The role of Carbon Capture, Utilisation, and Storage (CCUS) in achieving negative emissions

Negative emission technologies (NETs), also known as Greenhouse Gas Removal (GGR), Carbon Dioxide Removals (CDRs) or simply Carbon Removals, are vital for achieving domestic and global Net Zero targets.

Whether permanently stored underground in depleted oil and gas fields, in saline aquifers, or in manufactured products such as concrete, they encompass both nature and engineered-based solutions, where atmospheric carbon dioxide (CO_2) is captured and isolated in order to achieve a 'net removal' of carbon. To attain a net carbon removal, the amount of CO_2 removed from the atmosphere must be equivalent to the amount of CO_2 that is released.

Although these terms are often used interchangeably, it should be noted that NETs cannot be characterised as such unless carbon capture is incorporated.

The Paris Agreement outlines the need to hold the increase in the global average temperature to well below 2°C above pre-industrial levels with an aspiration to limit the temperature increase to no more than 1.5°C. The Agreement also aimed for all countries to work together to become net-zero within the second half of the 21st century. In 2018 the Intergovernmental Panel on Climate Change (IPCC) published a report which highlighted the need to reach net-zero by around 2050 in order to limit global warming to 1.5°C; in response the UK set its own net zero target in 2019.

It is important to note that to achieve the 1.5°C target it's necessary to keep going beyond net-zero after 2050. Becoming 'net negative' in order to effectively remove CO_2 from the atmosphere to mitigate the 'overshoot' which is considered inevitable under all pathways.
Therefore, NETs will play a pivotal role in meeting these targets, and offsetting emissions from carbon intensive industries.

To date (June 2023), a rapid increase can be seen in the number of governments making pledges to reduce GHG emissions to net zero, many of whom have made it a legal obligation to meet these targets, and others including their pledges in official policy documents. As of April 2021, the European Union as well as 44 countries have pledged to meet a net zero emissions target, accounting for approximately 70% of global CO_2 emissions. The use of NETs feature in the pledges, with varying approaches and scale of deployment.

The development of carbon capture, utilisation and storage (CCUS) infrastructure in the UK is the cornerstone to implementing GGRs and achieving NET targets.

As such, £20 billion investment has recently been announced in the UK Spring budget exclusively towards CCS efforts in the UK. This funding will support CCS over the following two decades, and builds upon prior CCS commitments made by the UK government, such as the target to develop several industrial CCS clusters in the country by 2030, including the **CCS Infrastructure Fund (CIF).**
Due to the existing barriers and challenges associated with the deployment of CCUS, the UK government has been progressing in developing several support mechanisms, aimed at incentivising the deployment of carbon capture technologies and the associated transport and storage infrastructure, an example being CIF.

In 2020, the UK announced the CIF; the primary aim of which is to contribute to the capital costs of establishing CO2 transport and storage infrastructure, as well as early industrial capture projects. A

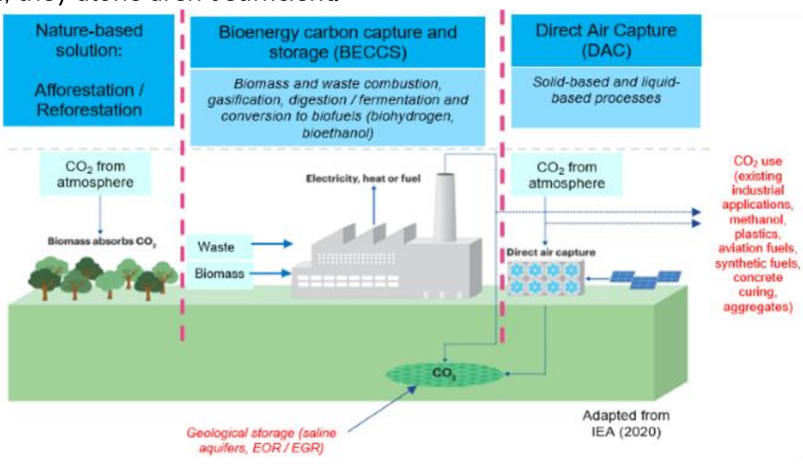
total of £1 billion of CIF funding is to be allocated through cluster sequencing, hence focusing on supporting the development of transport and storage infrastructure at existing industrial clusters within the UK. Industrial CCUS clusters takes advantage of economies of scale to provide feasibility for carbon capture to many industrial facilities, hence focusing the development of CO2 transport and storage infrastructure around industrial clusters.
In November 2021, the HyNet and East Coast Clusters were determined to be the Track-1 clusters for mid-2020s. In August 2022, following the selection of the Track-1 clusters, 20 projects within the two clusters have been shortlisted for Phase 2. These projects cover a range of CCUS technologies across power CCUS, industrial carbon capture, waste and CCUS enabled hydrogen projects.
Another CCUS policy incentive introduced by the UK Government include the **Industrial Carbon Capture (ICC) business model**; the basis of which is to provide support to CCUS projects to develop carbon capture technologies. The business model consists of a capital grant, funded through the CIF, as well as the potential to also receive additional support to cover operational expenses, and transport and storage fees.

Other CCUS support mechanisms in the UK include:

- **UK Emissions Trading Scheme (UK ETS):** a replacement for the EU ETS implemented following the exit of the UK from the European Union.
- **Industrial Energy Transformation Fund (IETF):** a funding programme designed to support industries to invest in energy efficiency and low carbon technologies.
- **CCUS Innovation 2.0 programme:** a programme aimed at reducing the cost of capturing and sequestering CO2, helping UK industry to understand the opportunity for development and deployment of relevant technologies. The CCUS Innovation 2.0 competition is part of the £1 billion Net Zero Innovation Portfolio (NZIP), where up to £20 million grant funding will be available over two calls to support innovation in novel CCUS technology, demonstrate and de-risk next generation CCUS technology and reduce the cost of deploying CCUS.

A technical over-view of Negative Emission Technologies (NETs)

NETs can be divided into two categories; 1) land-based (also known as nature-based) and 2) engineered removals.
Examples of land-based removals includes reforestation, peatland restoration, and soil carbon sequestration. The focus of this article will be on engineered removals, however, it should be noted that land-based NETs have the potential to make a major contribution to meeting carbon reduction targets, although, they alone aren't sufficient.

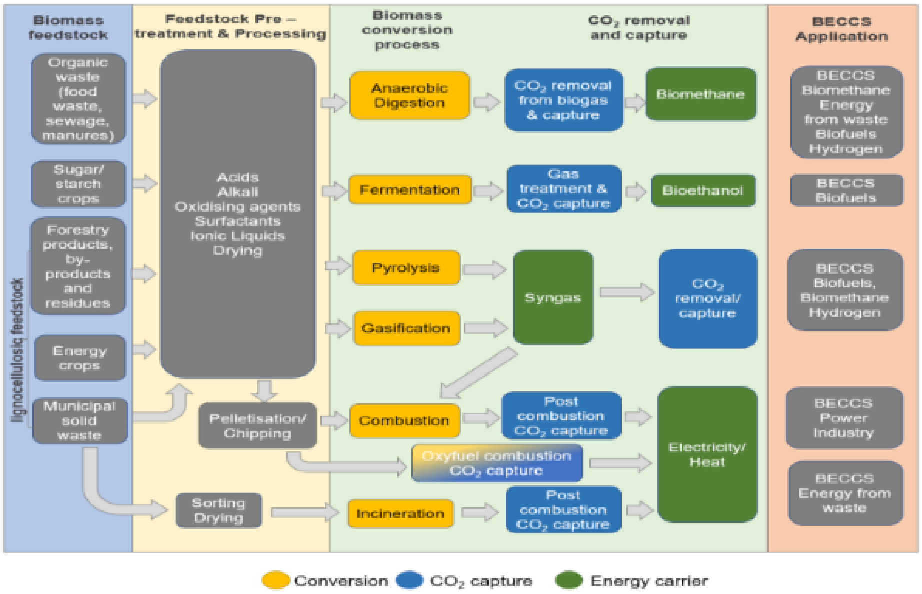


Engineered NETs can be categorised into pre-combustion and post-combustion carbon capture:

- **Pre-combustion** involves the capture of CO2 from the gas stream prior to combustion, where the syngas is produced through gasification. Not applicable to combustion processes or retrofit of existing processes.
- **Post-combustion** involves the removal of CO2 from the flue gas stream. Applicable to combustion processes and may be suitable for retrofitting on existing processes.

Engineered NETs consist of Bioenergy with Carbon Capture and Storage (BECCS), biochar and DACCS (Direct Air Carbon Capture and Storage), all of which are explained below.

BECCS refers to technologies which combine bioenergy applications with CCS; the final output depends on the technologies used. Typically, the final output of BECCS is the generation of heat and/or electricity, however, in some instances is the production of hydrogen, biofuels or biomethane.



BECCS includes BECCS power, BECCS energy from waste, BECCS hydrogen, BECCS biofuels, BECCS biomethane, and BECCS industry biochar. These will all be discussed further, along with other common NETs, including DACCS and biochar.

BECCS Power

BECCS Power refers to the combustion of biomass, e.g., wood pellets, for the primary purpose of exporting power to the grid, which is carried out in combination with carbon capture and permanent sequestration of the captured biogenic CO2. Both post- and pre-combustion carbon capture technologies are suitably deployed for BECCS power.

A key indicator of a technology's maturity, and hence likelihood of deployment, is known as its Technology Readiness Level (TRL). The TRL of BECCS power varies depending on the specific pathway, where biomass combustion with post-combustion CO_2 capture has the highest TRL, at TRL 8-9.

BECCS Energy from Waste

BECCS Energy from Waste (EfW) involves incineration of municipal solid waste, or commercial/industrial waste to generate electricity. [CHP (Combined Heat and Power)] EfW facilities have the ability to cogenerate heat and electricity, which is particularly advantageous in regard to CO2 capture, as a small portion of the heat produced from the facility can be utilised for the capture process.

The CO2 produced is captured utilising post-combustion carbon capture technology and is permanently sequestered.
Post-combustion carbon capture technology is the most conducive for effective CO_2 capture from EfW facilities, and as such has a TRL of 7. A TRL of 7 indicates that there are operational prototypes or planned operational systems, requiring demonstration in an actual operational environment. This technology is mature and has been successfully deployed for many years, however, it has yet to be integrated within a commercial scale EfW facility in the UK.

BECCS Industry

BECCS industry relates to the use of biomass as an energy source for industrial applications and the capture of CO_2 from the process and subsequent CO_2 storage. Typical industrial applications include wood-based products (paper & pulp industries), distillation & fermentation processes and steel production. Approximately one third of industrial energy demand is for high-temperature heat, hence limiting the potential decarbonisation options available. BECCS therefore provides a key opportunity to reduce emissions from industrial processes, while still maintaining the high-temperature heat required.
Due to the differences in industrial processes, the TRL of applying CCS varies between industrial sectors. Typically, TRLs from 5 to 9 have been observed.

BECCS Hydrogen

BECCS hydrogen is the process whereby biomass is utilised as a feedstock for the production of (bio-) hydrogen, with carbon capture and storage incorporated. There are different hydrogen production routes, one common route being the gasification of biomass to syngas, with subsequent conversion to hydrogen. Low carbon hydrogen can be produced via other routes, such as splitting biomass using steam methane reforming, or electrolysis; although, BECCS hydrogen is the only hydrogen production route that can generate net-negative emissions.
The technological maturity of biohydrogen is broad, with several institutions estimating a TRL of 4-6 (meaning that the technology is within its innovation/prototype phase), whilst others estimate a larger TRL of 5-9 (meaning the technology is closer to full commercial application).

BECCS Biomethane

There are multiple pathways to produce biomethane. The first being thermochemical conversion routes which covers gasification and pyrolysis. Other methods include anaerobic digestion, where biogas (syngas) or biohydrogen are produced and then converted to biomethane.
The two common practices of converting biogas to biomethane are upgrading, a process that removes any CO_2 and other contaminants present in the biogas, and methanation which makes use of a catalyst to promote reaction between the hydrogen and CO or CO_2 to produce methane.
Biomethane can be produced through multiple routes, namely anaerobic digestion followed by upgrading of biogas; the removal of CO_2 is an inherent part of the process and consequently "upgrading" technologies are already well established as they have been refined over the last 20 years. The TRL ranges between 8 - 9 for anaerobic digestion and biomethane/CO_2 separation, as the technology is commercially mature.

DACCS

Direct Air Carbon Capture and Storage (DACCS) works by drawing in ambient air using fans and contacting the CO2 present with specialist sorbents, where the CO2 is subsequently captured via adsorption or absorption. CO_2-depleted air is produced as an output. The sorbent is then regenerated by altering the process conditions, typically by elevating temperatures and/or reducing pressures, which in turn releases the CO_2 as a pure stream ready for capture.
The TRL ranges from 4-6 = meaning the technology is at the bench scale research to large scale deployment phase.

Biochar

The production of biochar begins with the pyrolysis of biomass, i.e., thermal decomposition in the absence of air. This creates a stable charcoal-like product that stores the biomass carbon in a form that is relatively resistant to decomposition, resulting in the storage of carbon for an extended period of time. Biochar is often spread over suitable land area, where it has the ability to provide a range of benefits to the soil, such as improved soil quality, water and nutrient retention.
Biochar is within a TRL of 3-6, suggesting the technology is within the 'proof of concept' and 'large [pilot plant] scale' phase. It is expected that readiness for implementation at large scale is anticipated within a decade.

BIOCCUS

BIOCCUS is an innovative GGR technology developed by Ricardo and Bluebox Energy, with funding awarded by the Department of Business, Energy and Industrial Strategy (BEIS, now DESNZ, the Department for Energy Security and Net Zero) through the Net Zero Innovation Portfolio (NZIP). The technology is a pyrolysis **BIO**mass-based cogeneration system with **C**O_2 **C**apture, **U**tilisation and **S**torage, and combines Bluebox Energy's hot air turbine technology with Ricardo's expertise in carbon capture technologies. BIOCCUS works by employing sustainably sourced waste wood and then processing it in the three following ways:

1. Production of biochar
2. Generation of heat and power
3. Carbon capture and storage

For more information and resources on BIOCCUS can be found here