to 7 bar
7. NGN/SP/P/16 – The Dimensions and Applications of Standard Weld End Preparations for Steel Pipe, Fittings and Valves

BS EN 61508/61511 – Functional Safety

The standard GEU design has been risk assessed in terms of the likelihood and consequence of physical injury or of damage to the health of people from occurring through techniques such as Hazard and Operability (HAZOP).

The outcome of these assessments has determined that there is no requirement for any risk reduction techniques that are over and above good engineering practice and compliance to the standards and specifications detailed in this FDS and the control of the GEU by the Basic Plant Control System (BPCS). As a result, there is no requirement for the design and implementation of engineered protection systems or Safety Instrumented Systems to either Functional Safety standards BS EN 61508 or BS EN 61511.

Appendix WELSH WATER UTILITIES

Utilities will be sourced from existing WwTW site services where possible. Where required, new utility systems will be implemented as part of the project scope.

Electrical Power

Electrical power is required to drive key plant items including compression, electrical heaters, control systems and ancillary equipment. Welsh Water advised that the WwTW has an incoming 132 kV supply and the site has its own 11 kV network. Site supply capacity is 7.5 MVA. Some of the low voltage motor control centre panels have compartments to allow for future expansion.

Potable Water

Potable water will be required for hydrogen production. Process water will be supplied from the current potable water supply at Welsh Water site which has a capacity of 140 m^3/h.

Instrument Air

The Welsh Water site use electrical actuated valves, therefore no instrument air will be required.

Nitrogen

Nitrogen is not available on the Welsh Water site. If required, nitrogen shall be provided by a dedicated package / bottles as part of the H2Juice scope

Natural Gas Supply

Natural gas is supplied to the Welsh Water site from the local IP gas distribution network operating at below 7 barg. Capacity of this connection is 1,600 Sm^3/h. Wales & West Utilities will confirm if the existing site connection is suitable for supply to the H2Juice process or if a separate connection will be required.

Discharges to Air

As per Section 3.2, emissions from the hydrogen production process will be routed via CCUS. Venting requirements from the H2Juice process will be evaluated. Flue gases from combustion at the Princes Ltd plant will be vented to atmosphere.

Drainage System

Drains shall be connected to the existing site drains collection system. Water treatment requirements to be evaluated including the treatment of waste streams in standalone facilities or as part of the WwTW infrastructure.

Appendix GAS SAFETY (MANAGEMENT) REGULATIONS 1996 (GS(M)R)

Property	***Range or limit***
Hydrogen sulphide	Less than or equal to 5 mg/m^3
Total sulphur	Less than or equal to 50 mg/m^3
Hydrogen Content	Less than or equal to 0.1% (molar)
Oxygen Content	Less than or equal to 0.001% (molar)
Hydrocarbon dewpoint	Not more than -2 °C at any pressure up to 85 bar
Water dewpoint	Not more than -10 °C at 85 bar
Wobbe Number	Shall be between 47.20 to 51.41 MJ/m^3
Incomplete combustion factor (ICF)	Not more than 0.48
Soot index (SI)	Not more than 0.60
Gross calorific value (real gross dry)	The Gross Calorific Value (real gross dry) shall be in the range 36.9 to 42.3MJ/m^3, in compliance with the Wobbe Number, ICF and SI limits described above. Subject to gas entry location and volumes, a target for the Calorific Value may be set within this range.
Inerts	Not more than 7.0% (molar) Subject to Carbon Dioxide (CO_2): Not more than 2.0% (molar)
Contaminants	The gas shall not contain solid, liquid or gaseous material that may interfere with the integrity or operation of pipes or any gas appliance within the meaning of regulation 2(1) of the Gas Safety (Installation and Use) Regulations 1998 that a consumer could reasonably be expected to operate
Organo Halides	Not more than 1.5 mg/m^3
Radioactivity	Not more than 5 Becquerels/g
Odour	Gas shall be odorised with odorant NB (80% tertiarybutyl mercaptan, 20% dimethyl sulphide) at an odorant injection rate of 6 mg/SCM, which may be varied at the DN Operator's request by up to plus or minus 2 mg/SCM to meet operational circumstances.
Pressure	The delivery pressure shall be the pressure required to deliver natural gas at the Delivery Point into our Entry Facility at any time taking into account the back pressure of our System at the Delivery Point as the same shall vary from time to time The entry pressure shall not exceed the Maximum Operating Pressure at the Delivery Point.
Delivery Temperature	Between 1°C and 38°C

Appendix DIGITAL CASE STUDIES

Costain digital case studies include:

St Fergus Gas Terminal

Demand forecasting has achieved next day accuracy to 97% and for 7 days ahead to 92%.

National Grid

Demand-style modelling of compressors increased emissions prediction accuracy from 50% to 94%. Significant CAPEX savings were realised as much of the compressor fleet could continue to be used, realising a 2.5 million kg carbon saving.

M6 Smart Motorway

Roadside visits reduced by augmented reality. This can also be used as a demonstrator for plant installation, commissioning and maintenance.

Thames Tideway

Approvals for lifting jobs were improved by two weeks by demonstrating avoidance of clashes using digital rehearsal.

St Fergus gas terminal demand forecasting has achieved next day accuracy to **97% and for 7 days ahead to 92%**.

M6 Smart Motorway: roadside visits reduced by augmented reality. This can also be used as a **demonstrator for plant installation, commissioning and maintenance**.

Thames Tideway: improved approvals for **lifting jobs by two weeks** by demonstrating avoidance of clashes using digital rehearsal

National Grid demand-style modelling of compressors increased emissions prediction accuracy from 50% to 94%. Significant capital expenditure (CAPEX) savings were realised as much of the fleet could continue to be used, realising a **2.5 million kg carbon saving.**

Appendix ELECTRICAL

Additional electrical load will be supplied from the existing site network. From initial studies, all load is expected to be low voltage.

The estimated electrical power requirement for hydrogen production is 720kVA. This is mainly inductive load in the form of compressor motors.

The estimated power requirements for blending and de-blending is approximately 740kVA.

Feed gas compressor - skid

400kW drive: motor soft starter cubicle or feeder with VSD required

Hydrogen-rich Blend compressor

190kW drive: new or retrofitted motor starter cubicle required

PSA Tail Gas compressor

70kW drive: new or retrofitted motor starter cubicle required

Auxiliary and Anciliary Loads

For each compressor, an additional 10 kW load is estimated for gas cooling pump/fan motors, lube/jacking oil pump motors, instrumentation, control valves, lighting, trace heating etc.

Compressor loads will be supplied by a 3-phase cable. Additional single-phase cables will be required for area lighting/small power and remote-control units/emergency stops. An additional 40 kW has been assumed for auxiliary / ancillary supplies. Given the gases involved (i.e. hydrogen), all electrical equipment including emergency stops, remote-control units, lighting and distributions boards will be ATEX-rated in accordance with their zone.

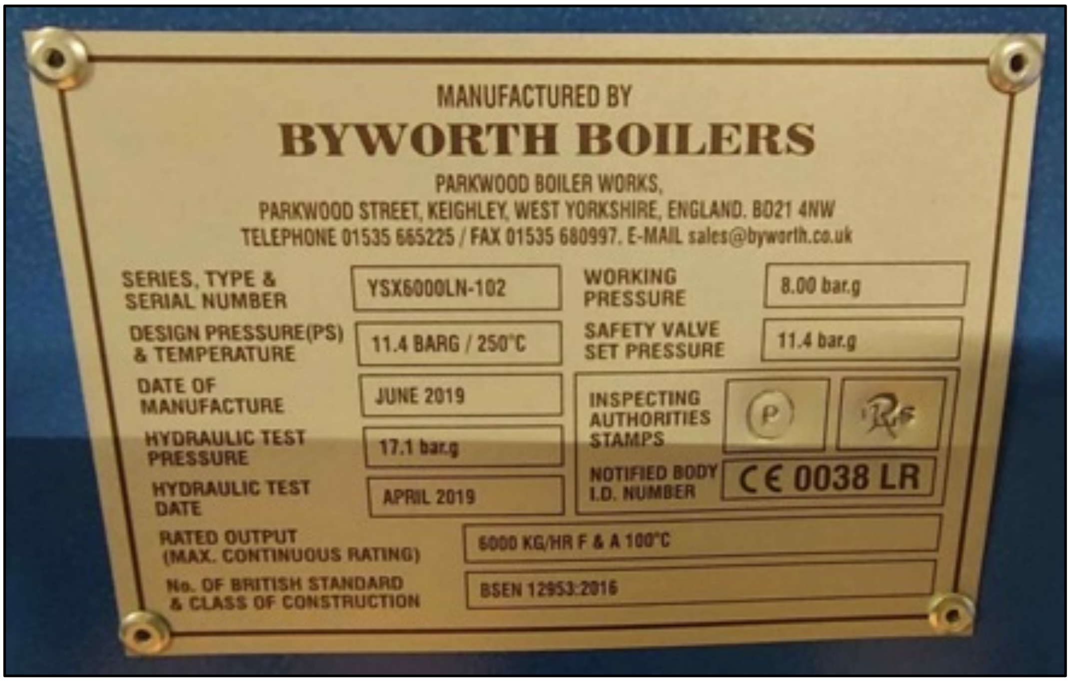
Electrical Infrastructure

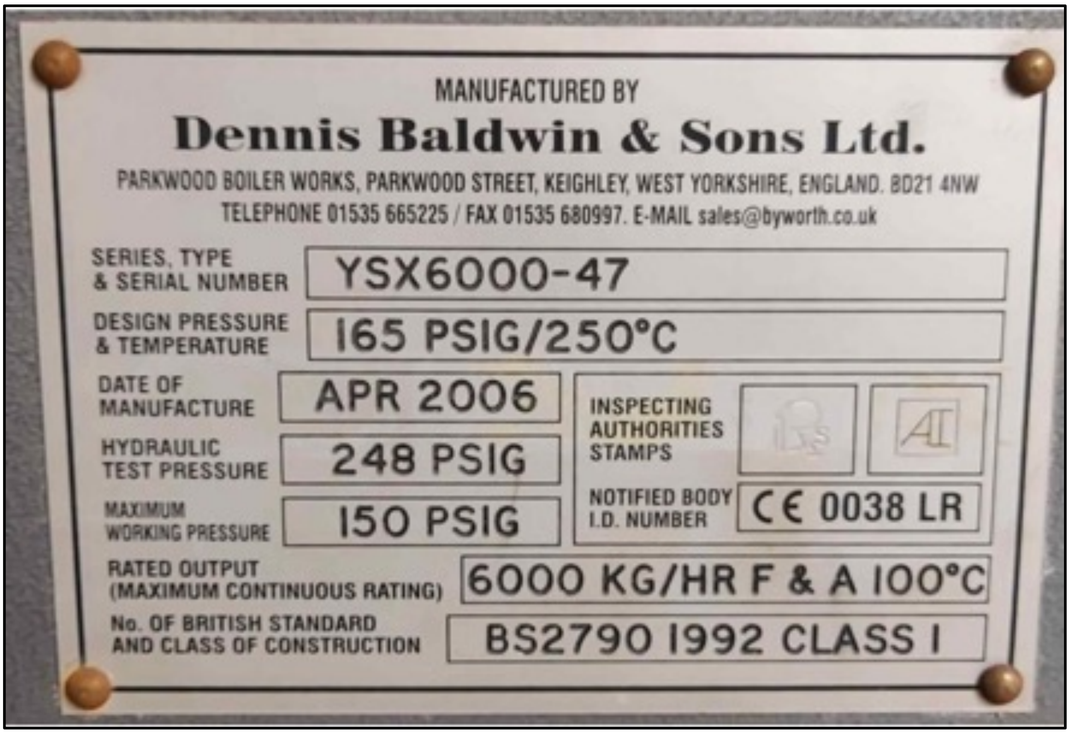
Additional load will be supplied from the existing site 7.5 MVA connection. The most cost-effective solution would be to supply the additional load via the existing 400 V network infrastructure. This could be facilitated by via spare starters/feeders or extending existing low voltage switchboards. This is dependent on available capacity.

Alternatively, a new 400 V packaged sub-station could be provided. To provide an N+1 supply, the new low voltage switchboard would be supplied by 2 x 1.6 MVA 11/0.42kV transformers. Extensions or modifications to the 11 kV network will be required to supply the new transformers.

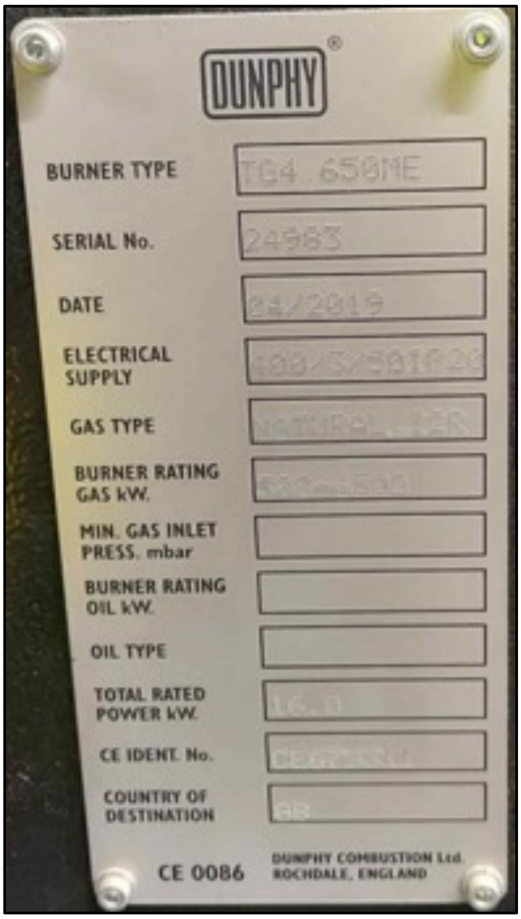
The electrical equipment estimate is based on a new LV substation being required.

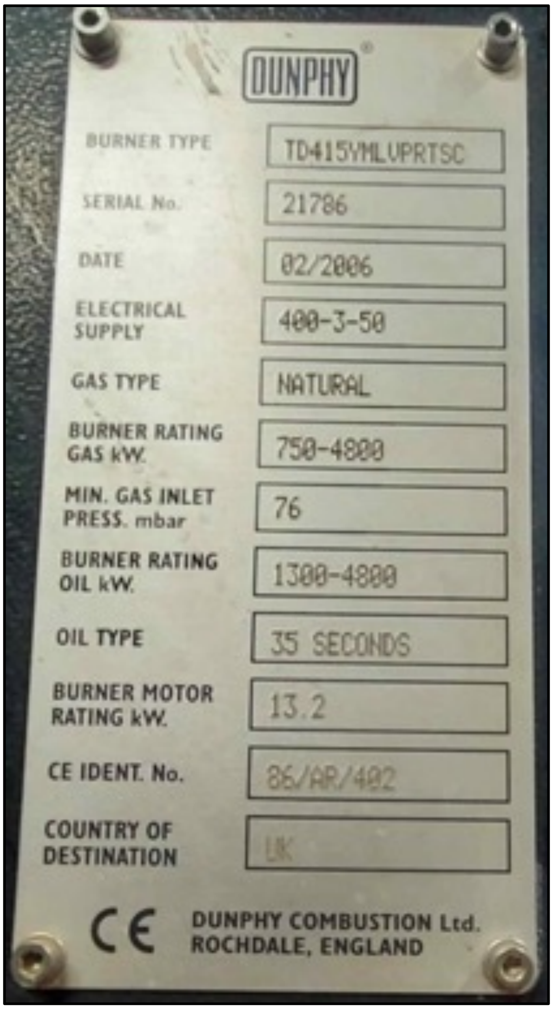
Appendix BOILER DATA, PRINCES LTD





Appendix BOILER DATA, PRINCES LTD





Appendix SOCIAL VALUE

Theme 2: Tackling Economic Inequality

The H2Juice partners recognise the opportunities that the project presents for social value for local communities. Although the initial scale of this project limits social value outcomes, the potential for further innovation and development provides opportunities to create a positive legacy. This is reflected in the long-term intended benefits for supply chain, upskilling, training, employment and community engagement.

This contract provides opportunities to create business growth and employment opportunities within the region. As Princes Ltd outlined in their mission statement, they have significantly invested in their Cardiff site to increase capability and capacity, leading to the creation of over 100 new full-time roles. This is indicative of the value to local employment through investment in industry within the South Wales region.

In addition, Costain have also developed a Supply Chain Academy in partnership with the Supply Chain Sustainability School, upskilling over 2,000 Small to Medium-sized Enterprise (SMEs) in its supply chain. This free of charge training includes project management, procurement and contracting as well as safety and assurance. Access to Costain's Supply Chain Academy can be extended to those throughout the lifecycle of this programme. Emphasis can be placed on modules such as carbon literacy, social value, and sustainability to ensure that H2Juice leaves a positive legacy on the local economy and supports wider social and environmental benefits for the future.

This experience and expertise would be used to develop a social value strategy based on an assessment of community priorities and stakeholder needs. This would include community research to identify appropriate partners such as local educational institutions. From this research, outcomes, targets and timelines would be outlined in line with the PPN 06/20 guidance on metrics and reporting.

+ 2,000 fully funded degree-level apprenticeships

Programmes for schools (STEM) and providing gateways to work experience and apprenticeships

2 days volunteering leave per year to support local communities

Supply Chain Academy upskilling over 2,000 Small to Medium-sized Enterprise (SMEs) in its supply chain

Create a positive legacy on the local economy and supports wider social and environmental benefits for the future

APPENDIX - SOCIAL VALUE

Theme 3: Fighting Climate Change

All partners involved in this project including Costain, WWU, Welsh Water and Princes Ltd. are working collaboratively to deliver innovation in hydrogen, supporting UK decarbonisation objectives. Each partner has made clear commitments to reduce operational emissions and invest in clean growth.

At Costain, we are committed to lead UK infrastructure into a zero-carbon future by 2035 at the latest, supporting the government in meeting their 2050 target. As part of the South Wales Industrial Cluster [SWIC], Costain are already developing greener solutions for the future. For example, Costain are partnered with a carbon transformation organisation who aim to build and commission the world's first commercial-scale alcohol-to-jet (ATJ) production facility using ethanol feedstock made from steel mill waste gases and other wastes. Costain are excited to build upon our legacy through this hydrogen accelerator programme."

"Welsh Water has ambitious plans to achieve Net-Zero by 2040 and advocates collaborative projects to help the Country transition toward greater environmental sustainability. Welsh Water is excited by the innovative prospect of converting biogas from its Advanced Digestion facility in Cardiff, into renewable Hydrogen for use in Industry. Reducing carbon emissions from industrial process is critical to achieving a more environmentally sustainable future. Welsh Water already generates 24% of its energy needs from its own renewable energy assets and is investing toward achieving 35% self-sufficiency in 2025. Welsh Water is proud to be a partner in this innovative Hydrogen project and is excited at the opportunity to deliver wider environmental benefits from our Advanced Digestion facility in Cardiff."

"Wales & West Utilities are looking to invest £400m to deliver a Net Zero ready gas network by 2035, while looking after the most vulnerable in communities across Wales and south-west England. The company is also committed to playing its part in getting to Net Zero carbon emissions by 2050. It has 49 power stations connected to its network to support renewables like wind and solar power, while 20 green gas sites inject enough decarbonised green gas to power approx. 180,000 homes. Wales & West Utilities are excited to be involved in the H2Juice project as a means to begin the development of the first hydrogen networks in Wales, whilst supporting the transformation of Wales's industrial heritage.

This project will support local and national decarbonisation ambitions, and closely compliment the collaborative network projects currently sitting within the BEIS Hydrogen Grid R&D programme and Industrial Decarbonisation Challenge."

APPENDIX - SOCIAL VALUE

"We are delighted to be engaged in the Governments' Industrial Hydrogen Accelerator programme and the feasibility study for conversion of biogas into renewable hydrogen that would provide energy to our juice production site in Cardiff. We take our environmental responsibility very seriously and have committed all of our production sites to be carbon neutral by 2030, for our Cardiff site this project would be a significant contributor to this and complement our move to 100% renewable electricity in early 2022. Princes Ltd Cardiff has recently completed a significant investment programme addressing capability and capacity and created over 100 new full-time roles. The IHA study will further cement Princes Ltd Cardiff as a leader in the region in modern and sustainable food and drink manufacturing."

Whilst GHG emissions are at the core of H2Juice, there are additional opportunities to minimise environmental impact across the contract. For example, the methodology and tools for calculating embodied carbon support the value engineering of a design that includes the priorities of cost and carbon. 'Cradle to grave' analysis using expert Life Cycle Analysis (LCA) tracks raw materials from acquisition to construction, quantifying the impacts on human health, ecosystem, climate change and resource. If successful in its Stream 2B application, LCA will be undertaken as part of the design process, including material selection.

Dissemination Plan

Through the steam 2A feasibility study the H2Juice project has already started to socialise the H2Juice project and disseminate information generated from the study. The H2Juice project has already been promoted through a variety of channels, listed below.

- Initial press release – issued on Costain website and social media
- Conference attendance and presentation at the Northwest Hydrogen Alliance Hydrogen Week, Liverpool Feb 2023
- Social media promotion and knowledge dissemination through the partner media channels

Events planned in the near term include,

- Dissemination webinar, 20th February 2023
- BEIS IHA 2A dissemination event, March 2023

In stream 2B a constant drumbeat of the project progress and knowledge dissemination will be maintained. To achieve this a dedicated H2Juice website will be developed. The website will be operated as a PMO function, and constantly updated to track the project progress and communicate the technological developments of the H2Juice scheme.

In addition to the project website, the partners have committed to promoting the project and providing technical updates on their respective Work Packages via their own established communication channels and social media platforms.

The stream 2B project will also publish interim, and a final report on technological development of the H2Juice project, providing details on the technology deployed, performance, delivery challenges and lessons learned at the following key stages of the project.

The project will also arrange and participate in a range of webinars and conferences to align with the reporting timelines noted above. Although the exact formats and event details are as yet to be decided we have included within our stream 2B submission to deliver a minimum of;

Webinars, 5 of, at:

- End of FEED
- Construction mid-point
- End of Commissioning
- Following completion of the demonstration phase
- Final report dissemination

Conference Attendance - a minimum of 3 Conferences.

Applicability

Context

The H2Juice end-to-end fuel switching scheme offers replication potential across the water sector whilst each individual element also offers replication potential on a wider scale. Stream 2A considered the potential applicability of H2Juice to industrial decarbonisation and the UK hydrogen supply in support of government commitments in its Industrial Decarbonisation and Hydrogen Strategies.

Industrial decarbonisation was considered at local, regional and national levels.

Local

Whilst the Stream 2A basis is a single hydrogen supplier (Welsh Water) and a single hydrogen end-user (Princes Ltd), the potential for increased hydrogen production and additional end-users in the Cardiff area was also assessed. Interest has already been shown from several industrial customers (subject to confidentiality) along the pipeline route to take advantage of this opportunity in the future.

The Welsh Water Cardiff East WwTW generates 60 GWh/yr of biogas. H2Juice would consume 35 GWh/yr of this biogas to generate 2 t/d of hydrogen [Ref. 65], which meets Princes Ltd demand (1.0 t/d) and provides the basis for the H2Juice end-to-end scheme. Hydrogen production could be scaled up in future to utilise all the biogas currently produced. This would increase hydrogen available to 3.4 t/d. As this is almost a doubling of the Stream 2A production rate, additional capacity would be delivered by an identical, parallel train of hydrogen production, blending and de-blending facilities.

Both the re-purposed NPS 8" (DN200) natural gas pipeline and the proposed new hydrogen pipeline have sufficient capacity to transport the additional volume of hydrogen, allowing further industrial customers to be connected in the future. This could almost double the carbon abatement potential of the scheme on a local level.

In Stream 2A, desktop research identified other major heat users in the Cardiff area [Ref. 23]. Industrial users requiring higher temperatures are the most suitable candidates for fuel switching to hydrogen e.g. Celsa steelworks [Ref. 66]. There also exists general commercial heat demand in Cardiff docks and Cardiff Bay (East), including offices and accommodation.

Major Gas User	Industry	Hydrogen Potential	Notes
Celsa [Ref. 66]	Steelworks	HIGH	Celsa aiming for net zero site emissions by 2030. Hydrogen identified as means of lowering emissions by 25%.
Red Dragon Centre [Ref. 67]	Indoor entertainment complex (non-industrial)	To be confirmed	Scheduled for replacement with Cardiff Indoor Arena via Atlantic Wharf Redevelopment Scheme.
SA Brains [Ref. 68]	Brewery	HIGH	Nearby InBev (Budweiser) Magor brewery investigating on-site hydrogen production (from local renewables) to supply boilers, fork-lift trucks and HGVs.
Senedd Building [Ref. 69]	Welsh parliament (non-industrial)	LOW	Intention to install air-source heat pumps by 2030
Wales Millennium Centre [Ref. 70]	National arts centre for Wales (non-industrial)	LOW	Intention to connect to Greener Cardiff District Heat Network in 2022

Table 13 - Future Expansion Potential, Geographic

Regional

Welsh Water are the sixth largest water company in the UK, operating WwTWs which produce a total of 180 GWh per year of biogas from effluent [Ref. 62]. Once H2Juice technology has been demonstrated successfully, it could be replicated to produce up to 3,757 tonnes per year of hydrogen across the Welsh Water region.

As the regional gas network operator, WWU owns and operates over 35,000 km of pipeline within the region of which approximately 1,558 km are steel IP mains. The WWU Regional Decarbonisation Pathways Report identified that 1,114 km of this total would be suitable for future conversion to hydrogen service (Ref. 71)

Once hydrogen is blended into the distribution network, de-blending technology would enable WWU to offer industrial customers a supply of hydrogen blends (or 100% hydrogen) in support of fuel switching whilst maintaining resilience on the gas network in the transitionary phase between natural gas and hydrogen. De-blending would also protect hydrogen-sensitive customers once hydrogen blends are introduced into the network.

The H2Juice burner conversion technology is already widely proven and could be replicated across most package burner installations. These include industrial steam applications and similar industrial applications using for space heating. A desktop survey identified around 50 potential applications in the SWIC area (subject to confidentiality), with an estimated up to 150 across Wales.

National

The UK wastewater treatment sector currently produces 1.8 TWh per year of biogas from effluent. This could be converted to provide 37,549 t/yr (1.25 TWh per year) of hydrogen. Outside the water sector, biogas from AD currently produces 6.5 TWh per year of biomethane which is currently injected into the gas network. The hydrogen production technology demonstrated in H2Juice could be applied to the majority of this biomethane, providing 135,000 t/yr of hydrogen for industrial decarbonisation.

Across the UK gas network, there are over 275,000 km of gas distribution pipelines. With steel IP mains making up 3.5% of this, thousands of kilometres could be re-purposed for hydrogen service if successfully demonstrated by the H2Juice project. Learning will also be applicable to high pressure pipelines, which constitute a large proportion of the UK gas network.

De-blending nationally has the potential to act as a key transitional enabler for industrial decarbonisation. Once hydrogen is introduced into the UK gas network, the HyDeploy programme (Ref. 72) has ascertained the maximum permissible blend will be no greater than 20 vol%. By contrast, the Hy4Heat programme concluded that many industrial boilers can tolerate blends far above this threshold and could even be converted to 100 vol% hydrogen via burner modifications.

The Hy4Heat programme WP6 identified that there are over 1,400 high temperature steam boiler installations in operation around the UK (Ref. 28). The Digest of UK Energy Statistics with large demand industrial and commercial space heating, account for approximately 34% of UK gas consumption (excluding power generation). Deploying the de-blending technology developed by H2Juice across this demand would provide a major reduction in UK industrial emissions.

Development & Commercialisation

H2Juice embodies a circular economy concept, turning sewage into hydrogen which can act as a net zero enabler. Currently, most biogas produced from sewage sludge AD is used to generate renewable electricity. In recent years, more water companies are converting a proportion of their biogas into biomethane for injection into the gas network for heat decarbonisation. Using biogas-derived hydrogen can generate an even lower emission solution.

AD already enhances sewage sludge stabilisation, reduces pathogens and reduces odours. It also reduces the dry matter of sludge, leading to a significant reduction in the final sludge volume. The H2Juice feasibility study has demonstrated that sewage sludge can be used to generate hydrogen which can be transported to an industrial end user for product manufacture. This significantly increases the benefits of the AD process by supporting customers with challenging decarbonisation requirements.

Renewable energy projects such as H2Juice enable Welsh Water (and similar companies) to become a carbon-neutral business and "one which produces its own energy using renewable sources". It will also enable companies such as Princes, who have invested significantly in efficient UK manufacturing processes, to leverage their value, supporting the transition to net zero.

Whilst H2Juice is focussed on Princes Ltd demand, there exists potential to widen hydrogen distribution to other local industrial users. There is also potential to utilise greater quantities of biogas produced from sewage sludge AD to produce more hydrogen. Hydrogen demand within 2 km of the Cardiff East WwTW is 150 t/d, a 75-fold increase from the H2Juice concept.

AD currently treats 66% of UK sewage sludge and is also used in the treatment of food waste. There are currently 650 operational AD facilities (excluding traditional water treatment plants) in the UK with many more in the planning stage [Ref. 65]. The location of WwTWs, particularly those with AD facilities, aligns broadly with UK population density (and industry) and is not geographically constrained. Welsh Water serves more than three million customers across Wales, Herefordshire and parts of Deeside and Cheshire.

Most WwTW's already have biogas production or are in the planning phase to develop it. The H2Juice concept is a repeatable solution across any WwTW producing biogas from Anaerobic Digestion of human effluence, however deployment would be dependent upon identification of local industrial demand or injection into the gas distribution network and subject to there being a robust business case to attract the CAPEX investment required..

The commercialisation pathway will include:

- Market definition: AD facilities, local energy users
- Assessment of UK-wide Princes facilities for potential fuel switching
- Assessment of potential for wider industrial use. Indications are that there is a minimum of 2,000 similar boilers in the UK with potential for conversion
- Assessment of the wider industrial use of hydrogen in the south Wales region via the SWIC cluster plan and Net Zero Industry Wales.

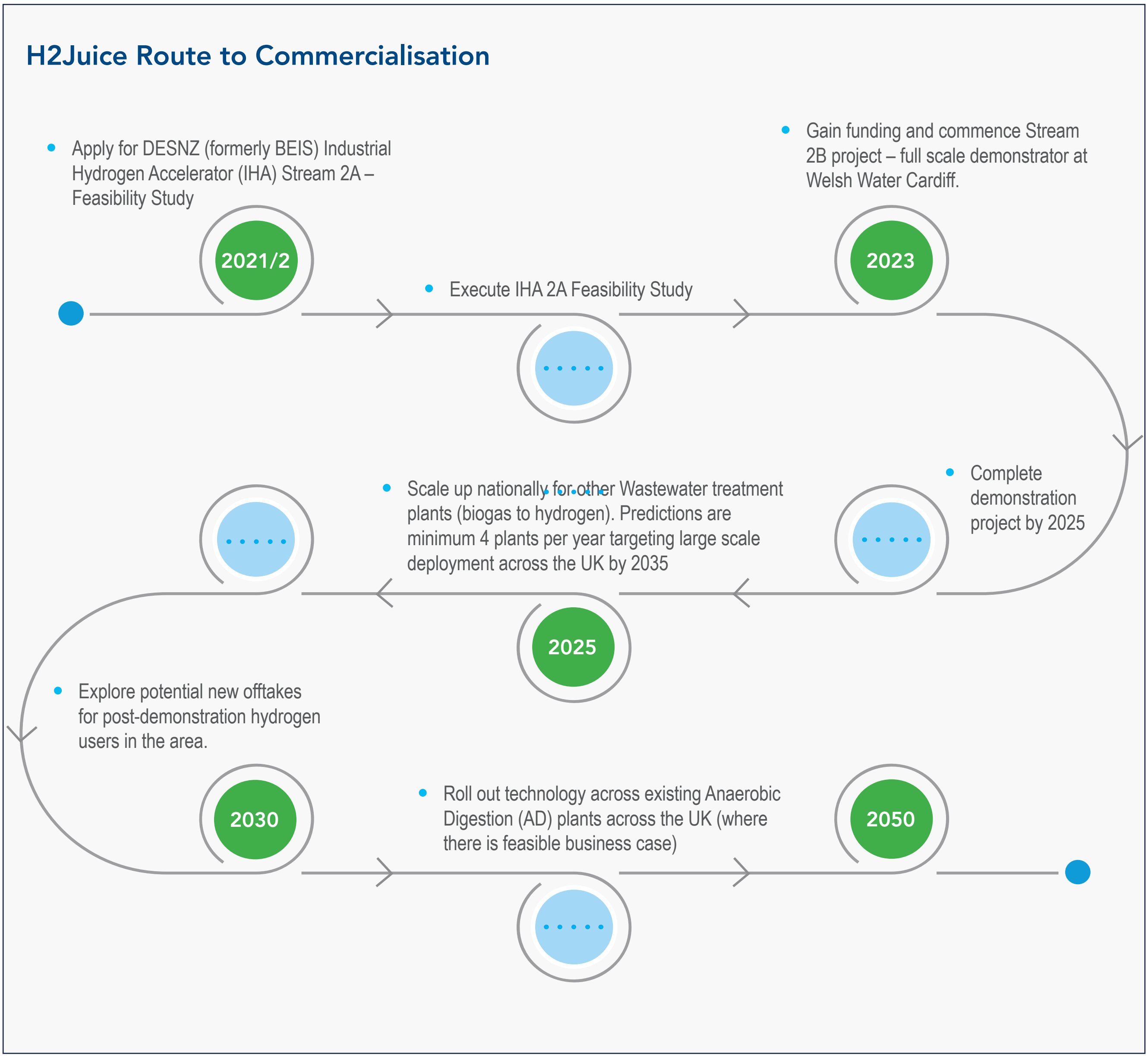


Figure 27 - H2Juice Commercialisation Route

An initial barrier could be the deployment of the demonstrator unit in Cardiff. It is expected that once operational, this will become an exemplar solution that can be established across the UK and across developed global markets, creating an export market for technology and skills. Additional market learning should be gathered via the demonstrator to set a basis for commercial operation and contracts between hydrogen users and producers.

APPENDIX - SOCIAL VALUE

Benefit	Measure	Performance		
		S2A start	S2A finish	Target 2025
Demonstrate potential for commercial viability of end-to-end hydrogen industrial fuel switching systems	Amount of follow-on funding received for the same or related projects during or after this project	Not applicable	Not applicable	£29.9M (stream 2B partner match funding)
	Amount of further R+D capital committed to the innovation (projects own capital)	Not applicable	Not applicable	£5.4M (addition of CCUS)
	Successful feasibility study of the end-to-end system (and plan for commercial implementation)	Not applicable	Project demonstrated as feasible and route to commercialisation identified	H2Juice concept moved to commercial operation
	Technology Readiness Level progression	5	5	9
	Forecasts for sales, revenue and export potential of demonstrated technologies	Not applicable	LCOH calculated	Hydrogen production and dual-fuel burner demonstration provides tech-nology export potential
Provide evidence and knowledge to support future hydrogen and industrial decarbonisation policy	Successful completion and publication of project reports providing evidence on costs and performance of system and technologies	Not applicable	Stream 2A report published	Dec 23 – End of FEED Phase
	Jan 25 – End of Commissioning phase	Not applicable	Public presentation of Project at 2 webinars to socialise the H2Juice concept	Public presentation of H2Juice Project outcomes at a minimum of 5 nr webi-nars. Set up project website to present project outcomes and learning. Attendance at a minimum of 3 confer-ences to promote the H2Juice project
	Mar 25 – Final report following demonstration.	0	2	8
	Number of other knowledge exchange or dissemination products or activities generated as a result of this project e.g. digital and printed media (leaflets, videos, etc.), and social networks	We intend setting up a project website for phase 2B Promotion of H2Juice project through all partner social media and comm's channels		

APPENDIX - SOCIAL VALUE

Benefit	Measure	Performance		
		S2A start	S2A finish	Target 2025
Increased awareness, understanding and confidence in end-to-end hydrogen fuel switching solutions for industry to facilitate future deployment	Feedback from key stakeholders reading project report or listening to project presentation(s)	Not applicable	Target 100 attendees for webinars	Target 250 attendees for webinars Q&A sessions to be part of every webinar
	Q&A sessions to be part of every webinar	Target 250 attendees for webinars	Each partner to publish stream 2A feasibility report through their websites	Regular project updates issued through H2Juice project website Final report to be published on partner websites
	Q&A sessions to be part of every webinar	0	1	4 nr total Stream 2A feasibility End of FEED Phase End of Commissioning phase Final report following demonstration
Potential reduction in carbon emissions of a specific industrial process	Carbon intensity of process before and after innovation is applied	0.20297 kg CO2e p/ KWh	0.20297kg CO2/ pr KWh	0.06444 kg CO2e/ pr KWh
	Potential volume of CO2 saved (kT CO2e/yr) for this particular site	0	0	1.68kt CO2e/yr
	Potential volume of CO2 saved (kT CO2e/yr) if this innovation was deployed across all UK sites that use this process	0	0	8,400kt CO2e/yr

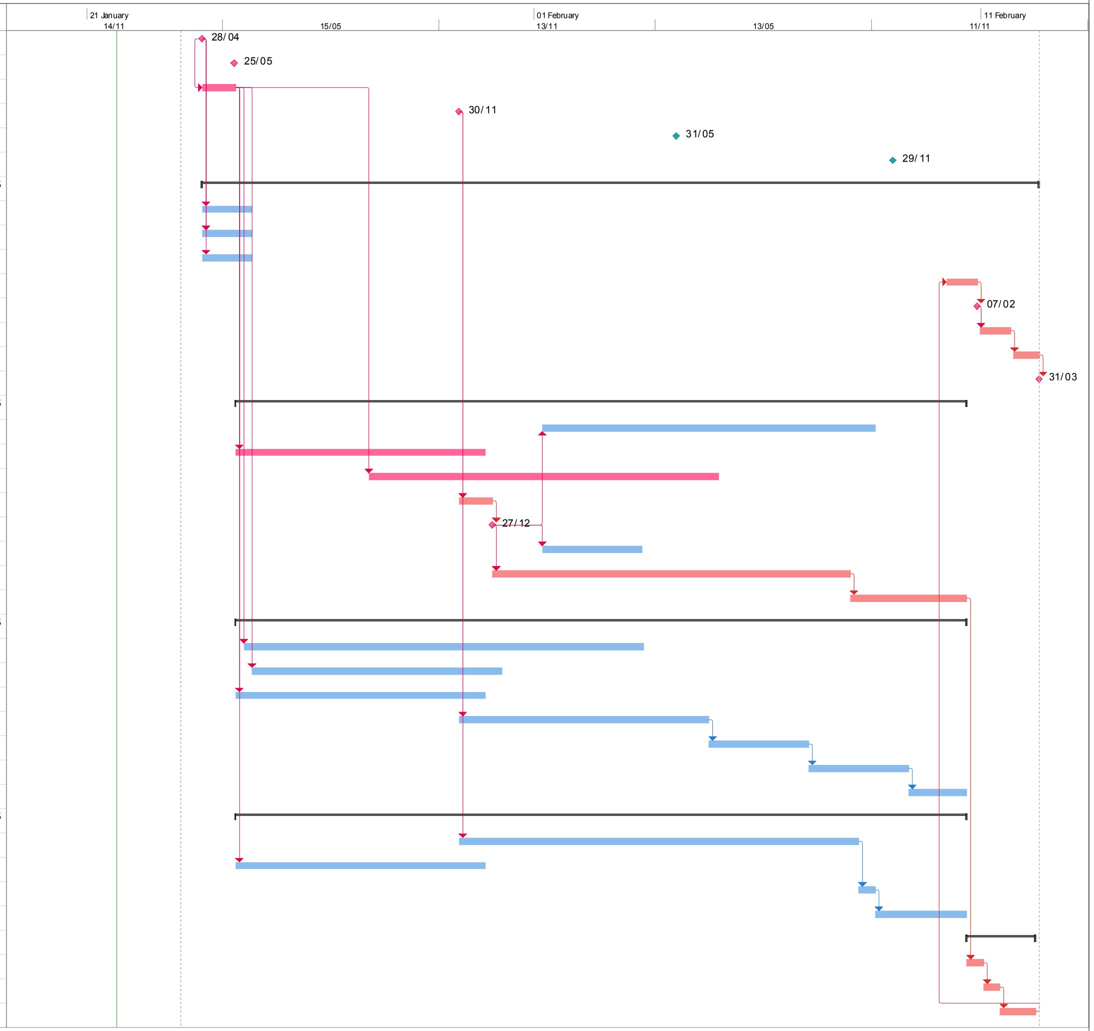
APPENDIX - SOCIAL VALUE

Benefit	Measure	Performance		
		S2A start	S2A finish	Target 2025
Development of more efficient, resilient and available H2 storage solution to support UK energy system	Potential ability of the system to ramp up and down and/or accommodate variable renewables	Not applicable	Feasibility assessment of system design to match biogas production and demand ramp up/ down completed	Successful demonstration of the H2Juice project concept to match varying biogas production rates and varying rates of demand ramp up/down
	Potential system availability (ability of the H2 system to run 24/7)	Not applicable	Feasibility assessment of system availability completed	Demonstration of system availability through commercial operation. Operational data made available to DEZNZ to inform the industrial decarbonisation programme
Ability of industrial processes to be flexible in their energy source	Potential number of alternative energy sources (e.g. hydrogen, natural gas, biofuel) industrial process is compatible with	Not applicable	Desktop assessment of technology applicability undertaken	Roll out of hydrogen production technology across water sector and biome
Emphasise UK's position and reputa-tion as a world leader in low-carbon energy	Applicability of the project on a global scale	Although not measurable the technology developed by the demonstration project is exportable and applicable on a global scale		
Innovation leading to reduced energy consumption	Potential % reduction in energy consumption for this particular site/process	Not applicable		

Appendix STREAM 2B PROGRAMME

H2Juice Stream 2B Programme

ID	Task Mode	Task Name	Duration	Start	Finish
1		Notification of Stream 2B Award	0 days	Fri 28/04/23	Fri 28/04/23
2		Project Start	0 days	Thu 25/05/23	Thu 25/05/23
3		Develop Consortium Agreement	20 days	Fri 28/04/23	Thu 25/05/23
4		BEIS 1st gateway (FID)	0 days	Thu 30/11/23	Thu 30/11/23
5		BEIS 2nd gateway	0 days	Fri 31/05/24	Fri 31/05/24
6		BEIS 3rd Gateway	0 days	Fri 29/11/24	Fri 29/11/24
7		**PMO**	**502 days**	**Fri 28/04/23**	**Mon 31/03/25**
8		Establish Reporting Procedures	30 days	Fri 28/04/23	Thu 08/06/23
9		Develop Meeting Calendar	30 days	Fri 28/04/23	Thu 08/06/23
10		Set Up Project Website	30 days	Fri 28/04/23	Thu 08/06/23
11		Draft Final Report	20 days	Mon 13/01/25	Fri 07/02/25
12		Issue 1st Draft Final report	0 days	Fri 07/02/25	Fri 07/02/25
13		Client review	20 days	Mon 10/02/25	Fri 07/03/25
14		Incorporate Client Comments	16 days	Mon 10/03/25	Mon 31/03/25
15		Issue Final Report	0 days	Mon 31/03/25	Mon 31/03/25
16		**WP1 Hydrogen Production**	**439 days**	**Fri 26/05/23**	**Wed 29/01/25**
17		Consents / Licences	200 days	Thu 08/02/24	Wed 13/11/24
18		FEED Study (Costain Subcontract)	150 days	Fri 26/05/23	Thu 21/12/23
19		Place Orders for Major equipment (incl. SMR)	210 days	Fri 15/09/23	Thu 04/07/24
20		Negotiate EPCM contract (Costain Subcontract)	20 days	Thu 30/11/23	Wed 27/12/23
21		Award EPCM Contract	0 days	Wed 27/12/23	Wed 27/12/23
22		Place Orders for Balance of Plant	60 days	Thu 08/02/24	Wed 01/05/24
23		Construction	215 days	Thu 28/12/23	Wed 23/10/24
24		Commissioning	70 days	Thu 24/10/24	Wed 29/01/25
25		**WP2 Hydrogen Pipeline**	**439 days**	**Fri 26/05/23**	**Wed 29/01/25**
26		Consents / Licences	240 days	Fri 02/06/23	Thu 02/05/24
27		Deblending FEED Study	150 days	Fri 09/06/23	Thu 04/01/24
28		Assessment of IP Pipeline for Repurposing	150 days	Fri 26/05/23	Thu 21/12/23
29		Construct Network Reinforcement	150 days	Thu 30/11/23	Wed 26/06/24
30		Construct H2 pipeline inside WWtW	60 days	Thu 27/06/24	Wed 18/09/24
31		Repurpose existing 200mm IP Main	60 days	Thu 19/09/24	Wed 11/12/24
32		Commission Hydrogen Pipeline	35 days	Thu 12/12/24	Wed 29/01/25
33		**WP3 Boiler Modifications**	**439 days**	**Fri 26/05/23**	**Wed 29/01/25**
34		Consents / Licences	240 days	Thu 30/11/23	Wed 30/10/24
35		Design Boiler Modifications	150 days	Fri 26/05/23	Thu 21/12/23
36		Install Temporary Boiler to Maintain Supply	10 days	Thu 31/10/24	Wed 13/11/24
37		Modify and Test Burners to Dual-Fuel	55 days	Thu 14/11/24	Wed 29/01/25
38		**Demonstration Phase**	**42 days**	**Thu 30/01/25**	**Fri 28/03/25**
39		Commission end-to-end System	10 days	Thu 30/01/25	Wed 12/02/25
40		Trial Boilers on Blends (20% - 100%)	10 days	Thu 13/02/25	Wed 26/02/25
41		Configure and Trial 100% Hydrogen Operation	22 days	Thu 27/02/25	Fri 28/03/25



Project: H2Juice stream 2B pro
Date: Wed 15/02/23

Task		Summary		Inactive Milestone		Duration-only		Start-only		External Milestone	
Split		Project Summary		Inactive Summary		Manual Summary Rollup		Finish-only		Deadline	
Milestone		Inactive Task		Manual Task		Manual Summary		External Tasks		Critical	

Critical Split, Progress, Manual Progress

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Appendix HASEMP CONTENTS

APPENDIX - HASEMP CONTENTS

Appendix CONTROL & INSTRUMENTATION

Vendor packages control and safety

Control and safety functions (including ESD) shall be controlled by the package vendor PLC. The package will trip and stop safely without the need to interact with other equipment or act on instruments and valves outside the vendor package.

The vendor package HMI screens shall reside in the Welsh Water control room. The HMI screens shall display alarms, controller data, modes, status, diagnostics, logs, and reports. Vendor package safety shutdown trips performed within the package shall be in accordance with the requirements of BS EN 61511 and BS EN 61508.

It shall not be possible for non-safety / control systems to influence the operation of the ESD functions. All ESD functions shall operate as defined in Cause & Effects charts based on the condition of the ESD system inputs. All control actions shall be initiated via I/O connected to the control system.

All Safety Instrumented Functions (SIFs) and safety systems shall be in accordance with the requirements of BS EN 61511 and BS EN 61508.

The blending unit will interact with the such as facilities the export pipeline PCV, valves controlling recycle flow, flow metering, odorant injection and gas analysis. The control for these signals shall be incorporated with the blending unit package scope of supply.

A small amount of signal transfer will be required between the blending unit and third parties: WWU, Princes Ltd. Thin client system architecture (i.e. connection of a remote user to a physical server machine or a virtual machine) will allow third parties visibility of selected signals from cloud-based technology. To protect against cyber threats, a de-militarized zone (DMZ) consisting of two firewalls will segregate the local enterprise network from the PLC operations LAN.

All other vendor packages requiring active control i.e. compressors and PSA will react to variations in inlet flow and pressure. The PSA will not see any changes in operation other than for safety reasons (trip). Bypass functions around the membrane and PSA will be operated manually. Packages will vent locally; venting considerations will be investigated further at the next stage of the project.

Fiscal Metering

Fiscal metering shall be provided at three points across the Welsh Water site: natural gas from grid at the inlet site battery limit, hydrogen from on-site production process and hydrogen export at the site battery limit to Princes Ltd.

The metering package shall meet the design parameters for the functional requirements (e.g. measurement accuracy, repeatability) and ensure system operability, reliability and maintenance. The metering systems shall follow OGA Guidance Notes for Petroleum Measurement, although not specific to hydrogen duty they shall still be applied accordingly. The package footprint and straight length requirements in pipework shall be considered when locating the package.

When assessing measurement equipment, the uncertainty requirements should take into account all components of the flow measurement system and the nature and flow rate of the application. Uncertainty in gas metering will be accordance with OGA requirement and shall meet an uncertainty of measurement of equal to or better than +/- 1% for volume and +/- 1.1% for energy. The flow metering system availability percentage value will be confirmed at the next stage of the project.

The fiscal metering system shall be provided with a metering panel housing for the flow computers and supervisory PLC mounted in a local equipment room. Each flow computer will receive inputs from its flow meter, temperature transmitter, pressure transmitter and gas analyser and calculate the required parameters. The gas composition at the three metering locations shall be determined via dedicated gas analysers. The gas analysers shall provide information on gas composition in the metering legs to the associated flow computers.

A supervisory metering PLC shall display the following values from flow computers:

- Instantaneous Flow as Volume (Am^3/h)
- Instantaneous Flow as Standard Volume (Nm^3/h)
- Power (MW)
- Totalised Flow as Volume (Am^3/h)
- Totalised Flow as Standard Volume (Nm^3/h)
- Totalised Energy (GWh)
- General alarms & status
- Instantaneous composition of Hydrogen and measured gaseous components
- Instantaneous composition of Natural Gas and measured gaseous components
- Water Dewpoint;
- Off-Network Specification Alarm (gas content)
- General alarms & status.

The supervisory metering PLC shall communicate with the blending unit PLC through redundant communications ports using a mutually supported and field proven communications protocol using redundant serial communication.

Instrumentation and Valves

In general, process control instrumentation shall be conventional 4-20 mA (HART) transmitters. NAMUR NE43 compliant transmitters will be used for SIFs. Valve position switches will be proximity types in accordance with EN 60947-5-6:2001. All fiInstrumentation forming part of a Safety Instrumented Function shall comply with IEC 61511 and IEC 61508.

Fire & Gas

F&G instrumentation and monitoring equipment will be installed in the field and LERs.

Building fire detection and alarm systems shall be supplied for occupied buildings on the site to meet the requirements of BS 5839 Part 1.

SIL-rated process F&G detectors will detect gas leaks or fires within the site. Plant areas will also be fitted with manual call points. All field F&G instrumentation will be appropriately certified for use in a hazardous area. F&G requirements and F&G systems will be developed at the next stage of the project.

Cyber Security

For all control and safety systems provided by suppliers, the security design shall be to current best practice according to HSE OG-0086 Operation Guidance, BS EN IEC 62443 and site cyber security procedures. A cyber risk assessment shall be undertaken with the suppliers for all systems. Suppliers shall provide industry-standard firewalls employing deep packet inspection for any communications links outside their packages.

EMC / RFI

Equipment supplied must conform to statutory European Electromagnetic Compatibility (EMC) requirements. These include both emission and immunity standards and the testing requirements to demonstrate compliance to an industrial environment. All electronic equipment, by law, shall be supplied with a mark (UKCA) to indicate compliance.

Provision for adequate screening and earthing of both input and output control and instrument signal cabling shall be provided.

The relevant standards and requirements for control and instrument equipment concerning the electromagnetic environment shall be followed as stated in BS-EN-61000 series – "Electromagnetic compatibility (EMC). Generic standards. Emission standard for industrial environments".