ARUP

NLHPP Environmental Stakeholder Management Task Order

CCUS review - Technical note

Sign off sheet

Document Details	
Document Number	
WBS Ref	
Confidentiality Level	• Confidential (top confidentiality level) • Restricted (medium confidentiality level) • Internal use (lowest level of confidentiality) • Public once finalised (everyone can see the information)
Revision No:	2.0

Assurance Record			
	Author	**Check & Review**	**Approval for Use**
Name			
Role	Technical Advisor	Technical	Technical
Signature			
Date	23/11/2020	23/11/2020	23/11/2020

Engagement Confirmation		
Function	**Role**	**Notes**
Programme Director	**C**	Consulted (xxx)
SRO	**C**	Consulted
SHE&W	**N/A**	
LEL	**N/A**	
Technical Advisor	**C**	Consulted (Arup, AECOM, Grimshaw, Ramboll, Wood)
Technical Authority	**C**	
Programme Office	**N/A**	
Project Delivery	**N/A**	
Commercial	**N/A**	
Financial	**N/A**	
Legal & Governance	**N/A**	

Revision Record		
Revision No.	**Date**	**Description of Revision**
1.0	15/10/2020	First draft
1.1	21/10/2020	Revised draft sent to all workshop attendees
2.0	23/11/2020	Final version following workshop

Table of contents

1. Project background

Project background

Scope of CCUS review for the ERF

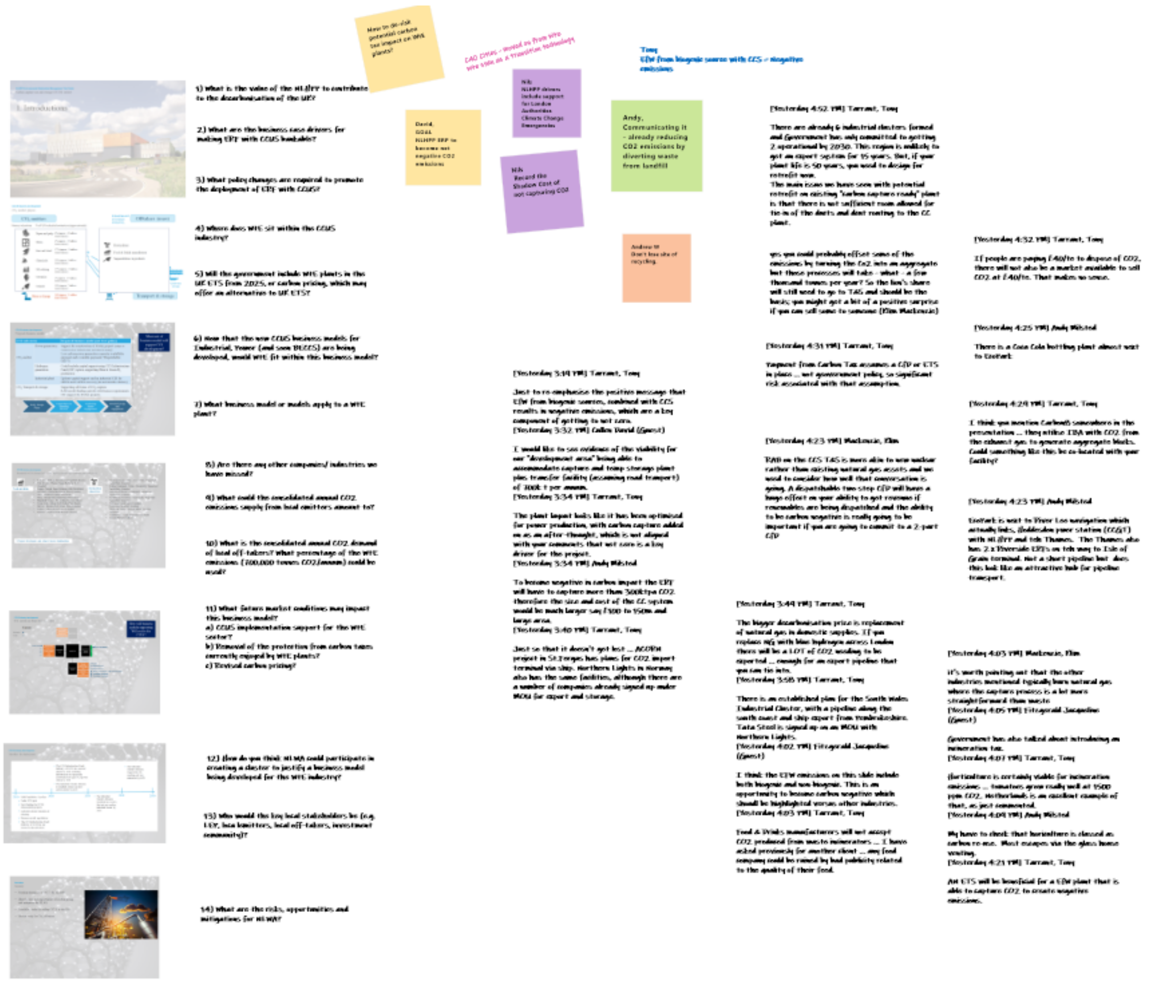
- Provide researched and reviewed up-to-date information on the current and likely future status of carbon capture, use and storage (CCUS) in the UK.
- Explore the role of waste to energy (WtE) facilities within the context of CCUS in the UK and beyond.
- Discuss how the likely status of CCUS in the UK and the potential role of WtE facilities in the CCUS context may affect decisions made on the energy recovery facility (ERF) at the Edmonton EcoPark in North London, which is planned to be operational by 2025.
- Discuss next steps with regards to implementing CCUS for the ERF.

NLWA

Project background

CCUS review workshop

- An online two-hour workshop was prepared and facilitated by Arup on 22 October 2020, which was attended by representatives from NLWA, AECOM, Ramboll, Wood and Grimshaw, as follows:
    1. **NLWA**: XX, XX, XX, XX
    2. **AECOM**: XX, XX, XX
    3. **Grimshaw**: XX
    4. **Ramboll**: XXX, XX, XX N
    5. **Wood**: XX
    6. **Arup**: XX, XX, XX
- Representatives were issued with a draft version of this technical note prior to the workshop, and were presented with a condensed version of it during the workshop, during which they were asked to provide their comments, ideas and other feedback.
- The information shared by the attendees during the workshop was captured in an interactive Microsoft (MS) Whiteboard and in the MS Teams meeting chat and is included in various sections of this revised technical note, as appropriate.
- A summary of the main comments made by attendees during the workshop is given in Appendix 1.

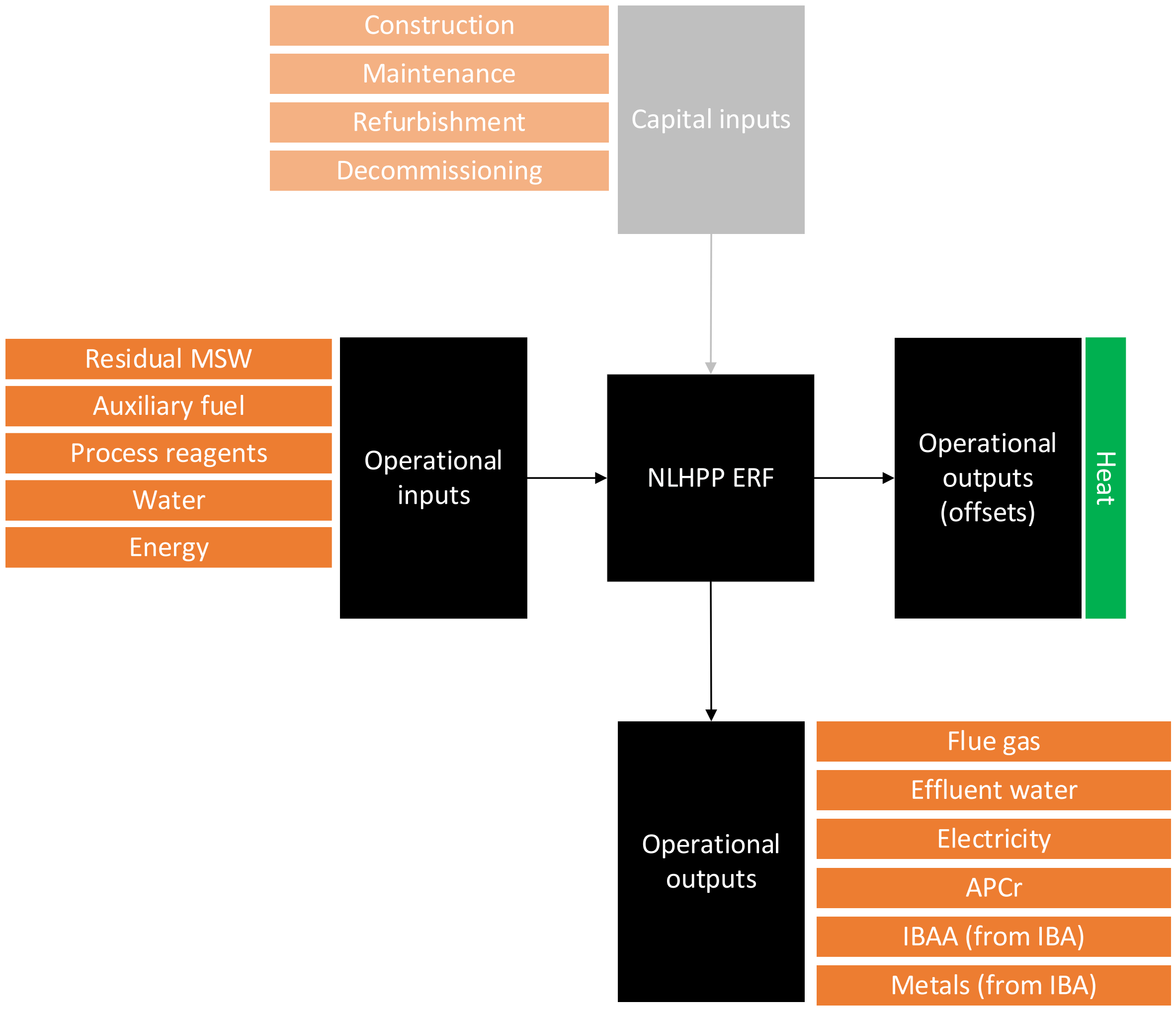


MS Whiteboard with workshop notes

Carbon objectives of NLHPP

ERF CO_2 operational emissions

- The ERF (which is planned to become operational at the EcoPark in 2025) is estimated to emit 318,500 tonnes CO_2/annum of operational Scope 1, 2 and 3 emissions (based on a carbon emissions study by Ramboll, which has used Defra's Energy recovery for residual waste carbon-based modelling approach and includes *only non-biogenic CO_2 emissions**).
- The ERF will operate in combined heat and power (CHP) mode, and therefore, it was deemed appropriate to discount some of the operational emissions of the ERF, if the heat exported to heat networks, would replace other fossil-based sources of heat (e.g. gas boilers). As a result, the discounted emissions would result in total non-biogenic operational emissions of 252,700 tonnes CO_2/annum (an approach supported by the British Standards Institution (BSI) via discussions with Arup).
- This annual quantity of emissions (i.e. 252,700 tonnes CO_2/annum) was deemed to be appropriate in a carbon offsetting context, to help the ERF achieve carbon neutral status. Nonetheless, the targeted emissions under a CCUS context would require further review, to ensure that any CO_2 captured from the ERF in the future is adequate to meet NLWA's carbon management plans (see page 8), and that the captured CO_2 would be financially and environmentally viably transported and managed at its destination (i.e. carbon use and/or storage).

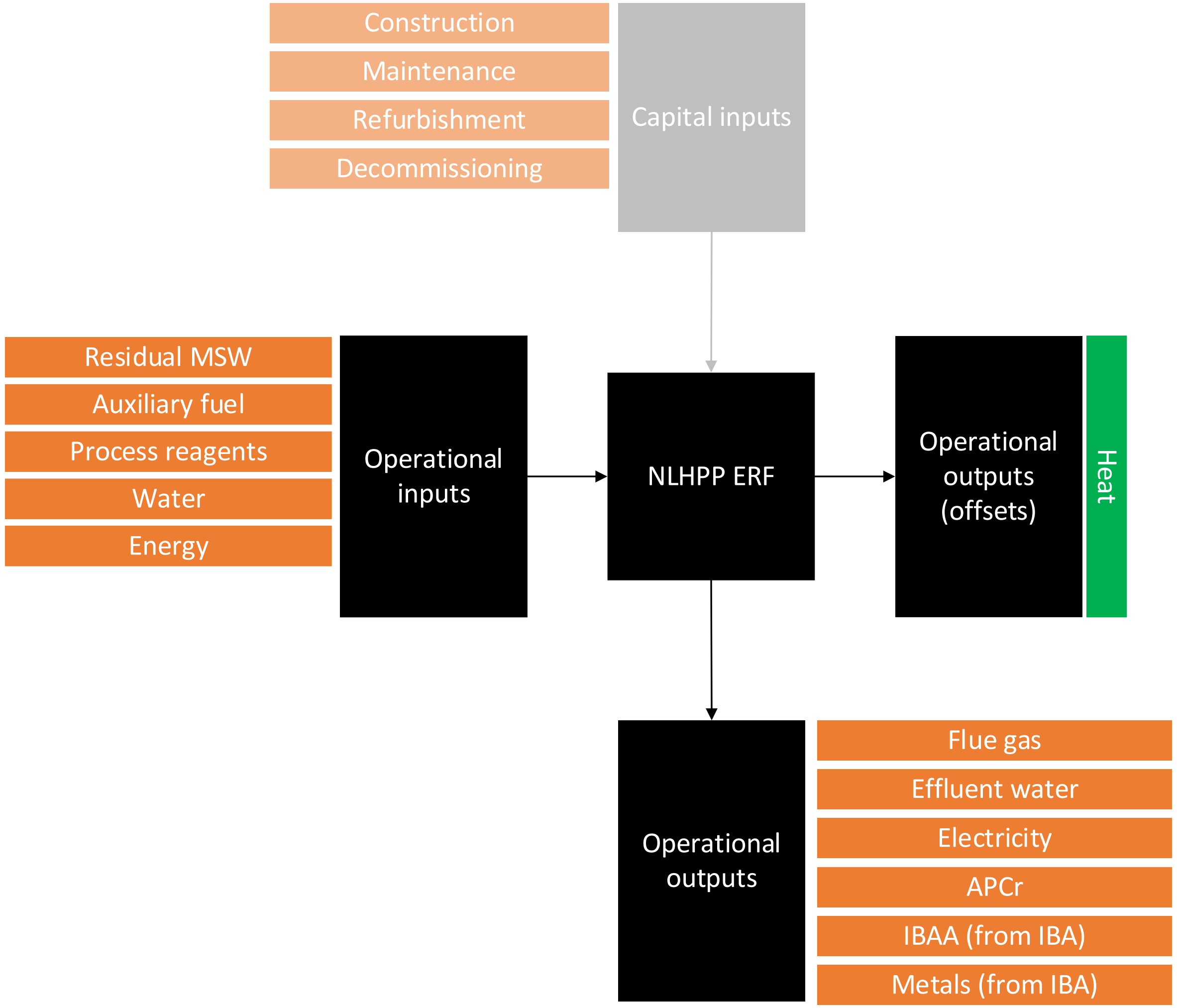


*Biogenic emissions can be discounted as they are considered to be short-lived emissions, which are sequestered quickly from the atmosphere back into plant biomass via the process of photosynthesis.

Carbon objectives of NLHPP

Carbon management plans for the NLHPP

- Short-term (i.e. up to approximately 10 years) carbon offsetting solutions have been explored, to help the ERF achieve carbon neutral status (following the principles of PAS2060), through a blended portfolio of UK and international carbon offsetting schemes.
- CCUS is thought of as a more viable medium to long-term solution, to help the ERF achieve and maintain, as a minimum, a carbon neutral status.
- NLWA has an ambition for the ERF to be a Net Negative CO_2 emissions WtE facility in the long term. To achieve this, addressing biogenic, as well as non-biogenic operational scope 1, 2 and 3 emissions would be required. Achieving this would likely require a combination of carbon reduction, CCUS and offsetting measures, in line with the carbon management hierarchy (see page 13).
- As an indication of the magnitude of the CO_2 emissions required to be addressed, the direct (i.e. Scope 1) biogenic and non-biogenic CO_2 emissions of the ERF are estimated at 700,000 tonnes/annum (assuming that one tonne of CO_2 is emitted for every tonne of waste combusted, which is an assumption supported by the Intergovernmental Panel on Climate Change (IPCC).

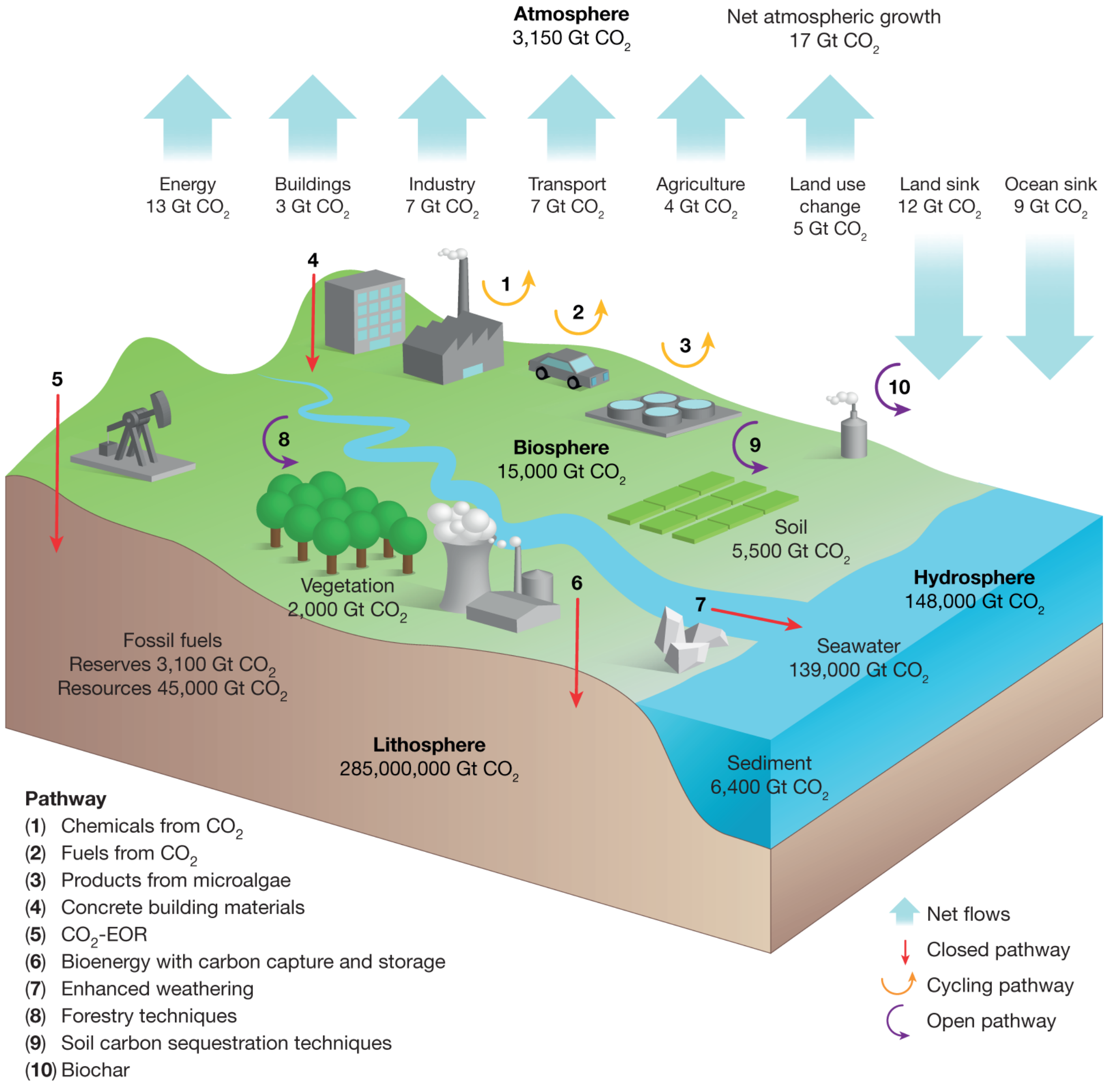


2. Introduction to carbon and CCUS

Why is addressing CO_2 emissions important? Global carbon cycle

Carbon sources and sinks

- Net atmospheric CO_2 growth due to excessive anthropogenic CO_2 emissions – resulting in climate change
- Climate change has many effects globally, including increased heat, drought, wildfires, insect outbreaks, declining water supplies and agricultural yields, health impacts, flooding and coastal erosion
- Net zero emissions can be achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period
- Potential pathways for restoring CO_2 imbalance – need to include carbon use and storage



Nature (Hepburn *et al.*)

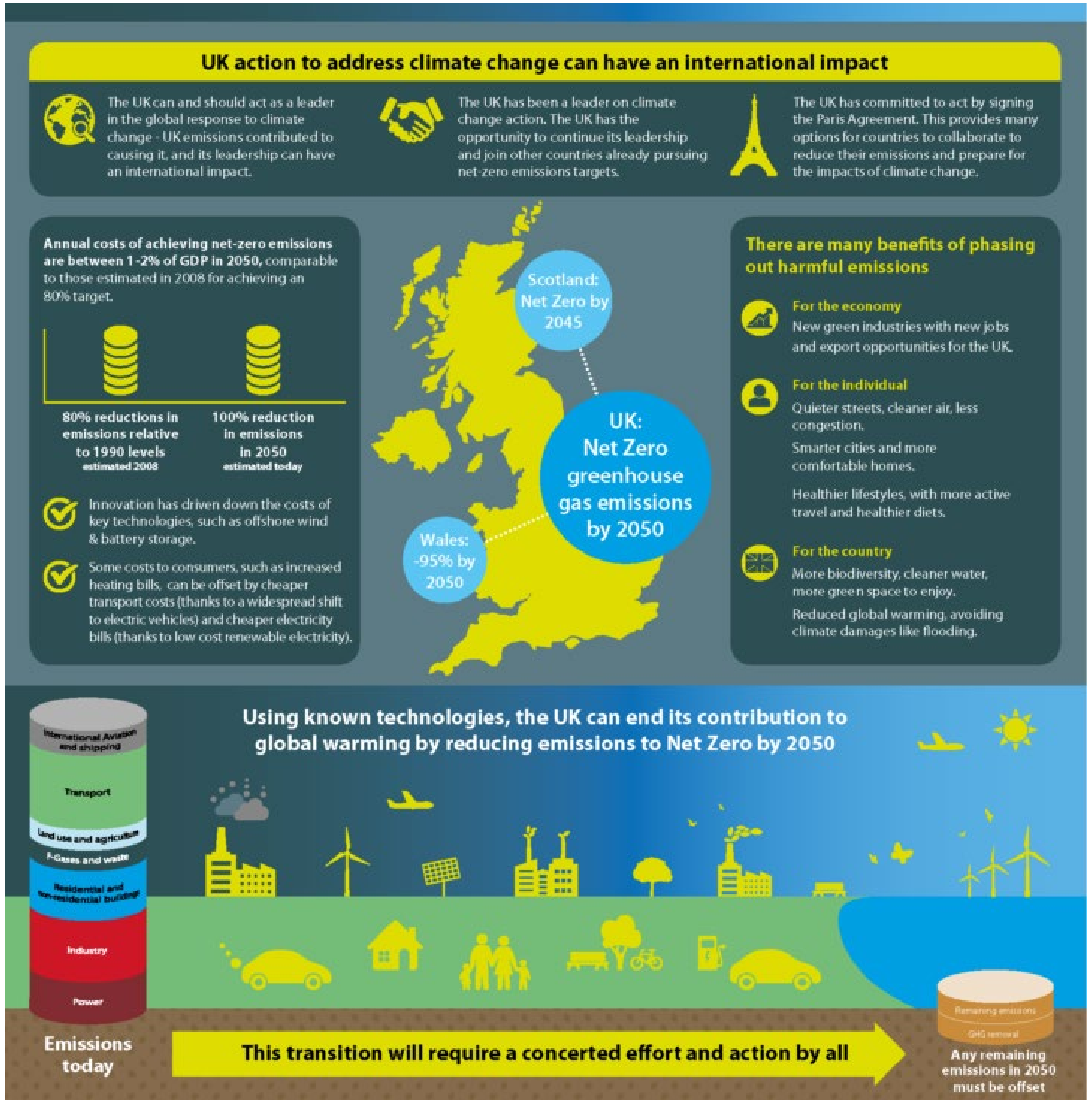
Why is addressing CO_2 emissions important? Regulatory context

International

- **United Nations Paris Agreement, 2015** - limit the global average temperature rise to 1.5 degrees Celsius (1.5° C) above pre-industrial levels

National

- **UK Climate Change Act, 2008** – Carbon emission targets and 5-year budgets
- **BEIS Industrial Strategy, 2018 –** Sets out the need to decouple industrial growth and carbon emissions
- **UK Clean Growth Strategy, 2017** – 25% of emissions from business and industry
- **Committee on Climate Change Net Zero report, 2019 –** CCUS is crucial to meet a net zero carbon target by 2050
- In 2019, the UK Government and the devolved administrations committed to the net zero carbon target

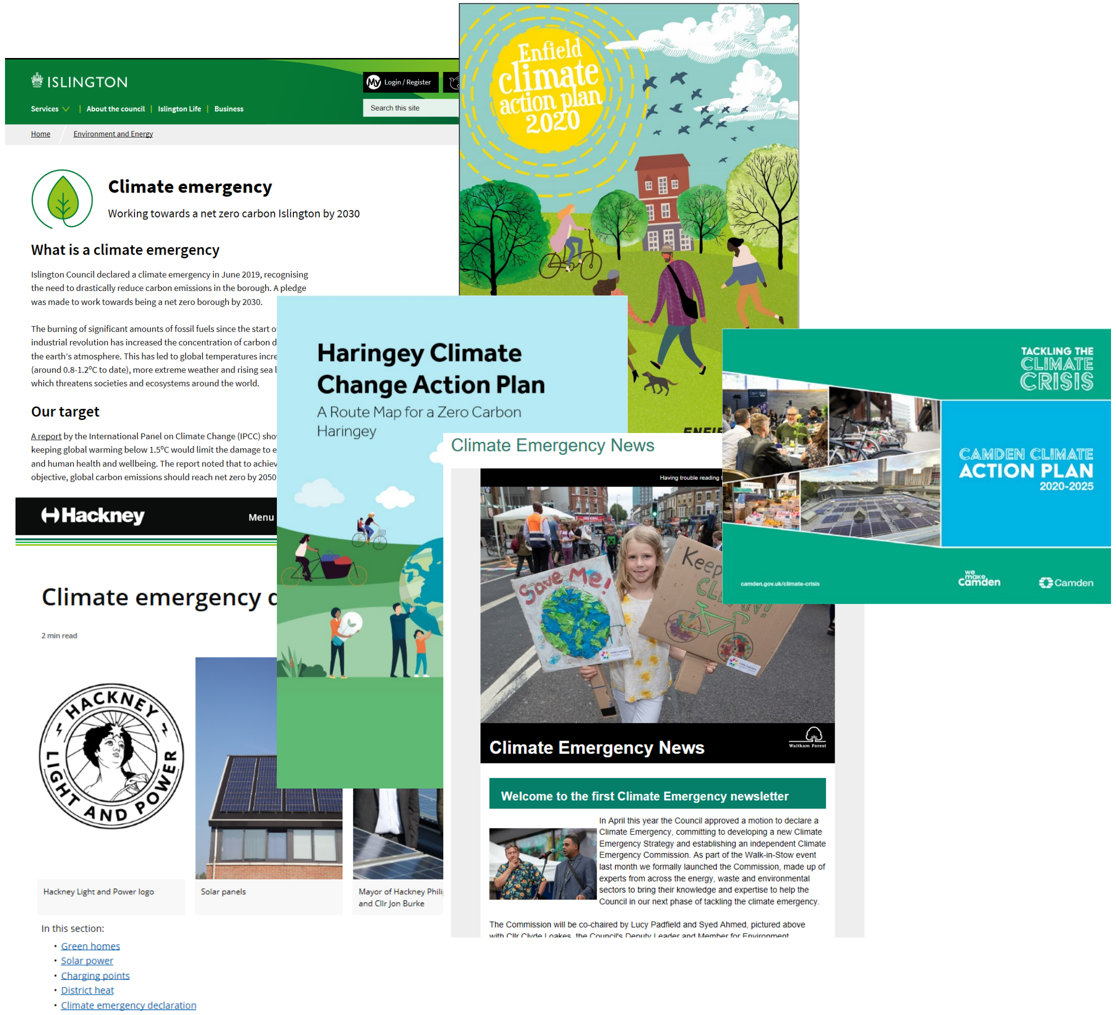


Committee on Climate Change

Why is addressing CO_2 emissions important? Local drivers

Six North London boroughs declared Climate Emergency

- **LB Camden**: Seeks funding opportunities to support community-led climate action
- **LB Enfield**: Aims to become a carbon neutral borough by 2040
- **LB Hackney**: Targets include a 45% reduction in emissions against 2010 levels by 2030
- **LB Haringey**: On target to deliver its 40% carbon reduction by 2020 from its 2005 baseline
- **LB Islington**: Set out to minimise its carbon emissions from buildings and fleet, as well as maximising renewable energy generation
- **LB Waltham Forest**: Overall target to reduce CO_2 emissions by 80% by 2050



CCUS role in targeting CO_2 emissions

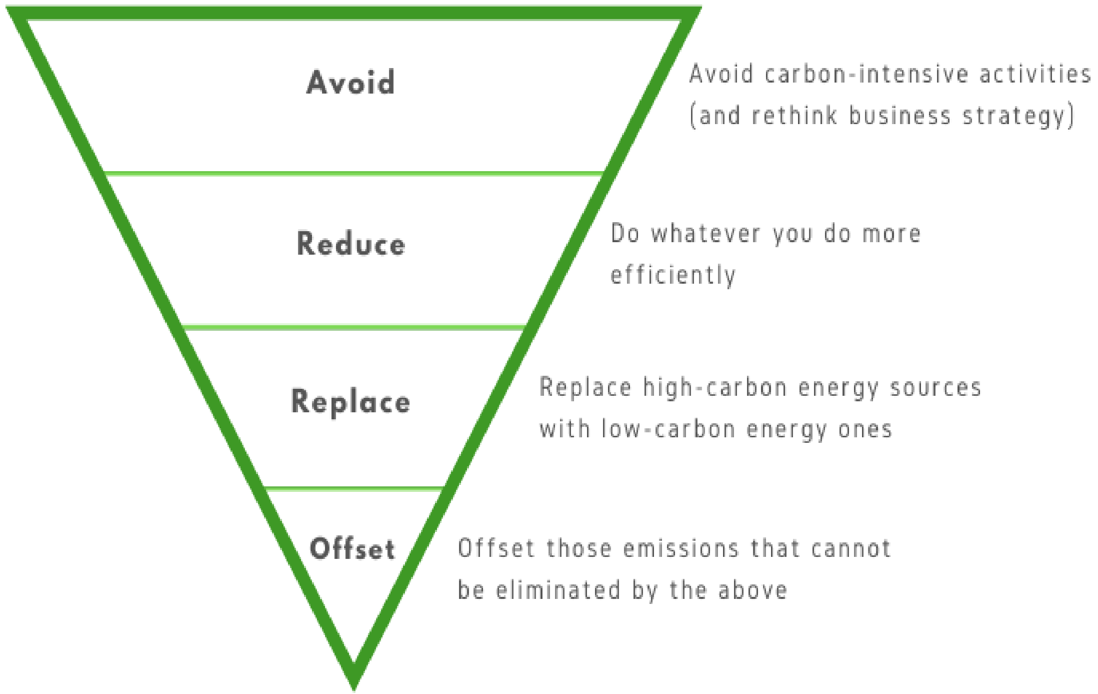
- CCUS provides 9% of cumulative emissions reduction - required for deep decarbonisation
- In the UK, the primary sector body for CCUS is the Carbon Capture and Storage Association (CCSA)

National legislation, policy and guidance

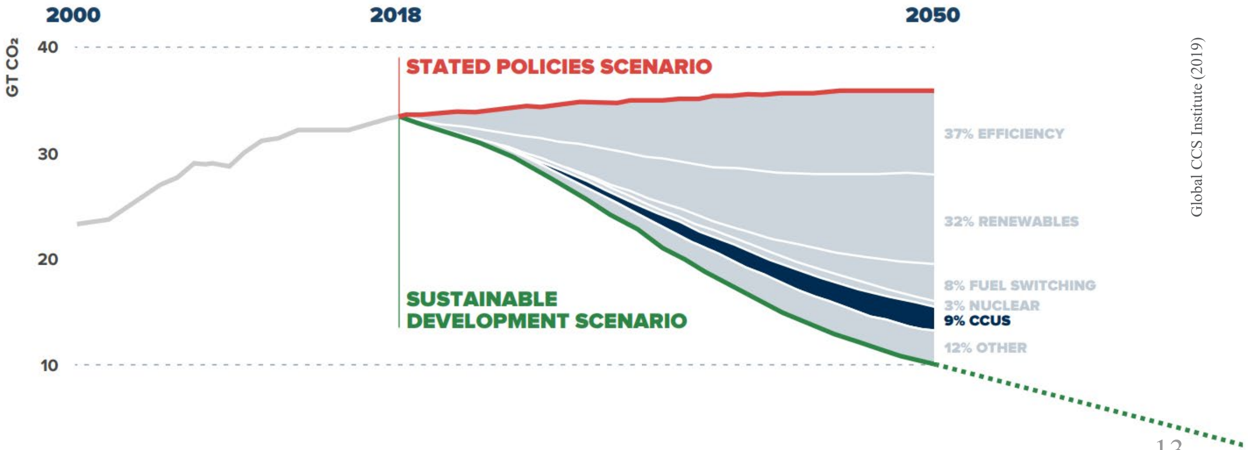
- Industrial Clusters Mission: Aim to create a net-zero carbon industrial cluster by 2040
- Delivering clean growth: CCUS Cost Challenge Taskforce report, 2018 - Informing and proposing a strategic plan to Government for supporting the development of CCUS in the UK
- UK CCUS deployment pathway: An action plan, 2018
- CCUS business models response to UK government consultation, 2020: industry, power, CO_2 transport and storage and low carbon hydrogen production, including a CCUS delivery action plan
- UK government will launch its industrial decarbonisation strategy in 2021

Regional policy and guidance

- The GLA, in its Zero Carbon London: A 1.5ºC Compatible Plan 2018, states that London encounters residual emissions (estimated at 10% of total emissions), which will need to be eliminated via CCUS or carbon offsetting



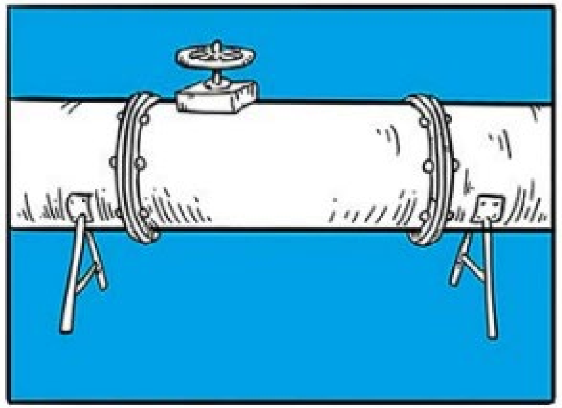
Green Restoration Ireland



Global CCS Institute (2019)

CCUS technology essential for reaching net zero carbon by 2050. Why?

- Hydrogen (H_2) is the key element providing energy in fossil fuels (e.g. Methane - CH_4), and has no emissions at the point of combustion/use.
- Replacement of fossil fuels used in heating, transport and industrial processes has proved difficult to date. Approximately 70% of industrial emissions relate to heat production. Fuel-switching from gas to hydrogen is a key plank in the complete decarbonisation of industry, and will contribute alongside electrification to the decarbonisation of domestic heat and transport*.
- Today, hydrogen is largely produced at scale through the reformation of fossil fuels, with unabated CO_2 emissions to atmosphere. Using CCUS with this process produces Blue hydrogen**.
- Green hydrogen is produced mainly via electrolysis of water using renewable power sources*** and is expected to be the enduring source of hydrogen, as these newer technologies are scaled up and reach parity on costs.
- To kickstart the transition to a hydrogen economy, CCUS must be developed in the short-term to support blue hydrogen production, at scale, in the mid 2030s. This will provide CO_2 infrastructure, including pipelines and storage, which will support industrial processes that cannot switch to hydrogen, even in the long-term.



Blue hydrogen
Made from natural gas, CO_2 emissions captured and stored

Green hydrogen
Made from renewable electricity, no CO_2 emitted

Energy Institute

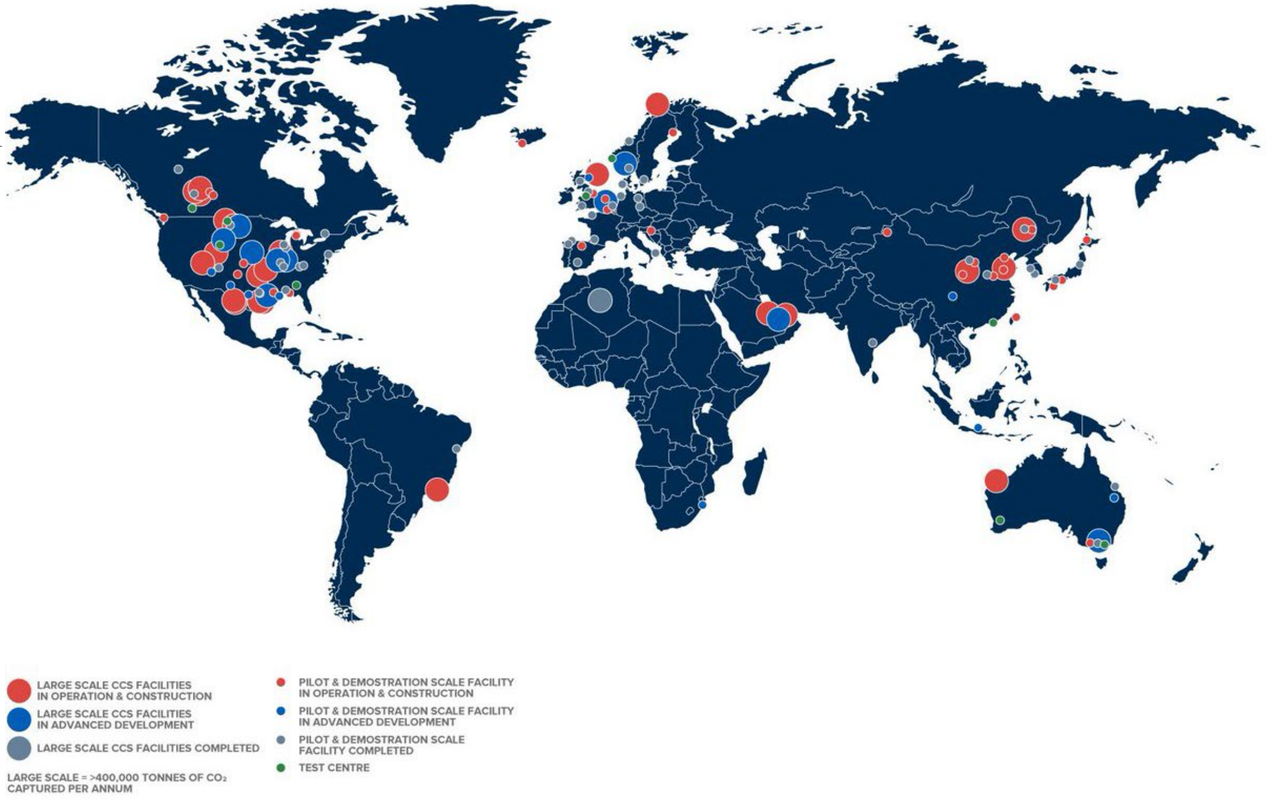
* H for use in heavy goods vehicles, public transport, especially.

** Through techniques include Steam Methane Reforming and Auto-Thermal Reformation. Note this has implications for balance of trade as the UK is already a net importer of fossil fuels

*** Low carbon power sources often included in this definition. Other techniques include through photosynthesis of algae.

CCUS facilities around the world

- According to the Global CCS Institute, there are 19 large-scale CCUS facilities in commercial operation worldwide, while there are four more in construction, 10 are in advanced development and 18 are in early development.
- There is one commercial scale CCUS WtE facility in the Netherlands and several pilot plants (see page 31).



Global CCS Institute

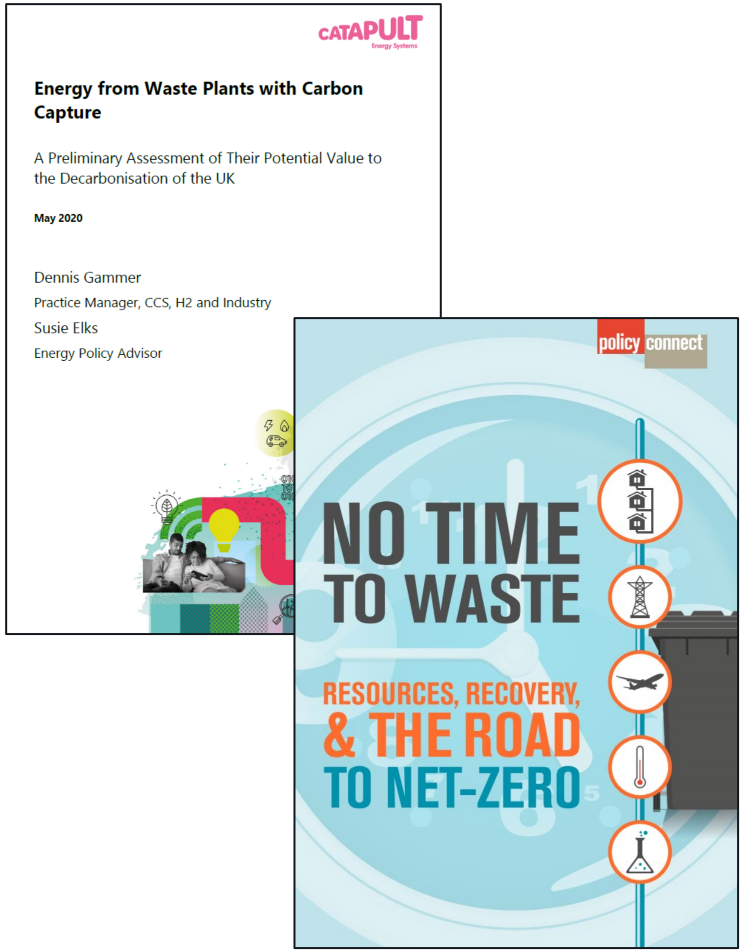
Why is CCUS important for WtE facilities?

Energy Systems Catapult on CCUS for WtE facilities (May 2020)*

- A significant proportion of the WtE facilities in the UK is relatively newer than other industrial facilities, and therefore has a longer life to benefit from CCUS investment.
- CCUS mitigates the system level environmental issues that threaten long-term sustainability of WtE facilities in the UK, including the achievement of net negative emissions.
- On a lowest system transition cost basis, fitting CCUS to WtE facilities could constitute 20% of all CO_2 captured in the UK by 2050.

Policy Connect report (July 2020)

- UK Government should support the development and integration of CCUS technology into WtE facilities, in anticipation of a future carbon tax.



"…CCS is a necessity not an option for reaching net-zero GHG emissions."
Source: Committee on Climate Change, May 2019

"Out of 90 scenarios considered by the IPCC, 88 assumed some level of net-negative emissions to limit future temperature increases to 1.5°C."
Source: International Energy Association "CCUS in Clean Energy Transition, September 2020

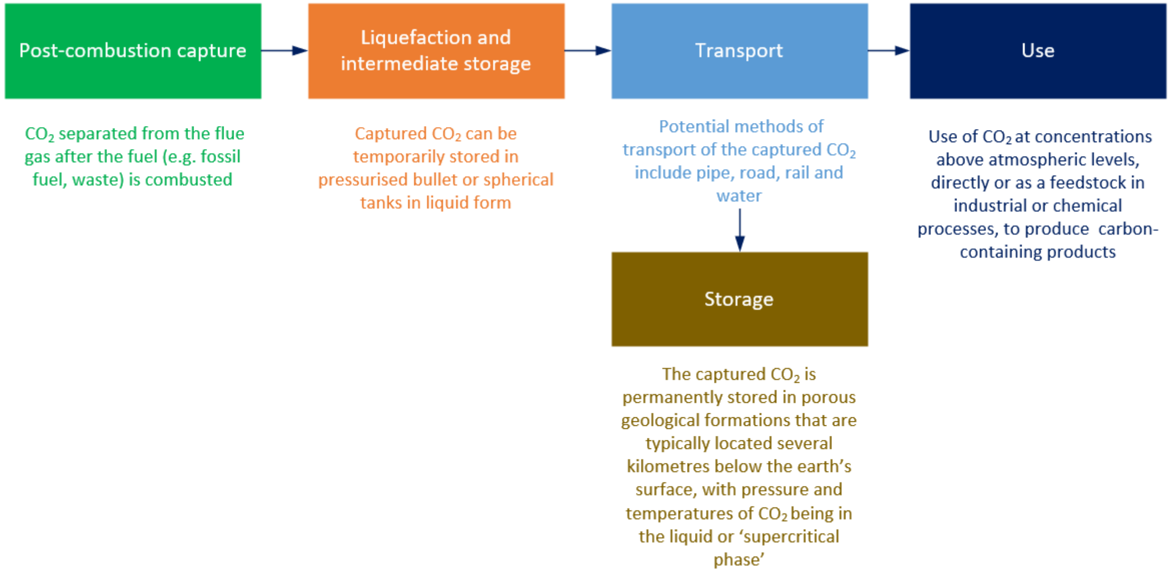
* Published date. Report actually written in 2018.

3. CCUS industry development

Carbon capture types

Three main routes of capturing CO_2 from industrial processes

- **Oxyfuel**: Fuel is combusted in oxygen rather than air to produce flue gas that is rich in CO_2. Following additional purification, the CO_2 can then be transported directly to the end user or to storage.
- **Pre-combustion**: Fuel is decarbonised prior to its use (e.g. Steam Methane Reforming to produce Blue hydrogen).
- **Post-combustion**: CO_2 is removed from the flue gas created from a process. This is the only directly suitable option for WtE facilities*.



Other CO_2 capture routes

- **Bioenergy with carbon capture and storage (BECCS)**: CO_2 from the atmosphere is absorbed via photosynthesis into the biomass of plants, which is then combusted in power plants, equipped with technologies that capture the CO_2, preventing it from returning to the atmosphere. BECCS may be beneficial but it can also be detrimental to climate change mitigation, due to its lifecycle carbon dioxide balance, energy balance and resource use.
- **Direct Air Capture with carbon Storage (DACCS)**: Uses chemical processes to capture and separate CO_2 directly from ambient air.

Grantham Institute Imperial College London

Climeworks / Julia Dunlop

* WtE facilities would also benefit from fuel switching to a carbon neutral heat source for net negative CO_2 emissions. If hydrogen is chosen as the carbon neutral source, this could either be blue hydrogen, which uses a pre-combustion capture method, or green hydrogen (no CCS involved).

Carbon use types

Mineralisation

- Sequestering carbon in concrete via mineralisation, is one of the most permanent CCU solutions
- More difficult to use in structural concrete than non-structural applications
- However, low carbon concrete materials (i.e. non-Portland cements) are more widely used than carbon sequestration in concrete, as a means of addressing CO_2 emissions reductions in construction materials

Biological uses

- Due to their fast growth, microalgae can actively store carbon in the form of biomass; this can be used in chemical and biotechnological processes to produce precursors for a variety of industrial processes
- Microalgae produce a comprehensive variety of bioproducts such as enzymes, pigments, lipids, sugars and could also replace fertilizer-intensive crops, such as corn and soy as fillers in processed foods

Chemical uses

- Catalytic hydrogenation processes to convert CO_2 from flue gas into fuels
- Manufacturing materials by using CO_2 in the chemical supply chain (polycarbonate polymers and polyols)
- Reusing CO_2 by capturing it from the flue gases of a WtE facility and using it to produce sodium bicarbonate ($NaHCO_3$)

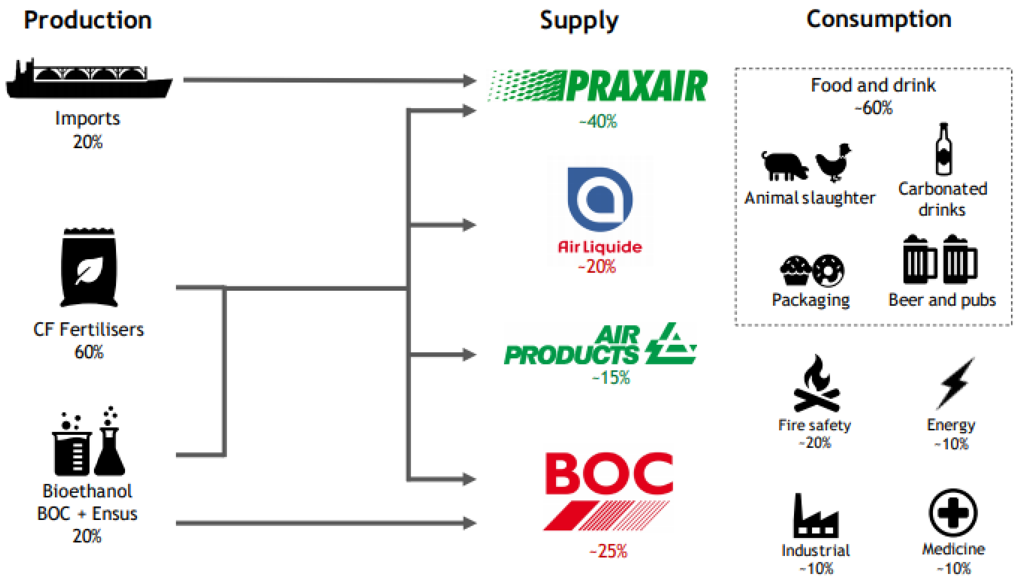
LafargeHolcim and Solidia Technologies

Amy Nordrum

National Geographic

Is carbon use a viable carbon sequestration option?

- According to the UK Committee on Climate Change '*whilst CCU could help to facilitate progress [on CCUS] in the 2020s, the volume of CO_2 that can be utilised as a feedstock rather than permanently sequestered appear likely to be small relative to the necessary role for CCS in the long-term. However, CCU could be of benefit in* ***particular niche areas*** *(e.g. where CO_2 capture costs are relatively low but geological sequestration of the CO_2 is impractical.*'
- According to BEIS, '*CCU is an important option and offers economic opportunities, but it is unlikely, on its own, to be sufficient, as not all CO_2 usage technologies lead to permanent CO_2 reductions. Importantly though, deploying CCU can reduce the costs of capture technology and can be tested at existing UK industrial sites. CCU can also lower the carbon footprint of products and provides opportunities for industrial symbiosis with commensurate economic benefits*[(1)].
- Consumer brands are looking at carbon as a viable feedstock for chemicals, polymers, and other materials that go into their products and supply chain executives are engaging with companies operating CCU facilities.
- The UK is one of Europe's largest users of CO_2. Industry sources estimate annual consumption of around 600,000 tonnes CO_2; around a fifth of Europe's total consumption[(1)].
- Of the 600,000 tonnes of CO_2 the UK consumes, around a fifth is imported, primarily from Scandinavia and the Netherlands, a further fifth is sourced as a by-product of bioethanol production, and the remaining 60% comes as by-product from the production of ammonia for fertiliser[(2)].



Climeworks / Julia Dunlop

- Demand is estimated to be growing at approximately 2-3% a year.

The UK is home to three innovators in carbon use

- **Econic Technologies** develops catalyst technologies that incorporate waste CO_2 into polyols to bring benefit to the plastics industry
- **Carbon8 Systems** developed the Accelerated Carbon Technology (ACT), which utilises CO_2 as a resource to treat and valorise a wide range of wastes into aggregates (manufactured limestone) used by the construction industry
- **CCm Technology** converts captured CO_2 into stable value-added materials with multiple uses including fertiliser, plastics and energy storage

CCUS funding and financing in the UK

Specific CCUS funding schemes

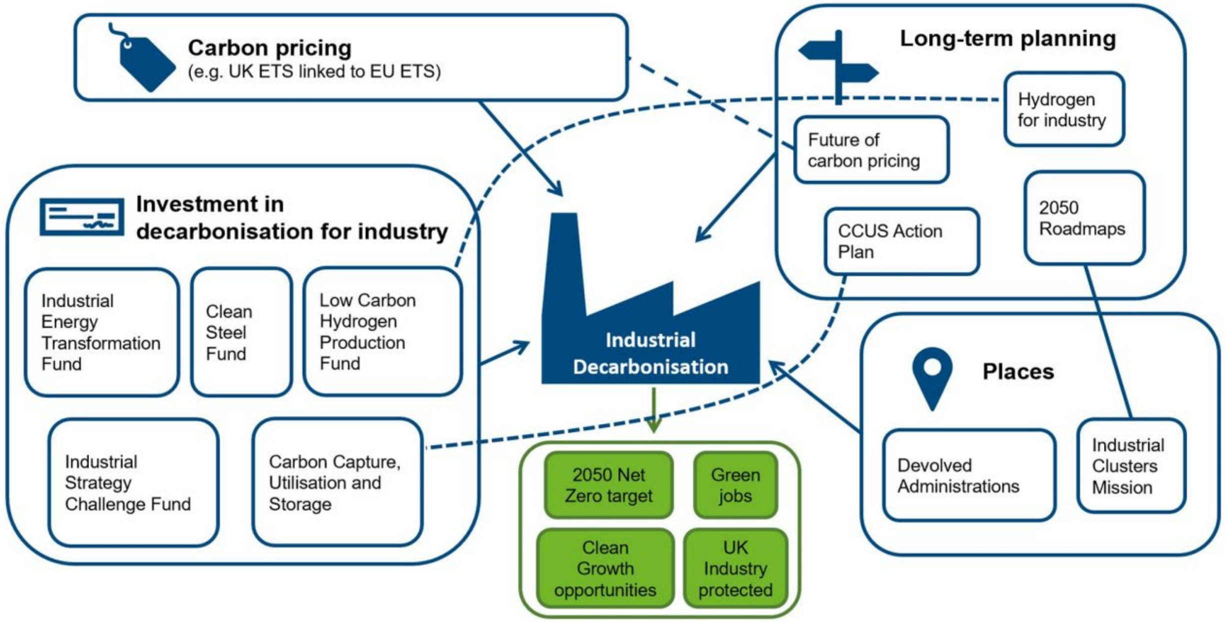
- CCUS Innovation Programme
- Carbon Capture Utilisation Demonstration innovation programme
- CCS Infrastructure Fund – £800,000[3]

Wider-focus schemes

- ISCF Industrial Decarbonisation Fund – £140M[4]
- Industrial Energy Transformation Fund – £315M[3]
- Clean Steel Fund – £250M
- Low Carbon Hydrogen production fund – £100M

Complementary funding

- Transforming Foundation Industries Challenge – £149M (resource and energy efficiency clean technologies)



BEIS - The IETF - Finalising the Design -Summary of consultation responses

Carbon market players

CO_2 emitters

UK heavy industry	(million tonnes/ annum[5])
Iron and steel	23.1
Chemicals	18.4
Oil refining	16.3
Waste to energy	11.0 [6]
Food & drink manufacture	9.5
Cement	7.5
Paper and pulp	3.3
Glass	2.2
Ceramics	1.3

Off-takers (users)

UK CO_2 consumption

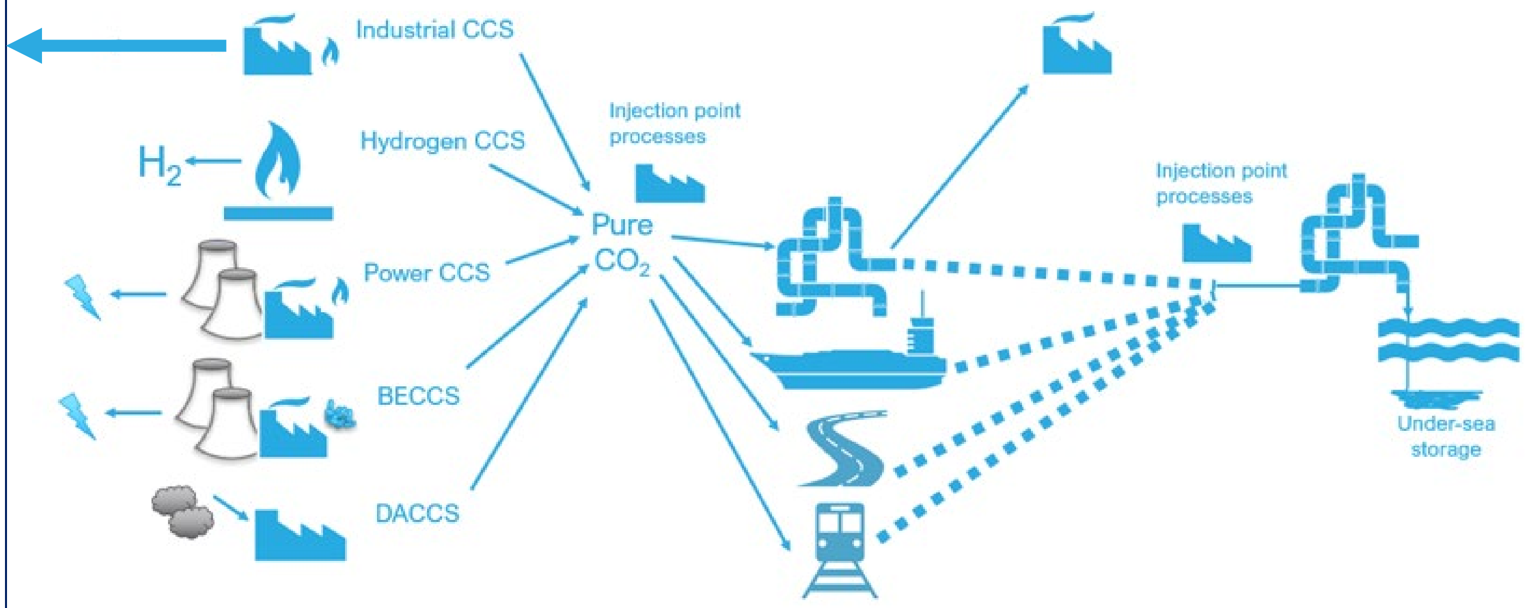
UK agricultural sector committed to reducing 3 million tonnes CO_2e, of which carbon sequestration in soils is considered a major mechanism

The food and drink industry in the UK accounts for approximately 360,000 tonnes/annum of CO_2 demand[7]

Of the cement industry's carbon emissions, 61% (i.e. approx. 793,000 tonnes/annum) comes from the calcination from limestone raw materials

Industries using CO_2

- Agriculture
- Food & drink manufacture
- Sequestration in construction materials

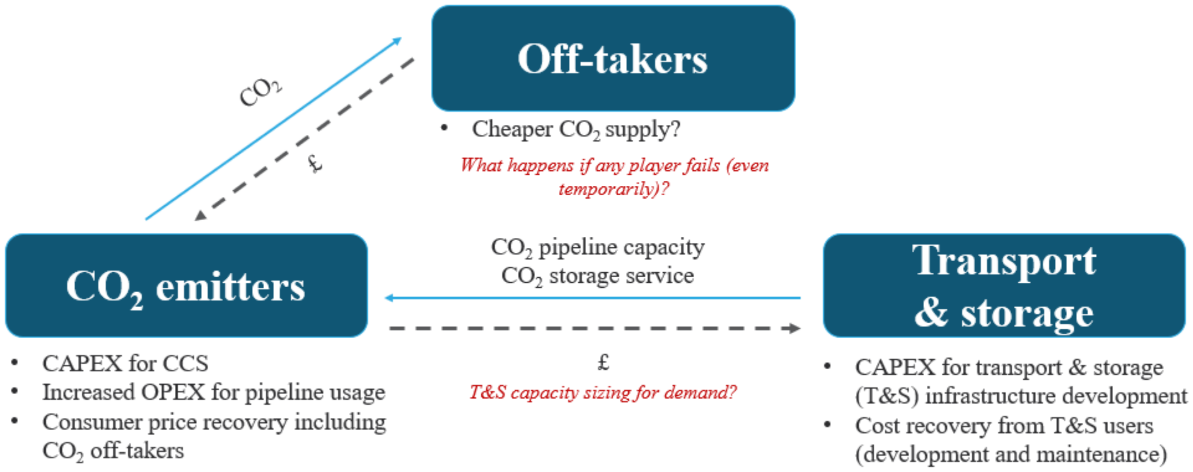


CO_2 capture points

Transport & storage

CO_2 market costs and revenues

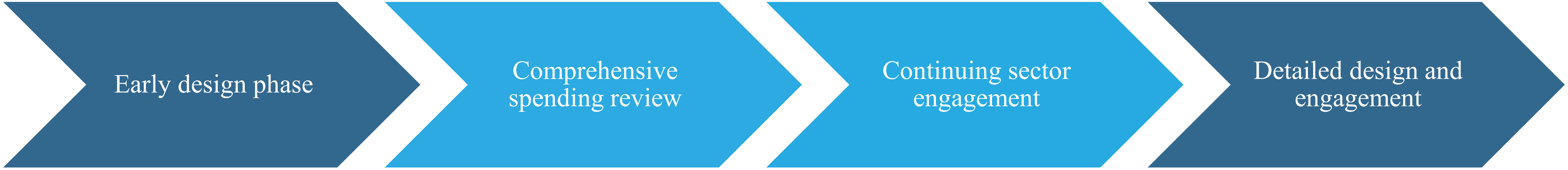
- The off-takers' price for CO_2 will include or contribute to the cost of using the transport and storage (T&S) infrastructure, whether that is for delivery by road tanker or pipeline. Off-takers are unlikely to be significant investors in any pipeline infrastructure but help pay for the T&S infrastructure.
- CO_2 emitters or capture points must find CAPEX for carbon capture equipment and CO_2 purification processes as required by their industrial operation. They also have ongoing OPEX payments for the use of the CO_2 pipeline capacity to ship the CO_2 to a point of storage and to reserve space in that storage. Finding off-takers for the CO_2 could potentially reduce the need for both pipeline capacity and storage payments. Both this CAPEX and OPEX add to the CO_2 emitter's end product cost and could make them internationally less competitive, unless all their international competitors have the same obligations.
- The CO_2 T&S owners make the case to invest in CO_2 pipelines (or CO_2 tankers – by water, road or rail) and CO_2 storage. Most in the UK are existing oil and gas operators, who will benefit from reuse of oil and gas fields assets under the North and Irish Sea and the pipelines that connect from UK coastline gas facilities to these under-sea storage areas, if they can put off decommissioning these. They will also be able to retain jobs and reuse skills of their workforces.
- Investing in further CO_2 pipelines linking up with heavy industry and re-purposing the oil and gas assets for CO_2 is risky. The question is how much is it safe to invest and how they can guarantee return on investment.



- The Industrial Clusters Mission sets out to identify the key sites with the largest groupings of CO_2 emitters, whose heavy industries have most to benefit from developing a joint plan with potential T&S owners to implement CCS and to commit to making use of those CO_2 pipelines and storage – under long term contracts. Six large industrial clusters were identified to implement early demonstrator projects at, and the first live implementations of CCS in the UK (see page 26).
- Other sites can be formed, but there is need to find a concentration of CO_2 emitters, of potential off-takers and the optimum route and mechanism to transport the CO_2 to a point of storage.

Proposed business models

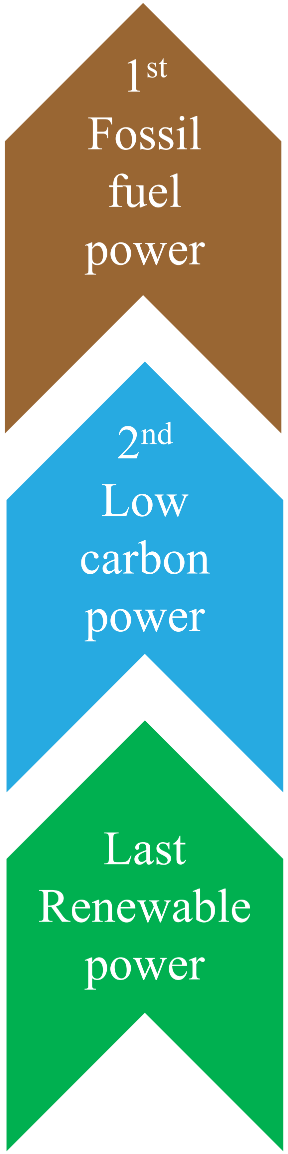
CCS sub-sector		Proposed business model (not government policy)
CO_2 emitter	Power generation	Support for construction of 'First of a Kind' (FOAK) project (subject to Control on Low Carbon Levies and value for money) Low carbon power generation support including a payment for availability generating capacity, and a variable payment (a 'Dispatchable Contract for Difference' (CfD)*)
	Hydrogen generation	Could include capital support using CCS Infrastructure Fund (CIF) option, supporting Blue & Green Hydrogen production
	Industrial plant	Upfront capital support and an industrial CfD for OPEX and CAPEX recovery (in and outside clusters)
CO_2 Transport & storage		Supporting all forms of CO_2 capture Regulated Asset Base (RAB) model funding periods with licence requirements. CIF support for FOAK projects.



*A Dispatchable CfD would use a dynamic strike price (linked to comparable but unabated power generators) with a fixed availability-based payment to maintain the merit order as input fuel (e.g. gas) prices changes (see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/819348/Cornwall_Insight_WSP_-_Market_based_frameworks_power_CCUS.pdf)

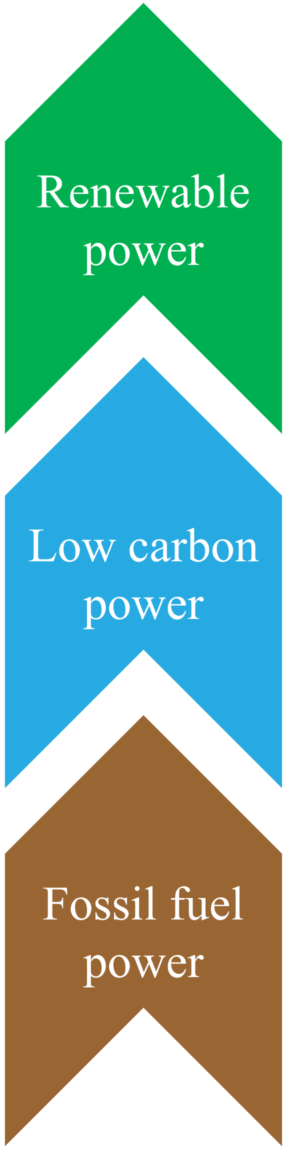
Carbon Capture, Usage and Storage – A Government Response on potential business models for Carbon Capture, Usage and Storage, Aug 2020

Power Merit Order and Dispatchable CfD



In the past, the Electricity System Operator (ESO) had a gross mandatory pool which determined the dispatch schedule. Fossil fuel-generated power dominated the market followed by nuclear. There was very little renewable power in the market (mainly Hydro-power).

Currently the market determines the power merit order based on the marginal cost per unit of power generation. Due to its low running costs, renewable power frequently tops the merit order and is used first.



This is not Government policy

In the future, if the Government decided to strengthen carbon pricing, then for WtE generating power from biogenic sources with CCUS, the merit order might change to recognise net negative emissions (i.e. 'renewable power generation').

A dispatchable CfD for this type of plant could be used to incentivise power production from net negative approaches over even renewables.

Before this could be considered, further UK Government work and industry consultation would be required to inform very careful design of the CfD so as to maximise whole energy system benefits from a wide range of technologies.

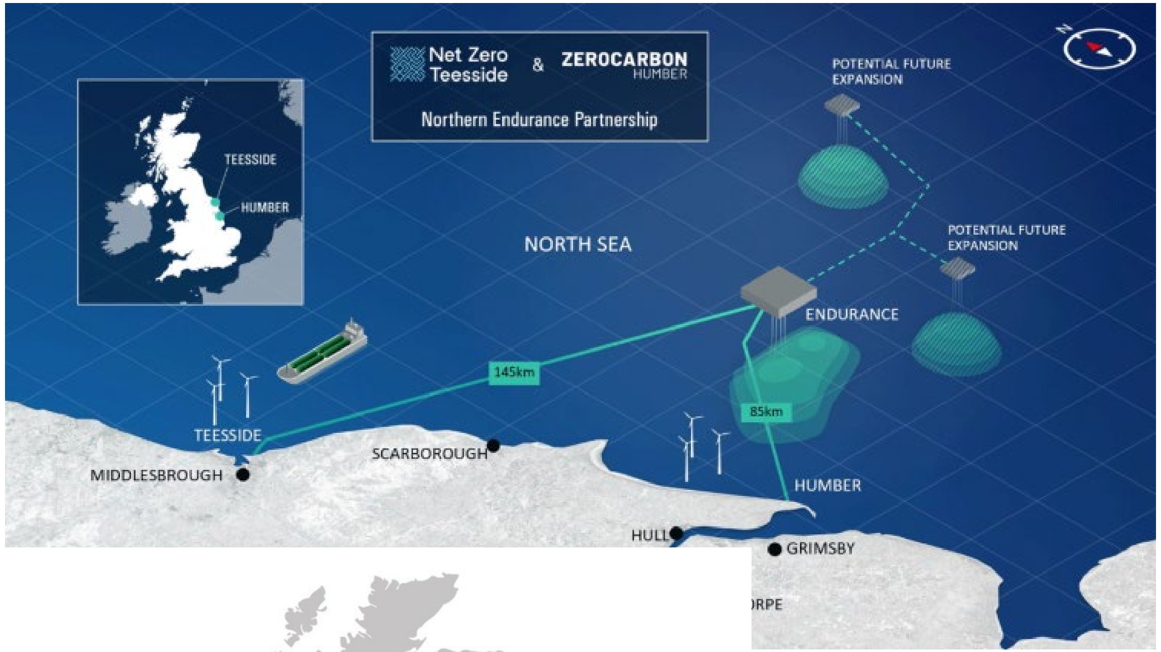
Planned industrial clusters

Six major industrial clusters

- **Scotland** – Where a third of the UK's gas supply lands
- **Teesside (Net Zero Teesside)** – Second largest English industrial cluster
- **North West** – Home of the HyNet project
- **Humberside (Zero Carbon Humber)** – UK's largest industrial cluster with three areas in close proximity
- **South Wales** – Welsh industrial heartland, dominated by Steel manufacture
- **Southampton** – UK's largest oil refinery operation (Exxon-Mobil)

Possible future CCUS/H_2 cluster

- **Project Cavendish** – Isle of Grain, Blue H_2 production with CO_2 capture for London supply (red dot on map of UK)



BP

Industrial Decarbonisation Research and Innovation Centre

Project Cavendish

- **Location:** Isle of Grain, Kent
- **Developer:** National Grid, Cadent, SGN
- **Arup role:** Feasibility study
- By 2040 create a zero-carbon, sustainable, hydrogen production facility providing London, and parts of south east England, with a zero-carbon energy for transport, industrial use, power and heating, as well as supporting economic growth.
- Possibly closest location to NLHPP for future interchange of carbon storage.

Arup

Timeline for CCUS deployment

2010

- Initial legislation & policy
- Failed CCS pilot
- New funding for CCUS demonstrator projects
- Industrial cluster formation & planning
- Business model negotiations
- The CCS Infrastructure Fund: Delivery of CCUS in one cluster by the mid-2020s

2020

- The CCS Infrastructure Fund: Delivery of CCUS in a second cluster by 2030, including infrastructure to support the construction of a gas CCS power station by 2030
- The Industrial Clusters Mission to establish at least one low-carbon cluster by 2030

2030

- The Industrial Clusters Mission: Establish the world's first net zero carbon industrial cluster by 2040

2040

- The Industrial Clusters Mission: Support the UK reaching net zero emissions by 2050

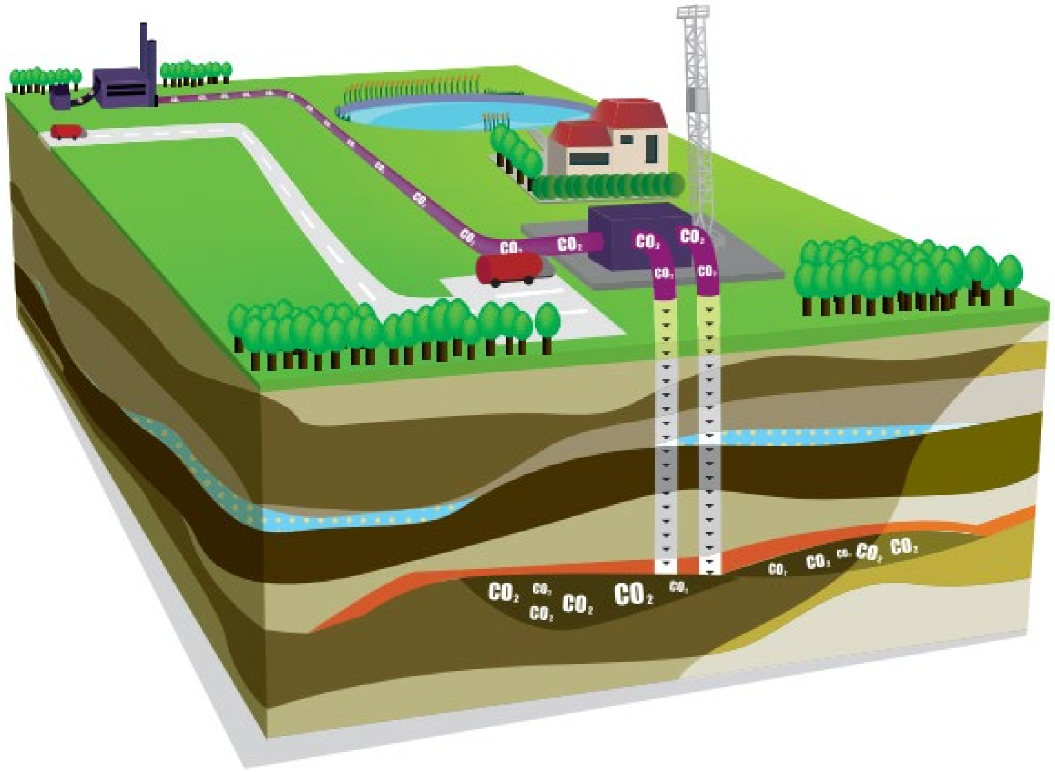
2050

4. International deployment of CCUS

Europe – Legislation

- CCUS is one of the seven building blocks in the European Commission's vision for a climate neutral Europe by 2050.
- CCS Directive (2019) – establishes robust legal framework for the safe geological storage of CO_2; it gives priority to the protection of the environment and human health, aiming to minimise risks and eliminate any negative effects.
- EU Member States are free to choose whether to allow geological storage of CO_2; if a country chooses to allow the activity in its territory, it must comply with the CCS Directive.
- The storage permit is the key tool in ensuring that CCUS takes place in an environmentally safe way and sites may not operate without one.

European Commission



Europe – Case studies of WtE facilities with CCUS

- **AVR Duiven, The Netherlands**: Commercial CCUS facility, capturing CO_2 six months/annum providing CO_2 to greenhouse farming sector in nearby areas, capturing 12 tonnes CO_2/hour (i.e. over 60,000 tonnes CO_2/annum).
- **Twence Hengelo, The Netherlands**: Test facility operations completed, and currently underway to becoming commercial, planned to capture up to 100,000 tonnes CO_2/annum, re-using some of captured CO_2 in the production of sodium bicarbonate ($NaHCO_3$), liquefied CO_2 is sold to customers for use in agricultural and industrial applications.
- **Fortum Klemetsrud, Norway** (see next slide for details).

AVR Duiven

Europe – Focus on WtE plant in Klemetsrud, Oslo

- **Carbon capture and transport in Oslo**: goal to capture approx. 400,000 tonnes CO_2/annum (both biogenic and non-biogenic), CO_2 transport via emission free cars, successful pilot testing on real flue gas, captured 90% of CO_2 in flue gas, using a technology supplier with full scale experience (Shell/Cansolv capture technology).
- **Pilot plant**: February 2019 test operation started, December 2019 CCS pilot shut down.
- WtE plant in Klemetsrud first one with CCS in network – a starting point for learning, development and cost cutting; ***Main KPIs: capture efficiency, energy requirement, solvent degradation, solvent emissions***.

Fortum Oslo Varme

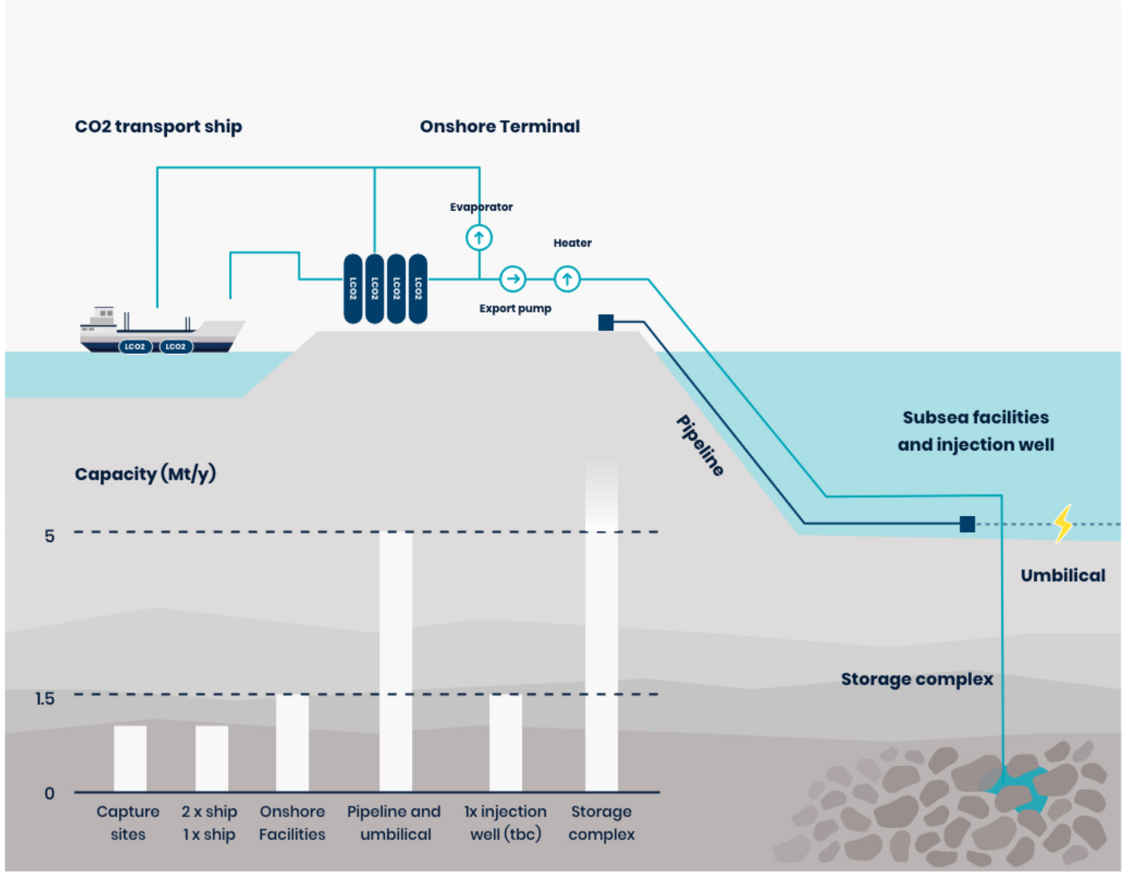
Europe - Northern Lights

Carbon capture

- **Norcem Brevik,** which may become the world's first cement factory equipped with a CO_2 capture plant.
- **Fortum Oslo Varme** plans to capture CO_2 from their WtE facility in Oslo.

Carbon transport and storage

- **Equinor, Shell and Total** plan to develop an open access infrastructure for CO_2 transport and storage; the three companies made an initial investment of $680million between them; of which approx. 57% will go toward Norwegian contractors.
- Phase 1 (to be operational by 2024) includes capacity to transport, inject, and store up to 1.5 million tonnes of CO_2/annum; once the CO_2 is captured onshore, it will be transported by ships, injected and permanently stored approximately 3,000m below the seabed in the North Sea.

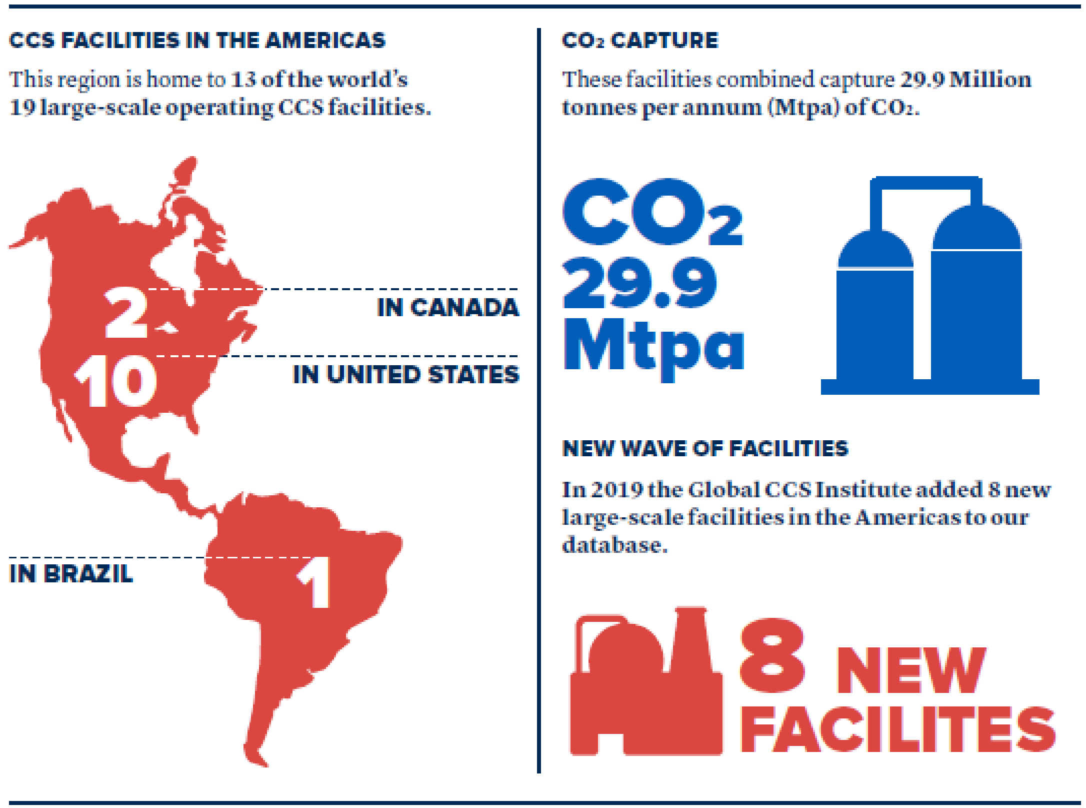


Northern Lights project

USA – Legislation

- Section 45Q of the Internal Revenue Code establishes tax credits for storage of CO_2; congress extended and increased these in 2018 so they provide for USD35/tonne of CO_2 permanently stored via enhanced oil recovery and USD50/tonne of CO_2 stored geologically – if projects commence construction by 2024.

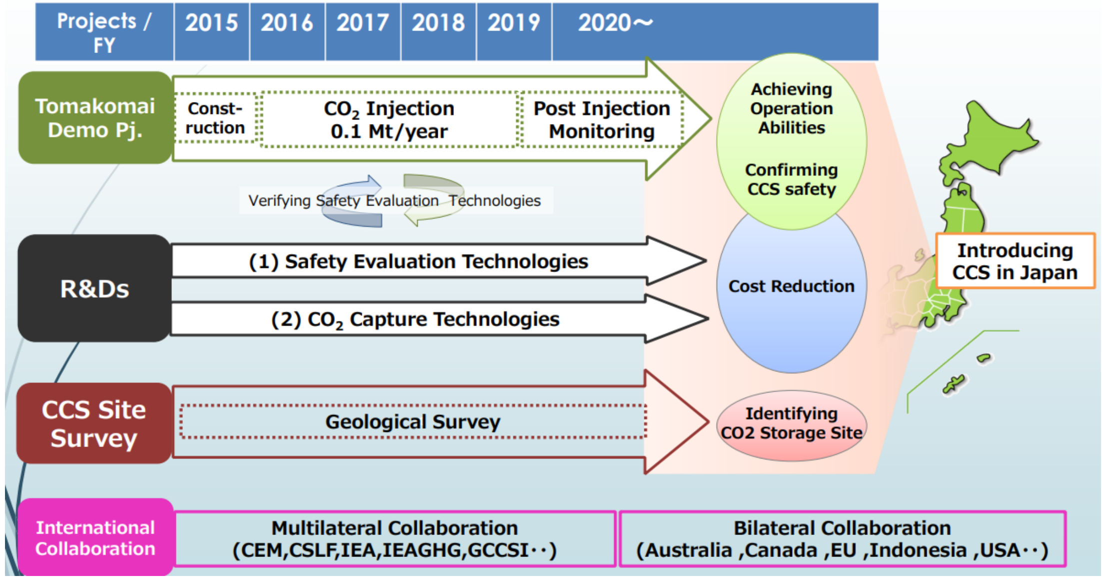
- Although seen as the world's most progressive CCUS-specific incentive, Section 45Q is yet to be formally implemented, creating ambiguity about which projects are eligible.



Global CCS Institute

Japan – Legislation and case study

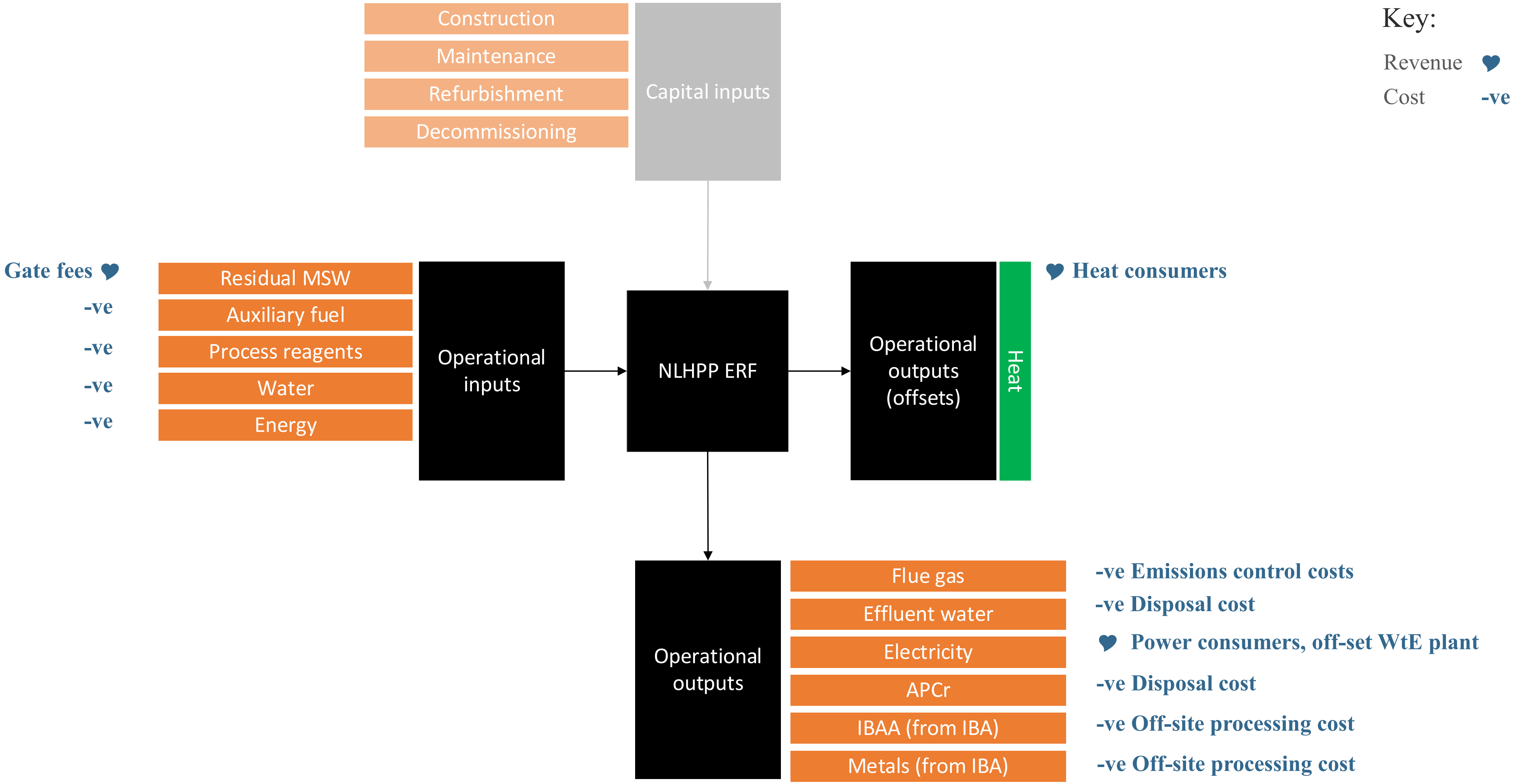
- Japan's Long-term Climate Strategy, 2019: Committed to commercialising CCU technology by 2023, and CCS used in coal-fired power generation by 2030.
- It also aims to slash production costs of H_2 to less than one-tenth by 2050.
- The plan was criticised for not tackling the country's coal dependency; coal powered 33% of the country's electricity in 2015.
- A CCUS study group consisting of research institutions in Japan, was set up to explore ways of supplying alternative energy combining industrial CO_2 emissions with H_2 produced from renewable energy sources.
- **Toshiba Saga City, Japan:** Commercial CCUS facility, with the captured CO_2 being used to cultivate crops and create algae cultures in the local agriculture sector, capturing 10 tonnes/day (i.e. over 3,000 tonnes CO_2/annum).



METI, Japan

5. CCUS development for the ERF

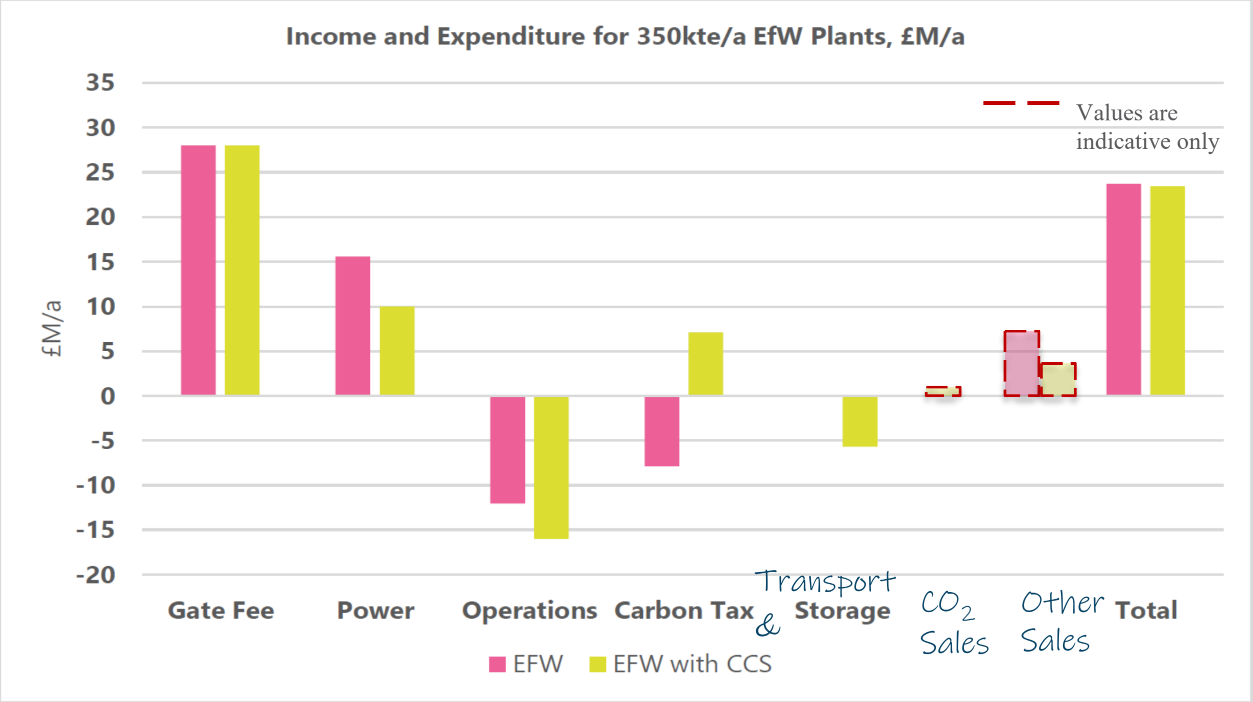
ERF current business model



ERF potential future business model (with CCUS)

- In the adjacent image, a WtE plant's revenues and costs are compared before and after a theoretical CCS plant implementation.
- This is based on the Energy Systems Catapult (ESC) report credited, but used to provide a general picture of how these might change.
- Gate fees would remain unchanged.
- Power revenues are reduced as more self-generated power produced by the CHP plant is needed to run the CCS.
- Operational costs are increased (e.g. power, amine feedstock for capture processes) after implementation of CCS.
- In this model, the WtE plant pays carbon tax on the non-biogenic CO_2 emitted and receives a tax credit for biogenic CO_2 captured and stored.
- The plant has to pay a cost per tonne of CO_2 transported and stored.
- CO_2 sales values to off-takers are thought to be very low value.
- Other Sales (e.g. heat) will reduce as some of the heat output from the CHP plant is needed for the carbon capture process.

Based on ESC report credited



Energy Systems Catapult – Energy from Waste Plants with Carbon Capture, May 2020

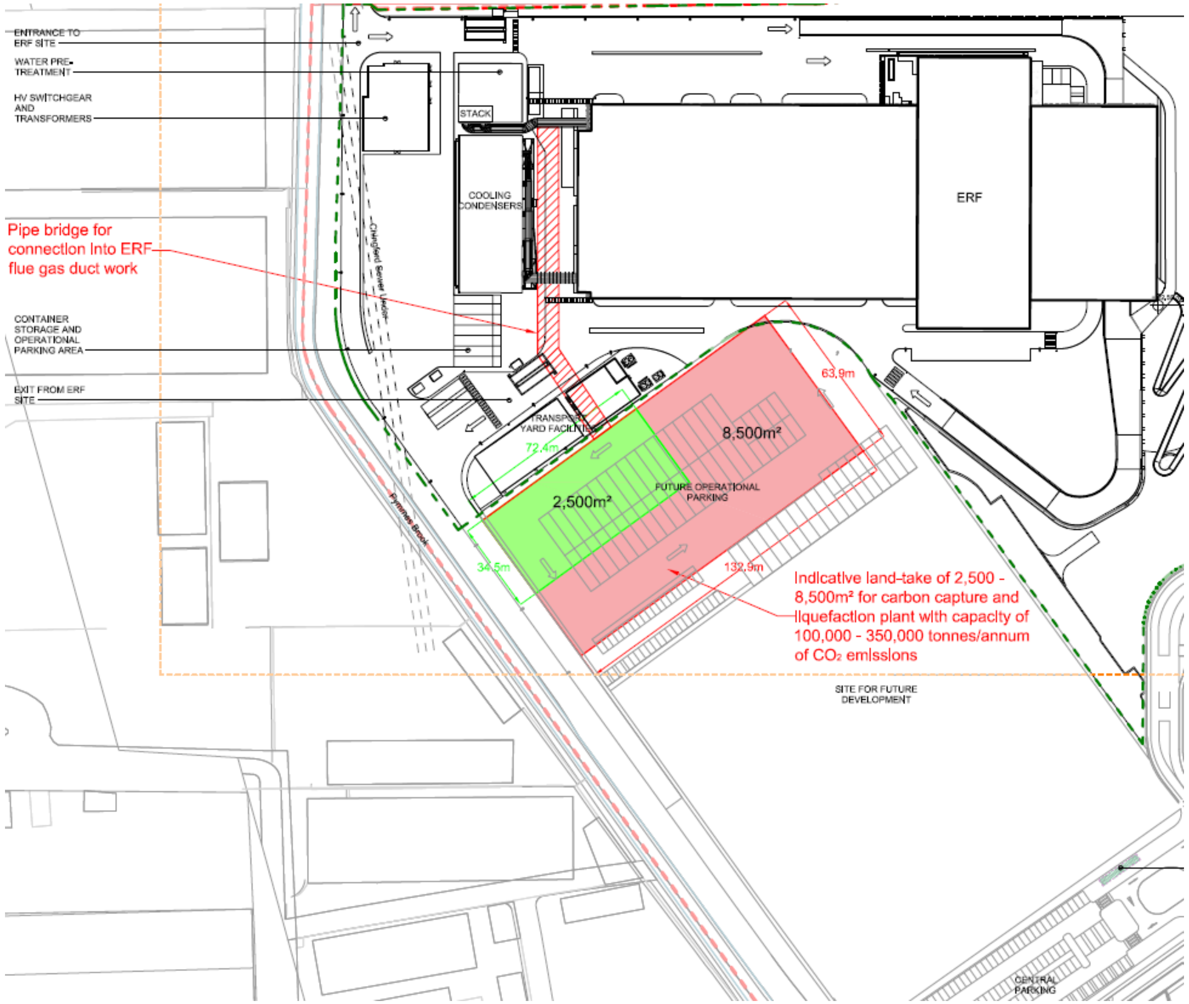
On-site carbon capture

- CAPEX for a standard modular 100,000 tonnes CO_2/annum plant comprising carbon capture, liquefaction, on-site storage and vehicle loading is approximately £26M (excluding costs for utility systems, ground hazards, building, mobile plant, taxes)*. Some public domain information suggests that the deployment costs for CCUS are currently as high as €3,000-5,000/tonne of waste treated.[8]

- OPEX of capturing direct CO_2 emissions (assumed at 100,000 tonnes CO_2/annum) could cost between £500,000-1,600,000/annum; assuming that the OPEX ranges between 2-6% of the CAPEX of the carbon capture plant (excluding transport and storage costs).[1] OPEX figures include cost of utilities (water, power), cost of amine (typical 0.2kg/tonne CO_2), annual maintenance cost, additional personnel (i.e. plant manager and one person to support and follow-up the plant) and no additional control room operators.

- The efficiency loss relative to the base facility (i.e. the ERF) is dependent on the base facility technology. The net power efficiency of a WtE facility due to post-combustion capture, drops by 8-12%, on average.

- The CAPEX and OPEX for capturing both the biogenic and non-biogenic carbon emissions (i.e. 700,000 tonnes CO_2/annum), therefore achieving negative emissions via CCUS alone, would be significantly higher, but may benefit from economies of scale and therefore, providing high level estimates may not be indicative.



- ***Disclaimer:*** **CCUS feasibility study to review development costs (incl CAPEX and OPEX)**

* Initial discussions with potential carbon capture technology suppliers for WtE

Potential carbon emitters and end-users in London and the South East

Chemicals

- TDG - Dagenham Chemical Terminal (London)
- Gasrec - Albury Biodiesel Plant (Surrey)
- Aesica - Queenborough 2 Pharmaceutical Plant (Kent)

Cement

- Cemex UK, Tilbury Cement and Ash Plant (Essex)
- Hanson UK, Purfleet Works (Essex)

Paper and pulp

- Smurfit Kappa - Snodland Recycling Paper Mill (Kent)
- DS Smith - Kemsley Recycled Paper Mill (Kent)
- ArjoWiggins - Chartham Paper Mill (Kent)

Glass

- O-I Manufacturing UK Ltd, Harlow (Essex)

Ceramics

- Wienerberger – Smeed Dean Brick Plant (Kent)
- Ibstock – South Holmwood Brick Plan (Surrey)
- Wienerberger – Ewhurst Brick Plant (Surrey)
- Ibstock - West Hoathley Brick Plant (West Sussex)

Oil refining

- Petroplus – Coryton Oil Refinery (Essex)

Food and drink

- Coca-Cola Edmonton Plant (London)
- 2 Sisters - Witham Meat Processing Plant (Essex)
- Tate & Lyle - Thames Sugar Refining Mill (London)
- Ragus - Slough Sugar Refining Mill (Berkshire)
- McVitie's - Harlesden Biscuit Plant (London)
- UCC - Dartford Coffee Mill (Kent)
- Mars - Slough Chocolate Plant (Berkshire)
- Shepherd Neame - Faversham Brewery (Kent)
- Coca-Cola - Sidcup Soft Drinks Plant (Kent)
- Britvic - Beckton Soft Drinks Plant (London)
- Fuller's - Chiswick Brewery (London)
- Ridley's - Hartford End Brewery (Essex)

Horticulture/ algaculture

- Growing Communities - Community Supported Agriculture (London)
- Sutton Community Farm - Community Supported Agriculture (London)
- Grace and Flavour - Community Supported Agriculture (London)
- FoodSmiles St Albans - Community Supported Agriculture (London)
- Barbican Conservatory (London)
- Petersham Nurseries (London)
- Grow Up Farms – Vertical Indoor Farming (London)
- AlgaeCytes – Algal oil production (Kent)
- Europa Nursery (Kent)

Iron and steel

- None

+ Project Developers and other Cluster Stakeholders

6. Next steps

Summary

Keep up-to-date with government plans

- NLWA to keep up-to-date with BEIS CCUS announcements and record them in an updated version of this Technical Note, at least every six months (or sooner if major new information becomes available)

Network with stakeholders

- Join Carbon Capture & Storage Association (CCSA)
- Engage with Project Cavendish
- Arup to introduce NLWA to both CCSA and Project Cavendish
- Engage with local gas distribution network operator (i.e. Cadent) on wayleaves and gas supply capacity, to understand what their plans are for supplying hydrogen to Greater London

Develop an overarching approach to CCUS for ERF

- Develop an NLHPP CCUS strategy (see next page)

iStock.com/teekid

CCUS strategy development

IEA

Carbon objectives, risks and opportunities

- Incorporate carbon objectives of the NLHPP as set out in the carbon management strategy, in the decision making for a future CCUS solution for the ERF (e.g. a target to achieve carbon neutrality may determine the CO_2 emissions to be captured annually from the ERF)
- Identify any risks and opportunities that future changes to carbon pricing and compliance associated with WtE facilities may pose on the ERF (e.g. any potential future taxation, UK ETS requirements)
- Identify opportunities for connecting to CO_2 transport and storage networks being developed across the UK

Detailed studies

- Carry out a feasibility study for adding a carbon capture, liquefaction and temporary CO_2 storage infrastructure at the Edmonton EcoPark for the CO_2 emissions of the ERF
- Carry out a detailed market study for CO_2 off-takers in the catchment area of the Edmonton EcoPark (i.e. London and areas such as Essex and Hertfordshire) and discuss options for industrial symbiosis/ cluster creation

Environmental impacts

- Carry out a lifecycle analysis of the CCUS infrastructure chosen to be used for capturing the CO_2 emissions of the ERF, in order to quantify the environmental impacts at each stage of the CCUS process for the ERF

7. References

References

1. BEIS (2017), *Cement Sector Joint Industry – Government Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan,* Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651222/cement-decarbonisation-action-plan.pdf (Accessed 27 October 2020).

2. Food and Drink Federation (2018), *Falling flat: lessons from the 2018 UK CO_2 shortage*, Available at: https://www.fdf.org.uk/publicgeneral/falling-flat-lessons-from-the-2018-UK-CO2-shortage.pdf (Accessed 27 October 2020).

3. UK Government (2020), *Carbon capture usage and storage*, Available at: https://commonslibrary.parliament.uk/research-briefings/cbp-8841/ (Accessed 27 October 2020).

4. UK Research and Innovation, Available at: www.ukri.org/innovation/industrial-strategy-challenge-fund/industrial-decarbonisation/ (Accessed 27 October 2020).

5. BEIS (2017), *Industrial Decarbonisation and Energy Efficiency Action Plans*, Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651276/decarbonisation-action-plans-summary.pdf (Accessed 27 October 2020).

6. Catapult Energy Systems (2020), *Energy from Waste Plants with Carbon Capture*, Available at: https://es.catapult.org.uk/reports/energy-from-waste-plants-with-carbon-capture/ (Accessed 27 October 2020).

7. Food and Drink Federation (2018), *Falling flat: lessons from the 2018 UK CO_2 shortage*, Available at: https://www.fdf.org.uk/publicgeneral/falling-flat-lessons-from-the-2018-UK-CO2-shortage.pdf (Accessed 27 October 2020).

8. Refinitiv (2018), *Will high European carbon prices last?*, Available at: https://www.refinitiv.com/perspectives/market-insights/will-high-european-carbon-prices-last/ (Accessed 17 March 2020).

Appendix 1

Appendix 1

Horizon scanning workshop input from participants

Topic	Comment
Carbon pricing	Government has also talked about introducing an incineration tax.
	Payment from carbon tax assumes a CfD or ETS in place ... not government policy, so significant risk associated with that assumption.
	If people are paying £40/tonne to dispose of CO_2, there will not also be a market available to sell CO_2 at £40/tonne. That makes no sense.
	An ETS will be beneficial for an EfW plant that is able to capture CO_2 to create negative emissions.
Carbon use	Horticulture is certainly viable for incineration emissions ... tomatoes grow really well at 1,500 ppm CO_2. Netherlands is an excellent example of that, as just commented.
	May have to check that horticulture is classed as carbon reuse. Most escapes via the glasshouse venting.
	Food & Drinks manufacturers will not accept CO_2 produced from waste incinerators ... I have asked previously for another client ... any food company could be ruined by bad publicity related to the quality of their feed.
	There is a Coca Cola bottling plant almost next to EcoPark.
	I think you mention Carbon8 somewhere in the presentation ... they utilise IBA with CO_2 from the exhaust gas to generate aggregate blocks. Could something like this be co-located with your facility?
CCUS business models	Yes you could probably offset some of the emissions by turning the CO_2 into an aggregate but those processes will take - what - a few thousand tonnes per year? So the lion's share will still need to go to T&S and should be the basis; you might get a bit of a positive surprise if you can sell some to someone
	RAB on the CCS T&S is more akin to new nuclear rather than existing natural gas assets and we need to consider how well that conversation is going. A dispatchable two-step CfD will have a huge effect on your ability to get revenue if renewables are being dispatched and the ability to be carbon negative is really going to be important if you are going to commit to a 2-part CfD.
	EcoPark is next to River Lee navigation which actually links, Hoddesdon power station (CCGT) with NLHPP and the Thames. The Thames also has 2 x Riverside ERFs on the way to Isle of Grain terminal. Not a short pipeline but does this look like an attractive hub for pipeline transport.

Appendix 1

Horizon scanning workshop input from participants

Topic	Comment
Decarbonisation potential	The bigger decarbonisation prize is replacement of natural gas in domestic supplies. If you replace natural gas with blue hydrogen across London there will be a lot of CO_2 needing to be exported ... enough for an export pipeline that you can tie into.
	I think the EfW emissions include both biogenic and non-biogenic. This is an opportunity to become carbon negative which should be highlighted versus other industries.
	It's worth pointing out that the other industries mentioned typically burn natural gas where the capture process is a lot more straightforward than waste.
UK CCUS clusters	There are already six industrial clusters formed and Government has only committed to getting two operational by 2030. This region is unlikely to get an export system for 15 years. But, if your plant life is 50 years, you need to design for retrofit now. The main issue we have seen with potential retrofit on existing 'carbon capture ready' plant is that there is not sufficient room allowed for tie-in of the ducts and cut routing to the carbon capture plant.
	There is an established plan for the South Wales Industrial Cluster, with a pipeline along the south coast and ship export from Pembrokeshire. Tata Steel is signed up on an MOU with Northern Lights.

ARUP