REPORT

Drax Negative Emission Gasification Report

Version 1.0

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This document has 11 pages including the cover.

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Contents

1. Introduction

Drax is committed to enabling a zero carbon, lower cost energy future through engineering, technology deployment and innovation. Meeting net-zero by 2050 will require negative emission technologies, offsetting residual emissions from other sectors still dependant on fossil fuels. Drax is leading a workstream in the Bioenergy with Carbon Capture and Storage sector (BECCS), where it is possible to generate renewable energy whilst simultaneously providing carbon negative emissions.

Gasification of biomass with CCS is a form of BECCS, which produces an energy vector in the form of useful gases, such as Hydrogen. This Negative Emission Gasification (NEG) project is focusing on the possibility of producing renewable negative emission Hydrogen. Gasification can also be configured to produce other carbon negative energy vectors, including sustainable aviation fuels and electricity.

Gasification, whilst an established technology for fossil fuels, requires further innovation for biomass feedstocks. Drax has partnered with BEIS to develop sustainable, reliable gasification technologies to rapidly accelerate the possibility of bringing carbon negative renewable energy generation to the UK. This forms a part of BEIS' Greenhouse Gas Reduction (GGR) workstream, that seeks to accelerate the deployment and capability of the UK in the negative emission sector.

2. The Role of Biomass to meet Net Zero

Sustainably sourced biomass-generated energy (bioenergy) can be carbon neutral, as plants absorb CO2 from the atmosphere as they grow. This, in turn, offsets CO2 emissions released when the biomass is combusted as fuel.

When sustainable bioenergy is paired with carbon capture and storage it becomes a source of negative emissions, as CO2 is permanently removed from the carbon cycle.

Experts believe that negative emission technologies[1] are crucial to helping countries meet the long-term goals set out in the Paris Climate Agreement. As BECCS is the most scalable of these technologies this decade, it has a key role to play in combating climate change.

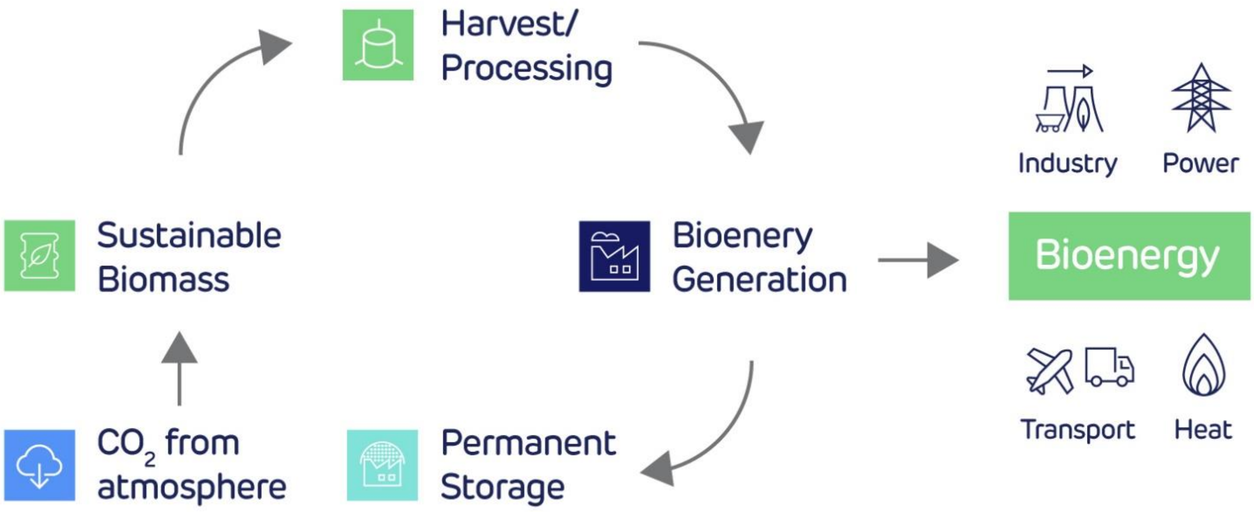


Figure 1 – Bioenergy Negative Emission Cycle

[1] https://www.drax.com/carbon-capture/uk-needs-negative-emissions-beccs-net-zero-why/

3. Gasification and Project Scope

Gasification is an established technology and has more commonly been used in the UK for producing Town's Gas from coal before the gas grid was converted to Natural Gas.

Gasification is a process of breaking down fuels to simpler molecules through applying heat in a low oxygen (non-stochiometric) environment. The heat provides sufficient energy to break the molecular bonds within a fuel, resulting in smaller, simpler molecules. In gasification, this typically is a mixture of gases predominantly consisting of Carbon Monoxide (CO) and Hydrogen (H_2), known as a synthesis gas (or syngas). The component gases are a useful mixture, as they can be used in a number of sectors including; directly as a gaseous fuel, combined to make Hydrocarbon chains (synthetic crude oil), or converted and separated into purified streams of Carbon Dioxide (CO_2) and Hydrogen.

Gasification of biomass can be a negative emission technology when coupled with Carbon Capture and Storage (CCS). The two technologies combined is called Bioenergy with Carbon Capture and Storage (BECCS).

In this Negative Emission Gasification (NEG) project, innovative activities have focused on developing an efficient end-to-end system for sustainable biomass gasification to negative emission Hydrogen. This BEIS call required innovative approaches to achieve at least 1 kt CO_2 of negative emissions, which would not be achievable with creating synthetic oil at this scale. This is because synthetic oil is eventually burned, typically without carbon capture, greatly reducing the negative emission potential of BECCS in this instance.

As such, a Feasibility and FEED study was carried out to design a first of a kind innovative negative emission c.1.4 MW_{th} gasification system to consider the technical requirements and costs to produce negative emission Hydrogen.

4. Design and Innovation

Gasification requires fuel, in this case sustainable biomass, to be heated to high temperatures to convert into syngas. The heating media, performing as an oxidant, provides the energy necessary to break down fuels into simpler gaseous molecules, leaving behind ash and slag deposits that need to be removed from the system.

Some gasification systems use air as the oxidant, but this can produce NO_x emissions as well as diluting the produced syngas with inert Nitrogen. Pure oxygen could also be used as an oxidant to form higher yields of CO and H_2, however sourcing pure oxygen can be costly and energy intensive. In this project, enough Oxygen is used to burn small quantities of fuel, raising heat, steam and hot gases to drive the gasification process. Steam has a relatively high thermal mass compared to air, meaning greater energy transfer can be achieved per unit volume.

The gasification process reduces the biomass to its simpler gases as discussed, with residual slag and ash mechanically removed from the process. The resultant gas mixture is still, however, contaminated with Sulphur compounds (depending on the Sulphur content of the biomass) and other contaminants that need to be removed.

The syngas is cleaned and polished to remove impurities (tars), compressed for sulphur removal. If targeting Hydrogen generation, the resultant de-sulphurised gas stream can then be passed through a water gas shift reactor. This process removes the majority of the Carbon Monoxide, as it reacts with water molecules, producing more Hydrogen and biogenic Carbon Dioxide as per equation (1):

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad (1)$$

The water gas shift reaction is exothermic but operates most efficiently between 320°C and 450°C. System integration has been a key component of the efficiency potential of the NEG system. For the Water gas shift reaction, waste process heat is utilised to maintain the ideal operating temperatures, only requiring external heat sources at start up when all systems are cold.

The remaining water vapour in the syngas stream can now condensed out, leaving a resultant syngas approximately 50/50 CO_2 and Hydrogen by molar volume, with some residual methane (CH_4) and CO.

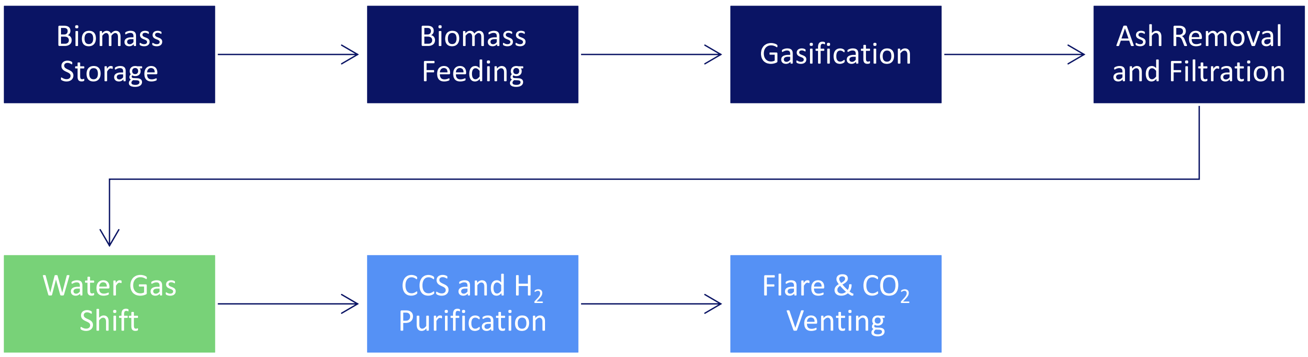
5. Gas Separation

In order to provide a negative emission Hydrogen rich gas stream, it is now necessary to remove the CO_2 from the syngas. Due to the boundaries of this project, the CO_2 will be vented to atmosphere. The intention of this BEIS programme is to prove the ability to isolate biogenic CO_2 from a process that could potentially integrate with a Carbon Capture and Storage (or utilisation) system when available in the future. This programme can therefore be used to inform BEIS how 50kt CO_{2e} greenhouse gas removal technologies might be built and integrated as part of the emerging net-zero energy economy by 2030.

Due to the presence of Hydrogen in the syngas stream, Amine solvents are not an effective CO_2 removal technique. This is because the Hydrogen reacts with the Amine more favourably than the CO_2, forming ammonia (NH_3). This results in costly, inefficient and ultimately failed capture of CO_2 as the Amine degrades.

For this project, it was considered to utilise a Pressure Swing Adsorption (PSA) technology to remove the CO_2 from the syngas stream. This technology uses an adsorption bed in a vessel, designed for the target molecules to preferentially adhere to the adsorbent, in this case CO_2. Honeywell UOP have provided an integrated solution for this programme, designing a two-stage Polybed™ PSA process. The first PSA separates CO_2 from the stream, with a Hydrogen rich overhead gas. This overhead gas can be further refined to meet specific commercial grade Hydrogen purities, depending on end use applications. Due to the test nature of this plant, all resultant flammable gases are measured (i.e. flow meters etc) to verify and record production quantities and end-to-end performance, but then safely diverted and consumed in a flare for their safe disposal.

6. Block Flow Diagram



The block flow diagram indicates the major steps in the process that will fulfil the requirements of the end-to-end process of a negative emission gasification system. The system has its current configuration to prove the ability to generate negative emission Hydrogen, however the green and purple boxes indicate how alternative steps could be designed in for the creation of other renewable energy fuels.

The Water Gas Shift in green is highlighted as this would be the first step in the process that may be altered depending on your targeted end product. For Hydrogen production, the aim is to convert as much CO in the syngas from the gasifier to Hydrogen using a water gas shift reaction to maximise Hydrogen yield. However, if wishing to synthesize oils or to burn the syngas directly for power generation, this step would be removed or controlled to achieve the required chemistry for the downstream equipment.

Similarly, the CCS and H_2 step could include injection to a future Hydrogen gas grid, removing the flare as part of the process and CCS could be connected to a CO_2 storage or utilisation operation. Different CCS systems may be used if the syngas was burnt to drive gas turbines. Alternatively, Fischer-Tropsch applications, or similar chemical processes, could be integrated at this point to produce synthetic carbon-based fuels. The addition of CCS to the Fischer-Tropsch process would capture any residual CO_2, making these fuels carbon negative.

7. Phase 2 Plans

This BEIS programme is split into two workstreams; in Phase 1 Drax undertook Feasibility and FEED studies. Phase 2 will include Detailed Design, Procurement, Construction and Trialling to be completed, in line with BEIS' guidance, by 31/03/25.

Phase 2 applications are due by close of 27 January 2022. If Drax are brought into Phase 2, subject to the application processes, Drax will look to progress Phase 2 activities including procuring relevant contractors to undertake Detailed Design etc.

Following revisions and finalisation to systems and engineering requirements, procurement of the end-to-end system will commence. The pilot location is currently proposed to be at Drax Power Station in Selby, UK. Drax intends to trial and test the gasifier to demonstrate its reliable and efficient operability so that evidence may be generated to prove how this innovative renewable technology could be scaled for commercial uses.

The Phase 1 studies concluded with an anticipated 227 kg/hr CO_2 capture rate per year from the stack and the potential production of 536 kWh/hr H_2 (LHV). Trial campaigns will aim to verify these values, with integrated monitoring (temperatures, flow rates, composition analysis, pressure etc) to understand the performance at a granular level across the NEG system.

The Heat and Mass balance calculations have been calculated on the basis of Miscanthus as a feedstock. Gasification trial campaigns will aim to reach steady state operating conditions, and sustaining operations for a significant duration of time. Drax propose to shut down the gasification system periodically to undertake a full systems inspection to verify the effectiveness of the end-to-end system and understand where improvements could be made. Through a cycle of testing, sampling and system inspection, Drax intends to build confidence in innovative gasification approaches for future large-scale BECCS applications.

8. How Gasification Technology Could Scale

The scaling of Biomass Gasification with CCS is dependent on policy and energy market conditions. Negative emission technologies that also produce renewable energy need to be recognised for the dual benefit they provide for the net-zero economy.

In addition, scaling of gasification will largely depend on the market demand for specific outputs – which are currently unclear. Gasification can use its flexible capabilities, scaling in synthetic fuel production to help decarbonise aviation or shipping. Alternatively, gasification could generate Hydrogen for a future Hydrogen gas grid or renewable power generation. During Phase 2 of this SBRI programme, Drax will review the potential commercialisation strategies to achieve scale.

9. Conclusion

A Feasibility study on a negative emission biomass gasification system was conducted with Drax and Black & Veatch. The study designed an integrated system, plot plan and energy requirements to operate the plant, supported with a Hazard Identification workshop to design out risk.

A Front-End Engineering Design study was subsequently conducted based on the success of the Feasibility study. This further refined the scope of the NEG system, identifying efficiency gains and the full identification of equipment, valves, piping etc required for the construction of the NEG system. A Hazard and Operability analysis was carried out to support the design and ensure safe operation is integrated by default.

This NEG programme has calculated a syngas that with CCS (pre or post combustion) could produce c. 1.8 kt CO_2 negative emission per year from the stack. With gasification's ability to produce renewable 'on demand' energy whilst reducing atmospheric CO_2 concentrations makes it a promising technology for the net-zero energy mix.