Final Report

Hydrogen BECCS Innovation Programme: Phase 1

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Executive Summary

1.1 Overview

The Hydrogen BECCS Innovation Programme has been set up by the UK government's Department for Business, Energy and Industrial Strategy to support the development of technologies which will enable the commercialisation and deployment of Hydrogen BECCS at scale to achieve negative emission and hydrogen production targets as outlined in the UK's Sixth Carbon Budget covering greenhouse gas emissions for the period 2033-2037.

Wood understands the effects of carbon dioxide and other greenhouse gas emissions and the urgent need to transition to a low-carbon economy and has significant experience in the development of novel renewable energy sources.

Under the Hydrogen BECCS Innovation Programme, Wood will assess the feasibility of deploying Wood's innovative biohydrogen production technology at an industrial demonstrator site (Biohydrogen Demonstrator). The project will demonstrate that cost-effective, clean and carbon-free hydrogen can be produced and deployed as a decarbonised fuel for domestic or industrial use.

During Phase 1 of the Programme, Wood has developed a feasibility study which determines the preferred site and feedstock source, derives practical execution plans for the detailed design, construction and operation and sets out a test programme to illustrate the capability of the innovative technology for application and execution during Phase 2 of the Programme.

1.2 Next Steps

1.2.1 Phase 2

If successful in the Hydrogen BECCS Innovation Programme Phase 2 Wood will include the completion of the detailed design of the demonstrator unit before fabrication and testing. This phase will involve the construction, commissioning and testing of the demonstrator in which the operating conditions resulting from the Phase 1 feasibility study are to be validated in an industrial envelope.

1.2.2 Beyond Phase 2

Successful demonstration of the innovative technology will offer a new route to increase the availability and drive down the cost of low-carbon hydrogen to industry or infrastructure and will assist in enabling part of the UK Government's Ten Point Plan for a Green Industrial Revolution.

After the programme, Wood, its selected partners and the UK supply chain will be well placed to deliver distributed or centralised scale biohydrogen solutions offering carbon neutral or, with carbon sequestration, a carbon-negative hydrogen production.

2.0 INTRODUCTION

2.1 Project Overview

A feasibility study was conducted during phase 1 to detail the development, commissioning and testing of a Bio Biohydrogen Demonstrator that utilises Wood's established Steam Methane Reformer (SMR) technology but proposes the use of a renewable biogenic liquid feedstock.

2.2 Purpose

This report identifies the key information obtained from the overall feasibility study for the application of a biogenic liquid feedstock in place of a fossil fuel feedstock in a Steam Reformer process and the successful integration of carbon capture into the process.

This document records the basic data, key design information and feasibility study findings.

2.3 Scope

The scope of this feasibility study is to detail the information on the design, engineering, and construction through the delivery of documents that present the findings and conclusions for the operation of a Steam Reformer demonstrator plant with an integrated carbon capture module.

All deliverable documents were submitted to BEIS individually, but the overall conclusions and findings are detailed in relevant sections throughout the report.

3.0 BASIS OF DESIGN

3.1 Design Basis

Wood has a significant history in the development and construction design of novel technologies and has utilised experience from past projects to assist in the creation of a design for this demonstrator.

The basis of design included the development of the following:

1. Heat and Mass Balance
2. Process Flow Diagram
3. Electrical and Instrument
4. Equipment List
5. Business Development Plan

These allowed Wood to identify the parameters required to design the demonstrator and also informed the primary requirements for scale-up to allow for the commercialisation of the process.

[redacted]

- [redacted]
- [redacted]
- [redacted]

A selection process was undertaken to identify a suitable carbon capture technology and process that would integrate with the biohydrogen demonstrator.

3.2 Feedstock Selection

The two potential feedstocks identified for use in the biohydrogen process are bioethanol and glycerol, with bioethanol as the feedstock selected for the demonstrator. While glycerol has been identified as a cheaper alternative to bioethanol – glycerol is a by-product of biodiesel production - bioethanol is more commercially available to source and purchase in smaller quantities better suiting the 1000 hours of testing planned during phase 2.

3.3 Biohydrogen Export

While the export of biohydrogen to downstream market opportunities will play a critical role in the full-scale future commercialisation of the process, due to the small scale of the demonstrator, there is additional complexity to enable integration with any potential user of the biohydrogen. There is potential that the biohydrogen produced by the demonstrator is not usable.

Wood has assumed that the biohydrogen produced by the demonstrator will either be taken and used by the selected demonstrator site or, if no uses can be found, any excess hydrogen will be routed to the flare for safe disposal.

4.0 **Process Description**

4.1 Overview

During the initial design phase Process Flow Diagrams and Heat and Mass Balance calculations were produced to derive the design of the demonstrator and expected stream details. The steady state design values were calculated using Wood's proprietary reformer simulation software and verified with commercially available process modelling software.

From the simulation, a supply of [redacted] of bioethanol was calculated to be fed into the Gas Heated Reformer (GHR) to give a production rate of [redacted] of biohydrogen from the Pressure Swing Absorber (PSA).

The integrated carbon capture unit will take a portion of the flue gas to determine the effectiveness of carbon capture integration before returning the flue gas for emission to the atmosphere.

Please see Appendix 1 for Process Flow Diagram.

A Hazard Identification (HAZID) exercise was completed to consider any potential safety hazards in the developing design and to implement mitigations into the demonstrator design and layout.

A control and operating philosophy was developed using the details above to describe the demonstrator process operation.

4.2 Fuel Gas

The demonstrator requires a supply of natural gas as a primary fuel for the process heating. Treated tail gas from the Pressure Swing Absorber is used as a secondary fuel to reduce the requirement for natural gas.

4.3 Gas Heated Reformer

Within the Gas Heated Reformer, a mixture of ethanol and steam undergoes a steam-reforming reaction in the presence of a catalyst. Steam acts as an oxidizing medium to convert the hydrocarbons to a mixture of hydrogen and carbon dioxide. Carbon monoxide, residual methane and excess steam are present in the product stream.

Excess steam is used to suppress side reactions to prevent carbon formation. The overall reaction that leads to the production of gas containing H_2, CO, CO_2 and CH_4 is highly endothermic (requiring heat). The external heat is supplied to the Gas Heated Reformer by the combustion of natural gas along with PSA tail gases generated within the demonstrator unit.

4.4 High-Temperature Shift Reactor

The reaction mixture from the Gas Heated Reformer is cooled to a temperature suitable for a High-Temperature Shift reaction. The reaction occurs in the presence of primarily a Chrome-iron catalyst, to enhance the yield of hydrogen. The reaction mixture from the HT Shift reactor is cooled further in the HT Shift Waste Heat Exchanger.

4.5 Air Cooled Heat Exchanger

Demineralised water from the battery limit serves two coolers well as the Shift WHE. The water streams from these coolers and the Shift Waste Heat Exchanger (WHE) are cooled by a final exchanger before being sent to the expansion tank.

4.6 Expansion Tank

Circulating cooling water along is passed to the expansion tank to allow any water vapour to be vented into the atmosphere.

4.7 Process Condensate Separator

Process fluid is quenched using demineralised water to condense steam from the reaction mixture, before being admitted to the Process Condensate Separator.

4.8 Pressure Swing Adsorber

A PSA is a separation unit bought as a complete package, in which non-hydrogen components are adsorbed into an adsorbent bed, whilst hydrogen can pass through. After a certain time, the process is switched to another second parallel bed, and the first (now offline) bed is depressurised to release the components as PSA tail gas.

After purification, the main product hydrogen has a purity of up to 99.9% and is exported to the end users at the battery limit.

The by-product from the PSA unit, known as PSA tail gas, has a high calorific value with a composition of carbon monoxide, methane and a small amount of hydrogen. The PSA tail gas is sent to the Gas Heated Reformer as fuel.

4.9 Carbon Capture Unit

Based on Wood's technology assessment, a C-Capture Carbon Capture Solvent Compatibility Unit (CCSCU) has been selected for integration into the Bio-Hydrogen Demonstrator. The selected skid has been developed under another BEIS programme and is owned by C-Capture. It is a scaled-down and simplified package that will simulate the conditions of a full-scale carbon capture plant.

A Carbon Capture integration document was prepared and submitted to BEIS to detail the unit dimensions for installation and utility tie-ins required for successful integration as a separate skid with the demonstrator. The skid is self-contained and operated independently of the main demonstrator.

4.10 Utilities

A utility summary was completed to identify the requirements of the demonstrator. This allowed for the proposed sites to be contacted for feedback on the availability of utilities and for Wood to source and cost both the rental of equipment and purchase of specific utilities that sites were unable to provide.

4.10.1 Power

The demonstrator will require a [redacted], 63A, 3-phase supply of electrical power to operate the [redacted] demand of the equipment.

4.10.2 Cooling and Process Water

Demineralised water will be provided via an external water treatment package.

Water is primarily used to cool the generated syngas in two primary coolers after passing through the GHR as well as process water.

4.10.3 Instrument Air

Instrument air will be supplied from an air compressor package designed to meet the total air requirements of the demonstrator.

In future phases, consideration should also be given to the use of electrically powered instruments in the demonstrator to remove the requirement for instrument air.

4.10.4 Steam

The steam requirement for the demonstrator will be met by an external boiler package. Steam is primarily used to heat the ethanol.

At a larger scale, there is potential for the integration of waste heat recovery to meet steam demand. Waste heat recovery would utilise the heat from the gas-heated reformer flue gas to provide the heat necessary for steam generation.

4.11 Process Conclusions

The following conclusions have been made as a result of the process design completed during the feasibility study:

1. The demonstrator is determined to be technically feasible.
2. The PSA and Shift reactors are tried and tested technology that is easily modelled based on Woods's prior experience. The requirement to include PSA and Shift reactors for the phase 2 demonstration should be considered as a method to simplify the testing and reduce the phase 2 demonstration costs.

5.0 Testing Plan

Effective testing of the technologies during a demonstration in Phase 2 will provide assurance for further development of the innovations and validate or update key design assumptions.

A testing plan was developed to detail the expected criteria for a successful test of the demonstrator.

5.1 Features to Test

The primary features of the test will be as follows:

1. To illustrate the application of a biogenic liquid (ethanol) as a renewable feedstock to produce biohydrogen in a novel steam methane reformer equipment.
2. To illustrate the integration of Carbon Capture with the novel steam methane reformer equipment.

5.2 Test Criteria and Operating Parameters

The criteria identified to demonstrate the success of the Bio Biohydrogen Demonstrator are as follows:

1. Achieve 1,000 hours runtime (with a small margin for an extension if required)
2. Achieve steady state reformer performance
3. Achieve steady-state carbon capture performance

Meeting these criteria while operating within the boundaries set here below should indicate that the process has successfully demonstrated the production of biohydrogen from bioethanol and the integration of carbon capture into the process.

The key target operating parameters for the Biohydrogen Demonstrator are as follows:

1. Quantity of biohydrogen Production: [redacted]
2. Carbon Capture effeteness: [redacted]
3. Reformer Process Duty: [redacted]

Carbon Capture effectiveness will be derived via the Carbon Capture unit's own instruments.

The following deliverables will be produced following the testing based on the obtained data:

- Test methodology
- Test data and key parameter logs
- Test results/reports
- Defect report – if any
- Lessons learned

Upon completion of testing in Phase 2 the data gathered should be used to complete a revised Heat and Mass Balance calculation as well as confirm that the data acquired meets the expected criteria set out in the feasibility study.

6.0 **Carbon Lifecycle Analysis**

To achieve its commitment to a low-carbon future, Wood will focus on global efficiencies including minimum standards to reduce carbon intensity from its sites, equipment and vehicle use, the increased utilisation of renewable energy sources and sustainable site procurement policies.

A CO_2 lifecycle analysis was completed to predict the expected emissions within the primary process block which includes the GHR, the Gas Shift and the PSA and a feedstock of ethanol.

It has been assumed that any carbon within a biogenic liquid feedstock, bioethanol or glycerol, would have been fixed during the growth of the crop, therefore when the reforming process takes place any CO_2 generated through the production of the hydrogen or combustion of the PSA tail gas will not be included in the overall CO_2 emissions.

The analysis identified that the Wood biohydrogen reformer offers a significant carbon intensity improvement over the incumbent hydrocarbon SMR even at the demonstrator scale is not wholly representative of the full capability of biohydrogen reforming can achieve due to the scale of the equipment, for example, limit the ability to effectively recover Waste Heat and reduce emissions related to steam creation.

Please see Appendix 6 for further detail on a lifecycle comparison for feedstocks.

Due to the uncertainty of the upstream and downstream lifecycle of the feed and product from the demonstrator Wood has identified the following areas for the development of the lifecycle emissions analysis:

1. Upstream
    a. Identification of biogenic liquid source from biomass
    b. Identification of direct and indirect land use change emissions.
    c. Identification of transport routes and methods
2. Downstream
    a. The method of transportation to the downstream market
    b. The method required to prepare biohydrogen for transport is either pressurisation or refrigeration.

Improvements to the overall carbon emissions that can be made are as follows:

1. Reduce transport emissions during upstream and downstream transit
2. Ensure at full-scale sufficient heat recovery is implemented

A revision of the CO_2 lifecycle analysis will be completed during phase 2. This will allow accurate reporting of emissions and Wood to understand the full extent of sustainability across the value chain of the process.

7.0 **Site Location**

During Phase 1, four potential sites have been identified to host the Biohydrogen Demonstrator. The potential sites, indicated in Appendix 5, are:

- [redacted] Scotland
- [redacted] Scotland
- [redacted] England
- [redacted] England

The benefits and detriments of each of these sites will be considered further before a site selection is finalised early in 2023.

7.1.1 [redacted], Scotland

This site is located on the coast at [redacted] in Scotland and is the current home of the [redacted].

The site has good road access but there are concerns over a lack of sufficient security at the site.

The site could also provide the necessary utilities of power, steam and water.

7.1.2 [redacted], Scotland

This site is located in central Scotland in a small town with very good road access both to the site and potential downstream market options such as the Grangemouth Refinery.

The site is clear and ready to use and is located within an industrial estate. There is good security for the site with a substantial fence and CCTV in operation. The site can provide power although steam and water supply would need to be sourced.

7.1.3 [redacted], England

This site is located in rural northern England and is the current home of the [redacted] with good road access but poor proximity to any other locations. There is excellent security due to the nature of the site.

There is good infrastructure with power, steam and water all available.

7.1.4 [redacted], England

The [redacted] site is located in a [redacted] and [redacted] with excellent road and rail connections. The security at the site is suitable and [redacted] can offer accommodation and offices for test resources.

There are already many similar demonstrator projects found at the location and there are utilities such as power water and steam available. [redacted]

8.0 Layout

To accurately create the layout plan for the demonstrator an equipment list was assembled from both previous projects' experience as well as with knowledge of Wood's novel SMR technology. This allowed the development of layout options and improvement through reviews and optimisation.

Please see Appendix 6 for a detailed demonstrator layout plan.

A conservative layout of the demonstrator equipment has taken into consideration the following:

- Minimising distance between skids to minimise energy losses during the process while still allowing for a minimum safe distance between high-risk portions of the demonstrator.
- Ensuring that whichever site is selected that the demonstrator can fit onto the plot provided and that if no partner is identified that the demonstrator will fit on a variety of sites.
- The proposed size of the site required to fit the demonstrator is 29m x 37m as illustrated in Appendix 6. With these layouts, potential host sites were approached to see if the proposed layout was feasible for the available plot.

9.0 Capital Cost

The section below details the capital expenditure expected to be used for the initial construction and commissioning of the demonstrator plant.

9.1 CAPEX Summary

The summary of the total capital expenditure expected for the demonstrator project can be found in the table below. All costs are quoted in GBP. Further detailed breakdown of Capital Costs can be found in Appendix 2.

9.2 Capital Cost Estimate Basis

9.2.1 Estimate Date, Currency and Location

The estimate is performed on a contemporaneous basis of 4Q 2022, no allowance has been made for forward escalation. The estimate assumes a test location as the UK and all costs are given in GBP.

9.3 CAPEX Exclusions

The following costs have been specifically excluded from the estimate:

- Site Preparation and Demolition of existing structures – assumed that the site will be available and free of any obstructions preventing the location of the demonstrator.
- Cost of Site – assumed to be nil
- Bonds, Insurances Taxes and Duties
- Forward Escalation
- Previously expended development works such as Pre-FEED / FEED Costs

10.0 Operating Costs

This section details the operating costs expected for the commissioning, start-up and resources used to complete the 1000 hours of testing of the demonstrator. Further breakdowns of Operation Oosts can be found in Appendix 2.

10.1 OPEX Summary

10.1.1 Operating Cost Estimate Basis

Operating and Maintenance costs are generally allocated as fixed and variable costs.

Fixed costs are made up of the following categories:

- Direct labour

- Administrative and general overheads

Variable costs assessed for this study are:

- Fuels and feedstocks
- Catalyst and Chemical Consumption
- Temporary Equipment Costs
- Utility Costs

10.2 OPEX Exclusions

There is a selection of exclusions from the OPEX which are as follows:

- Hydrogen export costs which are outside of the boundary of the demonstrator
- Security, Land Rent and Land Clearance as these are all site-based costs
- Cranage cost is not included as Wood has selected a Hiab to lift skids into place

11.0 Total Costs

11.1 Overview

Description	Cost (£)
CAPEX Total	3,327,890
OPEX Total	1,560,098
Summary	**4,887,988**

The total cost calculation is based on predictions made using 2022 values and the estimate does not include a contingency. Note that due to the instability in market conditions these values should be re-evaluated during phase 2.

Wood recognises that there is a programme price cap set of £5m set by BEIS. Based on the outcome of the CAPEX and OPEX studies of £4.85m, Wood has identified that there is only a margin of error value of 3%. Given the exclusions and the level of accuracy of the estimate carried out a 3% margin is not sufficient and has been identified as a significant risk.

As mitigation, Wood proposes the following:

1. To ensure an accurate total cost assumption the demonstrator site needs to be confirmed
2. To reduce the scope of the demonstrator equipment and produce syngas only.
    a. Testing of the PSA and Shift reactions to be modelled as they are proven technology.

11.2 Levelized Cost of Hydrogen

There has been no change from the initial LCOH calculations completed for the initial proposal provided to BEIS, but these should be completed in line with any significant market updates during phase 2. Please see Appendix 2 for a further breakdown of LCOH cost calculations.

12.0 Schedule

An implementation schedule for the development and deployment of the Biohydrogen Demonstrator was developed through a combination of Wood's experience on previous projects and consultation with supply chain manufacturers. The schedule overview is provided in Appendix 3.

The proposed schedule for the development, commissioning and testing of the demonstrator shows the timeframe provided by BEIS, with project completion and full submissions by Q1 2025 as set out by BEIS.

The proposed schedule is highly dependent on the assumption that the Grant Offer Letter is completed in Q1 2023. Should this milestone not be met, there is potential for knock-on delay to the delivery date due to long lead equipment design and time scale for fabrication.

Wood recognises that the schedule includes limited float. Refer also to the risk register in Appendix 4 , which captures several schedule-related risks and suggested mitigating actions.

The potential cost mitigations highlighted in Section 11 would also help to mitigate the schedule risk.

13.0 **Risk Management**

The development of a demonstrator inherently brings some risks due to the nature of technology that has only been laboratory tested, as well as more common project risks around the timing of key decisions, availability and pricing of sites, services, materials and labour. These risks can be categorised into financial, technical, environmental and commercial aspects. Primary risks were detailed in a risk register which can be found in Appendix 4, effects of the risk were identified, and potential mitigations were put in place to lower the risk potential of these events.

The most significant risks to the project have been detailed below:

1. All host sites are unavailable for use
2. Long lead items delaying construction and commissioning schedule
3. Project CAPEX and OPEX costs exceed expected values
4. Novel technology fails to work as expected or meet expectations/criteria
5. Viability of future large-scale projects in the absence of business models to support biohydrogen and CCS and transport and storage infrastructure

14.0 **Future Development**

Wood has identified hydrogen as a key enabler for energy transition and achieving a net-zero future. As Wood continues to expand its hydrogen expertise and value propositions through Making it, Moving it and Using it, we will continue to provide valuable hydrogen solutions to our clients.

Wood completed an initial target market study and a business development plan during phase 1 that has allowed Wood to identify opportunities in the market for future development of the technology and the infrastructure required for distribution.

14.1 End Uses

The market for biohydrogen is substantial and has the opportunity for integration in many downstream sectors including:

14.1.1 Decarbonising Gas Networks

Consultation between industry stakeholders and gas network operators is widely underway to identify regional opportunities for gas network decarbonisation through the introduction of a hydrogen blend. Gas network operators are also progressing with the development of demonstrator villages, which will be fuelled by renewable hydrogen providing a potential route for biohydrogen.

14.1.2 Mining and Minerals Extraction

There is a strong drive to decarbonise mining operations globally. Hydrogen can play a key role – being used to store electricity generated by renewables, and to power equipment and vehicles. Increasing focus on the integration of renewables, mines are generally in solar-intense and high-wind regions.

14.1.3 Heat and Power Production

The use of hydrogen blends in existing gas turbine fleets is feasible to an extent, but the availability of "clean hydrogen" to drive decarbonisation is currently low. Turbines capable of utilising 100% hydrogen or ammonia fuels are still in the development stage which may limit the deployment of hydrogen in heat and power production in the short term.

14.1.4 Biorefining

Heavy trucking and large-scale aviation requirements are hard to abate. Renewable diesel and sustainable aviation fuel (SAF) are premium products with a proven low-risk implementation that fit the immediate need. These products also offer opportunities to decarbonize in support of Environmental Safety Governance (ESG) efforts. Robust policy support is already in place through low-carbon fuel standards making the production of such products profitable today.

14.1.5 Transportation Fuels

Hydrogen remains a small component of the vehicle fuel mix but is gaining prominence and is likely to grow significantly in the next 10 years as fleets look to decarbonise. Hydrogen is already cost-competitive with diesel and petrol in certain transport applications (e.g., heavy goods vehicles and buses).

14.2 Location

The selected site of the demonstrator is unlikely to be the final location of any commercial deployment of the technology. When the process reaches an appropriate level for deployment several factors need to be considered:

1. Proximity to feedstocks for biohydrogen production
2. Proximity to downstream users of produced biohydrogen
3. Available transport links where proximity to facilities is not available
4. Proximity to export route for CO_2 where not stored or used on site

Further assessment is required to identify the most effective scenario before the deployment of the technology.

14.3 Export

While the goal of the BEIS BECCS Biohydrogen Project is to focus on UK supply and demand there is potential to export the biohydrogen to major consumers such as the United States, China and the Middle East.

The momentum behind hydrogen supply continues to be strong. It has been recognised as a key option to realise the net zero greenhouse gas emission commitments that Governments have announced in recent years. The industry is investing in large-scale projects to produce green hydrogen from water electrolysis or blue hydrogen from fossil fuels with CCUS.

14.4 Deployment Infrastructure

While achieving commercialization is the primary goal of the biohydrogen production process, it is important to factor in the infrastructure, supply and demand for biohydrogen.

The difference between large-scale production and smaller distribution centres is a major factor. Key challenges to hydrogen delivery at commercial scales include reducing cost, increasing energy efficiency, maintaining hydrogen purity, and minimizing hydrogen leakage.

Building a national hydrogen delivery infrastructure is also a big challenge and represents a major risk to any new hydrogen production project. It will take time to develop and will likely include combinations of various hydrogen production technologies. Delivery infrastructure needs and resources will vary by region and type of market - for example, urban, interstate, or rural. Infrastructure options will also evolve as the demand for hydrogen grows and as delivery technologies develop and improve.

15.0 Dissemination of Results

Where the demonstrator is proven to be successful, and progress is made to reach Technology Readiness Level 7 the dissemination of appropriate information and data will commence. There will be limitations to the level of detail included in the disseminated data due to the demonstrator being a proprietary piece of Wood equipment.

Dissemination mediums will include Wood's attendance at appropriate conferences, the publishing of articles detailing the findings and finally through Wood's network of digital feeds and internal articles.

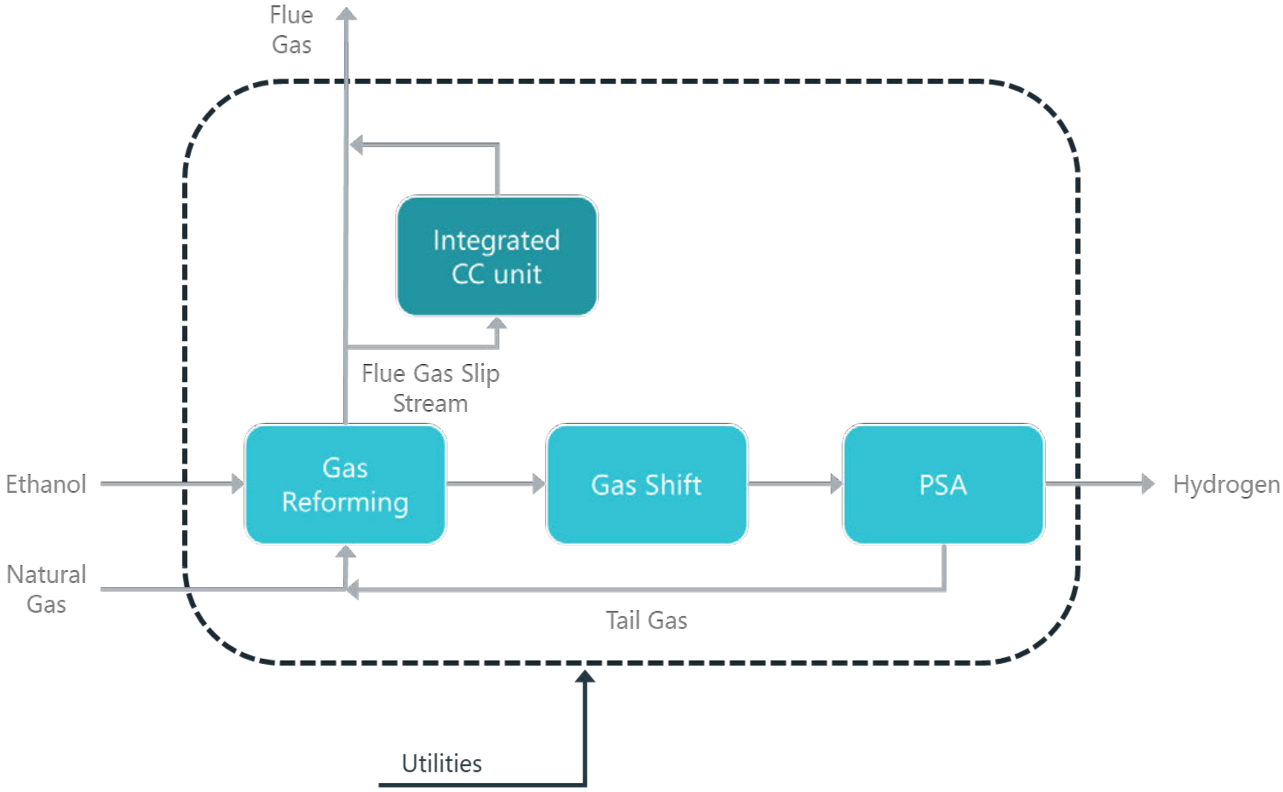
16.0 Conclusion

Over the course of Phase 1 of the BEIS Hydrogen BECCS Innovation Programme, Wood has developed the following key conclusions:

1. The Biohydrogen Demonstrator has been determined to be technically feasible.
2. Bioethanol is an effective good and commercially available feedstock, but Glycerol offers significant future opportunities for further carbon lifecycle reduction.

3. The carbon intensity of biohydrogen SMR technology has significant advantages over the incumbent hydrocarbon SMR technology. However, the carbon intensity of the demonstrator is not wholly representative of what the commercial biohydrogen reformer can achieve due to practical limitations at the small scale of the equipment.
4. The proposed size of the site required to fit the demonstrator is 29m x 37m
5. 4 potential host sites have been identified and the site selection process will be completed early in 2023.
    a. Due to the high temperature and pressure hazards of the process, it is challenging to easily arrange a suitable test site.
    b. The phase 2 feasibility is dependent on the selection of the site
    c. Suitable sites with the availability of utilities have a significant impact on cost.
6. The overall cost (CAPEX + OPEX) of the Biohydrogen Demonstrator is within the BEIS programme price cap of £5m. However, given the exclusions and the level of accuracy of the estimate, the margin is not sufficient to ensure the costs are achievable within the cost cap. As mitigation, Wood proposes to confirm the host site and associated utilities costs in Q1 2023, and to reduce the scope of the demonstrator equipment and produce Syngas only, avoiding the installation of shift and PSA equipment that are already proven.
7. The schedule for deployment of the Biohydrogen Demonstrator with project completion by Q1 2025 as detailed in Appendix 3 can be achieved, subject to the Grant Offer Letter being completed in Q1 2023 but has very little float.

Appendix 1 - Process Block Diagram



Appendix 2 – CAPEX and OPEX Overview

The section below details the capital expenditure expected to be used for the initial construction and commissioning of the demonstrator plant.

Table 1 Capital Cost Summary

Description	Cost (£)
Engineering - BEIS Permissible Costs	[redacted]
Travel & Living for Engineering Resources	[redacted]
Reporting & Close	[redacted]
Equipment Purchase	[redacted]
Materials	[redacted]
Fabrication	[redacted]
Transport	[redacted]
Installation	[redacted]
Installation Resources	[redacted]
Travel & Living for Installation Resources	[redacted]
Summary	**3,327,890**

16.1 Direct Costs

16.1.1 Equipment Costs

Equipment costs were obtained from either a suitable manufacturer or Wood's estimating database of previous projects. Proprietary item costs specific to the Carbon Capture Unit have been provided by C-Capture.

16.2 Labour Costs

16.2.1 Bulk Materials

The estimate for the bulk materials has been factored in based on the pricing of project equipment with the application of Total Installed Cost (TIC) factors.

These TIC factors are derived from statistical data from relevant projects and are adjusted to suit the location, market conditions and local working conditions/productivities for the proposed project site. The TIC factors include all bulk materials and construction associated with the equipment item to which they are applied, such as:

- Piping
- Electrical
- Instrumentation
- Steelwork

No civil or foundations were considered as the demonstrator will be placed on flat ground.

16.2.2 Installation, Pre-Commissioning & Commissioning Labour Support

An allowance has been made to cover the direct (trade) labour required for Installation, Pre-Commissioning and Commissioning. Wood will source and mobilise labour from its in-house resources. Labour costs are based on Wood's cost rates.

16.3 Indirect Costs

16.3.1 Vendors Engineers

An allowance has been made for Vendor Supervision at the site based on an average daily rate of [redacted] by a small number of critical vendors.

16.3.2 Home Office Engineering

The estimate covers the cost of the provision of a typical detailed design, procurement, HO construction and Project Management Services. The manhours have been generated from an equipment count and the number of hours per piece of equipment multiplied by a typical 'all-in' Engineering rate.

The estimate recognises a requirement for Construction Management Although this is reflective of the modularised approach that minimises site activities to installation and hook up.

16.3.3 Commissioning

The estimate recognises a requirement for Commissioning although this is reflective of the simplicity of the demonstrator.

16.4 CAPEX Exclusions

The following costs have been specifically excluded from the estimate:

- Site Preparation and Demolition of existing structures – assumed that the site will be available and free of any obstructions preventing the location of the demonstrator.
- Cost of Site – assumed to be nil
- Bonds, Insurances Taxes and Duties
- Forward Escalation
- Previously expended development works such as Pre-FEED / FEED Costs

17.0 Operating Costs

This section details the operating costs expected for the commissioning, start-up and resources used to complete the 1000 hours of testing of the demonstrator.

Table 2. Operating Cost Summary

Description	Cost (£)
Land/Prelims	[redacted]
Utilities	[redacted]
Hydrogen / CO2 Export*	[redacted]
First Fill	[redacted]
Operating Resource	[redacted]
Travel & Living for Operating Resources	[redacted]
Sampling	[redacted]
Equipment Rental	[redacted]
Decommission and Demobilisation	[redacted]
Decommission Resources	[redacted]
Travel & Living for Decommission Resources	[redacted]
Summary	**1,560,098**

*The export of hydrogen / CO2 has not been included in the cost estimate as it is assumed the selected site will utilise the product as part of the agreement for use of their site. Where the product is combusted, this will also be a zero cost.

17.1.1 Fixed Operating Costs

17.1.1.1 Direct Labour

The direct labour to support the development of the demonstrator is sourced and mobilised by Wood and is based on Wood's rates. It is assumed that no additional 3rd party staff will be required.

17.1.1.2 Administration, General Overheads, Insurance and Local Taxes

These costs include all other Wood services not directly involved in the operation of the demonstrator, such as Management, Personnel Services and Clerical staff. These costs are based on Wood's labour cost rates.

17.1.2 Variable Operating Costs

17.1.2.1 Fuels and Feedstocks

The variability of the overall energy market means that the cost of both fuel and feedstocks is in constant flux.

While fuel represents a significant cost this is exacerbated by current high energy costs. The total gas requirements for the demonstrator plant are estimated to be [redacted] over the 1000 hours. The cost of gas is based on 2022 Q4 costs of [redacted] per therm.

Costs for ethanol were obtained from a UK-based supplier for bulk delivered first generation industrial ethanol to ensure availability.

17.1.2.2 Catalyst and Chemical Consumption

Catalysts are required for the demonstrator. Costs were obtained from either a suitable manufacturer or Wood's estimating database of previous projects.

17.1.2.3 Utilities

As the site selection has not been finalised, the availability of necessary utilities is unknown.

As a mitigation, the hire of equipment required to supply all necessary demonstrator utilities has been included in the operating cost estimate. Costs were obtained from either a suitable manufacturer or Wood's estimating database of previous projects. This value may change if the selected site can supply the necessary utilities without the need for additional equipment.

17.1.2.4 Power Consumption

The total power requirements for the demonstrator plant are estimated to be [redacted]

An electricity price based on 2022 Q4 of [redacted] per MWhr has been considered for the estimate.

17.2 OPEX Exclusions

There is a selection of exclusions from the OPEX which are as follows:

- Hydrogen export costs which are outside of the boundary of the demonstrator
- Security, Land Rent and Land Clearance as these are all site-based costs
- Cranage cost is not included as Wood has selected a Hiab to lift skids into place

17.3 Levelized Cost of Hydrogen

Wood has several iterations of the BEIS BECCs programme format for Levelized Cost of Hydrogen (LCOH) calculations to compare its proposition to the other technologies available. Three LCOH calculation case studies have been developed for Wood's proposed 5-year [redacted] biohydrogen technology, however, given the intent of the Hydrogen BECCS Innovation Programme the Wood baseline position is based on the following case:

1. Integration of biohydrogen production with precombustion carbon capture (carbon negative process) without incentives for the carbon exported.

The other two cases were as follows:

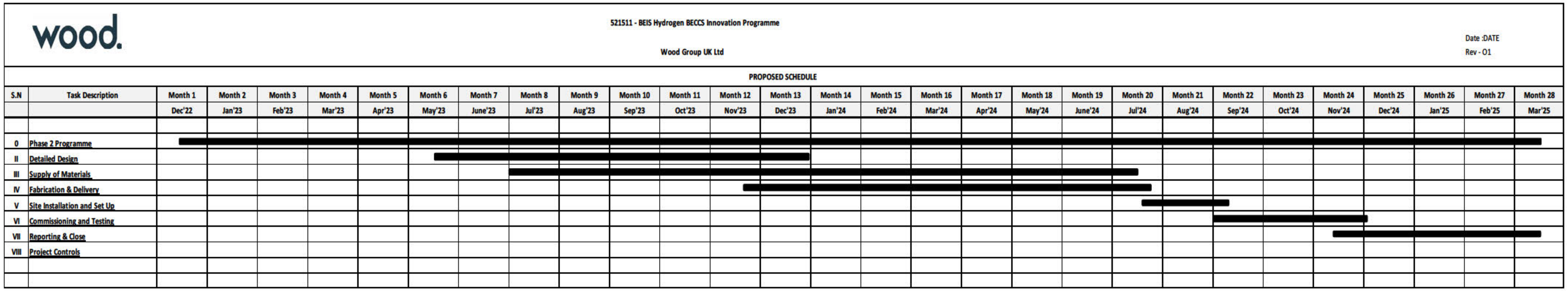
1. Biohydrogen production without carbon capture (carbon neutral process)
2. Integration of precombustion carbon capture (carbon negative process) and foreseen incentives for carbon sequestrated

The installation of the carbon capture positively impacts the variable OPEX with a lower feedstock consumption, thereby reducing the largest variable OPEX contributor to the LCOH. By not considering the CO_2 costs the LCOH would decrease from [redacted]

[redacted]

The biohydrogen project will accelerate the development of low-carbon and carbon-negative hydrogen by reducing cost in terms of capital investment for the system installation compared to the current state-of-the-art solutions. There has been no change from the initial LCOH calculations completed for the initial proposal provided to BEIS, but these should be completed in line with any significant market updates during phase 2.

Appendix 3 - Implementation Schedule



Appendix 4 - Preliminary Risk Register

Risk identification						Risk assessment				Mitigation & Action			Risk assessment after mitigation			
Risk #	Type (Technical, Commercial, Environmental)	Work package	Date Logged	Description of Risk	Potential impact	Likelihood	Impact	Current risk rating	Change since previous update and reason for change	Mitigation to date	Risk owner	Date to Close	Likelihood	Impact	Current risk rating	Change since previous update and reason for change
1	Technical		Dec-22	Engineering time and managerial oversight is needed for conflicting projects - especially high priority DoT work	Other projects could require resources and therefore delay progress	Possible	Significant	High		New staff will be employed, project resources will be well planned in advance Contracting out manufacturing activities	MN	Dec-23	Unlikely	Significant	Medium	
2	Technical		Dec-22	Employee absence, especially due to sickness	Delay in decision making and breakdown of communication Project suffers delays	Possible	Significant	High		All team members will have a person they can delegate work to in their absence. During reviews/meetings notes will be taken of issues that the absent member should be aware of and any decisions delayed until they are back. Project manager is also responsible for delegating a stand in if they are absent	MN	Dec-23	Possible	Moderate	Medium	
3	Technical		Dec-22	Loss of key staff	Delay in decision making and breakdown of communication Project suffers delays	Unlikely	Significant	Medium		All team members will have a person to whom work can be reassigned	MN	Dec-23	Unlikely	Minor	Low	
4	Technical		Dec-22	Long lead items delaying construction of deomonstrator skids	Delay in timeline	Possible	Significant	High		Long lead items will be identified in design and pre-ordered before the bulk procurement is done. C-Capture will work with chosen fabricator and host sites to ensure their long-lead items are also ordered in advance	MN	Dec-23	Unlikely	Significant	Medium	
5	Technical		Dec-22	Novel technology does not work as expected	Impacts the outcome of the project	Unlikely	Severe	High		Experience used to feed into the design and operation to de-risk.	MN	Dec-23	Negligible	Significant	Medium	
6	Technical		Dec-22	C-Capture Solvent does not work as expected	Impacts the outcome of the project	Unlikely	Severe	High		Experience used to feed into the design and operation to de-risk.	MN	Dec-23	Negligible	Significant	Medium	
7	Technical		Dec-22	Unit takes longer than expected to build and commission	Late delivery of units to host sites extends data collection with potential impact into Call2 scope	Unlikely	Severe	High		Working closely with fabricator, regular meetings, engineers spending time overseeing build	MN	Dec-23	Negligible	Significant	Medium	
8	Commercial		Dec-22	Other decarbonisation routes prove more attractive for the market sectors	Slowed commercial uptake post-project.	Possible	Significant	High		Success of other decarbonisation routes do not preclude Wood from gaining market share.	MN	Dec-23	Possible	Moderate	Medium	
9	Environmental		Dec-22	Solvent spillage on site	Release of solvent into surrounding environment	Possible	Significant	High		Safe handling of solvent and spill trays	MN	Dec-23	Unlikely	Moderate	Low	
10	Commercial		Dec-22	Host site not avaliable	Requirment to purchase land for cosntruction, potential for project to be overbudget	Unlikely	Significant	Medium		The model of deploying small units as a precursor to large scale projects, to assess solvent compatibility and understand the project in more detail before committing to very large, expensive infrastrucure projects, is well established, and used by many of our competitors. We have a huge amount of interest in our technology, which offers significant enough performance advantages to be considered disruptive, and provide an attarctive alterntative to industry.	MN	Dec-23	Unlikely	Moderate	Low	
11	Financial		Dec-22	Project CAPEX and OPEX costs exceed expected values	Impact on cash flow projections for the project	Unlikely	Significant	Medium		Full costing carried out as part of the aplication process.	MN	Dec-23	Unlikely	Moderate	Low	
12	Commercial		Dec-22	Viability of future large scale projects in the absence of business models to suport CCS and transport and storage infrastructure	Future large scale projects do not move forward quickly	Possible	Significant	High		BEIS are developing the business models to support CCS and CO2 offtake options will be reviewed as part of the feasibility study	MN	Dec-23	Unlikely	Significant	Medium	
13	Commercial		Dec-22	Crane cost not inclusive of more than one landing of the skids	Cost of extra cranage may exceed budget	Possible	Significant	High		Experience used to feed into the design and operation to de-risk.	MN	Dec-23	Unlikely	Significant	Medium	
14	Commercial		Dec-22	Local labour to be used, in the event labour must be regional or national	Cost of living and transport may exceed budget	Possible	Significant	High		Labour to be obtained in plenty of time to search and field replacements	MN	Dec-23	Unlikely	Significant	Medium	
15	Commercial		Dec-22	Cost of utilities and feedstocks increased due to cost of livinf crisis	Could cause the projec tto exceed already estimated fuel and power costs	Possible	Significant	High		Contingenices in the design that allow for reduced utiliites if required.	MN	Dec-23	Unlikely	Significant	Medium	

[redacted]

[redacted]

[redacted]

Appendix 7 Lifecycle Comparison

Lifecycle Comparison	
Incumbent Hydrocarbon Based Blue Hydrogen	11 – 15 tCO2e / tH2
Wood Steam Reforming Demonstrator 1st Generation Bioethanol	[redacted]
Novel Wood Steam Reforming of 1st Generation Bioethanol	Cumulative further reductions toward neutrality
Novel Wood Steam Reforming of 2nd Generation Bioethanol	
Novel Wood Steam Reforming of Glycerol	

Abbreviations

Abbreviations used in this document are listed below:

Abbreviation	Description
BECCS	Bioenergy with Carbon Capture and Storage
BEIS	Business, Energy and Industrial Strategy
CCS	Carbon Capture and Storage
CCU	Carbon Capture Unit
CO_2	Carbon Dioxide
E&I	Electrical and Instrument
GHR	Gas Heated Reformer
H_2	Hydrogen
H&MB	Heat and Mass Balance
HAZID	Hazard Identification
IPR	Intellectual Property Rights
LCOH	Levelized Cost of Hydrogen
PFD	Process Flow Diagram
PSA	Pressure Swing Absorber
SMR	Steam Methane Reforming
SR	Steam Reforming
TRL	Technology Readiness Level