Welsh Parliament
Senedd Research

Carbon Capture Utilisation and Storage (CCUS) in Wales
Research Briefing

September 2022

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Overview:
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Contents

1. Background

Carbon dioxide (CO_2) is a greenhouse gas and is released through natural processes such as volcano eruptions and human activities, including burning fossil fuels. Human activities have increased the atmospheric concentration of CO_2 by over 50 per cent since the start of the industrial revolution.

The increasing concentration of CO_2 and other greenhouse gases in the atmosphere **is driving climate change** and increasing the average global temperature and frequency and severity of **extreme weather events**. **The leading sources of CO_2 emissions in Wales** are industrial and domestic use of fossil fuels for heat and power, agriculture, transport, and international aviation.

In April 2019, **the Welsh Government declared a climate emergency**. In March 2021, the **Senedd legislated for a series of emissions targets** to reach net-zero emissions by 2050 to combat climate change. In its **second emission reduction plan**, the Welsh Government identified four main routes to CO_2 emissions reduction in Wales:

- resource and energy efficiency;
- substituting fossil fuels with low-carbon fuels;
- increasing the efficiency of buildings; and
- capturing and storing surplus CO_2 emissions.

Carbon capture utilisation and storage (CCUS) is a series of processes that capture CO_2 from waste gases produced by industrial processes (such as steelmaking) and either:

1. permanently store it in offshore geological storage sites (carbon capture and storage; CCS); or
2. reuse it to produce chemicals, minerals, and synthetic fuels (carbon capture and utilisation; CCU).

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change and provides a scientific basis for governments to develop climate policies. The IPCC use **integrated assessment models (IAMs)** to predict future emissions scenarios. IAMs combine models of energy technologies with economic and climate models. The IAMs produce pathways for reaching emissions targets and quantify the **consequences if they are not met.** CCS is a **critical technology** in most emissions reduction pathways modelled by the IPCC.

This briefing provides a scientific and technological background to CCUS. It outlines the role CCUS could play toward achieving Welsh emissions targets and the sector-specific opportunities for CCUS in Wales. It also summarises the function of CCUS-enabled power generation in a future low-carbon electricity grid and provides a wider policy context for Wales and the UK.

2. What is Carbon Capture Utilisation and Storage (CCUS) and how does it work?

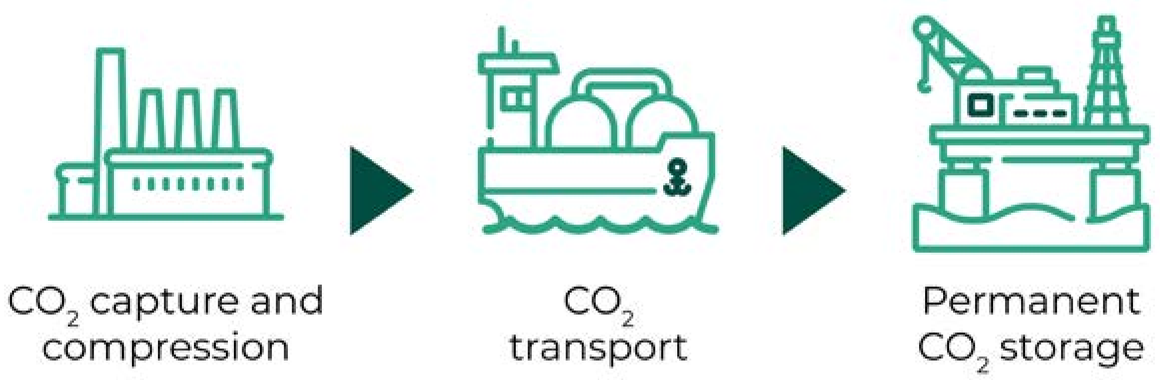
CCUS is not a single technology or process but a series of CO_2 capture, transport and utilisation or storage processes.

High purity CO_2 is needed to efficiently use storage sites and reduce transportation energy requirements. CO_2 typically makes up around 10 to 40 per cent of industrial waste gases by volume, so a CO_2 capture unit is needed to produce high purity CO_2 by removing it from industrial waste gases.

The following steps occur for natural gas-powered electricity generation with CCS:

- CO_2 is produced when natural gas is combusted to provide heat to produce electricity;
- CO_2 exits the combustor in the waste gas, which is made up primarily of nitrogen and CO_2;
- the waste gas is fed into a carbon capture unit to remove the CO_2 by reacting it with a chemical solvent;
- the CO_2-loaded solvent is transported to a regenerator where it is heated to regenerate the solvent and release CO_2; and
- the CO_2 is compressed to a liquid for transportation to a storage site where it is pumped into a deep, geologically-secure reservoir.

Figure 1: The basic principle of the CCS system



Source: Senedd Research from Bellona, **CCS**

Carbon capture can reduce the CO_2 emissions of industrial waste gases by 90 to 95 per cent. However, the true emissions reduction potential of CCUS is sector-specific and depends on the energy intensity of the CO_2 capture, transport and storage steps.

Life cycle assessments (LCAs) are used to analyse the true emissions reduction potential of decarbonisation technologies. There is no standard method, and differences in assumptions make comparing LCAs difficult.

Carbon capture

Many sectors can be decarbonised using CCS, including:

- power: low-carbon electricity can be generated by removing CO_2 from the waste gas following fossil fuel or biomass combustion;
- hydrogen: 'blue' hydrogen is produced by methane reforming with CCS and can be used as a source of low-carbon energy for industry, transport, energy storage, and heat; and
- industry: the production of iron and steel, cement, paper, glass, and agricultural fertiliser can be decarbonised by removing CO_2 at specific stages of each process.

Current advanced CO_2 capture technologies include:

- chemical solvents: CO_2 is removed from a waste gas by chemically absorbing it into a solvent and captured by heating the solvent;
- solid adsorbents: CO_2 adsorbs onto the surface of a porous solid and is captured by changing the temperature or pressure; and
- membranes: semi-permeable materials are used to selectively allow specific gases to pass through to capture CO_2 from a waste stream.

Capturing CO_2 requires additional energy, which lowers the efficiency of the overall industrial process and increases operating and capital costs. Cost is one of the **main barriers** to large-scale deployment and commercialisation of CCS.

Because of the high capital and energy costs, capture is the most expensive part of CCS. The capture cost is lowest for large waste streams with high concentrations of CO_2. Research and development and learning by doing will help to **bring down costs**.

Transport

Ideally, CO_2 would be stored or used where it is captured. Transportation by pipeline, ship or road to a site for storage or utilisation increases overall costs.

Pipeline transport is well-established. Globally, over **6,500 km of CO_2 pipelines were in operation in 2014** – most were used for enhanced oil recovery (EOR) in the United States. The CO_2 is transported using pipelines as a liquid at high pressure (>1000psi). Pipeline transport is considered the most economical transport option **below 1,500 km**.

Shipping CO_2 to a storage site is an option for industries on coastlines and rivers without access to pipelines. Shipping CO_2 is a relatively mature process, **though it is currently limited to small volumes**.

Operating costs are the main factor in **shipping costs**, unlike pipeline transport, where capital costs are the main cost factor. The reduction of this cost is a key barrier to their use. Additional barriers include regulations, port constraints and the lack of business models.

The food and beverage industry uses CO_2 tankers to transport food grade CO_2 by road. Due to logistical and cost barriers, road transport **would potentially only be used by smaller sites** where no other decarbonisation options are available.

In 2017, **the UK Government committed** to developing industrial clusters to deploy CCS and low carbon hydrogen in the UK. The industrial cluster strategy groups nearby CO_2-intensive industries into clusters. The clusters can develop and use shared transportation and storage infrastructure to lower the overall risks and costs associated with CCS projects.

Storage

For long-term removal, CO_2 must be permanently stored underground in suitable geological formations, such as depleted oil and gas fields or saline aquifers. Storage depths typically range from one to five km. The depleted North Sea oil and gas fields are estimated to **meet all the UK storage requirements.**

Many commercial CCS projects already store CO_2 for EOR in the United States, so there is a lot of experience and knowledge in this area. Risks of leaks from storage sites are estimated to be very low, with research showing that 98 per cent of the CO_2 can **remain trapped for 10,000 years if the site is appropriately selected**.

The Storage of Carbon Dioxide (Termination of Licences) Regulations 2011 set the obligations related to post-injection monitoring. The permit holder must conduct appropriate monitoring and necessary work to ensure the storage site is returned to the requisite state. The post-closure monitoring period will be no less than 20 years. However, the Oil and Gas Authority can reduce this time if the transfer conditions are met.

Utilisation

In CCU, captured CO_2 is used to produce a 'value-added product' instead of storing it deep underground. However, most CCU products **rarely store CO_2 for long periods**, and the **large energy requirements** of many CCU processes produce additional emissions.

CCU pathways can be divided into two categories:

1. Direct use: captured CO_2 is used directly within a commercial process, such as:

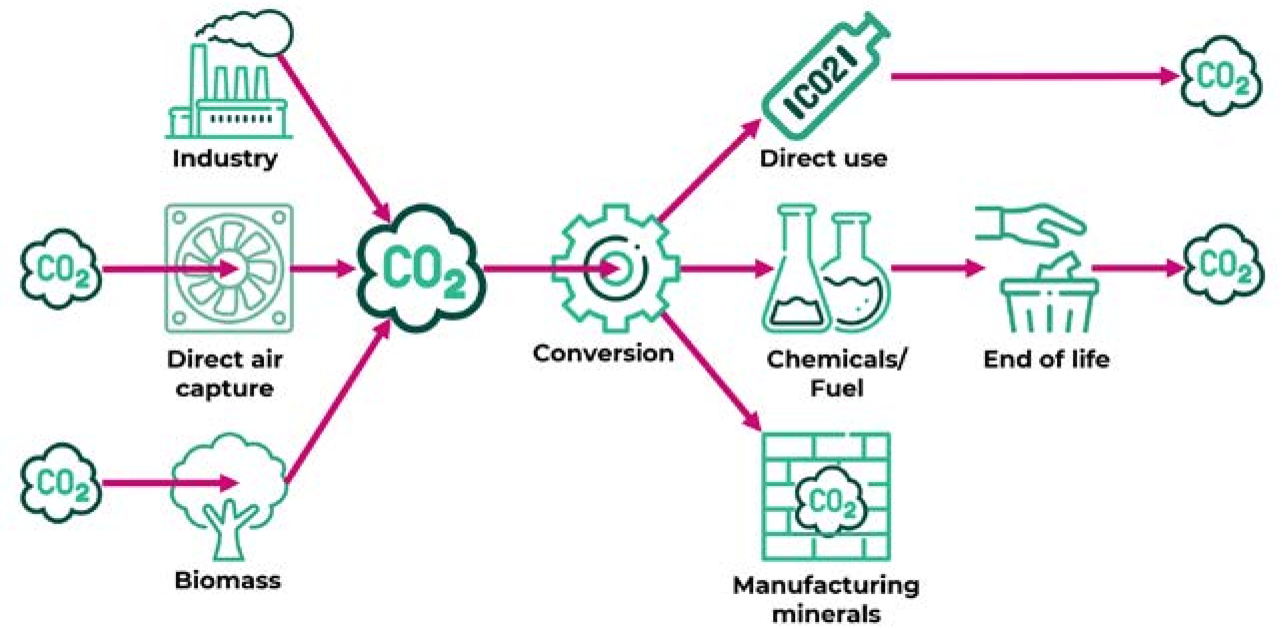
- enhanced oil recovery (EOR): CO_2 is injected into oil reservoirs to increase the production of an oil well. The CO_2 can be permanently stored, and it is possible to operate EOR to enhance CO_2 storage over oil recovery.
- food and drink: CO_2 is used to carbonate drinks, for food freezing and packaging. The CO_2 is not permanently stored.

- horticulture: CO_2 can be added to greenhouses to enhance the production of crops. The CO_2 is not permanently stored.

2. Indirect use: captured CO_2 is converted into a product using a chemical or biological process, such as:

- chemicals: including polymers (plastics) and urea (fertiliser). The CO_2 is not permanently stored.
- manufacturing minerals: CO_2 can be used to strengthen concrete or carbonate industrial waste materials to produce carbonated aggregates that can be used for building materials. The CO_2 can be permanently stored.
- fuels: CO_2 can be combined with hydrogen to produce hydrocarbon fuels for transport. The CO_2 is released when the fuel is burned.

Figure 2: Fate of CO_2 in CCU Pathways



Source: Senedd Research from **Carbon capture and storage (CCS): the way forward**

CO_2 is extremely stable. When a fossil fuel is combusted, it releases the energy contained within the fuel and CO_2 is left as a low-energy waste product. Therefore a large amount of low-carbon energy (in the form of heat or electricity) and catalysts are needed to convert CO_2 into useful products. This increases the cost of the CCU product relative to the conventional product.

Each CCU pathway must be evaluated on a case-by-case basis using a suitable LCA to determine the actual net emissions benefit, if any, using a **'whole systems approach'**.

Box 1: What is a whole systems approach?

A whole systems approach investigates how a system can be broken down into parts, how these parts influence one another and how changes affect an outcome.

In a net-zero context, a whole systems approach draws connections between the complex challenges of net-zero and potential solutions to identify measures that are more likely to succeed. The approach aims to understand the complex interactions between technical solutions and other issues, including economic and behavioural.

Policymakers can use the approach to better understand how sectors, technologies, behaviours and policies interact to determine the changes needed to achieve net-zero.

Only a small fraction of the CO_2 emitted each year is needed to meet **forecasted** CCU CO_2 demand. The **International Energy Agency estimates** 8 per cent of the CO_2 captured will be used for CCU in its core Sustainable Development Scenario, 2020-2070. Around 95 per cent of that will be used as a raw material for synthetic fuel production, which is a major change from today, where the majority of CO_2 is used for EOR. A 2017 **report commissioned by the UK Government Department for Business, Energy and Industrial Strategy (BEIS)**, assessed 25 CCU pathways. It is estimated that in 2030, the demand from CCU would be less than 1 per cent of the UK's carbon emissions.

Barriers to CCU deployment include the need for high-purity CO_2, public acceptability, lack of data on potential CO_2 market sizes, and lack of market research into the cost consumers would be prepared to pay for CCU products.

In 2018, the Committee on Climate Change **stated**:

> Whilst CCU could help to facilitate progress [on CCUS] in the 2020s, the volumes 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).

Negative emissions technologies: capturing CO_2 from the air

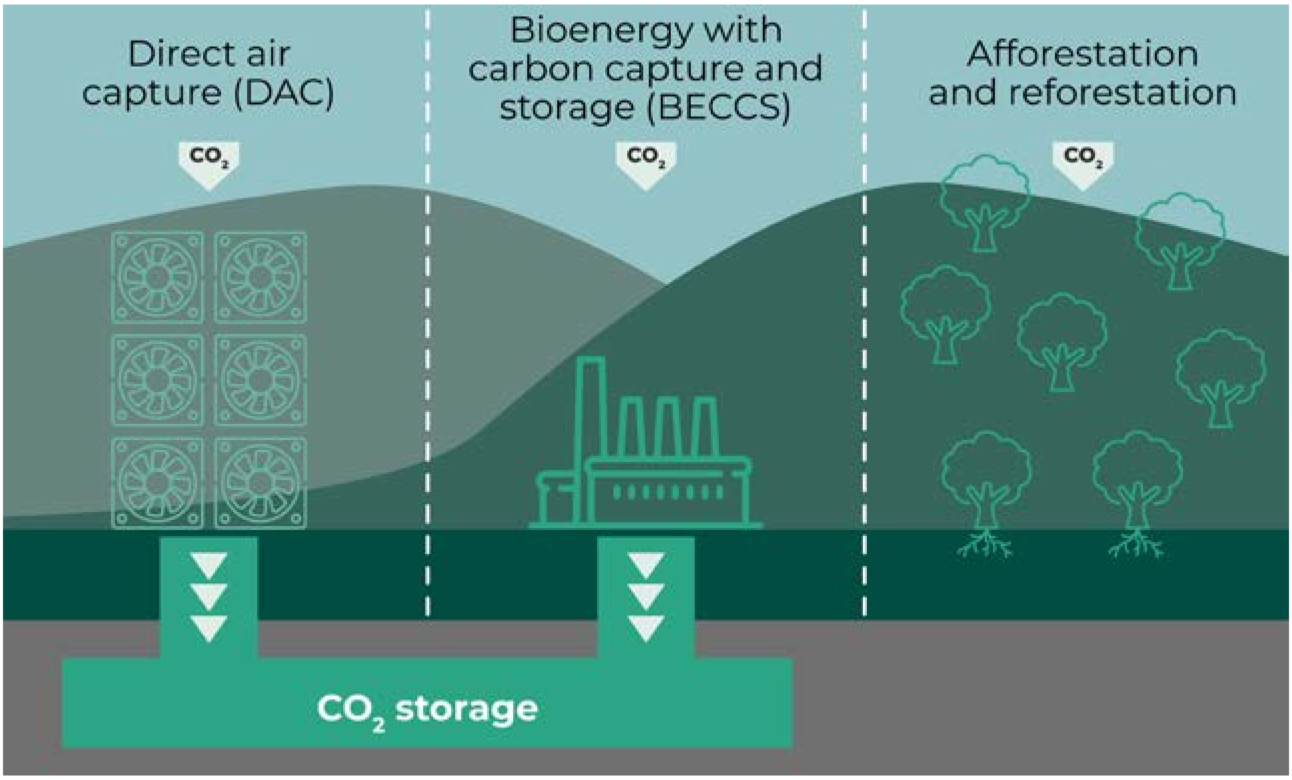
Negative emission technologies (NETs) remove CO_2 from the air and may be used to offset emissions in sectors that are difficult to decarbonise. NETs include bioenergy with carbon capture and storage (BECCS) and direct air capture with carbon capture and storage (DACCS or DAC). Greenhouse gas removal (GGR) technologies include NETs and other nature-based solutions such as planting forests and restoring peatlands.

In BECCS, crops or trees (biomass) remove CO_2 from the air as they grow and can be combusted to generate power. Negative emissions may be achieved by capturing and storing the CO_2 from the waste gas. Large scale deployment of BECCS plays a **central role in many IAMs**, but its true net emissions reduction potential is **heavily debated**. Ramping up biomass production for BECSS could create **unintended emissions** due to land clearing and harvesting, compromising food security and biodiversity.

DACCS removes CO_2 from the air using a chemical process. The concentration of CO_2 in the air is about 300 times less than from an industrial process. This makes it much harder and less efficient to capture CO_2 and means DACCS is much more expensive than capture from industrial waste gases. The **cost is estimated** to be between \$300 per tCO_2, using very cheap low-carbon electricity, and \$1,000 per tCO_2. Rapid deployment of larger scale modular DACCS plants and learning by doing could **bring these costs down**. Also, DACCS can be located next to storage sites, effectively eliminating transport costs and logistics.

The prospect of deploying low-cost NETs in the future may be more appealing than developing policies to deliver rapid and deep decarbonisation today. However, if NETs fail to deliver the significant quantity of CO_2 removals modelled in IAMs, by either failing to be deployed at the required scale or deliver the assumed environmental benefits, the world **risks significantly overshooting the 1.5°C pathway set out in the Paris Agreement**.

Figure 3: Options for GGR



Source: Senedd Research from Global CCS Institute, **carbon removal approaches**

3. Welsh climate targets

The ***Environment (Wales) Act 2016*** placed new duties on the Welsh Government to ensure the reduction of greenhouse gas emissions. It also introduced a carbon budgeting method to measure progress toward reducing emissions.

The Act set a target for an 80 per cent reduction in emissions by 2050 and a duty to set interim targets for 2020, 2030 and 2040. In 2019, the CCC **advised the Welsh Government** to amend its 2050 target and reduce emissions by 95 per cent. The Welsh Government **accepted this advice** and declared its ambition to achieve a 95 per cent reduction in emissions by 2050.

In February 2021, the Welsh Government **laid four further sets of regulations**, these:

- amended the 2050 emissions target to net-zero;
- increased the 2030 target to 63 per cent (from 45 per cent) and the 2040 target to 89 per cent (from 67 per cent); and

- set the third carbon budget (2026-2030).

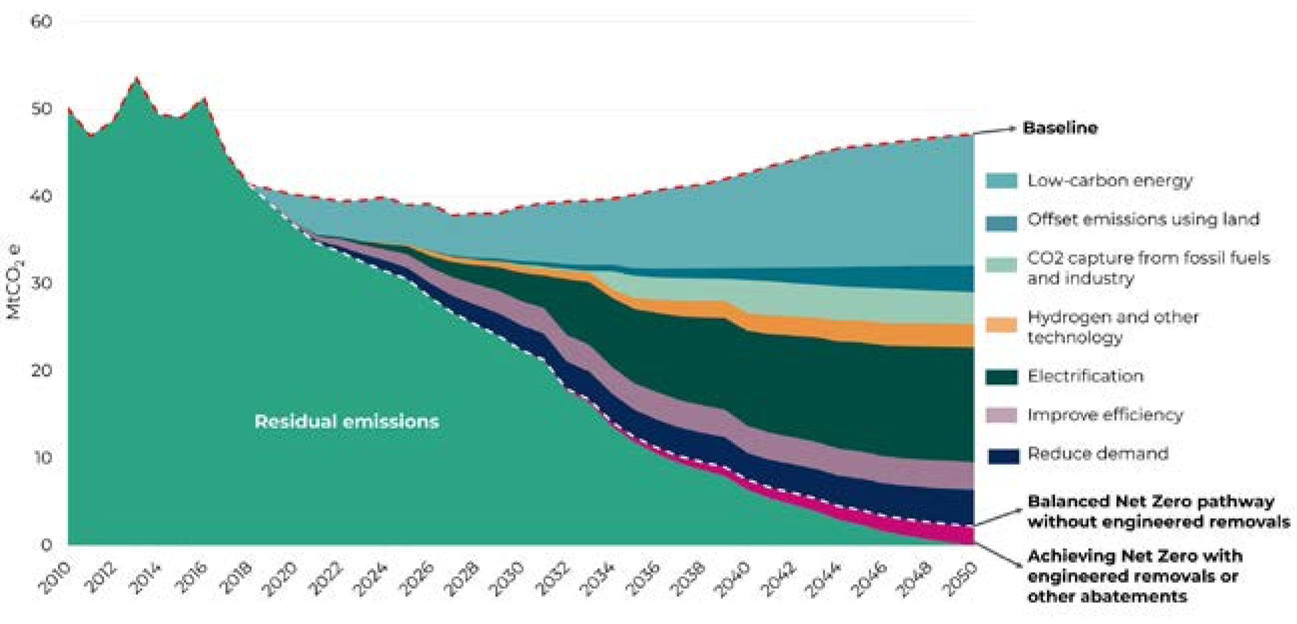
The following sections summarise the **CCC's latest recommendations** and outlines the current emissions targets, measures for emissions mitigation, and proposals set out by the Welsh Government in **its latest carbon budget**.

Climate Change Committee Recommendations

In 2020, the **CCC outlined a 'Balanced Pathway'** for Wales to meet net-zero emissions by 2050. It included recommendations for emissions reduction measures in four key areas:

- full decarbonisation of the power sector;
- full transition to electric vehicle sales;
- installation of low-carbon heating; and
- decarbonisation of manufacturing.

Figure 4: Types of abatement in the Balanced Net Zero Pathway for Wales



Source: Senedd Research from CCC, **The path to Net Zero and progress on reducing emissions in Wales**

In the Balanced Pathway, CCS begins to play a role in reducing emissions from 2030-2035. CCS is used to decarbonise industry, electricity generation and, potentially, hydrogen production.

BECCS and DACCS begin to contribute to decarbonisation through carbon removals by the mid-2030s. The CCC recommended that the UK and Wales start to build supply chains and scaling-up technologies for CCS deployment.

Table 1: Key metrics in the Balanced Pathway to meet 2050 net zero targets

Area	2018	2025	2030	2035	2050
Wales greenhouse gas emissions ($MtCO_2e$)	41	31	22	12	0
CCS in manufacturing in Wales ($MtCO_2$)	0	<0.1	0.1	1.6	1.9
CCS in other sectors in Wales ($MtCO_2$) (Excludes use in hydrogen production)	0	0	1	2	4
Low-carbon hydrogen demand (TWh)	<0.1	0.1	1.6	6.5	11.5
UK Greenhouse Gas removals ($MtCO_2$)	0.0	<0.1	5	23	58

Source: CCC, **The path to Net Zero and progress on reducing emissions in Wales**

Note: $MtCO_2$ = million tonnes of CO_2 emissions; $MtCO_2e$ = million tonnes of CO_2 equivalent emissions

Net Zero Wales Carbon Budget 2 (2021-25)

In 2021, the Welsh Government set out **its plan** to meet its second carbon budget, lay the foundations for Carbon Budget 3 and meet the 2030 and 2050 emissions targets. The Net Zero Wales (NZW) plan follows the recommendations of the CCC to limit the global temperature increase to 1.5 °C, consistent with the Paris Agreement.

The NZW plan outlines four broad areas of emissions mitigation:

- resource and energy efficiency: product replacement, material substitution, waste reduction, energy efficiency – equipment, heat recovery, clustering;
- fuel switching: switch to low carbon fuels, including hydrogen;

- CCUS: CCS, BECCS, and hydrogen plants; and
- commercial buildings: increase the efficiency of commercial buildings stock.

The Welsh Government **reviewed the feasibility of a CCUS network in Wales** and its potential contribution to meeting net-zero targets. The report found that CCUS is a viable option to support decarbonisation in Wales, but there is significant uncertainty related to cost and speed of deployment. Many of the powers related to CCS are currently reserved to the UK Government.

The NZW plan includes the following proposals to identify ways of reducing cost and deploying CCUS at pace:

Proposal 17 – Continue to build our evidence base on Carbon Capture Utilisation and Storage (CCUS) over Carbon Budget 2.

Early in the second carbon budget, the Welsh Government will build on its existing CCUS evidence base and undertake further research, including:

- an economic impact assessment of the deployment of hydrogen and CCUS; and
- the development of a potential infrastructure plan to facilitate transport and storage in Wales driven by the needs and decisions of industry.

Proposal 18 – Industrial Clusters – Carbon Capture Utilisation & Storage (CCUS)

The Welsh Government committed to working with the South Wales Industrial Cluster and stakeholders on fuel switching and CCUS. As many powers related to CCS are reserved, the Welsh Government will work with the UK Government to support the development of the South Wales cluster and use UK Industrial Decarbonisation Challenge funding to deploy projects for:

- the production and distribution of hydrogen power;
- low-carbon electricity production that uses carbon capture technologies;
- large industry decarbonisation through fuel switching; and
- the production of low-carbon transportation fuels.

The **HyNet project** in the North West of England will produce, store and distribute hydrogen while capturing and storing CO_2 in depleted gas and oil fields at Liverpool Bay and will aid the industrial decarbonisation of North Wales.

Proposal 19 – Greenhouse gas removals

BECCS and DACCS have been proposed as methods to remove CO_2 from the atmosphere. The Welsh Government recognised the need to avoid overreliance on future GGR technologies to avoid unnecessary delays to decarbonisation in this decade.

The NZW plan identified issues of biomass supply sustainability, public awareness and acceptance, and monitoring, reporting and verification (MRV).

For a GGR approach to be credible (remove more greenhouse gases than it produces), **the UK Government Task and Finish Group on MRV found** it will be necessary to:

- be able to quantify, robustly and transparently, the amount and permanence of removals;
- develop appropriate monitoring, reporting and verification protocols for a range of GGR approaches; and
- ensure genuine climate benefits and align to the UK's climate adaptation needs.

The Welsh Government **plans to engage** in a UK-wide discussion on GGRs and undertake a feasibility study to understand the place of GGRs in its net-zero strategy.

4. Policy and legislative context

The **early stages of CCS deployment** will require significant capital support to construct of capture units and transportation and storage infrastructure. Policy support is **needed to reduce the technological, economic and regulatory risks** to incentivise investment in the industry.

The following sections summarise the current policy and legislation surrounding emissions targets, emissions mitigation measures, and other proposals relevant to CCUS set out by the Welsh and UK Governments.

Wales

Net Zero Wales Carbon Budget 2 (2021 to 2025)

In 2021, **the Welsh Government set out its plan** to meet its second carbon budget, lay the foundations for Carbon Budget 3 and meet the 2030 and 2050 emissions targets. The plan accepts the recommendations of the CCC to reduce emissions to meet goals set out in the Paris Agreement.

The plan set out 123 policies and proposals to meet targets in line with the ***Environment (Wales) Act 2016* and *Well-being of Future Generations (Wales) Act 2015***. *The proposals include using CCUS for decarbonisation of electricity, industry and hydrogen.*

Around 60 per cent of the changes identified are influenced by powers mostly reserved to Westminster. The Welsh Government called on the UK Government to take action to unlock a "green future in Wales".

Environment (Wales) Act 2016

The **Environment (Wales) Act 2016** requires the Welsh Ministers to meet targets for reducing emissions of greenhouse gases in Wales. The Act also requires Ministers to set emission reduction targets and carbon budgets to ensure emissions are lowered by at least 80 per cent by 2050 compared to levels in 1990. In February 2021, the Welsh Government **laid four further sets of regulations** that amended the 2050 emissions target to net-zero.

Wellbeing of Future Generations (Wales) Act (2015)

The **Well-being of Future Generations (Wales) Act 2015 sets out seven interconnected goals for sustainable development in Wales**:

- a prosperous Wales
- a resilient Wales
- a healthier Wales
- a more equal Wales
- a Wales of more cohesive communities
- a Wales of vibrant culture and thriving Welsh language
- a globally responsible Wales

The Act provides requires public bodies to:

- take account of the long term effects of decisions;
- take an integrated approach;
- consider and involve people of all ages and diversity;

- collaborate to meet well being objectives; and
- help to prevent problems occurring or getting worse.

In 2021, the Welsh Government commissioned an **independent sustainability appraisal** to evaluate whether its NZW plan meets the commitments in the Well-being of Future Generations Act. Each proposal was appraised using a sustainability framework and a qualitative scoring system. The three CCUS-relevant proposals were evaluated to have no negative impacts on the wellbeing goals, apart from "Proposal 19 - Greenhouse gas removals", which was found to have a positive and negative impact on a prosperous Wales.

UK

British energy security strategy (2022)

The UK Government published its **energy security strategy** for England, Scotland and Wales in April 2022. The strategy includes commitments for hydrogen, renewables, oil and gas, nuclear and CCUS. The parts of the strategy that relate to CCUS are:

- £1 billion in public investment to decarbonise industrial clusters;
- the deployment of the first two industrial CCUS clusters in Teeside, the Humber and Merseyside;
- phase two of the **Industrial Energy Transformation Fund**, which will allocate £60 million to decarbonisation technologies (including CCUS), with a further £100 million delivered across May and October 2022;
- CCUS clusters to futureproof the North Sea;
- 1 GW of CCUS-enabled hydrogen to be operational or in construction by 2025; and
- the first business model contracts to be awarded to electrolytic and CCUS-enabled hydrogen projects by 2023.

Carbon capture, usage and storage (CCUS): investor roadmap (2022)

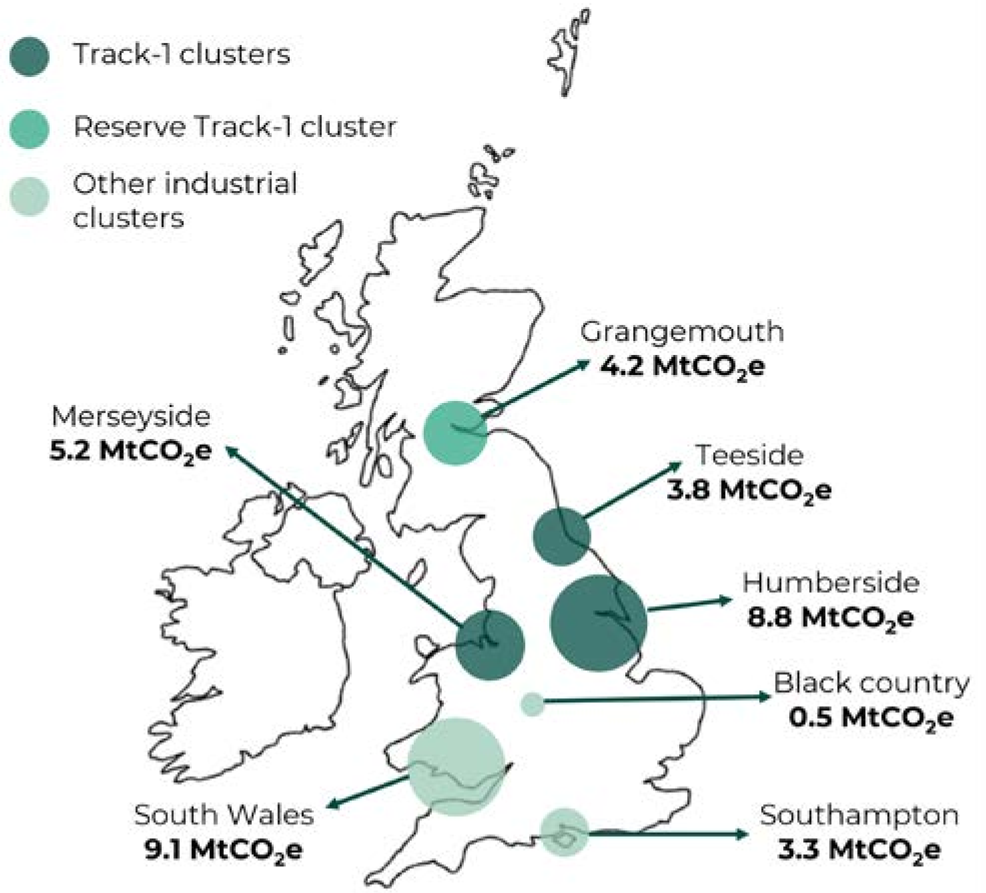
The **CCUS roadmap** outlines UK Government and industry commitments to deploy CCUS in the UK. Four CCUS industrial clusters are scheduled for deployment by 2030, capturing 20-30MtCO_2 per year. This will involve the construction of shared transportation and storage infrastructure at each cluster site.

Clusters scheduled for operation in the mid-2020s are 'Track-1' and **were**

announced in September 2021, and 'Track-2' clusters are scheduled for 2030.

The **South Wales cluster** was not confirmed as a Track-1 cluster. The North Wales industrial area can access the Merseyside cluster infrastructure for storage.

Figure 5: Sequencing of UK industrial clusters

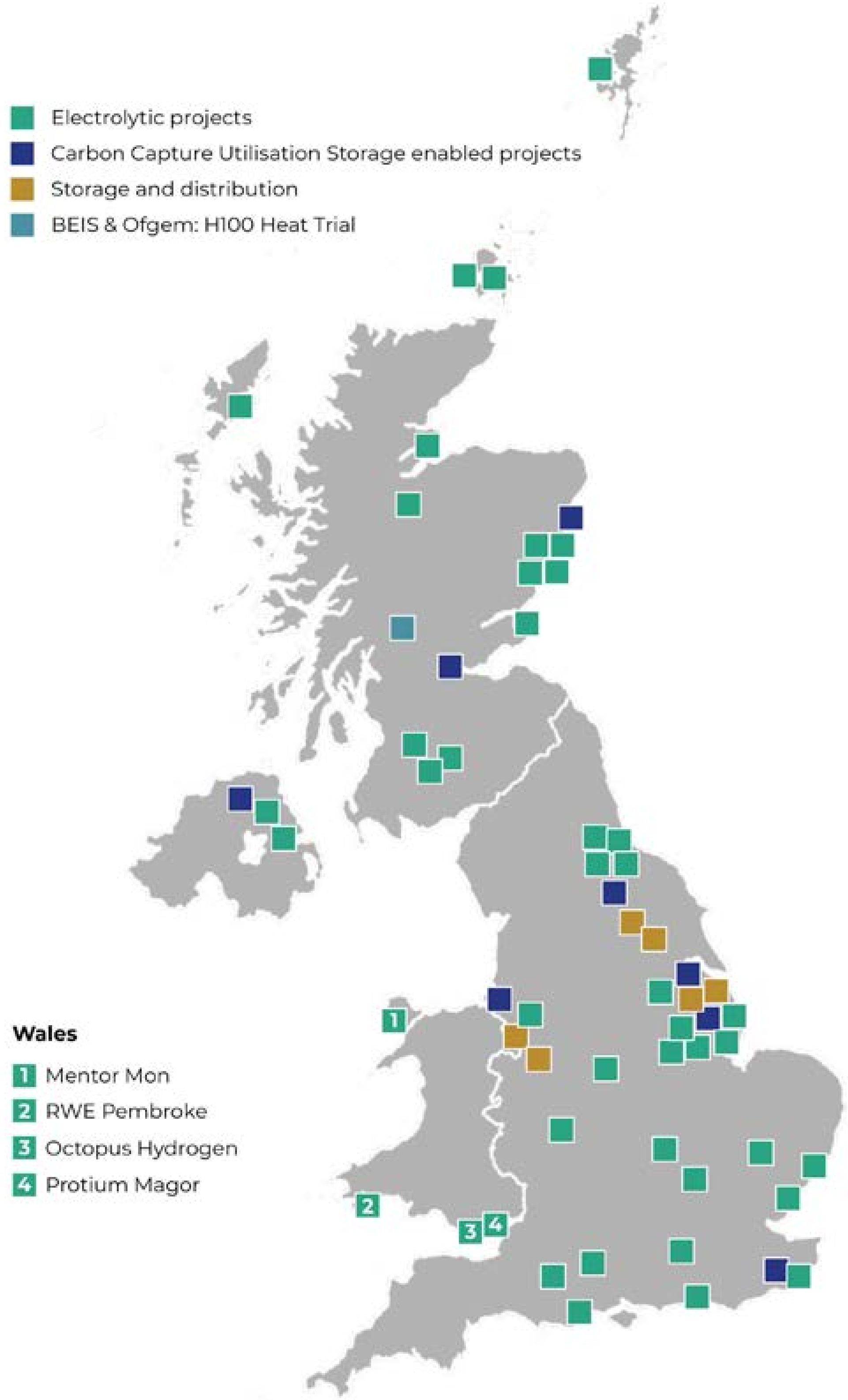


Source: Senedd Research from UK Government, **Carbon capture, usage and storage (CCUS): investor roadmap**

Hydrogen investor roadmap: leading the way to net zero (2022)

This **hydrogen roadmap** outlines the policies designed by the UK Government to support a low-carbon hydrogen economy in the UK. The roadmap doubled **previous** low-carbon hydrogen production targets to 10GW by 2030, with at least half generated from electrolysis. The roadmap identified four potential electrolytic hydrogen production sites in Wales.

Figure 6: Potential low-carbon hydrogen projects across the UK



Source: Senedd Research from UK Government, **Hydrogen investor roadmap: leading the way to net zero**

The Ten Point Plan for a Green Industrial Revolution (2020)

In its **ten point plan**, the UK Government committed to deploying CCUS in two industrial clusters by the mid-2020s and a further two by 2030, with targets to capture up to 10MtCO_2 per year by 2030.

Climate Change Act (2008)

The ***Climate Change Act 2008*** establishes a legally binding target to reduce the UK's greenhouse gas emissions by at least 100 per cent in 2050 from 1990. The Act requires the UK Government to:

- regularly assess the risks to the UK of the current and predicted impact of climate change;
- set out its climate change adaptation objectives; and
- set out its proposals and policies for meeting these objectives.

5. CCUS in Wales

In October 2021, **the Welsh Government released a report** evaluating the role of CCUS in achieving its net zero target. The report outlined different decarbonisation pathways considering varying levels of CCUS uptake, technology needs, CO_2 transport and storage options and costs.

The report suggested industries should first improve energy and resource efficiencies to reduce energy demands, waste and CO_2 emissions. Beyond these initial measures, the following sections outline the simplified sector-specific options for industrial decarbonisation in Wales. These include CCUS, fuel switching (to hydrogen) and electrification.

Figure 7: 2019 CO_2 Emission Map of Wales

Source: Senedd Research from Welsh Government, **A carbon capture, utilisation, and storage network for Wales: report**

Note: (1) Tata Steel Ltd, Port Talbot, 6.43 $MtCO_2$ per year; (2) Pembroke power station, 4.28 $MtCO_2$ per year; (3) Pembroke refinery, 2.16 $MtCO_2$ per year; (4) Connah's Quay power station, 0.89 $MtCO_2$ per year; (5) Uskmouth power station, 0.72 $MtCO_2$ per year.

Industrial sectors

Power

All large power stations **will need to be decarbonised** to meet net-zero targets. Other than decommissioning the power station, the two main decarbonisation options are:

CCS, using:

1. post-combustion carbon capture: CO_2 is captured from the waste gas after combustion; or
2. pre-combustion carbon capture: the fuel gas supply is converted to hydrogen and CO_2. Hydrogen is used as fuel after the capture of CO_2.
3. Fuel switching to hydrogen, using:

- locally generated blue hydrogen; or
- blue or green hydrogen delivered by the gas network or imported by ship.

Infrastructure constraints will influence which option succeeds. These include the availability of low-carbon hydrogen supply from the gas network or local storage, availability of CO_2 transport and storage infrastructure, technology readiness, future gas and hydrogen prices, predicted capacity factor and cost.

Box 2: Capacity factor - what is it and why is it relevant?

The capacity factor is the amount of electricity generated by a power station divided by the potential electricity output if the power station runs at full capacity. The capacity factor is a useful metric to compare different generators.

For example, a wind turbine of 1MW capacity would have a maximum output of 8,760MWh/year, as there are 8,760 hours in a year. In reality, the wind varies, and the turbine produces less energy. If the wind turbine produces 3230MWh of energy over the year, it has a capacity of 38 per cent (3230/8760 x 100).

Conventional fossil fuel power stations typically have much higher capacity factors, but this depends on their function on the grid.

Steel

The blast furnace-basic oxygen furnace (BF-BOF) route is used to **produce around 70 per cent of steel worldwide** and generates high levels of CO_2 emissions due to:

- being energy-intensive;
- the dependence on coal for the production of coke to convert iron ore into pig iron; and
- the large volumes of steel manufactured.

Decarbonisation of the BF-BOF route can be achieved by retrofitting **new technologies** such as top gas recycling with CO_2 capture from the waste gases of the BF, BOF, lime kiln, sinter plant, coke oven plant, and stoves.

Electrification is possible by replacing BF-BOF with scrap-based Electric Arc Furnaces (EAFs). However, **there is not enough steel scrap** supply to meet global demand.

Direct reduction of iron (DRI) is a relatively new technology that can produce sponge iron from iron ore and be fed to an EAF instead of scrap. **Fuel switching from natural gas to hydrogen** for DRI could be used to produce low carbon steel if low carbon electricity is used in the EAF.

Cement

Most CO_2 generated during cement production is **produced in the "precalciner" and kiln**. The underlying chemical process for cement production releases **around 60-70 per cent of the total CO_2 emissions**, so full decarbonisation is impossible without CCS. The **main options for decarbonisation** in the cement industry are:

- switching to low-carbon fuels;
- applying CCS to the waste gas of cement kilns; and
- replacing feedstock with other minerals with lower CO_2 emissions.

Glass and Ceramics

In glass manufacturing, 80 to 90 per cent of CO_2 emissions are generated on-site **by heating kilns using natural gas**. The capture of CO_2 from the waste gas is challenging because of aggressive components in the gas. **New capture technologies** may overcome these challenges.

Fuel switching to hydrogen would allow manufacturers to retrofit the existing furnaces, but this will depend on the future hydrogen costs. The glass industry is also considering **electrification**.

Refining

The main sources of CO_2 in the refining sector are fuel combustion for heat and electricity generation and methane reforming for hydrogen production. **CCS and low-carbon hydrogen are the main options for the industry**. As hydrogen is already widely used in refining as a feedstock, it could be used to supply local industries.

Chemicals

Similar to the refining industry, the main sources of CO_2 in the chemicals industry come from heating needs and process emissions. Decarbonisation is process specific and could be achieved **using CCS, fuel switching to hydrogen, and electrification**.

Manufacturing

Lower temperature heat is required for the majority of manufacturing sites, which can be **easily decarbonised by electrification**. Some sites may choose partial fuel switching to **partial fuel switching with hydrogen**, for example, engine works with foundries.

Papermills

There are several papermills in the South and North East of Wales. The majority of emissions are from heat requirements and could be **captured using CCS**. **BECCS is also an option** due to the similar raw materials and may be an opportunity for negative emissions.

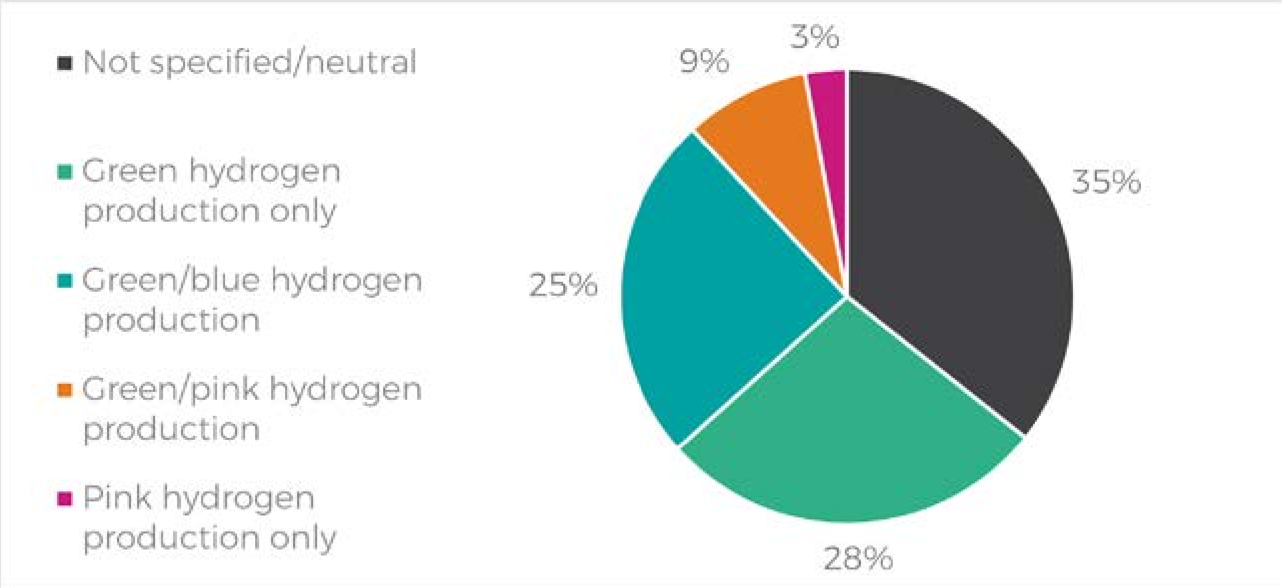
Future Hydrogen Industry

The number of countries with policies supporting the development of hydrogen technologies has **increased over the last five years**. Hydrogen can be used for transport and heat and potentially as an energy storage system for surplus power from renewables.

For hydrogen to contribute to industrial decarbonisation it must be low carbon. Technologies for **low carbon hydrogen production** include natural gas reforming with CCS (blue hydrogen) and electrolysis using low carbon electricity (green hydrogen).

In June 2022, a Welsh Government consultation on **developing the hydrogen energy sector** found significant support for green hydrogen and no support for only blue hydrogen production.

Figure 8: Proporation of respondents favouring different forms of low-carbon hydrogen production in Wales



Source: Senedd Research from Welsh Government, **Developing the hydrogen energy sector in Wales.**

Note: Green hydrogen is produced from renewable electricity using electrolysis. Blue hydrogen is produced from natural gas with CCS. Pink hydrogen is produced from nuclear electricity using electrolysis.

Onshore and offshore CO_2 storage

Figure 9 shows a map of potential offshore storage sites around the UK. The area to the west and south of Wales was not investigated for CO_2 storage in the **UK Storage Appraisal Project commissioned by the Energy Technologies Institute**. This is likely due to the lack of oil and gas exploration in the Irish Sea compared to the North Sea.

In 2006, the then UK Department of Trade and Industry (DTI) commissioned a **report** to investigate Wales's onshore and offshore CO_2 storage potential.

The report found onshore storage is possible using the coal deposits in South Wales, which have a proven CO_2 storage capacity of 70Mt and a potential capacity of up to 152Mt – around 15 years of storage needs. However, low public acceptability means this option is unlikely.

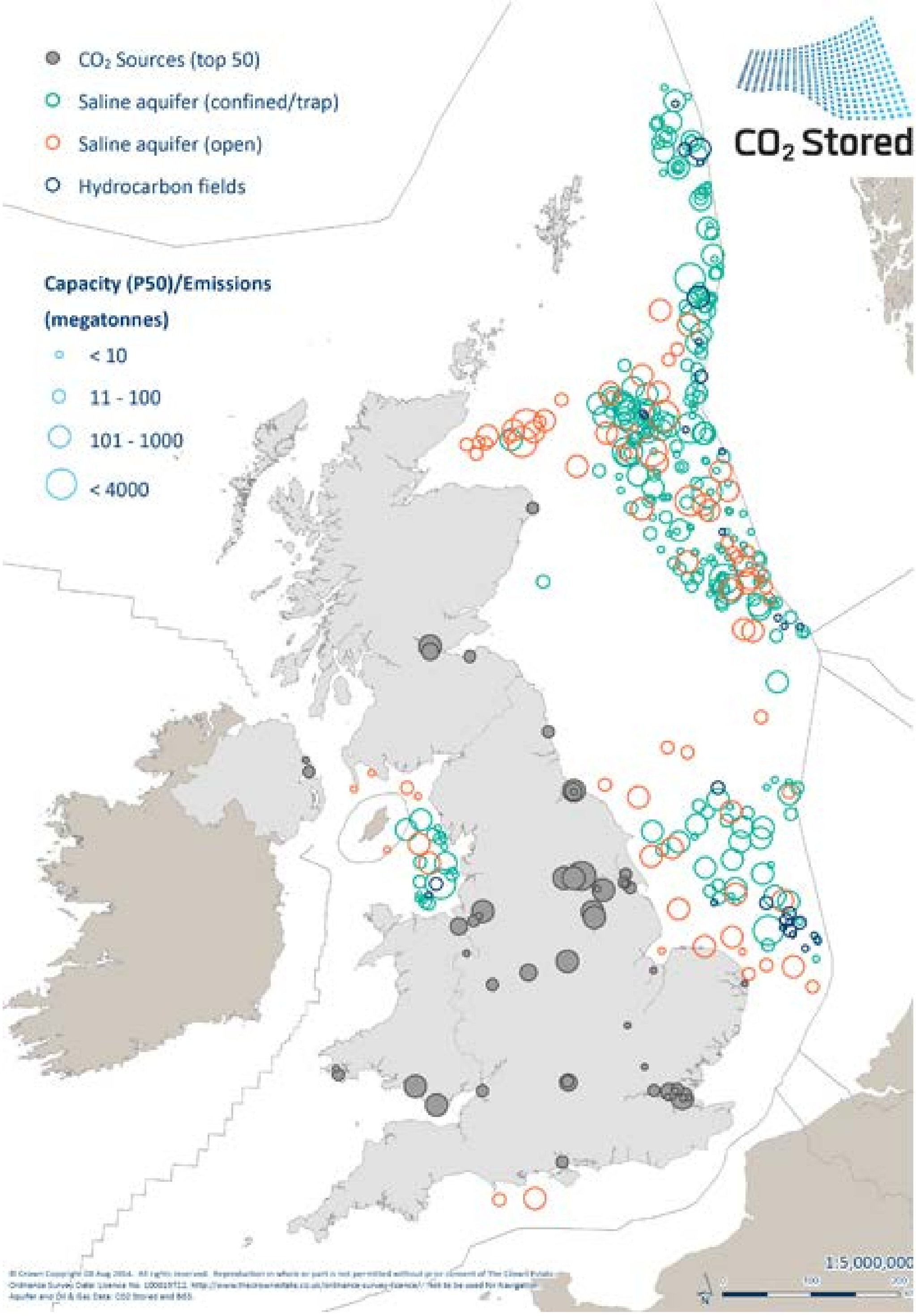
The potential for offshore storage around Wales is also low. Sites in the Bristol

Channel, the Celtic Sea and St George's Channel were screened, which lie to the south, south-west and west of South Wales, respectively. The study found limited opportunities for geological storage of CO_2 in the Bristol Channel, and the St George's Channel Basin was identified as the best potential storage site. Although, the amount of CO_2 the basins could hold was not investigated.

A **separate British Geological Survey report** found the potential for offshore storage around Wales is low, with some potential in the South Celtic basin.

New offshore sites closer to industries in South Wales could be investigated for storage. Alternatively, captured CO_2 will need to be transported to existing storage sites.

Figure 9: Estimation of UK CO_2 storage capacity and potential storage sites



Source: British Geological Society, **CO_2 storage capacity estimation**

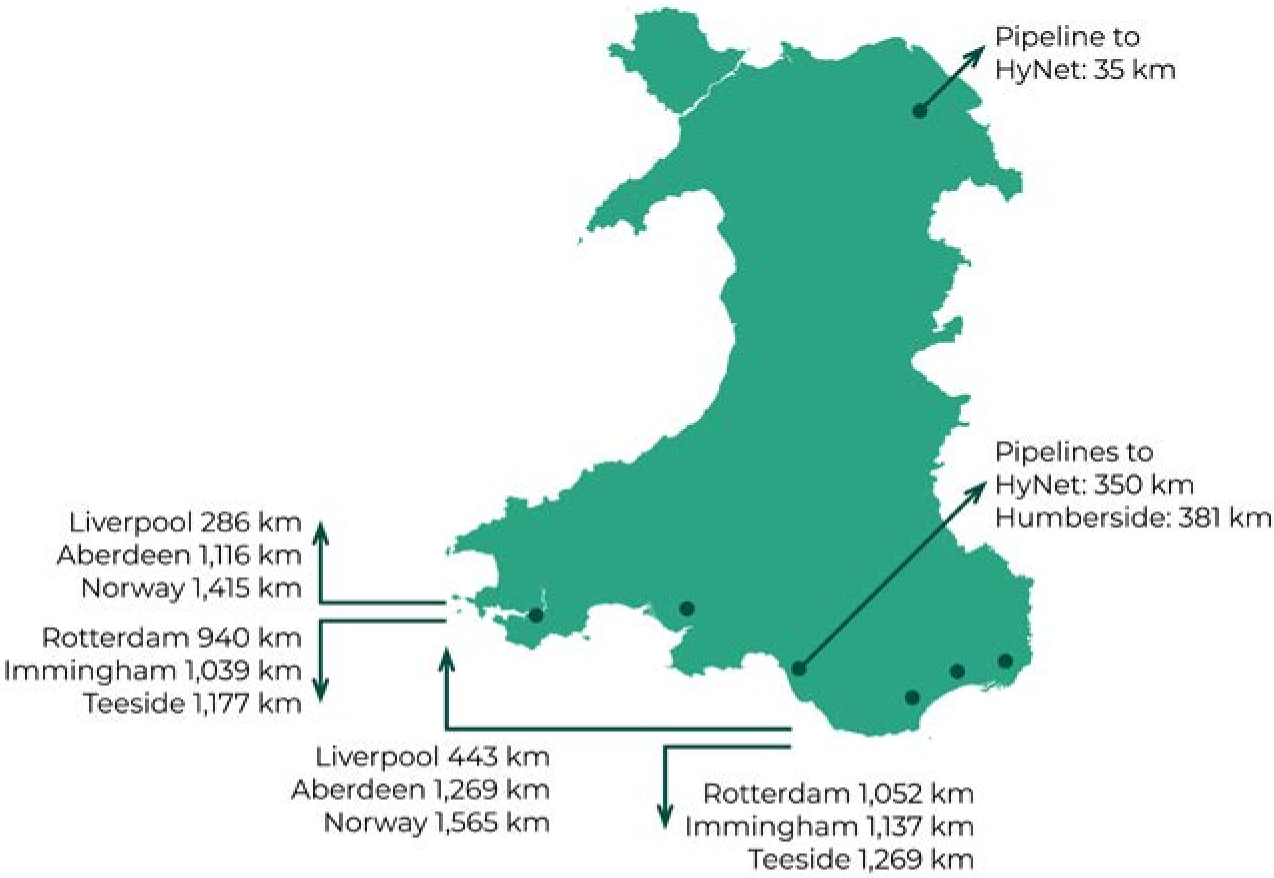
CO_2 transportation

Transportation is needed if the CO_2 capture are storage sites are not co-located. This increases the overall cost of CCS and may make other decarbonisation solutions more cost-competitive.

The large scale of CO_2 emissions means that pressurised pipeline networks and ship transport **are the only practical options for transportation in Wales**. The preferred option depends on the quantity of CO_2 and the distance to the storage site. Shipping is the lower cost option over very large distances.

Below is a **summary** of the possible routes and distances to CO_2 storage sites. North Wales can directly access the **HyNet storage sites** using a 35km pipeline. South Wales will rely on shipping to the HyNet storage site or sites in the North Sea and Europe. The barrier to cross-border CO_2 shipping in the **London Protocol**, was **removed** in 2019, enabling cross-border movement of CO_2.

Figure 10: Options and routes for CO_2 storage



Source: Senedd Research from Welsh Government, **A carbon capture, utilisation, and storage network for Wales: report**

Utilisation

The CCS networks in the **CCUS network for Wales report** were optimised for CCS and did not quantify opportunities for CO_2 utilisation because "it will not make a substantial impact upon overall CO_2 emission levels in Wales". Utilisation was encouraged as an alternative to storage but only for products which permanently store CO^2.

6. Renewable electricity and CCUS

Widespread electrification of transport, heating and industry for decarbonisation is predicted to **double the electricity demand in Wales by 2050**. **Electricity System Operators (ESOs)** are responsible for maintaining the electricity system in real-time. The electricity grid requires a high degree of flexibility to maintain the balance between supply (power output) and demand. ESOs can use reserve or ancillary services to balance supply and demand.

Intermittent renewable electricity generators with variable power outputs can put **new challenges on grid balancing mechanisms put in place by the ESOs**. The inability of renewables to ramp up power output may require large energy storage systems or **more extensive ancillary services** to deal with sudden fluctuations in demand.

ESOs can alter operational practices to improve the flexibility of renewable generators. These measures **include**:

- improved solar and wind forecasting;
- curtailing renewable generation to avoid shutting down conventional baseload generators;
- (international) interconnection to other grids; and
- large scale electricity storage systems like pumped hydro or batteries.

A future electricity grid will likely consist of a **portfolio of technologies to provide low-carbon electricity sustainably**. As the only type of power generation technology that can ramp power output and provide balancing and reserve services with low CO_2 emissions, CCS-enabled power plants will be valuable to the power system.

A whole systems perspective is needed to understand the impacts of a high percentage of renewables generation on the electricity grid. Key metrics to consider include the cost-effectiveness, sustainability, reliability, flexibility and stability of the grid. The emissions and costs from the manufacture and operation of additional support services, such as energy storage systems, must also be included.

In September 2021, the Minister for Climate Change **released a written statement** on evolving energy grids for 'net-zero Wales'. The Minister highlighted the need to re-think the infrastructure needed to deliver rapid and effective decarbonisation in Wales. She announced that all energy network operators in Wales, Ofgem and the Welsh Government would work together to develop a long-term plan for energy networks in Wales.