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Hydrogen Supply Programme – Novel Renewable Ethanol Steam Reformer

Phase 1 Final Study Report

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Report for

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1 Executive Summary

In order to support the UK Government's commitment to achieve net zero carbon dioxide emissions by 2050, new forms of bulk-supply, low-carbon hydrogen will be required to minimise emissions from domestic heating, transportation and industrial supplies. The Hydrogen Supply Programme has dedicated £20m in the period 2018-2021 to support development of UK-led hydrogen technologies that will contribute towards the energy transition within the UK and provide opportunities for the export of goods and services.

Wood is a global expert in hydrogen production by catalytic reaction and has been a world-renowned Hydrogen Technology licensor and supplier of Steam Methane Reformers since 1960. We have designed over 120 hydrogen plants for international clients with a capacity range from 8,000 Nm^3/h to 180,000 Nm^3/h in a single train. The total worldwide installed capacity of hydrogen plants designed by Wood exceeds 3.35 million Nm^3/h of product hydrogen.

Before the Hydrogen Supply Programme commenced, Wood had developed a flow sheet and process simulation for a hydrogen plant in which the traditional methane feed stream is replaced by liquid hydrocarbons derived from renewable sources. The scheme requires very little change from a Steam Methane Reformer, other than the addition of liquid storage and vaporisation equipment and a recycle of product hydrogen to upstream of the reformer. The main uncertainty in design is over the operating conditions of the reformer catalyst and, in particular, the need to avoid coking of the catalyst when processing longer-chain hydrocarbons. As part of Phase 1 of the Hydrogen Supply Programme, Wood was awarded Lot 2 funds to develop its Green Hydrogen concept further to feasibility level, developing an equipment list, plot plan, AACE Class IV capital cost estimate and economic model. The funds have also supported laboratory testing of conventional reformer catalysts for coking tendency at different operating conditions. This report summarises the results of the feasibility analysis.

Since Wood's Green Hydrogen design is an enhancement of our existing licensed technology, with a different reformer catalyst and modifications to operating conditions, the Technology Readiness Level (TRL) of the overall design can be rapidly brought up to TRL 7 (sub-scale demonstration, fully-functional prototype) through limited pilot-testing of the reformer with the new catalyst. Furthermore, the design can be readily retro-fitted to an existing Steam Methane Reformer to allow operators to improve their environmental performance in advance of carbon capture and storage clusters becoming operational.

As part of the feasibility assessment, the Wood Green Hydrogen concept has been compared against the counterfactual case provided by BEIS. This is conventional Steam Methane Reformer (SMR) designed for a capacity of 100,000 Nm^3/h, with post-combustion carbon capture on the reformer flue gas using a proprietary amine solvent. However, since the counterfactual is a fossil-fuel based configuration that benefits from a low-cost natural gas feed, whilst the Green Hydrogen plant has the potential to generate net-zero emissions (or net-negative emissions if combined with CCS), with additional value to the nation, this is not seen as the best comparison. Hence, Wood has also developed a cost-benefit analysis for the Green Hydrogen technology in comparison to electrolysis.

Based on economic assumptions taken from the 2018 IRENA report "Hydrogen from Renewable Power", an economic model of an electrolysis unit at the same 100,000 Nm^3/h scale has been developed (ignoring the fact that electrolysis schemes are not technically viable at this scale). The comparative results are shown in the table below.

Parameter description	Units	Electrolysis	Wood Green Scheme
Total OPEX (excl. Feed)	£M pa	32	8
Renewable Feedstock	£M pa	-	214
Total Project CAPEX	£M pa	400	80
Levelised Cost of Hydrogen	£/kNm^3	325	293

It should be noted that there is a high degree of uncertainty with respect to the renewable feedstock costs. Wood has assumed a mid-range UK price for bio-ethanol, since this data is readily available and applicable. However, as the energy transition continues, it seems likely that more sources of non-food or waste-based bio-fuels will become available on the market and this will drive prices down. The economics for the Green Hydrogen scheme are also likely to be more favourable in other countries with a well-developed bio-fuel infrastructure.

Wood has performed a market assessment for the use of hydrogen in the UK and globally. There are strong arguments for renewable biofuels to be reserved as a primary power source in transportation applications that cannot readily be electrified (e.g. aviation), although a market-driven strategy may struggle to enforce such an approach. However, early adopter organisations may seek the public relations benefits of converting to renewable feedstocks to generate hydrogen and public good will. The size of the addressable market is somewhat uncertain but there is a relatively straight-forward path to commercialisation and so Wood will be able to react quickly when the market opportunities arise.

In order to prove the Green Hydrogen concept, Wood intends to push ahead with development of a pilot plant facility and we have submitted an application to BEIS for funds to support the detailed design of a facility under Phase 2 of the Hydrogen Supply Programme. Once proven at pilot level, Wood intends to develop a standard Green Hydrogen offering for a smaller capacity that may be suitable for local authorities or transport hubs, seeking to lead the drive for net-zero emissions. Depending on the market, revamp opportunities for UK or overseas refineries may also be popular, since the degree of modification required for an existing Steam Methane reformer is small and the changes could be implemented in a regular plant turnaround.

Wood is confident that with funding support from the Hydrogen Supply Programme, coupled with its own internal resources, we can deliver a robust, cost-effective solution for net-zero or net-negative emission hydrogen, ready to address the market as it develops.

2 Abbreviations and Acronyms

AACE	American Association of Cost Estimators
ACCE	Aspen Capital Cost Estimator
BL	Battery Limit
BEIS	Department for Business, Energy & Industrial Strategy
BFD	Block Flow Diagram
BFW	Boiler Feed Water
CAPEX	Capital Expenditure
CCC	Committee for Climate Change
CCS	Carbon Capture & Storage
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Cr	Chromium
CuO	Copper Oxide
DOI	Department of Interior
E&I	Electrical & Instrumentation
EIA	Environmental Impact Assessment
EPC	Engineering, Procurement & Construction
EUR	Euro (€)
FCEVs	Fuel Cell Electric Vehicles
Fe	Iron
FEED	Front End Engineering Design
FID	Final Investment Decision
FOAK	First-of-a-kind
GBP	Great British Pound (Pounds Sterling)
H_2S	Hydrogen Sulphide
HHV	Higher Heating Value
HO	Home Office
HP	High Pressure
IEA	International Energy Agency
IHS	IHS Markit Ltd
IRENA	International Renewable Energy Agency
ITT	Invitation to Tender
LCOH	Levelised Cost of Hydrogen
LHV	Lower Heating Value
LP	Low Pressure
MCP	Multi-Cylinder Pack
MW_e	Megawatts Electrical

MW_{th}	Megawatts Thermal
Ni	Nickel
NOAK	nth-of-a-kind
NPSH	Net Positive Suction Head
NPV	Net Present Value
OPEX	Operational Expenditure
P&ID	Piping & Instrumentation Diagram
PFD	Process Flow Diagram
PSA	Pressure Swing Adsorption
R&D	Research & Development
RPI	Retail Price Index
S&T	Shell & Tube
SER	Steam Ethanol Reformer
SMR	Steam Methane Reformer
TEA	Techno-economic Assessment
TIC	Total Installed Cost
TRL	Technology Readiness Level
TWR^{TM}	Terrace Wall Reformer (Trade Mark)
UK	United Kingdom
USD	United States Dollar
ZnO	Zinc Oxide

3 Introduction

3.1 Hydrogen Supply Programme

In 2018, The UK Department for Business, Energy and Industrial Strategy (BEIS) launched the Hydrogen Supply Programme. This aims to identify and test novel approaches to supplying bulk low carbon hydrogen to the gas grid, industry, power, transport and / or import terminals, as part of the UK Government's drive towards achieving net zero carbon emissions by 2050. BEIS established a £20m fund for the Hydrogen Supply Programme in the period 2018-2021, to be spent in two phases.

Wood applied for and was awarded Phase 1 funding in each of the first two categories, developing low carbon versions of its successful hydrogen production technology, using our FW Terrace Wall™ Reformer. A full list of the successful applicants for Phase 1 funding may be found at https://www.contractsfinder.service.gov.uk/Notice/e07c3de7-a6a9-4ee8-bb3f-b76a9528fbd4 .

3.2 Wood History in the Supply of Hydrogen Technology

Wood is a global expert in hydrogen production by catalytic reaction as a worldwide recognised Hydrogen Technology licensor and Steam Reformer Heater supplier since 1960.

Our deep company experience in Fired Heaters resulted in the development of a specific design for Steam Reformer Heaters, named the Terrace Wall™ and branded using the historic 'Foster Wheeler' name. Due to its unique characteristics, the Terrace Wall™ design provides a number of advantages to hydrogen production in terms of performance, flexibility and reliability, bringing Wood technology to be very much appreciated all around the world. The Terrace Wall™ reformer accounts for 300 of the 2000 fired heaters that Wood has installed over the last 70 years.

Wood designed over 120 hydrogen plants for international Clients with a wide production capacity range (from 8,000 Nm^3/h to 180,000 Nm^3/h single train). The total worldwide installed capacity of hydrogen plants designed by Wood exceeds 3.35 million Nm^3/hr (~ 3 billion SCFD) of hydrogen.

These figures do not complete the long-established track record of Wood in supplying hydrogen technology. Wood has experienced recent success in the supply of very large modular designs. In this study, Wood presents the more recent and novel concept of advanced steam reforming that allows us to address a broader portion of the market, reaching more specific Clients' needs concerning revamp opportunities and minimisation of steam production for energy efficiency purposes.

3.3 The Novel Renewable Ethanol Steam Reformer Concept

The ever-increasing demand of low carbon economy is asking for competitive technologies able to avoid CO_2 emissions. The development of the technology that makes use of renewable energy resources is paying much attention to overcome the non-sustainable nature of current energy systems. Hydrogen is a highly efficient, storable, and transportable energy carrier that can be utilised in the heat market and for transportation purposes. Nowadays, nearly 95% of hydrogen is produced from fossil-based materials, of which steam reforming of methane is the most widely used and usually the most economical option. However, in this process, carbon is transformed into CO_2 and released to atmosphere. At the moment, the only viable way to avoid CO_2 emissions in hydrogen production is electrolysis. The same hydrogen production process can be tailored for syngas generation to ammonia, fertilisers, methanol and Gas-to-Liquid applications. For these large-scale applications, electrolysis is not considered as a viable option today.

Wood has started investigations to identify an appropriate fully renewable pathway to convert renewable ethanol into hydrogen by means of the steam reforming reaction. Ethanol Steam Reforming is one declination of the term "Green Hydrogen", which indicates a chemical pathway that converts a renewable material into hydrogen. The design and operation of the process itself does not present significant differences from hydrogen production from fossil sources. Indeed, it is based on modifications of the standard steam reforming process, which currently represents the most widely utilised option to produce hydrogen from non-renewable sources. Section 4.1.1 contains a detailed process description.

The main advantages of the Green Hydrogen coming from second generation bio-ethanol are detailed here below:

- The sustainability of the process in terms of the efficiency and feed and fuel consumption. Ethanol steam reforming does not require supplemental fuel gas consumption as in the traditional process scheme for which the fuel gas accounts for 15 - 20% of total firing for controllability purposes. The main fuel for the Steam Reformer Furnace is the tail gas from the PSA Unit, supplemented with syngas. This aspect will accelerate the development of bulk low carbon hydrogen.
- Independence from the electrical grid. Hydrogen production from ethanol steam reforming and associated costs are independent of the electricity cost.
- The system is proposed to be carbon neutral, but can become carbon negative if associated with a conventional capture scheme.
- Existing fossil-based SMRs can be easily converted to operate on renewable biofuels.

The wide capacity, virtually identical to that of a traditional steam reforming process, allows this process to access a broad market share, which at present has no realistic alternative for large-scale green hydrogen production.

3.4 Study Basis

The main requirement from BEIS is that the hydrogen production process operates at a bulk capacity of 100,000 Nm^3/h product hydrogen, to meet the needs of future low-carbon domestic heating, industrial processes and large-scale transportation. Thus, the focus is for industrial scale-production, rather than small-scale generation using electrolysis. The hydrogen is required to meet an industrial specification of 99.9 mol% purity at 20 barg and ambient temperature. The overall CO_2 capture rate needs to exceed 90% across the plant.

The feed stream for the SMR is a typical industrial ethanol produced from renewable non-food agricultural crops or residue.

The carbon dioxide product stream must be dehydrated, compressed to 30 barg and cooled to ambient temperature ready for export to a CO_2 collection system. Transportation and storage of the carbon dioxide is assumed to be conducted by others under a tariff arrangement.

4 Concept Definition

4.1 Process Engineering

4.1.1 Description of the Process

Refer to Block Flow Diagram 522037-8110-25-0001 for a diagrammatic flow scheme of the Green Hydrogen Production Unit.

The bioethanol passes through the feed S&T exchanger preheater, which vaporises the process stream using high pressure (HP) steam. A hydrogen recycle provides the feedstock for the downstream hydrogenation of sulphur containing compounds in the feed stream.

The preheated feed gas enters the sulphur adsorber column, where the gas passes through beds of catalyst-based adsorbent material to remove trace amounts of sulphur-based compounds in the gas stream. The removal of sulphur compounds is necessary to prevent the TWR™ catalyst from becoming poisoned and deactivated which would reduce the efficiency of the process and interfere with the temperature distribution across the reformer tubes.

The process stream is then further pre-heated by TWR™ flue gas, before entering the TWR™ reforming tubes. As the gas passes through the reformer tubes, methane is converted to hydrogen and carbon monoxide in an endothermic reaction. The reforming reaction is strongly endothermic and requires high process temperatures to favour the conversion of the feed to carbon monoxide and hydrogen.

The TWR™ is proprietary Wood technology, which features a high efficiency radiant section, providing a uniform heat flux to the single row catalyst tubes. The main fuel for the TWR™ is the tail gas from the PSA Unit.

The gas stream from the reformer is cooled in the reformer waste heat boiler, the syngas passes through the shift reactor catalyst, where the CO present in the syngas is 'shifted' to CO_2 through the water-gas shift reaction. The gas leaves the shift reactor and is cooled.

The vapour product from the cooling train is then sent to the PSA unit to separate out the product Hydrogen from the process gas. The Hydrogen is separated from the process gas by the PSA absorbent is the final product.

Although it has been demonstrated that the Wood Green hydrogen process is carbon neutral there exists the possibility to make it carbon negative and significantly reduce carbon emissions to the atmosphere. The Carbon Dioxide stream from the carbon capture unit will then need to be compressed and sent for use offsite or sequestered. Overall this addition makes the Wood Green Hydrogen process carbon negative and has the environmental benefit of preventing the captured Carbon Dioxide being sent to the atmosphere.

4.1.2 Equipment Sizing

Wood's feasibility study includes the engineering design for the proposed 'green' Steam Ethanol Reformer (SER). Each of the individual items of equipment have undergone a robust process design to meet the requirements of generating 100,000 Nm^3/hr of hydrogen product. The SER design is based on the in-house standard steam reforming process adapted to the requirement of the new green feedstock. The process design covers all aspects of the process defined in section 4.1.1, including, but not limited to, the following sections:

- Feed preparation

- Steam bioethanol reforming (SER)
- Shift reaction
- Syngas cooling/heat recovery
- Hydrogen purification
- Utilities and offsites

The equipment sizing enables the hydrogen product specification to be achieved whilst achieving a hydrogen production of 100,000 Nm^3/hr. The equipment employed in Wood's proposed SER technology is sized and optimised to maximise the hydrogen yield whilst eradicating fuel gas consumption and minimising steam production.

Wood's proposed technology utilises conventional hydrogen generation technologies combined in a novel way to further optimise the efficiency of the process. The combination of conventional equipment and the innovative approach employed by Wood reduces the technical risk associated with the scheme and delivers an innovative design for large scale, low carbon hydrogen supply.

Heat and material balances have been developed using industry proven simulation software, the output from which has been used for sizing process equipment. The equipment sizing methodologies are those applied in the design of Wood's 100+ hydrogen and synthesis gas plants installed world-wide, which have a total installed capacity of more than 3.5 MNm^3/hr of hydrogen. The equipment designs have also benchmarked against Wood's own project database to validate the design.

4.1.3 System Material Balance

A material balance has been developed using industry proven simulation software. The material balance is based on the definition of the system boundary (battery limit) of Wood's 'Green' hydrogen generation plant. The battery limits and material stream numbers are shown in Figure 4-1.

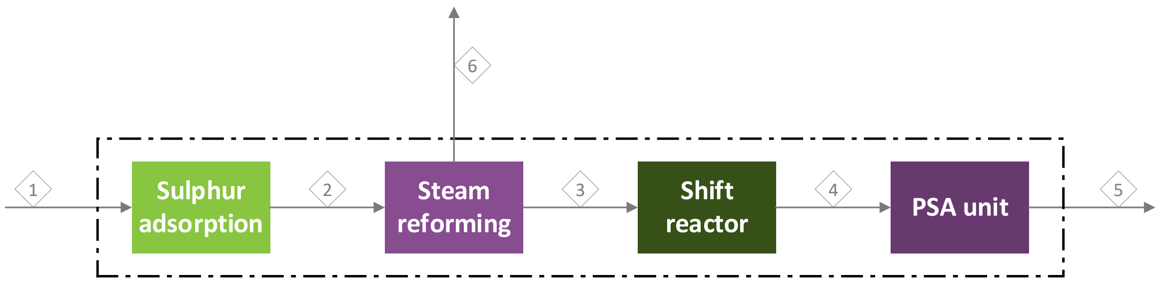

Figure 4-1: Summary Block Flow Diagram and Battery Limit Definition

The summary material balance is summarised in Table 4-1, giving details on the process operating conditions and compositions of the process streams given in Figure 4-1.

Table 4-1: Green Hydrogen Material Summary

Parameter	1	5	6
Temperature (ºC)	30	45	135
Pressure (bara)	33.0	21.2	1.3
Mass flow (kg/h)	57,000	9,000	316,200

Parameter	1	5	6
Molar flow (kmol/h)	1,240	4,460	10,625
Volumetric flow (Nm³/h)	2,125	100,000	237,800
Hydrogen (mol%)	0.0	> 99.9	0.0
Methane (mol%)	0.0	0.0	0.0
Carbon monoxide (mol%)	0.0	0.0	0.0
Carbon dioxide (mol%)	0.0	0.0	23.3
Nitrogen (mol%)	0.0	0.0	55.8
Water (mol %)	0.0	0.0	20.2
Sulphur compounds (mol%)	>0.1	0.0	0.0
Oxygen (mol%)	0.0	0.0	0.8
Bioethanol (mol%)	>99.9	0.0	0.0

The boundaries defined in Figure 4-1 illustrates the main process flows entering and exiting the battery limits. The description for the main import and export process flows are given in Table 4-2.

Table 4-2: Battery Limit Streams

Line number	Line description
1	Liquid bioethanol feed to process
5	Hydrogen product export
6	Terrace Wall Reformer™ flue gas

4.2 Plant Layout

Wood has developed a high-level plant layout as part of the concept design conducted in this feasibility study. The arrangement of process units is important in ensuing the hydrogen plant is safe, economical and easy to access for operations and maintenance. Refer to Attachment 2 plot plan (522037-8230-01-0001) for details on the layout of the proposed 'Green' hydrogen plant. For the purpose of this study, the steam reformer furnace is assumed to be upwind of the unit.

The most important considerations in designing the plant layout are those that concern the process. Initially the equipment is arranged in the general order of the process flow. The layout is then modified to accommodate specific process requirements: for example, elevating equipment to take advantage of gravity flow in the case of condensing service / two phase lines or to meet pump requirements (NPSH, suction lines etc.). The first example is particularly applicable to the heat recovery stage of the process, where water starts to condense out of the vapour stream as it cools to the PSA unit operating temperature. The heat recovery S&T heat exchangers downstream of the shift reactor are elevated on top of each other where condensation starts to occur in the process gas. This arrangement allows any condensate accumulating in the pipework to fall to the process condensate knockout drum under gravity flow. The BFW circulation pumps have deliberately been located adjacent to the reformer's furnace and generally pump suction line lengths have been minimised across the plant. Other factors are included such as minimising the overall length of pipework which directly impacts the installation cost. The pipework is minimised by adhering to the main process flow and the careful positioning of the equipment. Unit layout is a linear arrangement about a single interconnecting rack containing interconnecting piping and distribution headers, with spur racks serving the Steam Reformer Furnace.

The operation and maintenance of the plant is a key factor when designing the plant layout. Having good access for operators allows the plant to be run in a safe and reliable manner. This reduces the chance of accidents and makes detection of malfunctions more likely. Equipment that requires frequent attendance is located such that it is easy to get to via short and direct routes. Furthermore, the plant layout is configured such that there is adequate access around the site for construction and maintenance (e.g. cranes for lifting units, catalyst loading, packing changes etc.). The access for the units of equipment is from a perimeter road with dedicated areas for maintenance. The chemical dosing packages are located to provide easy access from the perimeter road for unloading.

Where possible, heat exchangers are positioned in groups to save capital on service pipework, structural work and maintenance provisions. Ideally, as in the case of this plant, the syngas cooling train heat exchangers are positioned in close proximity with each other due to the natural progression of the process flow through the heat recovery section of the process. Generally, the plant layout develops parallel to the sequence of the main process flow i.e. the process units of operation in the later downstream processes are positioned progressively further away from the battery limit. This is a natural result of the philosophy employed to minimise the length of pipework. However, some units, such as the PSA unit, require large footprint areas, and can, therefore, go against the general trend. The PSA unit has three product streams; the hydrogen product generated from the system, the furnace firing PSA tail gas, and the hydrogen recycle to the front end of the process. The three product streams from the PSA unit all require piping to the front end of the process and, therefore, justify the location of the PSA unit to minimise the length of the multiple product streams.

5 Techno-Economic Assessment

5.1 Capital Cost Estimating

The aim is to produce an instantaneous 2Q2019 capital cost estimate at Concept Level for Wood's Blue Hydrogen concept, reflecting Engineering, Procurement & Construction (EPC) costs.

The Estimate has been developed utilising the ACCE (Aspen Capital Cost Estimator) estimating software to generate the equipment costs and the application of Total Installed Cost (TIC) factors to generate the bulks and direct construction costs. The Wood version of ACCE is calibrated with real equipment cost data obtained from live FEED and EPC projects within the company.

5.2 Techno-Economic Assessment Conclusion

The purpose of the techno-economic is to evaluate whether Wood's Green SER process is technically and economically feasible. The techno-economic analysis concluded that Wood's SER process is technically viable in producing bulk low carbon hydrogen at the specifications set by BEIS. When comparing between the counterfactual case and Wood's SER process, the technical indicators show that the SER process delivers a lower hydrogen % yield but is more energy efficient in the process. The economics show that Wood's Green SER process is not competitive with the counterfactual at current bioethanol prices, but this comparison between a carbon positive and carbon neutral process may be considered biased. A comparison against electrolysis technology may be considered more realistic, against which the SER appears favourable.

The results of the technical analysis on the electrolysis process highlights that, when considering the electricity-to-wheel efficiency, the global efficiency of Wood's proposition is comparable. The economics indicate that the SER process is competitive with the electrolysis case but is subject to potential wide fluctuations due to the immaturity of the bioethanol market in the UK. The SER process can also be used bulk hydrogen production, many times the scale of viable electrolysis systems.

Wood's scheme is a novel arrangement of existing technologies using a different catalyst. This will need to be proven at a pilot level to demonstrate the benefits of the process. Wood is extremely confident that the process will deliver the technical improvements and performance described in the preceding sections and, therefore, believes it fully warrants funding for continued development and subsequent commercialisation.

6 Market Assessment

The market analysis for a green hydrogen supply solution indicated that conversion of ethanol to hydrogen should only be considered if there is excess bio-ethanol. The analysis indicates that within the UK the use of bio-ethanol as a fossil transport fuels replacement should be prioritised. At a more granular level it is expected that there will be opportunities for bio-liquid feedstocks to be converted to hydrogen. Applications include:

- Hydrogen for vehicle refuelling where there is no natural gas grid or there is a limited supply of renewable electricity / clean water for electrolysis;
- Decarbonising existing hydrogen (SMR) production facilities where there is no access to a CO_2 collection and storage system;
- Decarbonising new hydrogen production (SMR) facilities where there is no access to a CO_2 collection and storage system;
- Production of carbon negative hydrogen.

The production of carbon negative hydrogen is particularly interesting. If reforming of bioethanol and similar feedstocks is coupled with carbon capture and storage, the combined solution would be a route to a net-negative emission hydrogen supply. In the future, this could gain support in a similar way to Biomass Energy with Carbon Capture and Storage (BECCS) is today.

The size of the addressable market is somewhat uncertain but there is a relatively straightforward path to commercialisation of conversion of bioethanol to hydrogen and so Wood will be able to react quickly when the market opportunities arise.

In other parts of the world where there is a larger capacity for growing non-food biomass and renewable biofuels are more widely available at lower cost, Wood's Green Hydrogen design may be a popular option, especially if combined with carbon capture and storage. Early development of the Green Hydrogen concept for niche applications in the UK will demonstrate the commercial viability of the technology for export to other countries as they follow the energy transition.

7 Business Development Plan

7.1 Short Term

The short-term plan for the proposed solution is to build on the work in Phase 1 and carry out the following activities:

- Find a site for the demonstration plant;
- Detailed design for the demonstration plant.

Completion of the above will give confidence in the cost, schedule and deliverability of a demonstration plant.

7.2 Longer Term

Wood has a long track record of delivering process technology and complex projects. Wood is confident in being able to address the market as it develops.

The terrace-wall reformer technology has a modular building block design. The reformer can be prefabricated off-site with minimal hook up required on site. For smaller capacities, a total modular solution is possible. Maximising modularisation and minimising onsite work is key to the accelerated role of out of our Green Hydrogen solution as construction skills availability is likely to be a constraint.

With 15,000 people in the UK and 60,000 people globally, Wood has the flexibility to execute many complex projects in numerous locations and therefore we are confident in being able to progress many parallel projects.

The development of a demonstration plant is key and will achieve the following:

- Operating data, this data will validate the models that have been used to date in developing the hydrogen supply solution.
- Successful operation will give Wood the confidence to provide the required performance guarantees to customers.
- Optimisation, knowledge gained from demonstration plant will be incorporated into the design of the first commercial facility.

Hydrogen production from ethanol and other renewable hydrocarbon feedstocks is expected to be on a rather smaller scale compared to large scale hydrogen production for decarbonised heat networks. This technology could also be used for decarbonising existing hydrogen production assets where there is no CO_2 collection system.

Attachment 1 Block Flow Diagram

- 522037-8110-25-0001 – Green Hydrogen Block Flow Diagram Rev 1

Attachment 2 Plot Layout

- 522037-8110-01-0001 – Green Hydrogen Plot Plan Rev 0 wood.