Department for
Energy Security
& Net Zero

ASH
GROUP

Industrial Hydrogen Accelerator Programme:

Small-scale Hydrogen Production Utilising a Waste Company's RDF Feedstock to Power its Industrial Plant and Equipment

COMPACT SYNGAS SOLUTIONS
GREEN FUELS FOR A CLEAN FUTURE

pure
ENERGY CENTRE

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1 Glossary

1.1 Acronyms

ASH	Ash Waste Services Ltd	**IHA**	Industrial Hydrogen Accelerator
BAT	Best Available Technology	**JV**	Joint Venture
BC	Borough Council	**LA**	Local Authority
BEIS	Department for Business Energy and Industrial Strategy	**LCOA**	Levelised Cost of Abatement
BOO	Build Own Operate	**LCOH**	Levelised Cost of Hydrogen
CAPEX	Capital Expenditure	**LHV**	Lower Heating Value
CCGT	Combined Cycle Gas Turbine	**LoPA**	Layers of Protection Analysis
CCUS	Carbon Capture Utilisation and Storage	**MCP**	Manifold Cylinder Pack
CDM	Construction Design and Management Regulations	**MSW**	Municipal Solid Waste
CH_4	Methane	**N_2**	Nitrogen
CHP	Combined Heat and Power	**NRW**	Natural Resources Wales
CO	Carbon Monoxide	**O_2**	Oxygen
CO_2	Carbon Dioxide	**OPEX**	Operational Expenditure
COSHH	Control Of Subtances Hazardous to Health	**PC**	Principal Contractor
CSS	Compact Syngas Solutions Ltd	**PEC**	Pure Energy Centre Ltd
CW	Clean Wood	**PED**	Pressure Equipment Directive
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations	**PPE**	Personal Protective Equipment
DESNZ	Department for Energy Security and Net Zero	**PSA**	Pressure Swing Adsorption
ECS	Eddy Current Separator	**R&D**	Research & Development

EIA	Environmental Impact Assessment	**RAMS**	Risk Assessment and Method Statement
EPC	Engineering Procurement Construction	**RDF**	Refuse Derived Fuel
EPCm	Engineering Procurement Construction Management	**SAM**	Serviceable Attainable Market
FEED	Front End Engineering Design	**SBRI**	Small Business Research Initiative
FOAK	First-Of-A-Kind	**SIS**	Safety Integrated System
GHG	Greenhouse Gas	**SME**	Small Medium Enterprise
H&S	Health & Safety	**SMR**	Steam Methane Reformation
H_2	Hydrogen	**SOM**	Serviceable Obtainable Market
H_2O	Water	**SO_x**	Sulphur Oxides
HAZOP	Hazard and Operability Study	**SWIP**	Small Waste Incineration Plant
HEN	Heat Exchanger Network	**TAM**	Total Attainable Market
HGF	Hot Gas Filter	**TRL**	Technology Readiness Level
HMI	Human Machine Interface	**UKCA**	UK Conformity Assessed
HRV	Heavy Refuse Vehicle	**UKHFCA**	UK Hydrogen Fuel Cell Association
HSE	Health and Safety Executive	**ULEMCo**	Ultra Low Emissions Mileage Company Ltd
ICE	Internal Combustion Engine	**USP**	Unique Selling Point
IED	Industrial Emissions Directive	**WW**	Waste Wood

1.2 Project Terminology

In addition to the general terms listed in the above glossary, the following terms are used in this report.

Gasifier-500: This term will be used to describe a gasifier capable of producing a nominal 500 Nm^3/h of dry Syngas (with which all trials have been completed), 11.5 kg/h H_2.

Gasifier-1300: This term will be used to describe a gasifier capable of producing a nominal 1,300 Nm^3/h of dry Syngas (the scaled-up commercial unit), 20kg/h H_2.

MicroH2-Hub: This term refers to the complete hydrogen generation process from the gasifier feed inlet to the hydrogen outlet of the H2-PSA

Syngas: This term is used by CSS to represent the gas produced in their Gasifier consisting of CO, CO_2, H_2O, H_2, CH_4 and N_2 (regardless of its specific composition).

Note: In general gasifier literature, the term Syngas is generally used to represent a gas which consists of CO, CO_2. H_2O and H_2. When N_2 is present at a high level, with CO, CO_2. H_2O and H_2, then the gas is referred to as Producer Gas.

Parasitic Load: This term refers to any electricity which is used by the hydrogen generating plant, for example the running of motors, fans, and compressors.

Stream 2A – This refers to the first phase of the IHA Stream 2 competition (Stream 2A) i.e., this feasibility study.

Stream 2B – This refers to the second phase of the IHA Stream 2 competition (Stream 2B) i.e., the full design and building of a prototype at an ASH waste processing site.

1.3 Units & Symbols

%	Percent	**m^2**	Meters Squared
£	Pound	**m^3**	Meters Cubed
°C	Degrees Celsius	**mbar**	Millibar
bara	Bar Absolute	**MJ$_{H2,LHV}$**	Megajoules of Hydrogen at Lower Heating Value
barg	Bar Gauge	**MW**	Megawatt
bn	Billion	**MWh**	Megawatt Hours
h	Hour	**Nm^3**	Normal Meters Cubed
k	Thousand	**t**	Tonne
kg	Kilogram	**tpa**	Tonnes per Annum
kW	Kilowatt	**Vol%**	Percentage Volume
L	Litres	**yr**	Year
M	Million		

2 Executive Summary

Ash Waste Services (ASH) has three key waste processing depots in Wrexham, Chester, and Ellesmere Port, which produce significant Carbon Dioxide (CO_2) emissions with their waste processing activity. The depots all host "end-to-end waste processing" designed to refine and treat wastes. ASH considers a hydrogen (H_2) power solution, whether direct in combustion engine powertrains, or via fuel cell-based powertrains, has a role to play with current and future processing.

The current power options in equipment in its "end-to-end" waste processing rely mostly on diesel fuel, or electricity where possible. Diesel has an obvious carbon footprint, whereas electric powertrains (powered from a grid connection) are dependent on the carbon intensity of the grid at any one time – predominantly supported by Combined Cycle Gas Turbines (CCGT).

In this Industrial Hydrogen Accelerator (IHA) project, ASH has brought together partners Compact Syngas Solutions (CSS) and Pure Energy Centre (PEC) to undertake a feasibility study for an end-to-end solution that will deliver:

- A gasification system that will process RDF to produce H_2.
- A H_2 compression, storage, and distribution system.
- Multiple H_2 powered Internal Combustion Engine (ICE) generators to generate site power.
- A new RDF processing line which will run exclusively off electrical power generated by the new H_2 production systems.
- Additionally, outside the scope and funding of the IHA, ASH will begin hybridisation of its diesel collection vehicles and mobile plant to operate on diesel and H_2.

A process flow for this work is introduced in Figure 1.

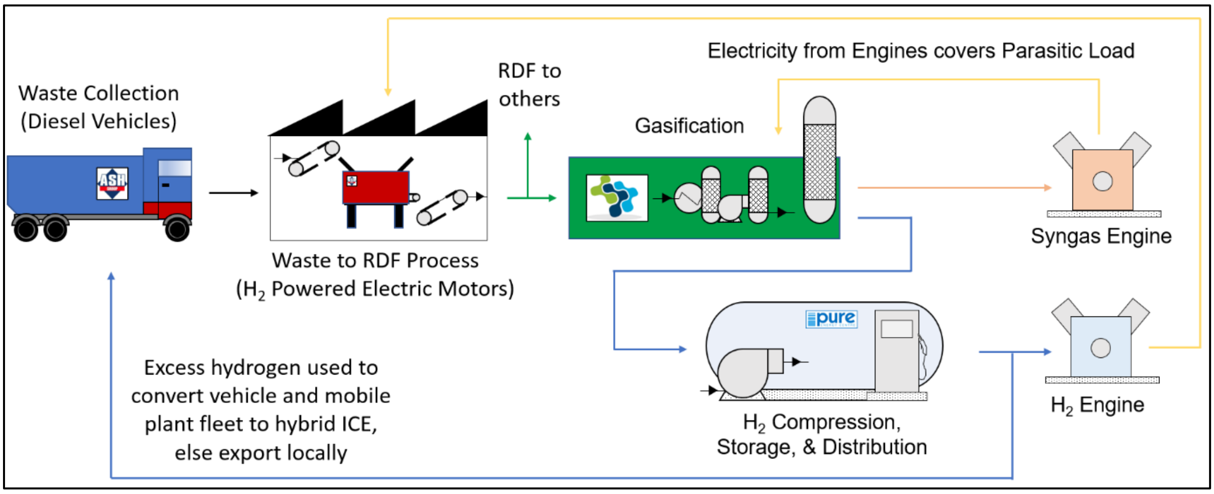


Figure 1 – End-to-end solution for hydrogen generation using RDF gasification

Surplus RDF from the process will continue to be exported to other RDF off-takers (with industrial equipment switched to a H_2 based power supply), whilst surplus H_2 will be used by ASH's other depots to continue a transition to H_2 power across the business.

In achieving the objectives laid out in this report, ASH, CSS, PEC, and other parties involved have laid out a comprehensive blueprint for the generation and use of H_2 on a waste management site. By using proprietary gasification technology from CSS, it has been possible to showcase the feasibility of H_2 generation using RDF, store this for later use, and ultimately generate mechanical power in fixed machinery.

We have demonstrated it is technically and economically feasible to produce low carbon H_2 efficiently and reliably both at a scale suitable to power the demonstration plant and at a larger scale, and that this can be done using RDF feedstock via gasification.

By participating in the feasibility study, the partnership between the three main participants developed further, and significantly de-risked a full demonstration project, enhancing the team's ability to deliver the project quickly and efficiently with significant experience and knowledge in the sector.

The plant location for Stream 2B has been finalised as the Redwither site, with the demonstration plant having a capacity to deliver 20 kg/h of H_2 (~0.67MW) per 1.4 tonnes of RDF.

All the H_2 generated by the gasification plant will be used to power the RDF production plant, which at full power is rated to consume 23.2 kg / h (via the H_2 ICE generators) and will therefore be slightly de-rated. The intended operation is to power the RDF plant at full power to produce a significant feedstock of RDF which is then stored and the plant powered down.

H_2 production whilst the plant is powered down will then be stored at 200 bar to prove the end-to-end solution for other off- takers to consume H_2. Secondary H_2 off-takers are not part of the scope of this project, however long-term ASH will explore the conversion of diesel mobile plant to H_2 powered plant.

The three main elements of the solution have been scoped, resulting in a costed design for the demonstration project. This feasibility study has shown that the elements required can be designed, installed and commissioned within 20-24 months of a project award.

A planning application for the demonstration plant has been drafted and submitted for pre-planning. An Environmental Impact Assessment (EIA), with full planning permission for up to eight gasifiers, will be sought during Q1 of the Stream 2B demonstrator project. A single demonstration gasifier will be operated under a Research and Development (R&D) application on ASH's site which already holds a waste permit and a variation to the existing permit is planned.

Feedstock trials have been undertaken using a Gasifier-500 and have determined that a H_2 purity of greater than 90% can be achieved using either waste wood or RDF feedstock. This specification meets the requirements of suppliers of end-user equipment,

Analysis by CSS has shown that the H_2 produced by the plant can have a gate-to-gate carbon intensity of 9.2 $gCO_2e/MJ_{H2,LHV}$, compliant with the UK Low Carbon Hydrogen Standard below 20 $gCO_2e/MJ_{H2,LHV}$. This is achievable through the use of inherent carbon capture in the gasification char, and active carbon capture in syngas scrubbing.

A commercial CSS plant can produce H_2 at a Levelised Cost of Hydrogen (LCOH) of approximately £180 / MWh, at an efficiency of approximately 34.3%. However, it is important to note that the primary purpose of the gasification process is to convert what would otherwise be a waste stream (sent to landfill or an incinerator), into H_2 as an energy vector. The commercial vision of the CSS plant has an estimated Levelised Cost Of Abatement (LCOA) of £1081.63 / tCO_2.

Overall, the commercial readiness of the end-to-end solution has been raised from Level 2 “Seed Stage” to Level 3a “Resource and Plan” stage; as a result of this feasibility study.

CSS has identified a significant market available for the gasifier + H_2 separation technology, predicting that, from 2025 to 2030, approximately 46 MicroH2-Hubs will be sold, generating 20 kg/h of H_2 per module. This will directly feed a yearly 1,173 MWh into the UK’s H_2 economy by 2030. CSS aims to license the plant design from 2028 onwards to allow large-scale rollout.

An additional outcome of the feasibility study is that the smaller-scale Gasifier-500 that was developed and tested will be available to “kick-start” the demonstration, Stream 2B, project by being upgraded to allow for continuous operation on waste feedstock at the beginning of the project. This will enable “gasifier to H_2” trials whilst producing power via H_2 engine generator at CSS’s Sandycroft site within 6 months from the start of the Stream 2B.

Feedstock trials using the Gasifier-500 have shown that more development work is necessary to select suitable operating conditions for the H_2-Pressure Swing Adsorption (H_2-PSA) system and will require additional funding to implement the changes proposed (e.g., build extra twin-bed PSA, higher capacity syngas compressor, pipework mods, extra flow measurement, extra H_2 analyser), and then to perform the trials which need to follow. When the equipment has been constructed and scheme modified, it will take 2 months to commission, and then 2-4 months of experimental trials need to follow.

Further development is required from engine suppliers in technologies to convert hydrogen to power mechanical equipment.

3 Introduction and Overview

3.1 Introduction

3.1.1 The Industrial Hydrogen Accelerator (IHA) Competition

The UK government has set out its ambition to generate 10GW of low carbon hydrogen (H_2) by the year 2030, subject to affordability and value for money. H_2 is intended to be used to decarbonise heat, power, and transport in the UK, as part of the UK government's net zero strategy [1]. Currently, the majority of H_2 produced in the UK is a product of Steam Methane Reformation (SMR) which is a carbon intensive process, and less than 1% of UK H_2 supply comes from green low carbon sources (e.g., electrolysis).

A significant proportion of the 10GW of low carbon H_2 is expected to be used in industrial applications. The Department for Energy Security and Net Zero (DESNZ) has established the Industrial Hydrogen Accelerator competition (referred to within this report as IHA) to provide funding to support the demonstration of end-to-end industrial fuel switching to H_2. The IHA aims to address current technical and commercial barriers and provide the proof of concept needed to underpin the use of H_2 in industry this decade. The projects will showcase First-Of-A-Kind (FOAK) blueprints to enable accelerated industrial H_2 deployment in the late 2020s and support the UK's 2030 10GW H_2 production ambition.

The evidence generated by the IHA on the use of H_2 by industrial users will also help to inform strategic decisions in 2026 on the role of low carbon H_2 as a replacement for natural gas in the gas grid, as outlined in the UK Hydrogen Strategy [2].

Stream 2 of the IHA programme is being delivered through 2 phases, with Stream 2A being a Small Business Research Initiative (SBRI) competition, which has funded this feasibility study and Stream 2B being a grant funding competition to carry out a demonstration / Front End Engineering Design (FEED) project, available only to applicants who have successfully delivered projects in Stream 2A.

3.1.2 ASH Waste Services

Ash Waste Services has several waste processing depots. These depots include sites at Redwither (Wrexham), Shellway (Ellesmere Port), and Bretton (Chester).

The waste processing depots all host "end-to-end waste processing" designed to refine and treat wastes. ASH considers H_2 power to be a suitable solution to achieve decarbonisation by using ICE or fuel cell powertrains to replace diesel powertrains on its vehicle fleet, mobile plant fleet, and waste processing systems (e.g. eddy current separators, conveyors, shredders, trommels, etc.).

Current power options for ASH's waste processing rely on diesel and electricity. ASH wish to displace the use of fossil fuels like diesel and increase its use of low carbon, green fuels as it develops its commitment to net zero directly, through its own waste processing as distinct from carbon offset.

Diesel powertrains are rapidly becoming unviable due to their emissions and the financial burden as costs steadily increase; particularly after the banning of red diesel in 2022.

Electrical powertrains are a lower carbon solution in the short term, however battery production for vehicles emits significant carbon for the extraction of raw materials, and the current global crisis has identified energy supply is sensitive and can fluctuate significantly, highlighting concerns for the financial viability of electrical powertrains in the short term. The use of electrical vehicles also has operational implications of vehicle charging; heavy vehicles and mobile plant (as used by ASH) when electrified have long charging times which leave the vehicle out of action for potentially 2 of ASH's operating days. ASH is also concerned the vehicle range is not suitable for waste collection during operational hours, with a maximum range requirement of ASH's catchment area being 200 miles.

ASH has also considered the use of H_2 fuel cells rather than ICE; however their commercial availability is limited with much of the UK hydrogen market focusing on the production of hydrogen through electrolysers (e.g. ITM Power). Vehicle based fuel cells appear to be limited to Toyota and Hyundai – neither of which have been developed for industry. Discussions with various suppliers have also identified that fuel cells are unviable for heavy vehicles due to their susceptibility to failure when operating over rough terrain. Fuel cells also prefer constant steady load; with heavy mobile plant such as excavators exposing fuel cells to sporadic extremes of torque requirements. Furthermore, this re-introduces the use of rare earth metals (e.g. platinum) which have significant emissions costs for extraction.

ASH have worked with CRJ services Ltd to scope transition of its industrial processes and equipment to H_2 driven powertrains. Processes that have been identified for decarbonisation are all items involved in the processing of waste, such as eddy current separators, trommels, shredders, and conveyors. While some mobile plant is a target for conversion to hydrogen power (e.g., tipping vehicles, loading shovels, excavators, etc.), these are mostly out of the scope of the IHA but their electrical powered fixed plant equivalent is not and it is this plant that this project is based on.

ASH are confident of being able to convert over 50% of the industrial processes and equipment to H_2, including the newly proposed fuel processing line that will provide the fuel (RDF and Biomass) to produce the H_2 and this plant will be 100% H_2 fuel powered.

ASH then proposes to use the H_2 produced across the business as fuel, inclusive of the equipment outlined in this report, and across other sites and equipment which ASH will look to adopt as hydrogen becomes available; noting this equipment is outside the scope of the IHA.

3.1.3 Switch Project

This project brings together expertise from ASH and its partners CSS and PEC, to develop a complete end-to-end solution which will: provide a disposal route for waste, generate small amounts of electricity (which will mostly cover parasitic load), and generate hydrogen for ASH and other local businesses.

Figure 2 illustrates the end-to-end solution of the project. Summarising the figure:

1. ASH waste services will collect waste from industrial, commercial, and residential sources which will be collected at the ASH Redwither depot for processing into RDF, for both existing clients and the new gasification process.
2. The RDF processing line will use electrical power generated by a hydrogen fuelled ICE. The electrical power generated will come from H_2 processed from RDF based fuels derived from general waste.
3. The CSS gasification system will gasify the RDF and produce:
    a. A high purity low carbon hydrogen – for further use
    b. Syngas – for ICE combustion to cover processing parasitic loads.
    c. Char – inherently sequestering carbon for long term storage.
4. Hydrogen will be compressed and stored at high pressure in PEC's system. Hydrogen will be used in an ICE engine to cover parasitic load of the RDF process (approximately 25% of total produced).
5. Excess hydrogen will be used to power any vehicles in ASH's fleet that have been converted to run on a H_2 hybrid mixed fuel using ULEMCo hybrid engine technology. In addition, H_2 can be exported to other local businesses.

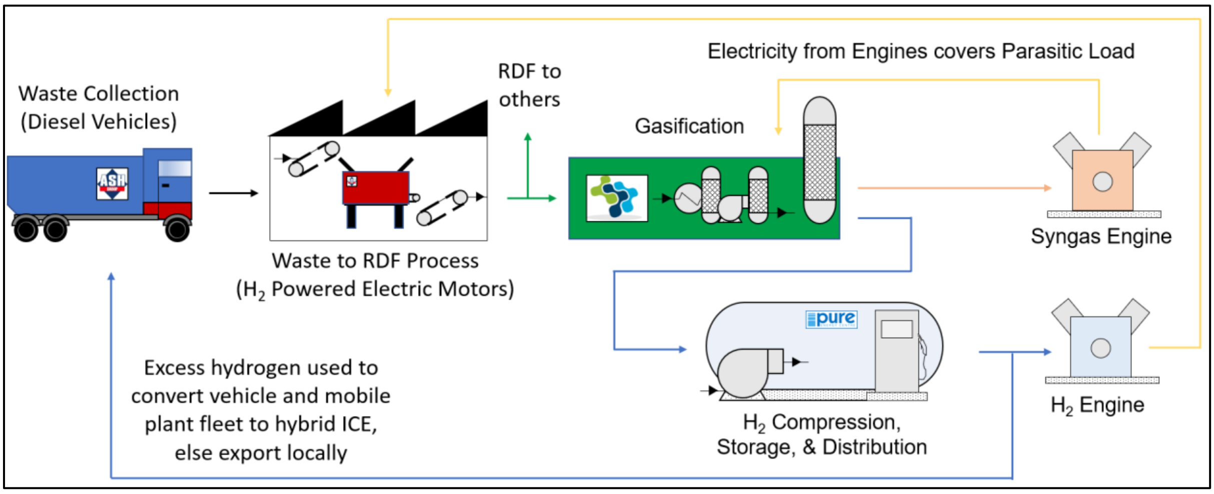


Figure 2 – End-to-end solution for hydrogen generation using RDF gasification

Figure 2 illustrates an end-to-end process flow to generate ca. 20 kg/hr of H_2 when working at full capacity. The solution could be further supplemented with an electrolyser which could provide pure oxygen to the gasifier increasing H_2 production through electrolysis and increased performance of the gasifier.

ICE engines will be provided by a third party.. At this time, it is not possible to power any of the parasitic loads of the process using hydrogen motors due to the technology not being available in the UK market – following extensive research and discussions by ASH.

The solution outlined in Figure 2 is preferred over a solution using direct combustion of syngas as the hydrogen produced by the gasifier effectively acts as a storage vector for energy, i.e. the energy can be used by several independent users subject to transportation.

Although syngas can be stored as an energy vector, it has some disadvantages:

1. If it is stored at low pressure it would require very large storage tanks

2. If stored at a high pressure it would require careful consideration for purification steps to minimise condensable species arising as the gas is compressed.

Although syngas could theoretically be stored and act as an energy vector, this has not been studied in this project. The study focus has been on the production of hydrogen and its use as a fuel to eliminate CO_2 emissions at the point of use.

By compressing and storing the hydrogen, if the gasifier is shut-down for repair/maintenance, then there is hydrogen fuel in storage, which can be used as a clean energy vector to keep hydrogen powered equipment operational on this waste processing site.

3.2 Objectives of Stream 2A

This project aims to demonstrate it is technically and economically feasible to produce low carbon H_2 efficiently and reliably at MW-scale by utilising an RDF feedstock via gasification. The project further aims to assess the feasibility of converting industrial waste processing equipment to be capable of using the hydrogen produced by the gasifier to complete an end-to-end solution.

This study will consider compliance with regulations and subsidy schemes, identify available feedstock, infrastructure, route-to-market, and end-user demand providing confidence across the UK hydrogen value-chain from production to consumption.

The primary objectives of Stream 2A were to:

1. Prove that it is technically and economically feasible to produce low carbon hydrogen efficiently and reliably at MW scale for industrial use, utilising RDF feedstock via gasification.
2. Prove that there is available feedstock to produce a purity of hydrogen that can be stored and transported to power industrial processes and equipment
3. Develop a fully costed plant design backed by commercial modelling and energy savings.
4. Develop an Industrial Equipment switch over report, costings and timeframes (targeting over 50% of equipment moved over to hydrogen).
5. Complete testing for gasification trials and feedstock optimisation, and gain confidence that the equipment operates on hydrogen were possible.
6. Complete Stream 2A feasibility report that enables ASH to make an application for the next round of funding.

In addition, this Stream 2A feasibility study aimed to move forward the commercial readiness of the end-to-end solution from Level 2 “Seed Stage” to Level 3a “Resource and Plan” stage.

4 Switching Viability

4.1 Site and Equipment Selection

ASH currently produces RDF at a rate of 95 tonnes per day at its Redwither site in Wrexham. The RDF is a 350mm shred product which is currently used entirely by Combined Heat and Power (CHP) plant operators.

The equipment used by ASH for the production of RDF at Redwither is shown in Table 1

Table 1 – Summary of process equipment used in the production of RDF at the ASH Redwither site.

Equipment	Process Description	Current Fuel	Fuel Use	Switch Options
Case 821G Loading Shovel	Feed MSW from stockpile to shredder	Diesel	9 L/tonne	1. Hybridisation of Diesel motor using ULEMCo technology 2. Replacement with full hydrogen powered vehicle (not commercially available)
Dopstadt 3060 High Speed Shredder	Shred MSW to 350mm product	Diesel	22 L/tonne	1. Hybridisation of Diesel motor using ULEMCo technology 2. Replacement with hybrid electric / diesel shredder 3. Replacement with full hydrogen powered shredder (not commercially available)
Metal Separation	Remove ferrous materials	Grid Electricity	50 kW	1. Local generation solution (i.e. H_2 ICE)
Dryer Conveyors	Remove residual moisture	Steam (From Biomass Boiler)	5 kW	1. Electrical heat source powered by local generation solution (i.e. H_2 ICE)

As made clear from the existing process fuels, a significant number of emissions can be associated to the RDF fuel line due to the use of diesel mobile plant.

ASH has seven depots in total, three of which are key processing depots: Redwither, Shellway, and Bretton. ASH has completed an analysis on the emissions produced by these sites, where approximately 5,300 tonnes of CO_2e generated by the three key depots annually. To decarbonise ASH's systems, ASH has looked at the use of ICE generators to generate electrical power which can be used to drive the powertrains.

ASH has selected the Redwither site as the prime processing site and destination for H_2 switching for the following reasons:

1. The site is already permitted for RDF production. Extension/variation of this permit to produce H_2 is both speedier and a lower risk than developing a totally new permit.
2. There is already a combination of wastes and processes on one site including RDF and Biomass Grades A-C.
3. The Local Authority in Wrexham is very supportive of ASH Group.
4. Redwither is ASH's most advanced site and has experience of delivering development projects over a 15-year period.

To decarbonise the plant ASH will use H_2 generated by the CSS plant. This requires a finer shred of 150mm RDF which must then be briquetted. Table 2 summarises the equipment required under the new RDF production line.

Table 2 - Summary of the proposed process equipment used in the production of RDF at the ASH Redwither site in Stream 2B.

Equipment	Process Description	Fuel	Cons.	Switch Options
Case 821G Loading Shovel	Feed MSW from stockpile to shredder	Diesel	9 L/tonne	Not switched as out of scope of IHA works (mobile plant) but will be switch in 2024.
Dopstadt 3060 High Speed Shredder	Shred MSW to 350mm product	Diesel	22 L/tonne	Not switched as out of scope of IHA works (mobile plant) but will be switch in 2024.
Metal Separation	Remove ferrous materials	Grid Electricity	50 kW	Not switched as already running on electrical supply but future switch will be considered to H_2 Genset in 2024/5
Dryer Conveyors	Remove residual moisture	Steam (From Biomass Boiler)	5 kW	Electrical heating inefficient, switch not appropriate at current time.
Eddy Current Separator	Remove non-ferrous materials	Local Generation (H_2 ICE generator)	50 kW	Extension of existing RDF process to be operated on local power supply from H_2 ICE generator.
WEIMA Power Line Slow Speed Shredder	Shred 350 mm MSW to 150mm product	Local Generation (H_2 ICE generator)	130 kW	Extension of existing RDF process to be operated on local power supply from H_2 ICE generator.
2x Briquetter Lines	Produce briquettes from 150mm RDF shred	Local Generation (H_2 ICE generator)	50 kW	Extension of existing RDF process to be operated on local power supply from H_2 ICE generator.

In future works ASH would like to prove operation of its mobile plant on H_2 using hybridisation technology (ULEMCo) however as the scope of the IHA competition is limited to fixed plant this is not possible at this stage of the project.

ASH has also identified high speed shredding could be completed using a HAAS TYRON Hybrid shredder, operating using a diesel engine for its tracks, whilst the shredder mechanism is fully electric. This could effectively be treated as fixed plant running on H_2 electricity supply. This may be possible in further works as this equipment has only just become available in the UK.

The current metal separation process will not be switched to operation of the H_2 system as the electrical supply will be on a separate system requiring significant works to switchover. As the new units will provide a proof of concept of H_2 switching this would be done as part of future works.

The new process plant will have the energy requirements outlined in Table 3, with a total consumption of 23.2 kg H_2 /h to produce approximately 8.1 tonnes of RDF per hour. As discussed later in this report, the CSS gasifier will only produce up to 20 kg H_2, therefore the equipment will be slightly derated to approximately 7 tonnes per hour, of which 1.4 tonnes will be consumed by the gasifier. The intended operation is to power the RDF plant at full power to produce a significant feedstock of RDF which is then stored, and the plant powered down.

Table 3 - Power/Hydrogen requirements for Stream 2B Equipment.

Equipment	Electrical Energy	H_2 input requirement at engine*
ECS	50	4
Fine shredder	130	10.4
Briquetter X 2	55 X 2 =110	8.8
Total	**290kW**	**23.2 kg/h**
*Hydrogen conversion based on V8 H_2 generator, approx. 7.36 kg/h H_2 required to generate 92kW$_e$		

The process plant shown above will be electrically powered by H_2 fuelled ICE generators. The current design for Stream 2B has not been finalised on whether this will be powered from a separated electrical circuit or a switchboard which will preferentially take electricity from the H_2 ICE generators. The latter option is preferred however this will be finalised during detailed design at the commencement of Stream 2B.

The total budget cost for this production line is £620,000 with a parasitic power load of 290 kW.

Eddy Current Separation (ECS) and Weima Power Line equipment has been tested by CRJ (project sub-contractor Engineering Procurement Construction Manager (EPCm)) and is thoroughly proven to operate well with electric motors and therefore the project risk is low. This evaluation is to be extended to the electrically powered HAAS Tyron hybrid shredder also in Stream 2B.

The system will still require feeding by a loading shovel using a diesel engine. ASH intends to switch to a hybrid H_2 / diesel powered loading shovel to further reduce the emissions generated by the RDF production line. This will be done outside of DESNZ funding.

ASH and CSS intend to develop a “pipeline” project approach to the opportunities that will follow before and after the ending of the grant phase in the feasibility project. This includes upgrading and expansion at Redwither with a roll out of H_2 supply to other ASH sites and processes alongside commercially developing a rollout program to associated local companies and contacts.

5 CSS Gasification Trials

CSS has completed trials on the gasifier assessing the performance of the hydrogen generation scheme when used with different fuels, with a focus on optimisation to RDF.

The feedstock was assessed for impact on syngas composition and the ability of the H_2-PSA process to produce H_2 from that syngas stream. Additionally, the char and CO_2 emissions which could arise from the processing of three different biogenic feedstocks on the gasifier were assessed.

An outline schematic of the gasification process is illustrated in Figure 3 with explanations for the key points 1-5 discussed below.

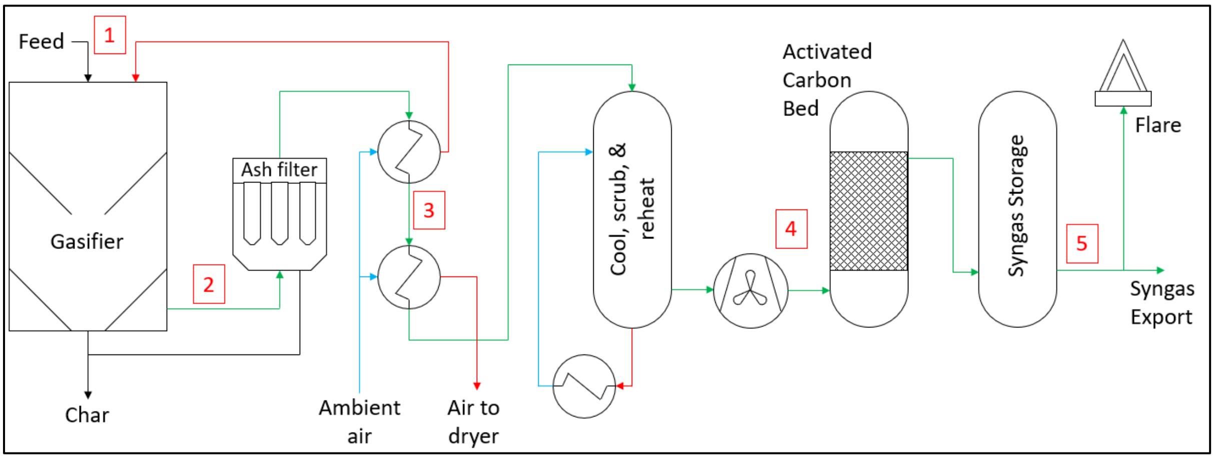


Figure 3 - Simplified outline PFD of the CSS Gasification System

The gasification process proceeds as follows:

[1] The feed into the gasifier consists of fuel and air.

[2] The gasifier generates dirty syngas and char. The gasifier is made up of several gasification zones, with the highest temperature zone in the “throat” (i.e. the narrow gasification section of the gasifier).

[3] A Hot Gas Filter (HGF) scrubs fine char particles from the dirty syngas and a Heat Exchange Network (HEN) reduces syngas temperature.

[4] Syngas passes through a second HEN and removes water vapour and bio-oils. Dry syngas passes through a carbon bed for decontamination before being stored.

[5] Syngas is removed from the syngas storage tank by a compressor to either flare or export for further processing.

Figure 4 gives further detail of the downstream process that converts the syngas into hydrogen, with key points 6-9 discussed below.

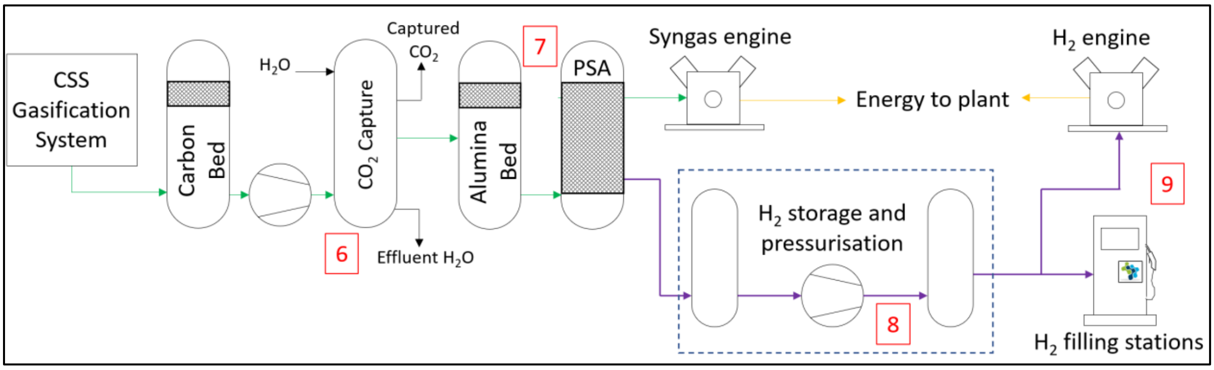


Figure 4 – Simplified outline PFD of the H2-PSA, H_2 storage and distribution, and syngas and H_2 engine.

[6] Syngas is passed through a water-based CO_2 scrubbing column to remove excess CO_2 present in the syngas. The process was developed as part of the BEIS H2BECCS phase 1 project completed in 2022.

[7] Syngas is passed through an alumina bed to remove excess moisture before passing through a PSA to extract a pure H_2 product stream. Excess syngas is passed to the syngas engine for electricity generation.

[8] The H_2 stream is compressed and stored at up to 450 bar.

[9] H_2 is distributed using a single hose dispenser or diverted to the hydrogen engine for electricity generation.

The trials described in the proceeding sections have been completed using a Gasifier-500 which generally is expected to generate a syngas flowrate of 500 Nm^3/h. In these trials the gasifier was not run at full capacity, but at a reduced flowrate of 300 Nm^3/h. This is due to limitations with the existing fuel feed system which was originally developed for pellets; pellets have better “flow” characteristics than briquettes and therefore switching to a briquetted fuel results in a reduced federate to the gasifier. CSS also wished to minimise the requirement for flaring and wasting useful feedstock and gas. The existing fuel feed system is in the process of being upgraded to give more throughput with variable feedstocks which will be complete for early trials in Stream 2B.

The PSA, whilst sized for a maximum peak flowrate of 400 Nm^3/h (at 8 barg) of syngas, was only operated at a maximum peak flowrate of 60 Nm^3/h (at 1.5 barg) due to the limitations of the compressor which feeds the H2-PSA system. Nevertheless, the performance was still impressive. The Stream 2B demonstrator will process the full flow of syngas (1300 Nm^3/h) using multiple H2-PSA units.

Syngas Composition: CSS has collected data that shows syngas generated by the CSS gasifier and sent to the PSA was fairly consistent and of good quality (i.e. high H_2 Vol%, good Lower Heating Value (LHV), lower N_2 Vol%) for each of the fuel types. The syngas was also produced at a consistent rate (300 Nm^3/h).

H_2 production appears to be increased on average when operating on RDF, however this also leads to a reduction in methane production resulting in lower LHV. This may have knock on effects to the operation of the syngas engine which will need to be optimised for this lower LHV.

The O_2 content of the syngas was slightly higher than expected, and this could have been caused by either:

- Instrument reading error;
- O_2 slippage past the gasifier hot zones; or
- Small amounts of air ingress into the system which operates under a negative pressure.

5.1 Product H_2 Concentration

Figure 5 shows the concentration of product H_2 generated by the PSA beds corresponding to the trials 1 to 3 for the different feedstocks. The data shown in Figure 5 shows the hydrogen product stream which is generated from the syngas. The graphs show that with a single H2-PSA stage hydrogen can be extracted from the syngas at a purity of over 90%.

As H_2 is produced, the vol% is increased (start of curve). The bed continues to operate for a short cycle where hydrogen concentration is high, before halting and the operating bed is switched.

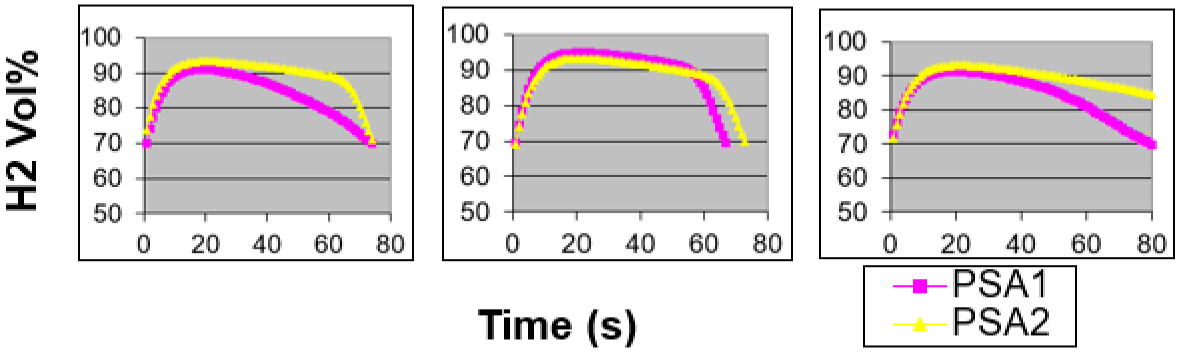


Figure 5 - H_2 concentration from the product H_2 in the H2-PSA beds from trial 1 WW (left), trial 2 CW (centre), and trial 3 RDF (right).

The above figures show that using the single stage H_2-PSA, the purity of H_2 produced followed the following general trends:

- vol% product $H_{2,\ CW} > H_{2,\ WW}$
- vol% product $H_{2,\ CW} > H_{2,\ RDF}$

Sampling of the H_2 product stream is done using an online analyser which is subject to fluctuation in measurements due to back-mixing, residence times, and sample purging. Considering these fluctuations, the differences are very small and in all three trials the vol% of H_2 exceeded expectations achieving greater than 90% purity in all cases for both beds.

It is also interesting to note that in trial three (RDF), the vol% H_2 remained high for a slightly longer duration, and this could also be due to the performance of the adsorbent being enhanced by low ambient temperatures on that day, when syngas inlet temperature to the H2-PSA beds was 4ºC (compared with Trial 1: 9ºC; Trial 2: 11ºC).

It is interesting to note that in all three trials, there is a difference in the way in which PSA1 bed and PSA2 bed performs. In general, the performance of PSA2 is better. There is no discernible difference in the construction of the two beds apart from the presence of temperature measurement probes (15 in total, at 100 mm intervals), which protrude from the side wall of PSA1. This may alter flow in the beds and cause fluctuations in performance. This must be analysed in further trials.

To summarise, these trials have shown that there is no significant loss in hydrogen generation when using an RDF feedstock compared to biomass or waste wood.

5.2 Product H_2 Flow

Figure 6 shows the product flowrates of H_2 generated by the PSA beds corresponding to the trials 1 to 3 for the different feedstocks.

Similar to the curves for H_2 concentration above, as H_2 is produced the flowrate is increased (start of curve). The bed continues to operate for a short cycle where hydrogen concentration is high, before halting and the operating bed is switched.

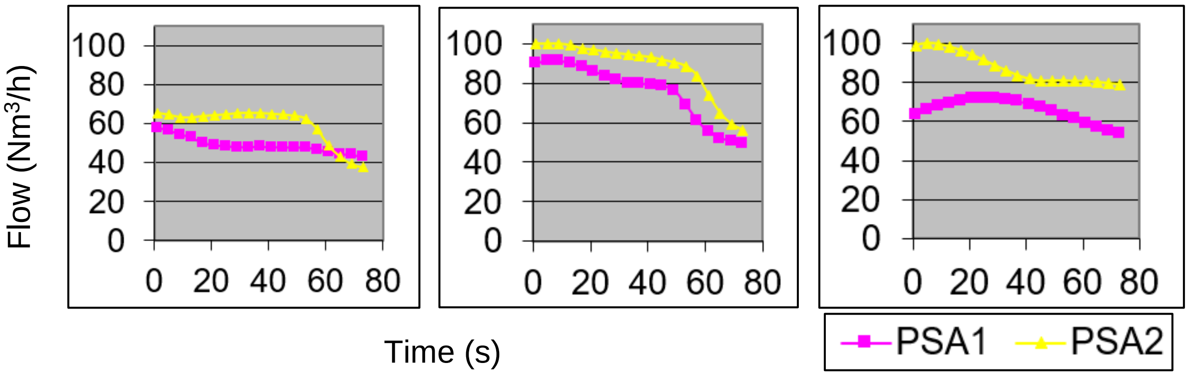


Figure 6 – H_2 flowrates from the H2-PSA beds from trial 1 WW (left), trial 2 CW (centre), and trial 3 RDF (right).

The above graphs show that the flowrate of hydrogen follows the general trend:

- Flowrate product $H_{2,\ CW} > H_{2,\ RDF} > H_{2,\ WW}$

During the time interval in the cycle when product is taken, the RDF appears to consistently produce H_2 at a flowrate around 60 Nm^3/h in PSA1, and 80 Nm^3/h in PSA2. This again arises from small fluctuations in gas flow through the bed and would not create any operational problems, especially when the 2nd Stage Twin-Bed PSA was added to the scheme.

The flowrates correspond to a peak range of 4.8 to 6.4 kg/h, in H_2 production in that production part of the cycle. As discussed previously, the peak syngas flowrate to the PSA was only 60 Nm^3/h of syngas (during the syngas feed part of the cycle), showing a significant improvement to hydrogen generation can be made when operating the PSA system at higher flows and pressures to match its design capacity.

The results from these trials are very encouraging and levels of H_2 > 90 vol% were easily achieved - well in excess of what had been expected (> 60 vol%) in a single-stage PSA twin-bed process. However, it must be noted that a H_2 back-flush cycle was included into the feasibility study works.

The significance of the back-flush step (in the PSA Cycle) is that this was an important finding during the development of the H2-PSA which increases the purity of H_2 produced from the PSA bed. Without the back-flush hydrogen purity is only achieved at approximately 60 vol%. The additional backflush step has therefore significantly increased performance of the system.

5.3 Operating Conditions

From previous R&D, CSS has identified that the vol% of H_2 in the syngas can be increased with the following methods:

- Operating at higher temperatures in the gasifier.
- Pre-heating the air to a higher temperature.
- Using an O_2 enriched gasification air feed.

This has led to some lessons learned:

- Restrictions on operational hours prevent reaching a steady state in the gasifier.
- Being unable to achieve steady state results in cold gasification temperatures which reduce performance.
- Performance in the gasifier is expected to increase over longer operating periods (i.e. greater than 8 hours).

The trials in this IHA feasibility study have led to additional findings for the operating conditions of the gasifier:

- RDF feedstock has a similar calorific value to wood. This has no detrimental effects to H_2 generation, however does have secondary effects:
    - Extra energy may be required to dry the feedstock.
    - The amount of char produced per kg of feedstock may be different.
    - With an RDF feedstock it will be necessary to add lime with the feed to mitigate the impact of higher levels of sulphur and chlorine which are released by the feedstock (i.e. mitigate emissions of sulphur and Chlorine).
    - The carbon guard beds and alumina guard bed which capture residual contaminants, when operated with RDF may need more regeneration.

CSS also identified that small particles, for example as were present with chipped wood, resulted in lower rates of H_2 production and higher CO_2 production rates. This has resulted in the selection of briquettes as the feedstock shape to slow the rate of combustion and increase the release of volatile gases consisting of H_2, CO, and hydrocarbons.

From the PSA trials with a real syngas stream, CSS has learned that even with a single-stage twin bed PSA that a H_2 purity of > 90 vol% can be achieved easily. In plans for the Single-Stage scheme only a > 60% purity level was expected, so this result has exceeded expectations. This result has also been achieved at a relatively low pressure of 1.5 barg. Performance is expected to improve with greater pressures from 4 to 7 barg in future trials.

Having detected higher O_2 levels in the syngas in all three trials (between 1.9 to 4.2 vol%), the temperatures in the throat of the gasifier (high temperature zone) were compared with results from an earlier design of gasifier (Mk 1). What was noticed, is that the throat temperatures in the new gasifier (Mk 2) are only reaching 500ºC, whereas in the earlier design (Mk 1), throat temperatures quickly increased to over 800ºC and O_2 levels dropped to ~0.5 vol%. Further work is being done on the new design, so as to optimize its performance, by lowering the position of the hot zone to coincide with the throat, and thereby reduce the O_2 content in the syngas down to <0.5 vol%. This will be completed during the detailed design phase in Stream 2B.

5.4 Carbon Capture Performance

To ensure the H_2 generated by the CSS plant is compliant to the UK Low Carbon Hydrogen Standard [3] the greenhouse gas (GHG) emissions intensity must be at or below 20 $gCO_2e/MJ_{H2,LHV}$.

CSS has completed analysis on the carbon produced by the plant during trials and has identified that the Gasifier-1300 plant (the plant that will be used in Stream 2B) emits the equivalent total of 590.3 $gCO_2e/MJ_{H2,LHV}$.

Due to the inherent carbon capture that forms part of the gasification, carbon is captured in the char that is ejected from the gasifier. If this char is sequestered by depositing in long term geological storage locations (e.g. disused mines) the Gasifier-1300 plant emissions reduce to an equivalent total of 181.4 $gCO_2e/MJ_{H2,LHV}$.

This can be further improved by implementing CSS' in-house water-based carbon capture system. This system captures carbon in water which can then be sequestered in long term geological storage locations. This addition reduces the Gasifier-1300 plant emissions to an equivalent total of 9.2 $gCO_2e/MJ_{H2,LHV}$.

The CO_2 capture by scrubbing from Syngas was not part of this IHA project. However, CSS have performed some preliminary trials and are planning to build on this in Stream 2B, using water scrubbing of the Syngas as a method of capturing CO_2 which can be concentrated and compressed. Water scrubbing is performed at an elevated pressure (e.g. 6 - 8 barg) and when the pressure is released from the spent water, CO_2 is released. The spent water is further treated to release residual CO_2, and then the clean water is returned back into the scrubbing column. The water is therefore recirculated, and there is no use of chemicals (such as amines) in this CO_2 capture scheme.

During the Stream 2 demonstration, as there is no infrastructure in place to take away captured CO_2, once captured this will either need to be released, or made available to a 3rd party to try to use as a product. The purpose of the carbon capture use in the Stream 2B demonstrator is to ensure the CSS system is technology ready to sequestrate what is captured.

6 End-to-End System Performance

6.1 Efficiency

This gasification process can be described as a FOAK type of project, and hence, there is no specific definition within the context of this particular project which can apply to calculate efficiency. Therefore, as advised by the IHA support Team, this report uses the prescribed definition on p.19 in 'Hydrogen Production Costs 2021' [4].

For Reformers and gasification technologies, efficiencies refer to the conversion of MWh fuel/feedstock/electricity input and MWh (HHV) of hydrogen output.

The efficiency of the end-to-end process is calculated taking into account that 60% of the cost of the process is assigned to the production of H_2. Therefore, after apportioning 60% of the feedstock to the production of H_2, the calculated efficiency is 34.3% for the commercial vision of the process.

The conversion of thermal to electrical energy is approximately 42% efficient (based on datasheets supplied by a third party), and the conversion of electrical into mechanical work is approximate 70 to 90% (based on average data from various sources) efficient which depends on how the equipment is used and load placed etc. Further efficiency calculations will be completed in Stream 2B once the system has been fully built and tested, where accurate figures can be given.

6.2 Levelised Cost of Hydrogen (LCOH)

Our process, which leads to a commercial design, could be described as a FOAK type of project. Hence, a number of assumptions are made. This report has prepared two separate cases for the LCOH.

Case 1: For a single Gasifier-1300 train consisting of: feedstock preparation and feed system; gasifier; O2-PSA; gasifier; HGFs; HENs; syngas blower; carbon guard beds; syngas compressor; syngas CO_2 scrubber, purification, and compression system; alumina guard bed; H2-PSA to produce H_2; gas engine with electric generator; H_2 compression and storage.

Case 2: For eight Gasifier-1300 trains which equate to 8 x Case 1 (this is the commercial vision of a fully functioning MicroH2-Hub).

For clarity, Case 1 is not the LCOH for the demonstrator project which will be constructed in Stream 2B, rather a commercial version of a single gasification train once the initial optimisation and lessons learned from Stream 2B can be used to optimise the price and efficiency of installation. The CAPEX for Case 1 and Case 2 are built up separately from this project.

The assumptions for the LCOH are as follows:

- Year 0 – Plans are submitted for the site
- Year 1 – Construction phase
- Year 2 – The plant is commissioned and operational by year end
- Year 3 – The plant is operational and producing H_2
- Year 30 – At the end the plant is shut-down and decommissioned

Table 4 outlines the inputs and outputs of the LCOH and final values for Case 1 and Case 2.

Table 4 – Summary of LCOH calculations for Case 1 and Case 2.

	Units	Case 1	Case 2
Feedstock	n/a	Waste Wood	RDF
Number of Gasifier-1300s	n/a	1	8
Fuel throughput per annum	tpa	7920	63,360
Cost of feedstock	£/tonne	0	-30
Plant life-span for discounted calculation	years	30	30
Discount Rate	%	10	10
Onstream time	h/year	7,500	7,500
H_2 production	kg/h	19.8	158.4
Apportionment of costs to H_2 production	%	60	60
Total Cost (CAPEX + OPEX)	£M	26.055	147.72
LCOH with Step 1 capture of Char and Step 2 capture of CO_2 from the Syngas.	£/MWh	248	172
LCOH with potential Step 3 – CCUS (Note 1)	£/MWh	248 + 6 + 2 = 256	172 + 6 + 2 = 180

Note 1**:** From the BEIS report [4] there is no infrastructure in place to support Carbon Capture, Utilisations and Storage (CCUS) even at the 300 MW SMR scale. However, SMR carbon capture technology would be similar to that which is applied to the CSS gasifier and a similar efficiency could be obtained, and hence using the metrics in the annex of the BEIS report for CO_2 transport and storage cost (LCOH = £6/MWh H_2) and for carbon cost (LCOH = £2/MWh H_2) are both added into Table 4, to obtain an estimate of LCOH with CCUS.

6.3 Potential Carbon Emissions Savings

ASH has completed an assessment of emissions savings that can be achieved by introducing H_2 into its processes. This has been completed for the Stream 2B project, and forecasted into the future operations of ASH's Redwither plant.

In the Stream 2B demonstration, ASH will be introducing additional processes that will operate on H_2 generated electricity. These processes require 230 kW of electricity to operate.

Using data collected by ASH on its fuel consumption and CO_2 emissions , it is estimated that each kW of electricity emits approximately 1.3 tonnes of CO_2 per year (tCO_2e/yr).

Therefore, for the equipment outlined for use in the Stream 2B demonstrator ASH will be avoiding emissions of 299 tCO_2e/yr.

Following this assessment, ASH has identified in the future a total of 6,162 tonnes of CO_2 emissions can be prevented by gradually switching all of its sites from grid electricity and diesel power through a mixture of H_2 ICE electricity generation and vehicle conversions to H_2 fuels. This would ultimate reduce ASH's CO_2 footprint from 6,731 tCO_2e/yr to 569 tCO_2e/yr.

6.4 Scaling Against a Counterfactual

6.4.1 Steam Methane Reformation (SMR)

Table 5 shows a comparison of the key performance indicators for the CSS plant compared to SMR.

Table 5 – KPI comparison of the CSS hydrogen generation technology and unabated SMR.

Item	Units	CSS (Single Train)	SMR [5]
Hydrogen Flowrate	kg/h	20	8,375.2
Hydrogen Purity	%	>90%	99.99%
Hydrogen Yield	%	61	66.6
Carbon Capture	n/a	Inherent capture in char Water based syngas scrubbing	Amine based scrubbing of combustion flue gas
Carbon Emissions	gCO_2e / $MJ_{H2,LHV}$	590.3 unabated 181.4 with char abatement 9.2 fully abated with water scrubbing	74.4 unabated 6.7 abated
Total Cost (CAPEX + OPEX)	£M	26.055	794
LCOH	£/MWh	256	46.76

It should be noted that this report does not include credit taken for biogenic content that may be included in the RDF which may reduce the equivalent carbon emissions further. Future work will explore the emissions impact of the upstream RDF collection / processing and the biogenic content.

Table 5, and other information presented in this report, show clear benefits for the CSS gasifier when compared to the predominant technology for H_2 generation in the UK (SMR), those being summarised as:

Low Cost – The total capital investment of the CSS gasification system is less than 5% of a full-scale SMR site, making it affordable to a wider selection of investors.

Low Carbon – The CSS gasification process is considered low carbon under the UK Low Carbon Hydrogen Standard (i.e. <20 gCO_2e / $MJ_{H2,}$LHV). Whilst emissions are higher than SMR, the system is significantly smaller scale and therefore has a smaller carbon impact during construction and decommissioning. SMR also significantly benefits from economies of scale.

Waste Disposal – The CSS gasifier can dispose of 7,920 tonnes of waste on a yearly basis. This is a Unique Selling Point (USP) when compared to SMR and can significantly add to the UKs waste treatment network.

6.4.2 Large Scale Fluidised Bed Gasifier

ASH estimate that they occupy 1% of the UK Waste market, translated to eight sites with only one site producing RDF. The RDF facility (Redwither) has a 30 – 35 mile collection radius and is able to produce up to 150 tonnes per day of RDF. The RDF is transported in 25 tonne walking floor trailers. The transport of fuel introduces:

1) Emissions from transport
2) Waste dust
3) Hazards on multiple sites for the storage of wastes
4) Excessive vehicle movements

Large scale fluidised bed gasifiers will require significant throughput which will require a wide geographical area of waste collection. This would aggravate the above factors tremendously.

An advantage of the solution proposed in this report is that the gasification process is on a site that is producing the waste. This therefore removes the requirement for secondary waste transport.

Additionally, the H_2 produced is to be consumed on site, which further saves transport for use somewhere else. Furthermore, the UK waste industry is moving towards Municipal Solid Waste (MSW) rather than treated RDF. This in turn reduces the viability of large-scale fluidised bed gasifiers that rely on significant RDF throughputs.

The plants also have less environmental and visual impact – this means that there are more potential locations for such facilities, including being installed in the heart of industrial estates for example.

7 Stream 2B Delivery Plan

ASH currently uses several items of large industrial equipment such as shredders, trommels and dryers within the existing operation. As discussed in section 4.1 there is an intention to develop a switch of equipment to operate on H_2.

In Stream 2B it is planned to install an integrated solution to produce, from waste materials, H_2 which will subsequently be used to power waste processing equipment. A Gasifier-1300, which produces 1300 Nm^3/hr of syngas from 1000 kg/h of RDF will be installed along with a H2-PSA unit which will generate 20kg/h H_2 (0.67 $MW_{H2,LHV}$) using the syngas. Additionally, a H_2 storage and distribution system will be installed. This will distribute the H_2 to power the waste processing equipment.

Stream 2B will also take the opportunity to use the Gasifier-500, that has been developed and tested during Stream 2A, to “kick start” the demonstration of the “gasification to H_2 to power” process. During Stream 2B, it will be upgraded to allow for continuous operation on waste feedstock at the beginning of the project. This will enable gasifier to H_2 trials whilst producing power via the 3rd party H_2 engine generator at CSS's Sandycroft site by six months from demonstration project start.

Experience and lessons learned from these early trials, beyond work carried out in Stream 2A, will help to de-risk the larger plant development as more reliability running will highlight any operational issues at an earlier stage and can be rectified without affecting the project deadline.

7.1 Waste Processing to Produce Gasifier Feedstock (RDF)

Feedstock supply to the gasifier requires processing beyond ASH's current needs for their waste streams. At present, processed waste is generally sent for incineration and therefore does not need to be as refined as required for gasification. The current RDF product produced by ASH is therefore limited to a 350mm.

Additional equipment such as metals screening, fine shredding, and briquetting is therefore needed to produce a feedstock suitable for gasification as detailed in section 4.1. This will result in a briquetted RDF fuel rather than a shredded fuel.

It is not the intention that the fuel processing output will feed directly into the gasifier. Feedstock will be produced and stored on site until needed. Separation and storage will allow for stockpiling of fuels for the gasifier and potentially for export to other off-takers such as cement kilns and refined fuel Combined Heat and Power (CHP) plants. This is no different from current operations.

The new plant is capable of producing 4-6 t/h of briquetted fuel, which will be the feedstock for the gasifier (whilst still supplying RDF to existing clients), for the production of H_2 that will be used to power both this plant and other items of equipment on site.

The equipment used to produce the feedstock from dried waste is an important part of the H_2 switch. ASH has investigated the feasibility of converting existing equipment and/or procuring new equipment to be directly powered by H_2 fuel.

Discussions have identified there is currently uncertainty around the availability of H_2 powered waste-processing equipment and this is likely to persist during Q1/2 in 2023.

Given this fact, and to ensure that H_2 produced from waste on site can be used on the same site, ASH are planning to use electric powered machinery fuelled by H_2 fuelled generators. This is a practical interim step prior to major suppliers of waste processing equipment introducing shredders and screeners powered directly by ICE fuelled by H_2. In this way, the power source for the processing equipment can be decarbonised via the intermediary of the H_2 gensets.

The final list of equipment to be powered by H_2 sources is listed in Table 3 together with the electrical power requirement and the expected H_2 consumption for each. Power to this plant will be supplied from a H_2 genset that will be fuelled by the gasification and H2 plant described in section 7.2.

7.2 CSS Gasification and H_2 Production

For Stream 2B, CSS will supply a Gasifier-1300 model gasification system. This system is larger than the Gasifier-500 which has been used for this Stream 2A feasibility study. The Gasifier-1300 will be scaled from the Gasifier-500 using data gained in this report and previously commercially supplied gasification system.

The Gasifier-1300 shall also be provided with a H_2-PSA system which will be fully sized to generate up to 20 kg/h of H_2. Each bed, for the PSA and also the activated carbon and alumina guard beds, shall be provided in duty-standby pairings to allow regeneration of one bed whilst the other is in operation. This will allow for continuous operation. Furthermore, the CSS proprietary CO_2 capture system, utilising pressurised water to remove CO_2 from the syngas, will be supplied with the system.

Both the PSA and CO_2 technologies are at a lower Technology Readiness Level (TRL) (Both TRL4) level than the gasifier (TRL8) and therefore require further development to be commercially ready. Due to the combination of the technologies the gasification system is considered to be TRL4 overall.

Trials, optimisation, and performance testing will be done on the full CSS system during the Stream 2B works to bring the full system to TRL8.

7.3 PEC H2 Compressor, Storage and Distribution

PEC will supply the equipment for the compression, storage, and distribution of the H_2 generated by the CSS plant. PEC have done an initial front-end design for the H_2 plant as detailed in this section.

When discharged from the H2-PSA, the H_2 is at 1 to 2 barg and would need to be pressurised and stored at low pressure (approximately 5 barg) before being compressed. The H_2 produced by the PSA needs to be pressurised to 200 barg for use in industrial applications (this is lower than required for vehicles which is typically 350 or 700 barg).

PEC have designed and will supply, a Pure Hydrogen® compression, storage and fuelling station for the Stream 2B project. Descriptions are provided in the proceeding sections.

All components within the compression, storage, and distribution systems have been designed in accordance with the ATEX Standard (such as EX and EEx levels). All pipe work holding hydrogen are manufactured from 316 stainless steel to avoid any issues associated with hydrogen embrittlement. The system has been designed to eliminate fugitive H_2 emissions with the use of fully welded connections and venting only occurring in the compressor during start-up where minimal H_2 will be lost.

A control panel with functional Human Machine Interface (HMI) will be provided with the PEC system to fully automate the dispensing system for use of H_2 on site.

7.3.1 Pure H2-200 Diaphragm Compressor

This compressor allows to pressurise H_2 gas from 5 barg up to 200 barg with a flow rate of 120Nm^3/h. The compressor is installed within a Hypod outdoor container enclosure. An example PEC compressor system is shown in Figure 7.

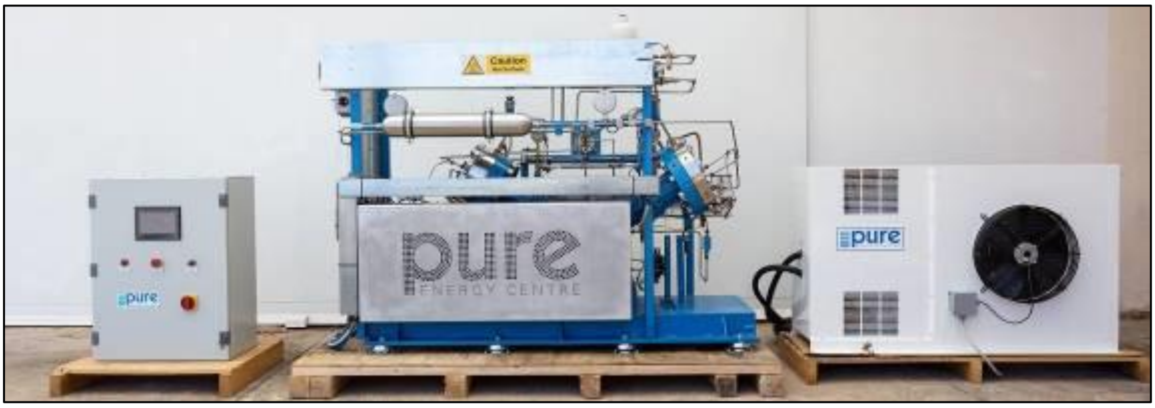


Figure 7 – Example PEC hydrogen compressor. This will be containerised on the ASH site.

7.3.2 H_2 Storage

Storage will be supplied in the form of a 22 Manifold Cylinder Pack (MCP). The MCPs are designed and manufactured to be easily transported and moved by both a forklift and/or crane. Hence the installation of these cylinders shall be easily achieved. Hydrogen will be stored with a capacity of 600L of H_2 at 200 barg per pack, totalling a storage capacity of 197 kg.

7.3.3 Distribution – Dispenser / Filling Panel

A dispenser unit in the form of a filling panel will be provided capable of dispensing fuel to a vessel at 200 barg. An example dispenser unit is shown in Figure 8.

Figure 8 – Examples of cylinder filling panels

7.4 End-to-End Process Layout

The gasifier, syngas processing, H_2 and process equipment requires a relatively small footprint thanks to the compact containerised design of the CSS and PEC equipment and can fit into an area as small as 800m^2. The site layout is shown in Figure 9 which is contained within the aforementioned 800m^2 area.

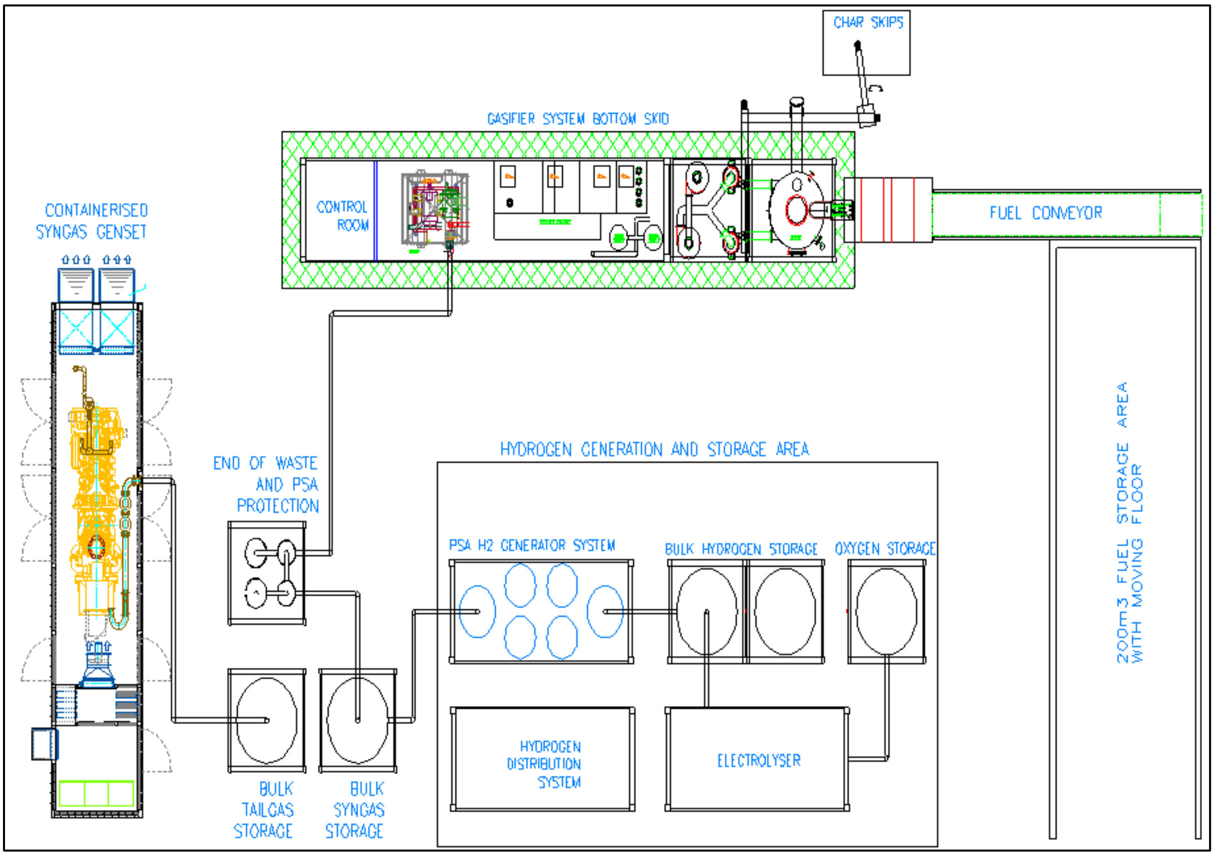


Figure 9 – Layout of the gasification system including hydrogen compression, storage, and distribution, and the inclusion of the syngas genset.

The site plan does not currently include the locations of the H_2 generator and additional ASH equipment. This will be planned as additional information becomes available in the detailed design phase at the beginning of Stream 2B.

7.5 Costs

ASH has detailed a budget for a Stream 2B IHA project in line with DESNZ' cost headings. The total Stream 2B project costs are estimated to be just below £6.7M.

7.6 Post-Funding Developments

Once the demonstrator funding has ended, the intention would be to continue to use the demonstrator plant for R&D purposes. This has applications in several functions:

- Continued development of fuel switching at ASH's depots, including switching mobile plant, refuse collection vehicles, and ICE generators.
- Export of H_2 to other ASH depots to continue switching other processes. This may include decarbonising heat and power needs by generating steam from hydrogen based burner systems.
- Export of H_2 to third parties to support switch over and development of other equipment. This will include the provision of tours to the site to inspire local interests.

- Testing carbon capture technology with an aim of further reducing post-gasification CO_2 emissions. This may extend to capture of emissions from the syngas engine.
- The demonstrator may also be used for further development and optimisation of other feedstocks for the gasifier, and optimisation of the gas train layout.

When no further trials are expected to proceed, the gasifier and H_2 equipment will be decommissioned, with the intended strategy being to reuse any parts that may feasibly be refurbished and reused on another gasifier. Any spare equipment that is not re-usable will be sold for re-use, and the remaining equipment will be dismantled and recycled with the support of project partners. This decommissioning activity has not been accounted for in the project budget, owing to the intention to undertake further long-term testing post-project. The intention is, therefore, that any value from the resale of equipment will be used to cover the dismantling costs.

There is an alternative outcome, that there could be an opportunity for the gasifier to continue production of H_2 on the ASH site, should the demonstrator perform at a sufficient level once any modifications have been completed.

7.7 Planning and Permitting

The construction of a H_2 generation plant has implications on planning permission and the permitting of the ASH Redwither site, which currently holds permits for waste processing.

ASH has engaged third party contractors to assess the needs for planning and permitting to allow for a successful bid to proceed with a Stream 2B project. It is likely that ASH will need to proceed through one of two routes:

1. Application through the variation of an existing permit
2. Application for an R&D licence
3. Application through a Small Waste Incineration Plant (SWIP) permit

The route taken will be dependent on what the Stream 2B project is eligible for and how the project is viewed by local authorities which ASH continues to be in communication with.

7.8 Safety Assessment

The end-to-end solution for the generation of H_2 on the Redwither will introduced several hazards once the Stream 2B project begins. These hazards are summarised in the sections below. The key hazards are:

- Construction.
- Explosions (Syngas / H_2).
- Process Risks – High Temperature / High Pressure.
- Compressed Gas.
- Asphyxiants.
- Waste Disposal.

It should be noted that many of the actions that will be implemented for the mitigation of risk will be identified and developed during the detailed design phase of Stream 2B.

Furthermore, ASH will look to minimise hazards on the site by using Health and Safety Executive (HSE) best practice, i.e., following the safety hierarchy (elimination, substitution, isolation, engineering controls, administrative controls, Personal Protective Equipment (PPE)). An example of this in practice can be demonstrated by CSS' development of a water-based CO_2 scrubber, eliminating the need for dangerous amine solvent on site.

In this safety assessment ASH has not considered waste and moving machinery as an additional hazard as these are well managed hazards which already exist on site.

7.8.1 Construction

Construction introduces significant risk to workers on the ASH site and any contractor completing works to develop the Stream 2B demonstrator. This includes risks such as working at height, hot works, and excavations.

The construction risks shall be managed by following the 2015 Construction, Design and Management Regulation 2015 (CDM) with ASH acting as the client. An Engineering Procurement and Construction (EPC) contractor will be appointed to take on the principal designer and principal contractor roles to manage site health and safety, mitigating key risks identified by the project partners.

7.8.2 Explosions

Syngas and Hydrogen are extremely flammable and in some cases explosive. With occupancy of the ASH site and surrounding location likely to be fairly high there will be a low tolerable risk due to the potential for a multiple fatality incident should an explosion occur.

To mitigate the risk of explosion a full Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) assessment shall be completed to identify ATEX areas around the plant where vehicles shall be excluded from entry, naked flames shall be banned, and instrumentation shall be specially selected to prevent ignition sources. The DSEAR assessment shall be completed by a third-party specialist.

7.8.3 Compressed Gas

Hydrogen and other gases will be stored on the plant in various vessels which will be subjected to pressures above ambient pressure (1 bara). Should these vessels rupture this may potentially create missiles that cause fatalities. Further high-pressure loss of containment may occur through leaking seals etc. which may impinge and injure personnel.

All pressure vessels will be specified to be constructed in accordance with the Pressure Equipment Directive (PED) and therefore have suitable contingency in the allowable design pressure of the vessel to minimise the chance of rupture. Furthermore, these vessels will be subject to statutory inspection under a Written Scheme of Examination to secure insurance.

To mitigate against leaks the plant will be constructed using best practice for flange torques, with pressure testing of the equipment following maintenance to ensure no leaks have been introduced.

7.8.4 Other Process Hazards

All process plants introduce various hazards due to pressure, temperature, flow, hazardous material, or maloperation. This could lead to a catastrophic loss of containment event with multiple fatalities.

Despite previous safety studies having been completed on the CSS and PEC technologies, the combination of the various systems warrants the completion of new studies. Systems will be assessed using appropriate methods such as Hazard and Operability Studies (HAZOP), where necessary followed up with Layers Of Protection Analysis (LoPA) studies to determine whether Safety Integrated Systems (SIS) are required, and if so, to what level.

7.8.5 Asphyxiants

Syngas, its components such as CO, and the CO_2 removed by the carbon scrubber are all considered asphyxiants in high enough concentrations. Should a gas excursion occur (e.g. leaking flanges, loss of suction, etc.) this may cause injury or fatality on site.

To mitigate against this risk a full risk assessment shall be completed during the design and construction of the plant to assess suitable locations for gas monitoring to allow evacuation of the plant where necessary.

7.8.6 Waste Disposal

The CSS gasifier creates by-products of char and effluent water. These are not considered hazardous however disposal may prove difficult in the short term due to their unusual nature.

During the detailed design phase in Stream 2B additional trials will be run to further identify the potential contaminants within these waste streams and to secure off-takers.

7.8.7 Residual Risk Mitigations

The risk mitigations above identify and mitigate against risks identifiable at this stage. During the detailed design of the plant additional risk management will be put in place for other hazards.

To combat any residual risks in the plant the operators shall be given a bespoke operator training package which will be put together by ASH, CSS, and PEC to manage and operate the plant.

In addition to this, all equipment shall be designed and constructed in accordance with the requirements of all UK regulation and the plant will be marked with a UK Conformity Assessed (UKCA) marking on final completion.

Finally, service contracts shall be offered by PEC and CSS to manage the maintenance and provision of operational advice to the plant once in operation.

8 Value, Future Plans and Dissemination

8.1 Value Summary

As described earlier in this report, the proposed solution would result in a reduction in carbon emissions from the ASH waste processing equipment. The changeover of fuel source from diesel to H_2 would result in a 39% reduction in carbon emissions, from 74.4 kg CO_2 per tonne of waste, to 45.1 kg CO_2 per tonne of waste.

There is a range of impacts derived from the work undertaken in the IHA feasibility project and its potential for altering processing in the waste management sector in the UK. Historically and recently, waste management solutions have developed broadly in line with waste hierarchy and adhered to sustainability drivers of reuse, recover, recycle.

The growing influence of sustainability is now at the heart of many industrial processes in the UK when less than a decade ago this was not true. The design and delivery of the IHA feasibility project has allowed ASH and CSS to plan and develop a change in waste processing at a pace previously viewed as impractical.

The IHA Feasibility program will bring with it the following social and economic benefits within a short timespan:

- Change in waste processing practice that will result in lower CO_2e footprint, as well as creating more waste disposal capacity in the UK.
- Development of new processing that will bring with it new skills and learning resulting in a shift from combusting of waste (High CO_2e) to a higher proportion of waste treatment on a “resource” based approach.
- Workplace and vocational opportunities for new skills within the sector where waste will become a key contributor to H_2 production for use throughout UK industry and not just in the waste sector.
- Job creation will be delivered both in processing, equipment engineering and among contractors directly and indirectly involved in fuelling and operating a fuel processing and gasification plant designed to produce H_2 for power applications as well as CO_2 for industrial use.
- The direct job creation for the switch project in the feasibility program is estimated to produce the following full- time jobs based on an initial single plant (i) Gasifier plant operators x 2 (ii) Fuel plant operators x 3 (iii) Distribution and admin staff x 2 (iv) Health & Safety (H&S)/Compliance x 1.
- Among contractors to the feasibility project, job creation will initially be focussed on construction. Beyond that, specialities in the fuels, gasification and associated EPCm disciplines will be significant.

The development of H_2 from waste will stand as an alternative to H_2 being electrolysed from water. The impact that the technologies and processes can yet have will continue to depend upon speed of delivery across a range of disciplines and in short, we are moving well but have a long way to go.

8.2 Benefits Summary

In this section, all the applicable benefits of the solution proposed in this report are listed with evidence of the appropriate measures provided.

Demonstrate potential for commercial viability of end-to-end H_2 industrial fuel switching systems.

This benefit has been realised through the successful completion of a feasibility study for the end-to-end system and plan for commercial implementation. Furthermore, a suitable market has been identified and strategy for future rollout of small-scale H_2 hubs as demonstrated in section 8.4.

Provide evidence and knowledge to support future H_2 and industrial decarbonisation policy.

This benefit has been realised through the successful completion and publication of project reports providing evidence on costs and performance of system and technologies, as demonstrated in section 5.

Increased awareness, understanding and confidence in end-to-end H_2 fuel switching solutions for industry to facilitate future deployment.

This benefit has been realised through a number of dissemination activities as outlined in section 8.3. Furthermore, feedback from key stakeholders has been achieved through online showcases of the end-to-end technology, engagement with public and private stakeholders, and face-to face/online dissemination activities such as webinars.

Potential reduction in carbon emissions of a specific industrial process.

As described earlier in this report, the proposed solution would result in a reduction in carbon emissions from the ASH waste processing equipment. The changeover of fuel source from diesel to H_2 would result in a 39% reduction in carbon emissions, from 74.4 kg CO_2 per tonne waste to 45.1 kg CO_2 per tonne of waste.

Development of more efficient, resilient and available H_2 storage solution to support UK energy system

The solution detailed in this report has the potential ability to ramp up and down and/or accommodate variable renewables and therefore can realise this benefit.

Ability of industrial processes to be flexible in their energy source

The solution detailed in this report has the unique ability and advantage to be able to generate H_2 from waste material, and therefore has the capacity to be very flexible in its energy source. As shown in section 5 of this report, three different feedstocks were all shown as viable for generating H_2.

8.3 Dissemination Plans

Early in the project, ASH and the project partners developed a dissemination plan which has been actioned throughout this project.

ASH and the partner organisations have completed dissemination over the course of Stream 2A, including weekly team meetings, quarterly reports, in person and online showcases of the end-to-end technology, engagement with public and private stakeholders, and face-to face/online dissemination activities.

Early in the project, ASH engaged a PR Agency, who produced a press release about ASH, the project and the funding. The article was picked up by several media outlets (see Table 6)

Table 6 – Table of dissemination activities

Activity	Category	Description	Stakeholders Engaged	Date
Publicity	Press Release	Press release was issued and pubished on Business Live, Circular Online, Global Financial Market Review, Let's Recycle, Fuel Cells Work, Insider Media, Wrexham.com, and Resource	General Public, Government, Competitors, Potential End Users, and Suppliers	Nov 2022
Events	Decarbonisation Forum	Event – attended by CSS	General Public, Government, Competitors, Potential End Users, and Suppliers	Nov 2022
Sponsorship	Membership of UKHFCA	ASH joined the association in November 2022	Association membership and lobbying activities centred on H_2 from waste	Nov 2022

ASH and CSS also held several face-to-face meetings with several high profile companies which are producing H_2 based equipment.

A public version of this feasibility report will be distributed post-project online, both on the ASH and CSS websites and LinkedIn. The report will also be sent to all stakeholders that ASH have engaged with during the IHA Stream 2A project.

If successful in Stream 2B, ASH will host several stakeholder meetings with Government bodies, local community, supply chain, and end-users. Project information will be presented, and feedback collated to help shape the commercial development and support local engagement.

8.4 Continued Development

8.4.1 Joint Venture Development

. Utilising the consortium's experience and established relationships with waste management companies, private investment groups in the energy sector, and fuel suppliers, additional units can be rolled out on the blueprint of the Stream 2B demonstrator.

ASH and CSS to date have collaborated to progress planning permission, which is currently ongoing for the ASH Wrexham site, Redwither. The application is extensive with development anticipated for eight modular CSS gasifiers working in parallel as shown in Figure 10, below.

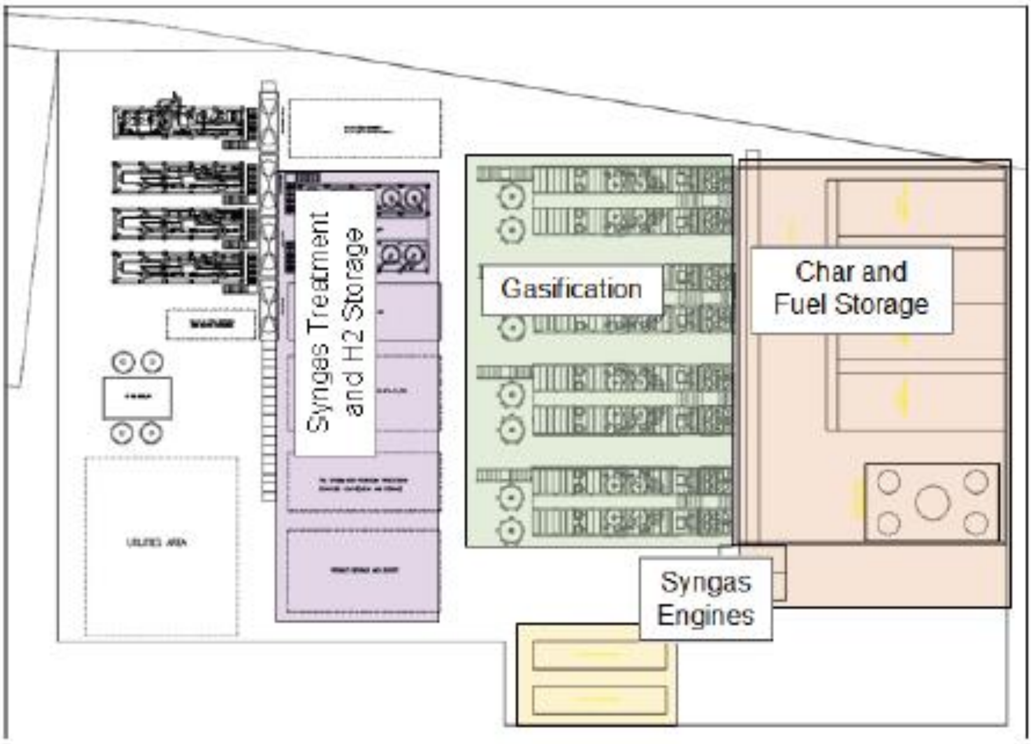


Figure 10 - Schematic of the planned site design for the ASH Wrexham site with highlights for significant components to support planning permission.

It should be noted that the plan shown in Figure 10 is for a commercial scale hydrogen generation plant taking in eight tonnes of waste per hour to generate 240kg of hydrogen per hour (9.45 MW). This is achievable by integrating electrolysers into the system which delivers additional H_2 whilst producing O_2 for gasification air enrichment. This will be delivered in stage 2 as per Table 7.

8.4.2 Firm Up Costs for Commercialisation

Confidence in lifetime costs will be improved during the Stream 2B project as part of the project will be to firm up CAPEX/OPEX and H_2 costs and subsidies.

The project will allow the project partners to cost fully all internal labour and overhead costs, plant preparation, H&S, regulatory requirements, and all CAPEX Engagement with sub-contractors used during Stream 2B for additional specialist expertise to firm up costs and strengthen commercial partnerships as supply-chain partners.

The ability to conduct scaled trials to prove the solution, with a commercial Gasifer-1300 to demonstrate the potential off-take and value chain partners, will strengthen the consortium's position to leverage future finance. Success in a Stream 2B IHA application process will provide access to funding for the first-of-its-kind commercial demonstrator and ASH waste has also committed future investment once the technology has been proven at scale in a commercial environment.

8.4.3 Future Development – CSS Route-to-Scale

Future development for CSS will be around the commercialisation of the MicroH2-Hub. Having completed a BOO model in the Stream 2B demonstrator, CSS will have the operational data, evidence and a commercial demonstrator to deploy the technology into the market.

CSS has therefore developed an accelerated timeline to market and are taking a phased approach to commercial development having already successfully completed H_2 production and carbon capture trials using the Gasifer-500 plant. The next stage of development is to make the Gasifer-1300 commercially operational (MicroH2-Hub) while we enter the feed stage for a IHA Stream 2B project at ASH as per Table 7.

Table 7 – Anticipated production rollout of the CSS gasification technology.

Stage	Scale	Year	Location	Project Intent	Funding Req.
1.1	Gasifier-500 *(Pilot)*	2022	CSS (Deeside)	Proof of H_2 generation from RDF / biomass gasification. Proof of carbon capture with water.	n/a
1.2	Gasifier-500 CCUS *(Pilot)*	2023 – 2025	CSS (Deeside)	Prove 1000 operational hours whilst generating 15 kg / h on biomass feed. Finalise CCUS concept.	H2BECCS £5M
2	Gasifier-1300 (scale-up)	2023 – 2025	ASH Waste (Wrexham)	Prove 1000 operational hours whilst generating 20 kg / h on RDF feed. Switching 50% of industrial equipment to run off H_2.	IHA £7M
3	Multiple Gasifier-1300 with CCUS	2025 - 2027	UK/EU	Build seven additional MicroH2 hubs for ASH. Commercial generation of 20kg / h per hour with carbon capture using RDF or biomass feedstocks for the market.	Private funding & commercial sales.
4	License	2028	Global	Commercial generation of 20kg / h per hour with carbon capture using RDF or biomass feedstocks.	Commercial sales.

Stage 1.1 – Small-scale H_2 production has been proven utilising our Gasifer-500 plant and inhouse built PSA technology, achieving a 15 kg / h flow of >90% pure H_2.

Stage 1.2 – Further development of the CSS carbon capture technology to include a 2nd stage of CO_2 removal. CSS are currently applying for funding through the BEIS BECCS program to fund further development.

Stage 2 – IHA Stream 2B plant will be operational in 2024 at ASH Wrexham. FEED has been completed as per this feasibility study.

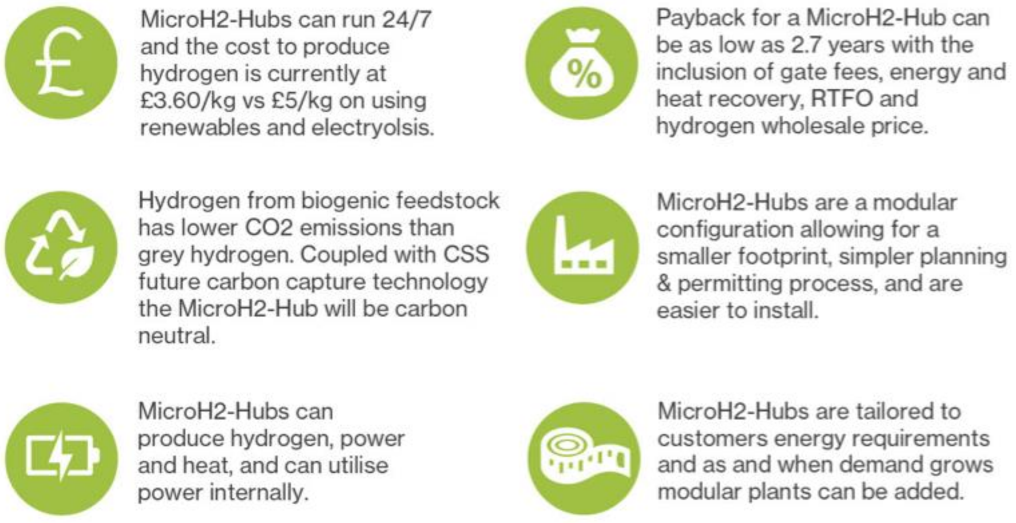
Stage 3 - Deployment of multiple commercial plants – from 2025 onwards, CSS will engage with end users selling MicroH2-Hub plants of which the first seven will be allocated to ASH.

Stage 4 – The final phase in the technology roll out is for CSS to license out the technology, as a Small Medium Enterprise (SME) there is a limit to our capabilities for large-scale roll out. From 2028, CSS business will switch to large-scale manufacturing partners constructing under license, significantly increasing the deployment.

As per the counterfactual analysis in 6.4, the CSS gasifier has significant USPs compared to competitors, particularly lower CAPEX and OPEX which allows quick investment decision, and the small modular capability which minimises planning risk.

CSS offer a unique small-scale plant that enables companies to utilise their waste feedstock and supply their own H_2 for industrial use and transport as a steppingstone technology while the infrastructure for H_2 is being built and adopted.

Further outlining of CSS' USPs are shown in Figure 11. The combination of what this technology offers combined with the JV potential with ASH waste allows the rollout of the technology to other sites where waste may not be immediately available, where ASH may be able to directly supply waste, or advise on waste procurement.



MicroH2-Hubs can run 24/7 and the cost to produce hydrogen is currently at £3.60/kg vs £5/kg on using renewables and electryolsis.

Payback for a MicroH2-Hub can be as low as 2.7 years with the inclusion of gate fees, energy and heat recovery, RTFO and hydrogen wholesale price.

Hydrogen from biogenic feedstock has lower CO2 emissions than grey hydrogen. Coupled with CSS future carbon capture technology the MicroH2-Hub will be carbon neutral.

MicroH2-Hubs are a modular configuration allowing for a smaller footprint, simpler planning & permitting process, and are easier to install.

MicroH2-Hubs can produce hydrogen, power and heat, and can utilise power internally.

MicroH2-Hubs are tailored to customers energy requirements and as and when demand grows modular plants can be added.

Figure 11 - CSS Micro H2-Hub information

CSS' market focus is industrial and transport quality H_2 users with a H_2 purity requirement of 95 – 98%. The waste management sector is a primary target, marrying the need for decarbonising heavy industrial processes and goods vehicles with CSS' market experience and network. Target market customers have the following key characteristics:

1. 10,000 tonnes of waste production per year.
2. Typically have large fleets of HGV vehicles.
3. Are actively looking at ways to reduce emissions.
4. Heavy energy users, impacted by recent increases in energy and vehicle fuel costs and removal of red diesel.
5. Comfortable with environmental and vehicle permitting.

Analysis has shown that the diversion of 10,000 tonnes of waste can produce enough hydrogen with power equivalent to 1,100,000 litres of diesel. This is the equivalent of a direct saving of approx. £1.87M (based on £1.70 / L diesel) per annum. Major cities are also introducing low emission zones to encourage the heavy vehicles to reduce emissions. Vehicles must meet the emission standards or face penalty charges. This will have a major impact on the waste sector, and several companies are turning to full or hybrid H_2 vehicles to meet emissions standards.

Having ASH site as showcase demonstrator, will enable CSS to showcase the industrial fuel switch and H_2 technologies. For industrial use the market is at a much earlier stage than use of H_2 for transport. The IHA will showcase the technology for use with a Genset and in time for H_2 fuelled equipment.

8.4.4 Market

CSS has identified a significant market available for the technology and have developed a business plan which can bring the company forward. CSS predicts that from 2025 to 2030 approximately 50 MicroH2-Hubs will be sold, generating 30kg/h of H_2 per module. This will directly feed 1,173 MWh into the UK's H_2 economy by 2030. CSS aims to license the plant design from 2028 onwards to allow large-scale rollout.

9 Conclusions

As outlined in section 3.2 the project set out to achieve objectives to prove feasibility of the end-to-end project. Reviewing those objectives:

Prove Gasification Feasibility Utilising RDF

In trials within this project CSS has been able to demonstrate the reliable production of H_2 at a flowrate of ca. 5 kg/h with >90% H_2 purity (%vol in product gas stream) when at a severely restricted operational window (i.e., low pressure and low syngas flowrate), and whilst operating on an RDF feed. This objective is considered a success by ASH.

Prove Feedstock Availability to Produce High Purity Hydrogen

This Stream 2A project has not completed a comprehensive report for feedstock availability in the UK. However, in the absence of full reporting within this study ASH has completed analysis of the waste stocks available companywide in its assessment of whether it is feasible to operate a gasification on the Redwither site.

ASH has identified there is an annual available 63,200 tonnes of suitable wastes that can be processed through the RDF processing line to produce a similar amount of briquetted RDF for the use of the gasification plant to generate H_2. In this respect whilst this has not been formally reported on during the process, this objective is considered a success by ASH.

Project Plan Development

This report has outlined the costing, timeframes, and engineering design required to take this IHA project forward into a Stream 2B demonstrator. On this basis the objective is considered a success by ASH.

Industrial Switchover Report

ASH has completed a comprehensive report under the reporting work completed under this Stream 2A project. The report has detailed the equipment which has been targeted for a switch to run exclusively on H_2 power through an electrical powertrain supported by H_2 fuelled ICE generators. This has been included within this feasibility study report. This objective is considered a success by ASH.

Gasification Trials and H_2 Testing

Gasification trials were completed and a full assessment of the H_2 produced by the plant has been completed, with high purity H_2 at a high production rate being generated whilst disposing of difficult to treat waste. Whilst not possible to test the end-to-end system due to lack of equipment availability on the market, ASH has identified suppliers of ICE equipment that can operate with the H_2 produced by the CSS plant which will be available for use within 6 months of starting a Stream 2B project. This objective is considered a moderate success by ASH on the basis of the inability to physically test the H_2 equipment.

Feasibility Report

This report categorically fulfils the requirements under this objective and is therefore considered a success.

To conclude; ASH, CSS, and PEC have all contributed significant resources to research and develop a package of works that can cost-effectively be implemented to decarbonise a waste management depot, and this sets out a blueprint for the industry on how the UK can decarbonise decentralised industries with significant waste at their disposal. This project should be considered a success in proving the viability of such projects and is the steppingstone to allow ASH to fully decarbonise its operations.

This project aims to demonstrate it is technically and economically feasible to produce low carbon H_2 efficiently and reliably at MW-scale by utilising an RDF feedstock via gasification. The project further aims to assess the feasibility of converting industrial waste processing equipment to be capable of using the hydrogen produced by the gasifier to complete an end-to-end solution.

This study will consider compliance with regulations and subsidy schemes, identify available feedstock, infrastructure, route-to-market, and end-user demand providing confidence across the UK hydrogen value-chain from production to consumption.

10 References

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