WHEN TRUST MATTERS

A CARBON CAPTURE, UTILISATION, & STORAGE NETWORK FOR WALES

Welsh Government

Llywodraeth Cymru
Welsh Government

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MAIN REPORT

Content

1 Executive summary

The Climate Change Committee (CCC) recommended that to meet the Paris Agreement, the UK should achieve net-zero Green House Gas (GHG) emissions by 2050, and this recommendation has now passed into UK law.

Amongst the devolved nations, there are variations in the timescales, as the opportunities for decarbonisation within each nation are different. In March 2021 the Senedd legislated for a net zero 2050 target in Wales, following CCC advice published in December 2020.

Carbon Capture, Utilisation and Storage (CCUS) has the potential to enable the decarbonisation of many parts of the economy including industry, power generation, heating and transport. It can substantially reduce emissions from the combustion of fossil fuels or enable the production of low-carbon hydrogen from methane reformation.

Compared to other parts of the UK, Wales has less opportunity for carbon dioxide (CO_2) storage due to the lack of suitable geological stores. Sites in the North East of Wales do however have the option to connect into the HyNet CO_2 storage project being developed in the North West of England, whereas sites in South Wales, where most of the heavy industry is based, do not have ready access to a suitable CO_2 store. Therefore, different solutions need to be developed, when considering how to meet the net zero goal across Wales.

The purpose of this report is to lay out a series of options for the Welsh Government to consider in establishing the pathway to achieve net zero through the potential implementation of a CCUS strategy. Although the strategy for CO_2 capture, utilisation and storage (CCUS) has yet to be finalised, it can be argued that Wales is already ahead of the rest of the UK in emphasising the importance of the potential health and environment benefits, of decarbonising their economy, and for the need for a just transition. As an example of this, Wales' Wellbeing of Future Generations Act plays an important role in ensuring that the transition to a net zero future is achieved justly across society.

The Welsh Government has a statutory target to reduce emissions by at least 100% (net zero) in 2050 compared to 1990. There are also interim targets set in law for 2030 (63%) and 2040 (89%), along with carbon budgets throughout the 2020s.[1]

In its December 2020 Advice Report to the Welsh Government, the CCC recognised that the Welsh Government should now set a Net Zero target for 2050. In the same report, whilst recognising that the Welsh Government had made significant steps and that Wales was likely to achieve its 2020 target, the CCC also concluded that Wales was not on track to meet its original 80% reduction target by 2050, and was a long way away from the trajectory needed for a net zero 2050 target. It is against this background that DNV has been engaged to report on the feasibility of a carbon capture, utilisation and storage network for Wales.

1. Carbon Budget 2 (2021-25) requires an average reduction of 37% and Carbon Budget 3 (2026-30) requires an average reduction of 58%.

This report outlines how CCUS could help meet the net zero goal in Wales. It considers a range of different CCUS uptake levels, in order to model a range of decarbonisation pathways driving varying technology needs, CO_2 export options and associated costs.

The primary focus of the report is related to CO_2 emissions from large industrial, power generation and commercial emitters (such as municipal buildings, shopping centres etc). It does not address all forms of CO_2 emissions, for example from transport or domestic sources, although these sectors could of course benefit from the development of a large scale CCUS infrastructure in Wales. Methane emissions from agriculture or industry, although important from a climate change perspective, are not within the scope of this CCUS research.

The project has evaluated technology options along the entire CCUS value chain. Utilisation of CO_2 is possible, and should be encouraged, as a preferable option to storing CO_2, but it will not make a substantial impact upon overall CO_2 emission levels in Wales, so storage will still be needed. As it does not make a material impact upon emission levels in Wales, utilisation has not therefore, been included in the modelling.

The research has considered four cases for possible CO_2 capture demand in Wales in order to provide the Welsh Government with a series of scenarios to be considered for future policy consideration.

MINIMUM CCS CASE

- Only those industries which require CCUS for decarbonisation of processes adopt it.
- No CCUS is assumed to take place on power plants.
- All other industry is assumed to decarbonise through fuel-switching or electrification.
- Any hydrogen used for decarbonisation is assumed to be either green or imported.
- The steel works at Port Talbot is assumed not to use CCUS.

MEDIUM CCS CASE

- Assumes the Minimal CCS case plus:
- Other industries which are amenable to decarbonisation via CCUS (on account of the processes involved and/or their proximity to essential CCUS users) use CCUS.
- All large-scale power generation (including biomass and energy from waste) is decarbonised by fuel-switching to Welsh produced hydrogen. The "blue" fraction of that hydrogen requires CCUS.
- The steel works at Port Talbot is assumed to not use CCUS.

HIGH CCS CASE

- Assumes the Medium CCS case plus:
- Port Talbot Steelworks is converted to a hydrogen and electrically fuelled steelmaking process. This is assumed to generate a CCUS demand (via hydrogen) of 25% of that for the existing steelworks.

MAXIMUM CCS CASE

- Assumes the Medium CCS case plus:
- Port Talbot Steelworks is refurbished to operate with the conventional Blast Furnace - Basic Oxygen Furnace route with decarbonisation via a combination of CCUS, hydrogen, and electrification.

Each case has been modelled to determine the CO_2 emissions to be captured and transported, and the costs of each option for every major emitting site has been determined. Where alternative export options for storage may need to be considered, they have also been evaluated and costed. Modelling results have been grouped, where relevant to ensure confidentiality of the sites concerned.

The approach adopted for this project has been to focus on the most significant emitters in Wales, as the development of a CCUS network related to these facilities will unlock the capability of smaller emitters to link to a developing network. Resolution of the CCUS strategy for the largest emitting sites will act as a catalyst, enabling deep decarbonisation across the Welsh economy.

1.1 Conclusions

1. CCUS is a feasible technical option to support Wales in achieving its statutory emissions reduction targets. The technology that is needed to create a CCUS network in Wales is available, and the capacities that need to be captured, transported and stored are within the capabilities of proven technologies.

2. Although the technology to build a CCUS network exists, as with many lower carbon solutions, it is an expensive answer to the decarbonisation challenge for all emitters in Wales. As such, it must only be part of the solution, and other measures such as reduced energy demand, improved energy efficiency, increased recycling, and changes to alternative energy vectors such as electrification or hydrogen should be seen as primary solutions. Energy demand reduction must be seen as the priority action in the merit order of decarbonisation. Where other solutions cannot be deployed due to process needs, cost or practicality, then CCUS will, however, be essential for the treatment of residual emissions. As a result, it will be important for the Welsh Government to maintain a flexible approach to decarbonisation that supports a range of decarbonisation measures and allows for solutions to be scaled up or down as demand changes, or new solutions emerge.

3. The modelling work completed as part of this project forecasts that the cost of carbon capture and storage ranges from £95 to £345 per tonne, with the majority of emissions falling into the lower cost range. These values are within the range seen in other international CCUS projects. The wide variety of costs is driven by the location of the site respective to an export "hub", the nature of the capture technology needed, the choice of ultimate export route (pipeline or ship) and the quantity of CO_2 emitted. As would be expected, larger emissions sources close to export hubs have significantly lower costs whilst small sites, remote from the export hubs have very high costs. The distribution of potential CCUS costs across different emitter groups is presented in this report. Shared export pipelines to a hub give small export savings for some sites, but it is the grouping of emissions from adjacent, compatible sites which offers large savings. This again supports the need for the Welsh Government to maintain a flexible approach and oversight to solutions that protect industrial capacity and employment levels.

4. Sites in the North East of Wales have the option to tie into the HyNet project being developed in the North West of England. The cost of capture and transport to the HyNet infrastructure is forecast to be between £96 and £268 per tonne depending upon site location, capture solution and emission levels. The cost of accessing the HyNet infrastructure is currently

unknown, and would need to be added to these values. Permitting and planning approval for pipeline routes across the Welsh/English border would also need to be carefully addressed; discussions on this subject are currently underway with the OGA and other regulatory bodies.

5. It is unlikely that onshore storage of CO_2 at sites in Wales such as coal mines or coal seams would be permitted. A review of the Welsh Government's Petroleum Policy and Planning Policy, and discussions with Welsh Government officials have indicated that this would not be likely. As a result, storage options outside Wales would need to be prioritised.

6. Securing access to suitable CO_2 storage capacity will be crucially important for Wales in general, and South Wales sites in particular. Although it is likely that a CCS Transportation & Storage Company (T&SCo) would be responsible for the actual transactions needed to safely move and store CO_2 from Wales, it will be important for the Welsh Government to play a role in the initial discussions with potential storage locations to secure future capacity on behalf of Wales. Stakeholder discussions during this project with a number of potential storage operators has indicated that significant levels of interest have already been expressed in securing capacity, with some organisations and governments having already signed Memoranda of Understanding (MOU's) with currently planned stores in the UK and Northern Europe.

7. Key to enabling a cost-effective solution to CCUS deployment in Wales will be the creation and deployment of suitable business models that support CO_2 emitters with the CAPEX and OPEX associated with the initial buildout of CCUS capacity. BEIS is currently finalising their approach to business models and in December 2020, published a detailed update setting out the Government's preferred options for CCUS business models, covering carbon capture in power, carbon capture in industry, CO_2 transport and storage, and, with less detail, hydrogen production. The issue of CO_2 export by ship was conspicuously absent from the BEIS proposals, and for Wales in particular, this gap needs to be addressed with some urgency.

8. On 10 February 2021, BEIS published its draft approach to the sequencing of CCUS clusters, alongside a consultation which ran until 10 March 2021. The sequencing of industrial clusters is designed to meet the ambition to have two clusters operational by the mid-2020s and a further two by 2030, although the document notes that all clusters will need to decarbonise. South Wales is not currently considered as one of the key industrial clusters for Track 1, and we believe it is important that the Welsh Government takes the necessary steps to ensure that the future needs for CCUS in Wales are recognised as part of the Track 2 process. However, North Wales is integral to NW England's HyNet project, with a CO_2 pipeline across to Connah's Quay scheduled for Phase 1 (2025) and plans for a hydrogen pipeline in Phase 3 (2030 onwards). HyNet could very well be selected as one of the first 2 clusters.

9. The modelling work has shown that a land based pipeline route across South Wales from Milford Haven to Newport, and then across England, to a location such as Immingham, is the cheapest option per tonne of CO_2 for sites in South Wales. This aligns with the analysis published in the 2018 BEIS shipping costs study[2], although the overall values predicted in this report are slightly higher than the BEIS study. This reason for this difference is explained elsewhere in the report. The following factors have to be borne in mind when considering the implications of this conclusion however:

   a. The construction of a pipeline across South Wales would cross several areas of environmental significance.
   b. Pipeline distances have been estimated "as the crow flies". The reality for any pipeline route is that longer distances would realistically be needed to avoid population centres, environmentally sensitive areas, and difficult terrain.
   c. Securing the necessary planning permission for a long-distance pipeline is not easy, and as this pipeline route would cross country, county and local authority boundaries, significant delays in securing planning permission can be expected. It is always the case in large infrastructure projects such as these, that local opposition can be expected, and NGOs are likely to be involved in opposition.
   d. A pipeline option limits flexibility for the Welsh Government, and the emitters in Wales. Tying Wales into a single CO_2 storage location has adverse commercial implications, and a pipeline option does not allow for cost effective scaling down as the CO_2 demand changes in the future. The pipeline would have to be sized from day one for the maximum anticipated capacity from Wales, and that introduces the risk for the pipeline owner (the T&SCo), that at some point they could end up with a stranded asset.
   e. It is also the case however, that the construction of such a pipeline could be attractive to other emitters based in the Midlands or South West of England who may be close to the pipeline route, and would wish to take advantage of the transport option provided by the pipeline. This could make a pipeline option more attractive to a T&SCo.

2. 'Shipping CO_2 – UK Cost Estimation Study' Final Report by Element Energy and others for Business, Energy and Industrial Strategy Department (BEIS), November 2018

f. Re-routing the South Wales section of the pipeline via an offshore (marine) route adds approximately £5 per tonne to the cost of the pipeline export option.

10. Depending upon the location of the emitter, and the scale of the emissions, the option of transporting CO_2 by ship to a suitable storage location is forecast by the model to be between £100 and £345 per tonne including capture. Shipping costs are forecast to be between £5 and £20 per tonne more expensive that the equivalent pipeline option. The CO_2 shipping option, whilst forecast to be marginally more expensive, provides a much greater degree of flexibility for the Welsh Government, both in terms of ramp-up and potentially ramp-down in the future, as the need for CCUS declines. The shipping option is not however without its challenges, which will need to be resolved, these include:

    a. The creation of liquefaction and storage capacity at port hubs. Issues of ownership, permitting, and land access all require further consideration.
    b. The routing of CO_2 pipelines from emitters to the port.
    c. The additional ship movements required in each port. Depending upon the size of the vessel, the quantities of CO_2 being exported from the hub, the storage destination, and the availability of vessels, in the maximum output case the number of vessel movements varies from 150 per year at the smallest hub (Barry) to 246 per year at the largest hub (Milford Haven). These are not insignificant numbers of additional vessel visits to each port and could have a detrimental impact upon port/berth access, local pollution (ship emissions), tourism, fishing, and local social/community use of a port. Additional dredging and pilotage support would also most likely be needed to ensure safe navigation. The costs and impacts of such changes on the local area have not been factored into the model, but they will need to be addressed. There will however be upsides associated with berthing/pilotage fees and increased local employment opportunities for the development of the port infrastructure to provide a CO_2 export facility.

11. Stakeholder feedback confirmed the need for the Welsh Government to continue to recognise that the major emitters in Wales are largely headquartered outside GB. Any additional costs incurred by subsidiaries in Wales could make them uncompetitive, in the views of their parent company, increasing the risk of offshoring emissions as a result.

1.2 Recommendations

1. As the option for export of CO_2 by ship appears to be the best strategy for South Wales, it is important that this approach is reflected in the BEIS thinking for CCUS business models. Therefore, the Welsh Government should engage with BEIS as soon as possible, to stress the importance of a shipping export option being included in the business model framework.
2. Whilst HyNet is a Net Zero North West led project, there is a dependency on North Wales for the CCUS pipeline and NE Wales could, as a result, be seen as being included within the HyNet project plan as a BEIS defined Track 1 site. Currently, South Wales is currently not considered in the BEIS thinking for Track 1 of the CCUS cluster sequencing programme as the Track 1 sites, according to the BEIS definition, must have a CO_2 store. The Welsh Government should raise this issue with BEIS and establish how South Wales can be represented in Track 2 projects.
3. In order to achieve the net zero target, a number of solutions will be required, and the Welsh Government needs to recognise that ongoing innovation could develop new solutions to decarbonisation that would impact the overall needs for CO_2 storage. It is important that all solutions are considered in a holistic fashion, and are not seen to be competing. Therefore, the Welsh Government should ensure its forthcoming climate change action plan provides sufficient flexibility to allow the development of a range of solutions. This is particularly important during the early deployment phases, where innovation in decarbonisation solutions should be encouraged, and resilience is built into the plan. In this context, it is important to consider CCUS as part of a package of solutions, which also includes options such as energy efficiency, hydrogen and renewable electricity sources.
4. DNV's engagement with the currently planned CO_2 stores indicated that capacity was already being booked by industrial emitters and in some cases governments. Although it is unlikely that the Welsh Government would take responsibility for storage availability for emitters in Wales, (that should be the role of the T&SCo), we do recommend nevertheless that the Welsh Government engages with the currently planned stores to secure agreements in principle for storage capacity that matches the potential CO_2 export needs of the Welsh emitters.
5. As ship export of CO_2 will be crucial to the delivery of a successful CCUS network in Wales, we recommend that the Welsh Government establishes a CCUS working group with the ports in South Wales to begin the necessary planning work to secure capacity in the ports for the necessary CO_2 liquefaction and storage facilities, berthing arrangements and navigational capacity needs.
6. The Welsh Government should enhance its collaboration with the HyNet project in North West England to secure sufficient capacity in the project to meet the needs of the CO_2 emitters in North Wales.
7. The Welsh Government should begin a proactive programme of work to develop the necessary skills and supply chain base in Wales. Key experience from the development of successful integrated supply programmes could be gained from the aerospace and automotive industries.
8. As all CCUS solutions will require the development of local pipeline infrastructure from the emitters to the export hubs, it is important that the Welsh Government continues to build on work already done to ensure that planning and permitting systems are aligned for low carbon developments such as CCUS, to prevent potential bottlenecks in the implementation process.
9. As public perception is key to the successful implementation of infrastructure programmes such as CCUS, we recommend that the Welsh Government begin a proactive programme of communication to build support for the development of CCUS. We would recommend focussing this initially in those industrial and port areas across Wales where the deployment of CCUS solutions have the potential to both protect jobs and bring substantial new employment benefits. However, the issue of CO_2 storage also requires a long-term perspective, so it will be important to recognise this when considering the wellbeing of future generations.

2 Introduction

2.1 Background to the project

The debate on decarbonisation is moving at an accelerating pace. In November 2020, the UK government has issued its Ten Point Plan[3] for a Green Industrial Revolution; and its Energy White Paper[4]. Both documents stress the importance of CCUS in meeting Net Zero. The Climate Change Committee also released its sixth carbon budget advice[5] in December 2020 recommending a target to reduce UK territorial emissions by at least 78% in 2035. The Welsh Government has also recently issued a hydrogen pathway to net zero for consultation[6].

The CCC issued its Advice Report – The Pathway to a Net Zero Wales in December 2020[7]. It recommended a net zero target for 2050, with the following stretch targets on the pathway to Net Zero for Wales:

- The Second Carbon Budget for Wales (2021-2025) must be tightened to a 37% reduction compared to 1990 levels as an absolute minimum to account for the early closure of Aberthaw power station (as set out in their 2017 advice). Emissions will likely have to fall more quickly than this to meet the Third Carbon Budget.
- The Third Carbon Budget (2026-2030) should be set at an average 58% reduction compared to 1990 levels.
- Interim targets for 2030 and 2040 should be set on the Balanced Pathway to Net Zero at 63% and 89% respectively compared to 1990 levels

3. The Ten Point Plan for a Green Industrial Revolution https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution
4. Energy Whitepaper: Powering our Net Zero Future BEIS, 14 December 2020.
5. Climate Change Committee Sixth Carbon Budget, December 2020
6. https://gov.wales/developing-hydrogen-energy-sector-wales
7. Climate Change Committee Advice Report – The Pathway to a Net Zero Wales in December 2020

2.2 The Role of Carbon Capture, Utilisation and Storage

CCUS could play an increasingly important role, in moving from ambition to action in Wales, which is reflected in the variety of reports outlining the strong contribution required from CCUS.

CCUS has the potential to enable the decarbonisation of many parts of the economy including industry, power generation, heating and transport. It can substantially reduce emissions from the combustion of fossil fuels or produce low-carbon hydrogen from the reformation of methane. However, it is important that the Welsh Government balances the ambition for CCUS, and the associated investments required, against the risks of supporting the development of assets that could subsequently become redundant should industry choose alternative solutions (such as hydrogen or electrification) which may not require CCUS solutions to be developed at the same scale. It is equally important to consider fully the interplay between CCUS, hydrogen (and alternative forms such as ammonia, methanol, or liquid organic hydrogen carriers) and electrification.

For the purposes of the scope of this report, CCUS is defined as follows:

- Carbon capture, utilisation and storage (CCUS) is a set of technologies which can enable the capture of carbon dioxide from waste gases at industrial, power generation or commercial facilities to be indefinitely sequestered in offshore geological storage sites (carbon capture and storage - CCS), or reused in industrial processes (carbon capture and utilisation – CCUS)
- The primary focus of the report is related to CO_2 emissions from large industrial, power generation and commercial emitters. It does not address all forms of emissions, for example methane from agriculture or industry, or CO_2 from transport or domestic sources.

2.3 Key Objectives for CCUS in Wales

The Welsh government has been working with the CCC and the UK Government to determine what the Net Zero ambitions would mean for Wales and its economy. This determination needs to factor in, that although North Wales could have access to the HyNet cluster, South Wales, where much of the country's heavy industry is based, has far less opportunity for CO_2 storage than some other industrialised areas of the UK.

In its December 2020 Advice Report to the Welsh Government, the Climate Change Committee (CCC) recommended that the Welsh Government should, in fact, now set a Net Zero target for 2050. In March 2021 the Senedd legislated for a net zero 2050 target, along with interim targets for 2030 (63%) and 2040 (89%), and carbon budgets throughout the 2020s.

This project has also contrasted the ambition of an accelerated decarbonisation programme with other Welsh Government ambitions such as:

- The Well-being of Future Generations (Wales) Act (2015)[8] which expresses seven goals to improve the social, economic, environmental and cultural well-being of Wales.
- The Prosperity for All: A Low Carbon Wales (March 2019)[9] publication which contains policies and proposals which describe how the first carbon budget was to be delivered. Proposal 18 of that publication confirms that without significant contribution from CCUS, Wales would be unable to achieve its previous, lower target of 80% reduction by 2050 relative to 1990, let alone its more ambitious net-zero target.

This report outlines how CCUS could help Wales meet the net zero goal. It considers a range of different CCUS uptake levels, in order to model a range of decarbonisation pathways which in turn drive varying technology needs, CO_2 export and utilisation options and associated costs. It examines and builds upon other initiatives in, and near, Wales, such as the "South Wales Industrial Cluster (SWIC)", the FLEXIS research consortium, the decarbonisation objectives of the North Wales Economic Ambition Board, and the nearby HyNet project. However, we have also examined the lessons to be learnt for Wales from other relevant projects such as Northern Lights in Norway to examine CO_2 capture and shipping, the Net Zero Teesside project to examine deep decarbonisation of an industrial cluster, and the Greensand project in Denmark to evaluate subsurface CO_2 storage solutions.

A map of CO_2 emissions in Wales was created using the Microsoft Power BI tool based on emissions data from Natural Resources Wales and is shown below in Figure 2-1. Data from 2019, the latest data set available, was used in creating the map.

An outline timeline for the deployment of CCUS is shown in Figure 2-2.

A list of the key documents reviewed as part of this study is given in Appendix A.

8. The Welsh Government has issued Guidance to this UK legislation: https://gov.wales/well-being-future-generations-guidance
9. Prosperity for All: the national strategy https://gov.wales/sites/default/files/publications/2019-06/low-carbon-delivery-plan_1.pdf

Site	Nearest Hub	Site Reported CO2 Emissions
Port Talbot, Tata Steel Ltd	Port Talbot	6432847
Pembroke Power Station, RWE Generation UK Plc	Milford Haven	4280280
Pembroke Refinery, Valero Energy Ltd	Milford Haven	2161067
Connahs Quay Power Station, Uniper UK Ltd	HyNet	886409
Uskmouth Power Station, Severn Power Ltd	Newport	716346
Padeswood, Hanson Cement (Form. Castle Cement) Ltd	HyNet	478483
Aberthaw, Tarmac Cement and Lime Ltd	Barry	365472
Baglan Bay, Baglan Operations Ltd	Port Talbot	339161
South Hook LNG Terminal	Milford Haven	236755
Barry, Dow Silicones UK Ltd	Barry	151422
Chirk, Kronospan Ltd	N/A	136959
Bridgend, Rockwool Ltd	Port Talbot	78865
Dragon LNG Terminal	Milford Haven	70118
Shotton, Tata Steel UK Ltd	HyNet	55760
Point of Ayr Terminal, ENI Limited	HyNet	53946
Newport, Solutia UK Ltd	Newport	48491
Tremorfa 2, CELSA Manufacturing (UK) Ltd	Cardiff	46650
Castle Works, CELSA Manufacturing (UK) Ltd	Cardiff	45377
Trostre, Tata Steel UK Ltd	Llanelli	44457
Bridgend Paper Mill, WEPA UK Ltd	Port Talbot	40061
Llanwern Steelworks, Tata Steel UK Ltd	Newport	38792
Broughton, Airbus Operations Ltd	HyNet	35321
Queensferry, Knauf Insulation Ltd	HyNet	34776
Pont-y-felin, Knauf Insulation Ltd	Newport	28743
Oakenholt Paper Mill, Essity UK Ltd	HyNet	25505
Tremorfa Sections Mill, CELSA Manufacturing (UK) Ltd	Cardiff	23543
Baglan, Intertissue Ltd	Port Talbot	21715
Mostyn, Warwick International Ltd	HyNet	20641
Newport, Liberty Steel Newport Ltd	Newport	20356
Magor Brewery, AB InBev UK Ltd	Newport	19570
University Hospital of Wales	Cardiff	16959
Orb Works, Tata Steel UK Ltd	Newport	16948
Total		**16971801**

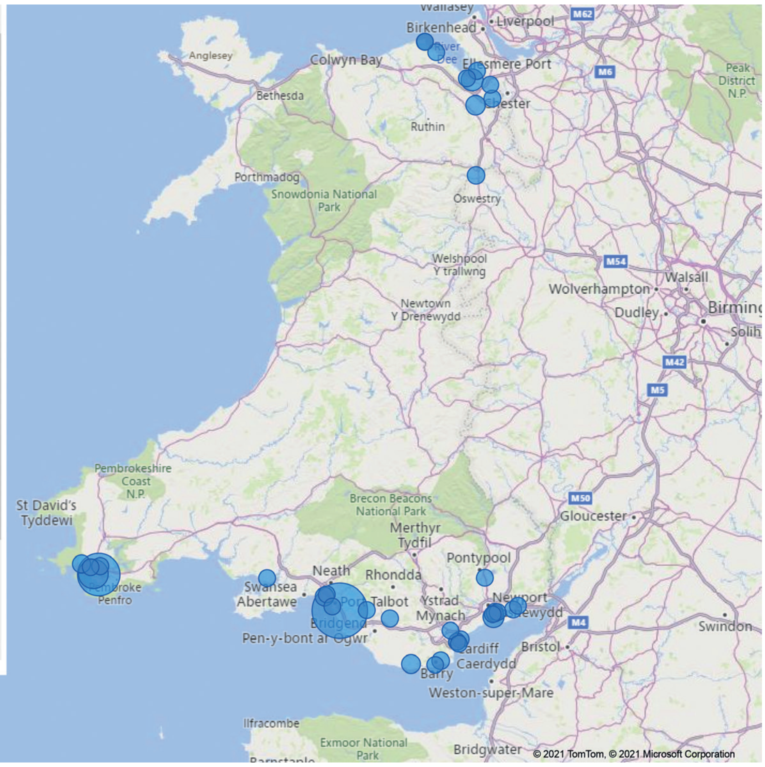


Figure 2-1 CO_2 Emission Map of Wales (2019 Data CO_2 Tonnes Per Year)

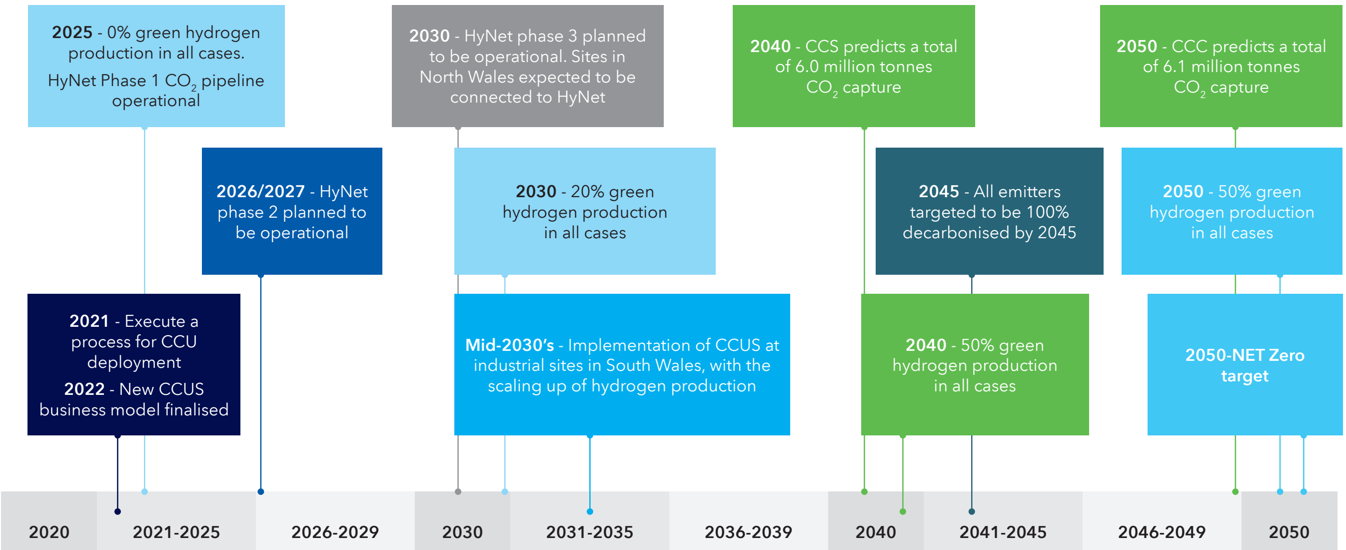
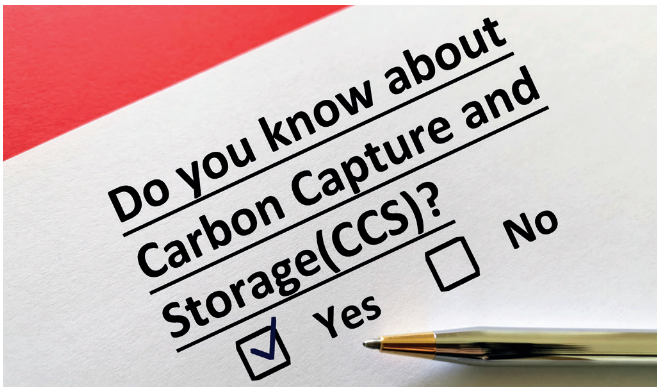


Figure 2-2 Timeline for CCUS in Wales

3 Stakeholder feedback

3.1 Stakeholder Engagement

This section provides an overview of the feedback we received from two stakeholder workshops in January 2021, each with around 50 people, together with over 20 one-to-one or small group discussions – covering major industry, power sector, cluster leads, potential CO_2 transport and storage operators, regulators, gas networks and academia. The comments below reflect the views of the stakeholders, not the report authors or the Welsh Government. The key points from the stakeholder feedback included:



Capture – CO_2 capture will be required, but this is not the only option for many emitters:

- **Capture sites:** For power generation, hydrogen may be a more attractive option than post-combustion CCUS for lower load factors. The majority of cement plant emissions are from the process, where there is little alternative to CCUS. For steel, views differed, with some scepticism on the ability of CCUS to achieve net zero in the sector, but other views that CCUS is an essential stepping stone, with innovative solutions developed in the UK to be able to be exported. Both CO_2 capture and hydrogen are options for refineries, and for LNG terminals, other options such as methane leak reduction and fuel switching were preferred to CCUS.
- **Business models:** All emitters told us that the BEIS business models are critical to investment in CCUS or other decarbonisation technologies such as hydrogen.
- **Electrification:** For some of the large emitters, electrification was seen as too costly, with operating costs 4 times higher than gas, and some other sites need a carbon source for their process, so electrification could only take them so far on a decarbonisation pathway.
- **Flexibility:** Overall, CCUS was not seen as the only option, and fuel switching would be preferable for some. Answers would be very plant-dependent, including for issues such as available space to fit new equipment. It was agreed that the implication of the above is that flexible and modular CCUS infrastructure is needed, and that the right scale will not be known at the start.

Transport – there is a clear potential pipeline link to HyNet in North East Wales, and shipping can offer flexibility in South Wales:

- **Ports:** There are multiple ports in South Wales that have potential for CO_2 shipping, including Newport, Cardiff, Barry, Port Talbot and Milford Haven, although safety and other studies would be needed to determine suitability. Port operators would like to handle CO_2, although volumes need to be in the hundreds of thousands of tonnes to make it worthwhile, and business models need to be in place. Freeport or Greenport development may be an opportunity, although land that the ports own may have competing development opportunities.
- **Shipping:** Shipping options could involve several smaller terminals, with possible small ship transport to larger terminals, or one or two larger terminals only, with onshore transport to those larger terminals. CO_2 shipping at scale is not seen as likely before 2025, although it was agreed that shipping can provide flexibility.
- **Pipelines:** HyNet Phase 2, from 2026-27, may link to CO_2 capture from plants in North East Wales. Old redundant pipelines do exist in both North and South Wales, although they would need to be assessed to determine suitability and safety for repurposing. It was generally agreed that a new CO_2 pipeline from South to North Wales was unlikely for a number of reasons including obtaining planning consents and wayleaves across rural areas, and uncertainties over the size of pipeline due to doubts around the future plans of major emitters in South Wales.

- **Business models:** There are, as yet, few answers for CO_2 shipping from the BEIS business models work, including on the question of liabilities for CO_2 leakage. Views differ on whether this is a problem, with some preferring a contract with a single T&S provider who would take the risk away from them.

Storage – some stores are already booked up, but there are several UK storage options:

- Several planned stores in the UK expressed an interest in engaging with the Welsh Government as a potential resource to be used to store CO_2 shipped or transported by pipeline from Wales.
- **Potential stores – overseas:** Northern Lights in Norway has a planned start-up in 2024, although most of its capacity is already spoken for. Porthos in the Netherlands does not have spare capacity for CO_2 imports in its current phase, although other potential stores off the Dutch coast are being considered. Ireland has potential storage at Kinsale, but is itself looking to ship CO_2 overseas, so at this stage it is an unlikely destination for Welsh CO_2.
- **Wales:** Although there may be CO_2 storage options in Wales, including in the St George's Channel and in coal seams/former coal mines, in the first case these have not been well mapped and in the second their development would conflict with other Welsh Government policies on petroleum development and planning, and therefore both should be seen as much less likely.

Utilisation – CO_2 usage is an important opportunity, but it is at the scale of thousands of tonnes, not millions of tonnes:

- **Advantages:** A lot of work is being carried out through the SWIC cluster plan on utilisation. Utilisation may be cheaper than storage, can create high-value jobs, and would be viable with smaller investments (e.g. £20 million). Utilisation is also seen as a preferable option to storage in some sectors of society.
- **Disadvantages:** Utilisation, however, is not large-scale, with volumes of perhaps 1,000 tonnes from a single site, and it will take time to develop jet fuels, acetates or other carbon-based chemicals that could require much bigger CO_2 usage volumes. For cement, carbon usage is not really applicable – it will cost more to capture emissions compared with ammonia plants, and usage would only amount to a few percentage points of the CO_2 stream.

Hydrogen – hydrogen has potential and may be a preferable solution for some sectors:

- **Hydrogen production potential:** Hydrogen has the potential to support deep decarbonisation across multiple sectors in Wales, including transport, industry, domestic heat and power. Use of hydrogen as an energy carrier could reduce the demand for capture of CO_2, as it burns to produce only water. There is significant potential for hydrogen production and distribution in several parts of Wales, including blue and green hydrogen in Milford Haven, blue hydrogen at Port Talbot, blue and green hydrogen in North East Wales, and green hydrogen in Anglesey. The proposed tidal lagoon at Port of Mostyn is also a potential source of renewable power that could be used to produce green hydrogen. Any blue hydrogen produced in Wales would of course require CCUS to mitigate its carbon emissions. Hydrogen produced from nuclear power via the next generation Small Modular Reactors (SMR) is also an option in North Wales. A new hydrogen pipeline may be difficult to construct, given the planning issues previously experienced for new gas pipelines. Therefore, the hydrogen may need to be utilised close to its production source for local industrial and power uses.
- **HyNet:** HyNet Phase 3, planned to be operational by 2030, would see expansion of hydrogen production and extension of the hydrogen pipeline to North East Wales.
- **Risk reduction:** Hydrogen can reduce risk for major consumers. Companies worry about CO_2 liabilities and don't know how to price the risk, and they also worry about the cost of CO_2 shipping. Both of these can be taken care of for them by the option of the delivery of clean hydrogen.

The Welsh Government needs to support CCUS in Wales more strongly, as part of an integrated package, keeping industrial competitiveness front of mind:

- **SWIC:** Many of the South Wales options, including for specific emitters and ports, will be studied in more depth through various projects under the SWIC banner. In March 2021, the Department for Business, Energy & Industrial Strategy announced that £171 million of funding was being made available to support 5 projects through the Industrial Decarbonisation Fund. SWIC were granted phase two funding of nearly £20m following successful completion of phase one assessments looking at decarbonisation schemes and the infrastructure required for a hydrogen economy in South Wales. Phase Two of the project involves engineering studies to explore the routes to decarbonisation, including the use and production of a hydrogen supply, carbon capture usage and storage (CCUS) and CO_2 shipping from South Wales.

- **CCUS as part of an integrated package:** CCUS will be needed to reach net zero in Wales, and it would provide opportunities to attract low carbon manufacturing. The Welsh Government needs to provide a strong voice for Wales with BEIS, particularly on the CO_2 shipping issue, and should increase coordination with SWIC. This should be done as part of an integrated package, including CCUS, hydrogen and floating offshore wind in the Celtic Sea.
- **Industrial competitiveness:** There are competitiveness risks through higher costs for steel, cement, refining etc in the UK compared with other countries, so the funding of CCUS and associated carbon pricing and allocation of emissions permits needs to be considered carefully. Most of the larger emitters in Wales have headquarters outside of the UK, so decarbonisation in Wales needs to take place within the context of a global market. Carbon border adjustments will help in theory, but they are complex to implement.
- **Skills and supply chain:** Skills are critical, and maximum use of existing industrial skills needs to be made. There are good examples of supply chain development work from the nuclear, automotive and aerospace sectors, which can inform the development of local CCUS supply chains. Lessons need to be learnt from the growth in offshore wind, where the UK did not secure sufficient local content for the supply chain.
- **Other important considerations:** Other sustainability considerations, including the Wellbeing of Future Generations Act and Sustainable Management of Natural Resources, imply that CO_2 storage should be minimised if possible and the long-term aspiration should be green hydrogen, with CO_2 storage playing an interim role, and CCS required for chemical CO_2 and BECCS in the longer term. It is critical to ensure that the different layers of planning and permitting are properly coordinated, and work is underway to map the regulatory roadmap. Public perception is also a potential issue, with densely populated areas close to many possible CCUS locations, and people wanting to see that CCUS investment provides value for money.

4 Options for CCUS in Wales

4.1 Capture, transport, and storage

Technical details associated with the properties of CO_2, capture technologies, the processing and handling of CO_2 are important when considering CCUS options. Capture technologies create the concentrated CO_2 stream and these are largely mature technologies. The processing of the captured CO_2 determines the purity, temperature and pressure which, in turn, determines the transport options for transfer to the storage site.

Figure 4-1 schematically shows CO_2 production, capture, transport and storage options from a range of different industrial sources including power generation, cement and manufacturing. Transport options include pipeline, road and ship.

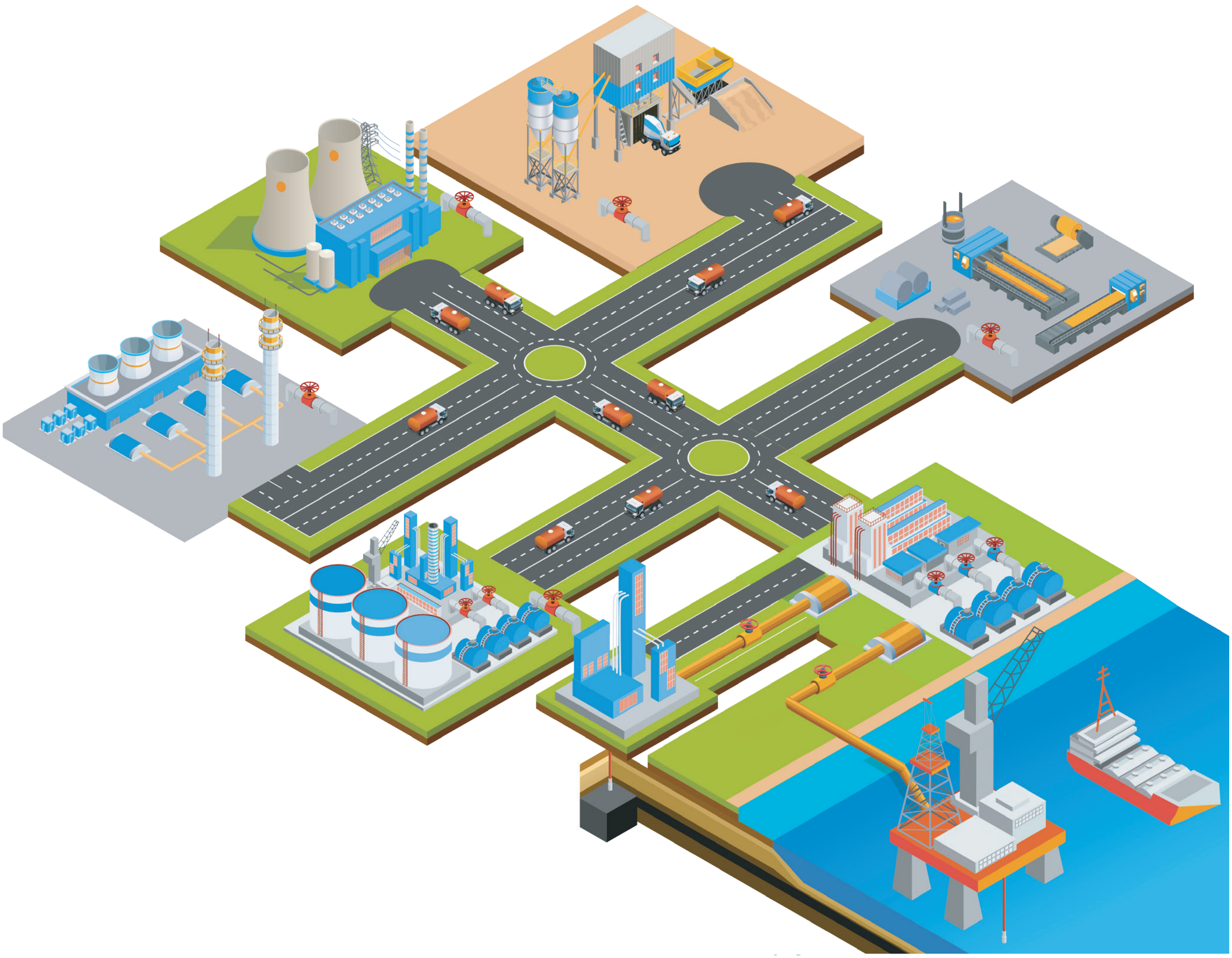


Figure 4-1 Carbon dioxide production, capture, transport and storage

4.2 Transporting CO_2

4.2.1 Choice of transport conditions

A 2018 study[10] for BEIS looked at the transport of CO_2 in detail. The report suggested that transport of large amounts of CO_2 over long distances by pipeline or ship is only attractive if the CO_2 is in liquid or dense phase form at high pressures.

A summary of transport methods, options and CO_2 processing required is shown in Table 4-1.

Transport Method	Options	CO_2 processing required
Pipeline	Low-pressure gas – low cost for local CO_2 networks and least treatment needed. May feed a high-pressure system and additional processing needed. High-pressure gas – more stringent treatment and drying levels needed plus compression Liquid – highest treatment levels plus energy cost of compression and cooling for liquefaction. May be possible to achieve through repurposed redundant pipelines.	Drying Removal of impurities Compression Metering Liquefaction
In bulk by road, rail or sea	Compressed gas, low-pressure, medium pressure or high-pressure Liquid CO_2	Compression, loading bays, and local storage Shipping requires chilling, liquefaction, storage and loading facilities (storage density too low to ship as gas)
Other	Adsorbed onto a transportable and regenerable solid Absorbed in a regenerable liquid carrier As solid CO_2	Adsorb, absorb facilities and regeneration of solid carrier Specialist loading/unloading handling

Table 4-1 Summary of transport options for CO_2

10. 'Shipping CO_2 – UK Cost Estimation Study' Report by Element Energy for Business, Energy & Industrial Strategy Department November 2018 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/761762/BEIS_Shipping_CO2.pdf Note that table 3-1 in the report could cause confusion as it implies that carbon dioxide exists in both the liquid and gas phases at the temperatures and pressures quoted which is not strictly correct.

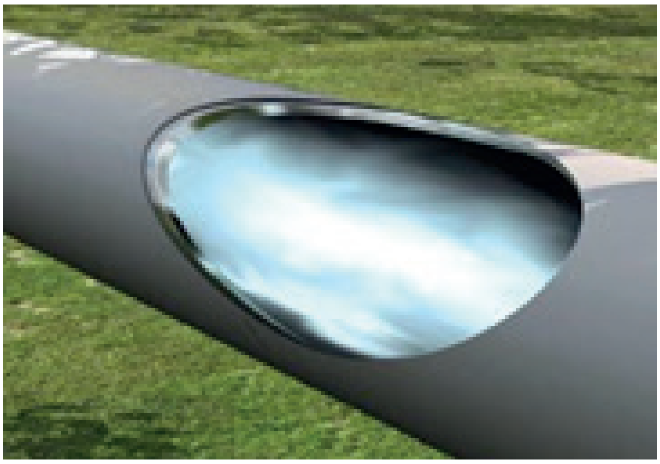
4.2.2 Pipelines

Building and operating CO_2 pipelines is well-established technology. An IEAGHG report in 2014[11] identified over 6,500 km of CO_2 pipelines worldwide. The majority of these were transporting CO_2 for enhanced oil recovery[12] projects in the US and passed through relatively uninhabited areas but there were also a growing number associated with CO_2 transport for re-use or storage in Europe.

A key feature of CO_2 is that its behaviour is strongly affected by the presence of impurities. The pressure required to liquefy the mixture increases and this affects the pipeline materials, permitting and operation. Transporting relatively pure CO_2 as either a liquid or a gas is preferable to managing a pipeline flowing a two-phase mixture. This means that it is preferable to transport CO_2 either in the gas phase at up about 35 bar or as a dense liquid phase above 100 bar, well above the two-phase region.

Permitting of CO_2 pipelines
In GB, CO_2 is classed as a 'substance hazardous to health' under the Control of Substances Hazardous to Health Regulations 2002 (COSHH). The planning application process is non-trivial and requires a strong evidence base. However, a report for BEIS[13] notes that the evidence base provided through the cancelled White Rose project in its permitting process proves that CO_2 pipeline transport can, be done safely.

Challenges of building pipelines
Construction of major pipelines can be extremely controversial, especially so if the pipeline runs through sensitive landscape or close to built-up areas. The most recent major pipeline built in Wales was the 317 km, 48" high-pressure natural gas pipeline from the LNG terminals at Milford Haven to a National Grid Gas Transmission connection in Gloucestershire. On its route, this passed through 25 km of the Brecon Beacons National Park and faced a series of local protests along its route, at one point causing National Grid to declare Force Majeure on the date of completion for the system[14]. The original estimated cost was £700 million but the actual cost is believed to be £1.08 billion.



Re-use of existing pipelines
Whilst re-purposing pipelines and other facilities is superficially attractive, there are several potential barriers that make may make it infeasible either for safety or economic grounds. DNV issued a whitepaper on the topic of repurposing existing infrastructure[15], which highlighted:

1. Onshore natural gas transmission systems and pipelines are largely designed to operate at the local ground or ambient temperatures and at pressures between 40 and 85 bar.
2. Pipelines transporting dense phase fluids or high vapour pressure liquids are susceptible to long running pipeline fractures and must be assessed as to whether the design toughness is suitable.
3. Dense phase liquid CO_2 is an excellent solvent for organic material. Hence, special attention must be paid to the suitability of components like seals, valves, gaskets and lubricants that could come into contact with CO_2.
4. Since the properties and hazard potential of CO_2 differ significantly from those of natural gas, so the risks related to the transmission of CO_2 will also differ. The zoning around a re-purposed pipeline will thus need to be redefined to reflect zoning requirements for CO_2 pipelines.
5. An additional hurdle to repurposing a pipeline could be missing documentation which would hinder or prevent the assessments needed to identify modifications, such as cleaning, valve replacements and the identification of the measures required to ensure that the reused pipeline is operated safely and reliably.

11. 'CO_2 Pipeline Infrastructure', Report 2013/18 by Ecofys and SNC-Lavallin for the IEAGHG, January 2014.
12. Enhanced Oil Recovery is a technique of injecting carbon dioxide into an oil reservoir to extract hydrocarbons that would otherwise be unrecoverable.
13. BEIS distributed report https://www.gov.uk/government/collections/carbon-capture-and-storage-knowledge-sharing
14. https://www.marketwatch.com/story/national-grid-declares-force-majeure-on-milford-haven-lng-pipe/
15. Safely Re-using Infrastructure for CO_2 Transport and Storage, DNV, September 2019.

Figure 4-2 shows an aerial photograph of a CO_2 pipeline that had been deliberately ruptured at DNV Spadeadam; experiments such as these are used to understand the hazards and mitigations required for operating CO_2 pipelines so that they can be designed, routed and operated safely. The likelihood of failure is very low, but research such as this allows us to improve our understanding of potential consequences.

Figure 4-2 Aerial Photograph of a CO_2 Pipeline Fracture Test at DNV Spadeadam

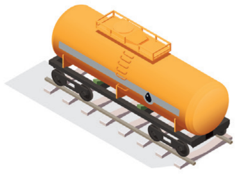
4.2.3 Small scale batch transport of CO_2

Road Transport

CO_2 tankers, typically operating at 20 bar pressure and -20 °C can carry 20-26 tonnes of CO_2 as a liquid. They are currently used to transport food grade CO_2 for use in the food and beverage industry. There are route choice constraints because CO_2 is a potentially dangerous substance and large numbers of lorry movements produce congestion, noise, visual and air pollution.

Road transport of CO_2 to an export hub would probably only be considered for smaller sites where CCS was essential for process reasons. There are a number of small sites in Wales which emit less than 10,000 tonnes/a of CO_2. These sites would require 400 tanker movements per year, equivalent to one or two per day. As well as installation of carbon capture, the site would need to invest in CO_2 liquefaction, CO_2 storage and loading facilities. The reception site, at a port or CO_2 pipeline terminal, would also need unloading and storage facilities.

Rail Transport
Cryogenic rail tanker wagons can carry approximately 60 tonnes of CO_2 each, thus a full train of 25 wagons would be able to carry 1,500 tonnes.



The storage of CO_2 between train movements would require additional storage capacity at the capture site. This could be accomplished by usage of additional rail wagons, but this will be at the expense of CO_2 losses through boil-off, since the wagons are not usually refrigerated, just insulated. In practice this boil-off could be limited further by scheduling more frequent train transfers of smaller numbers of wagons.

Barges
Gas barges with a capacity of up to 5,538 m³ have recently been built by INEOS for use on the Rhine[16]. The only location in Wales where use of such vessels is an option is the Dee Estuary where barges are currently used by Warwick Chemicals and Airbus for shipping of some products.

Large Scale Shipping
Brownsort[17] undertook a detailed literature survey of shipping of CO_2 and concluded that although CO_2 shipping is currently limited to small scales, there is a good level of understanding and definition of what would be needed for scale-up to capacities appropriate for CCS.

Repurposing of LPG ships for CO_2 transport is feasible but is not without issues such as the difference in cargo density which may lead to structural issues unless ship capacity is reduced[18].

Port facilities
It is recommended that at least one full ship volume (some authors suggest up to 1.5 times)[19] is stored ready for loading to ensure rapid turnaround of ships in port. As discussed above, this local storage should be at -50 °C to allow some margin between the liquid and the solid transition temperature and will thus need to also be at 7 bar or higher. For ship loading, the CO_2 can be pressurised further if needed by the pumps loading the ship.

Loading and unloading systems
Loading a CO_2 ship can be performed using articulated loading arms (which are currently often used for other cryogenic liquids such as LPG and LNG) or using insulated flexible hoses. Loading arms are to be preferred on reliability and integrity grounds. The liquid is transferred through an insulated pipeline, specified for the chosen pressure and temperature, from the storage to the loading arm and ship, using pumps located near the storage. As with loading of other cryogenic liquids, a return line will be needed to take boil off gas, generated in the ship's tanks during this process, back to the onshore storage tanks or liquefaction plant. Figure 4-3, from the BEIS/Element Energy study summarises the port loading and unloading options.

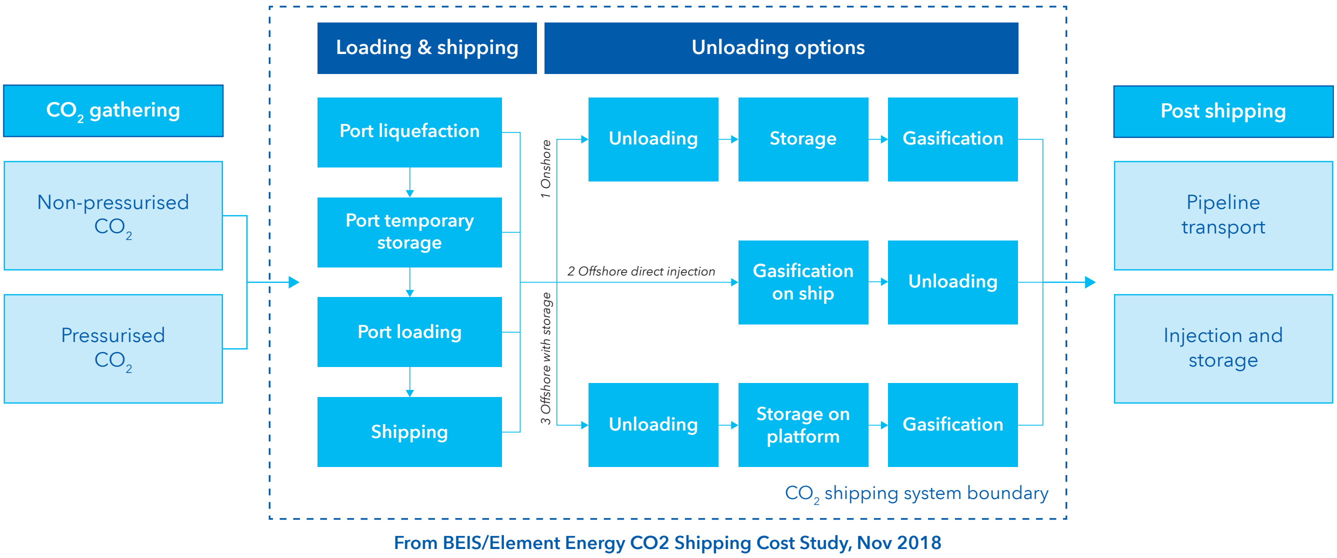


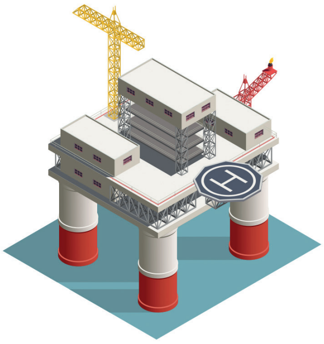
Figure 4-3 Port loading and unloading options at ports

16. https://www.ineos.com/news/shared-news/ineos-builds-new-efficient-class-of-barges-to-supply-raw-materials-on-the-rhine/
17. Brownsort, P. Ship transport of CO_2 for Enhanced Oil Recovery – Literature Survey' Scottish Carbon Capture & Storage, January, 2015
18. 'Shipping CO_2 – UK Cost Estimation Study' Report by Element Energy and others for BEIS, November 2018 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/761762/BEIS_Shipping_CO2.pdf
19. Brownsort, P. Ship transport of CO_2 for Enhanced Oil Recovery – Literature Survey' Scottish Carbon Capture & Storage, January, 2015

4.2.4 CO_2 Sequestration and Re-Use

Carbon dioxide can be stored underground in several different ways including in depleted oil, gas and coal fields, in saline aquifers and it can be reused for enhanced oil recovery.

Depleted oil and gas fields
Storage of CO_2 in depleted oil and gas fields is analogous to their use for natural gas storage – an IEAGHG Report of 2009[20] suggests that over 600 such stores exist. BEIS has recently undertaken a consultation on the reuse of existing offshore infrastructure for CCS[21].



Various projects in the UK and North Sea are proposing the use of depleted hydrocarbon fields for CO_2 storage, and they have formed part of the stakeholder engagement for this project:

- HyNet/Net Zero NW – Hamilton gas field
- Spirit Energy – South Morecambe gas field
- Humber V Net Zero – Various undisclosed Southern North Sea depleted gas field(s)
- Acorn – Goldeneye and other Central North Sea fields
- Athos and Porthos – Various Dutch North Sea depleted gas fields.

Saline Aquifers
Saline aquifers lie below many oil and gas fields and offer potentially larger scale reservoirs for CO_2 storage than gas fields. However, due to their nature the geological structures have been less well studied so there will be more uncertainty regarding the amount of CO_2 that can be stored and the resistance of the formation to leakage. There will also be no existing facilities available for re-use. The Northern Endurance and Northern Lights project are seeking to use saline aquifers.

A summary of sequestration options, requirements and facilities is shown in Table 4-2.

Option	Requirements	Facilities
Saline aquifer	Specific pressure, injection rates and purity requirements	Reception depot including metering and unloading facilities Local pipeline injection facilities including regasification (if transported as liquid), compression, subsea pipelines (if storage is offshore) and injection wells
Depleted gas/oil fields	Specific pressure, injection rates and purity requirements	
Enhanced oil recovery	Specific pressure, injection rates and purity requirements and may not be rigorous enough in terms of carbon capture	
Utilisation	Industrial purity specification and pressures For food use – low volumes, compressed and high-purity requirements. For synthetic gas production in combination with hydrogen. For synthetic fuels production e.g aviation fuels.	Reception depot including metering and unloading facilities

Table 4-2 Summary of sequestration options

20. 'CO_2 Storage in Depleted Fields' Report by Poyry, Element Energy and British Geological Survey for the IEA GHG R&D Programme, March 2009.
21. Response to BEIS consultation on reuse of offshore oil and gas assets for CCS https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/909642/CCUS-government-response-re-use-of-oil-and-gas.pdf

4.3 Alternatives to CCS

4.3.1 Improved Energy Efficiency

Improvements in energy efficiency and overall reduction in energy demand are key drivers for decarbonisation. Efficiency comes not just from how energy is supplied but also how it is used. The Welsh Government has published an energy efficiency strategy[22] which supports the Well-being of Future Generations Act, the Environment Bill, the climate change strategy, fuel poverty strategy and Child Poverty strategy. The DNV Energy Transition Outlook 2020 reports[23] that increases in efficiency are the most cost-effective method for transforming the energy system and should be the number one priority for authorities and other stakeholders in the energy industry.

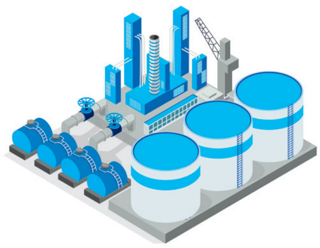
Historically, energy demand has grown in step with population growth and improvements in standards of living. The next three decades are likely to be different however: DNV forecasts that efficiency gains, largely enabled by accelerated electrification, will start to outpace economic growth. Despite the rapidly increasing consumption of energy services by a growing economy, we forecast that final-energy demand will, in fact, peak in 2034, and at a level only 4% higher than that of today. In the manufacturing sector, substantial energy- efficiency gains, including increased recycling, will outpace the growth in demand for goods, such that manufacturing energy use will peak in the 2030s.

4.3.2 Fuel switching to hydrogen

Hydrogen has rapidly gained prominence as an energy vector in the last five years. Hydrogen is found only as part of a compound, most commonly in the form of water but also in, for instance, hydrocarbons such as methane, gasoline and coal. It is seen as a route to low-carbon conversion of existing gas transmission and distribution infrastructure[24, 25, 26] if it is produced with a low carbon footprint and can be generated using excess renewable electricity generating capacity through electrolysis of water. Its widespread use in the steel and chemical industry means that there is reasonable familiarity with hydrogen in the industrial sector. Hydrogen can heat buildings, fuel transport, provide heat to industry, and be a medium to valorise surplus power from renewables. Various routes to hydrogen production can be seen in Figure 4-4 .

Grey and brown hydrogen
Grey and brown hydrogen are generated by reforming or gasification of fossil fuels without CCS. This process has been widely used in the past as the first step to ammonia production from coal or gas and is widely used in refineries worldwide to produce process hydrogen from heavy oil fractions. Due to the energy losses involved in its production, use of grey hydrogen as a fuel effectively increases CO_2 emissions. Note that the term grey hydrogen is usually used for oil or gas derived hydrogen and brown hydrogen for that produced from coal.

Blue hydrogen
Production of blue hydrogen represents a major investment and has longer lead times than green hydrogen production. In addition to building the hydrogen production and CO_2-capture facility, blue hydrogen production requires a permit for injection and storage of CO_2 into a qualified site for geological storage of CO_2. Getting this permit can take 3–10 years, depending on site characteristics. It is therefore likely that investments into large-scale blue hydrogen production towards 2030 will be made only as part of government-supported initiatives.



Blue hydrogen-based projects such as HyNet[27] and H21[28] are currently proposing the use of Autothermal Reformers (ATR) to convert natural gas to hydrogen at around 80% efficiency on a chemical basis. When coupled with 95% carbon capture this results in only 6.25% of the CO_2 emissions vs direct use of natural gas.

22. Energy Efficiency in Wales – A strategy for the next 10 years 2016-2026 https://gov.wales/sites/default/files/publications/2019-06/energy-efficiency-strategy.pdf
23. DNV Energy Transition Outlook 2020 https://eto.dnvgl.com/2020/index.html#ETO2019-top
24. NGN H21 Project which aims to convert the gas network to hydrogen https://www.h21.green/
25. SGN H100 Fife project which is building a new hydrogen gas network https://www.sgn.co.uk/H100Fife
26. National Grid Gas Transmission FutureGrid project which is investigating conversion of high-pressure pipelines to hydrogen https://www.nationalgrid.com/uk/gas-transmission/insight-and-innovation/transmission-innovation/futuregrid
27. HyNet is a project proposing to use blue hydrogen in NW England. https://hynet.co.uk/
28. NGN H21 Project which aims to convert the gas network to hydrogen https://www.h21.green/

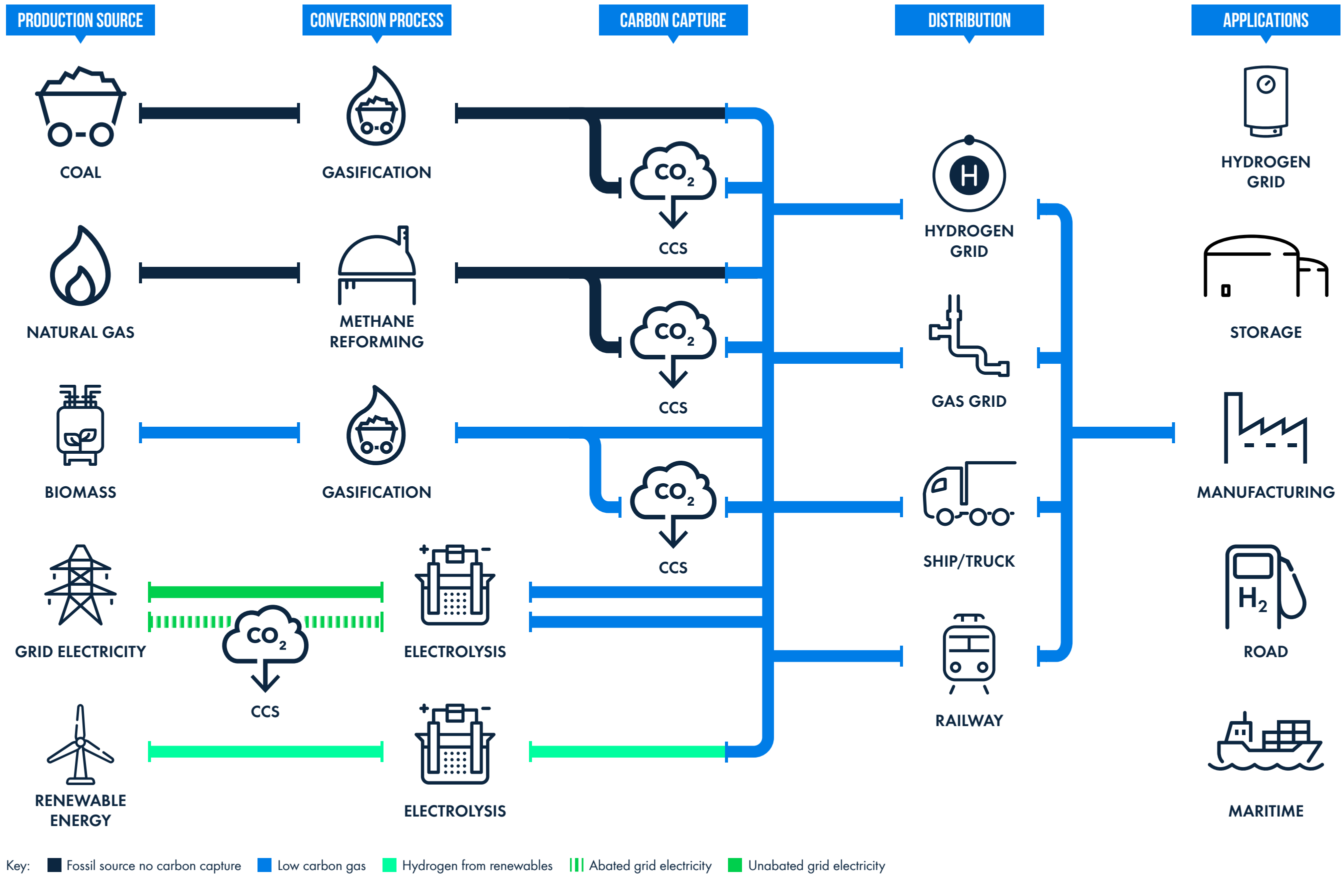
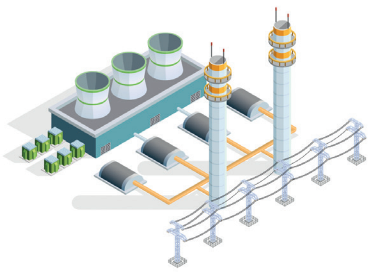


Figure 4-4 Routes to hydrogen production.

Green hydrogen



Hydrogen can be generated by electrolysis of water using either dedicated renewable electricity, or electricity delivered from the grid. Electrolysis efficiencies are currently in the range 70-80%. We expect rapid decline in the cost of green hydrogen with it achieving price parity with blue hydrogen in the early 2030's. Continued development of hydrogen refuelling infrastructure will trigger broader uptake of fuel-cell electric vehicles, particularly in HGV's.

The production of hydrogen gas from renewable electricity through electrolysis has a very low carbon footprint since there are virtually zero GHG emissions during operations.

Such hydrogen production is promoted as a clean and cost-effective way to valorise excess electricity generation from variable renewables, and thereby enable greater fractions of renewables, principally solar PV and wind, in the electricity mix.

Guaranteed green hydrogen can be produced in two ways:

1. By physically connecting production to specific sources, such as a local solar farm, or a wind farm.
2. By sourcing electricity from the grid and purchasing real-time green electricity certificates or establishing real-time power purchase agreements.

Soon, it may also be possible to produce hydrogen through electrolysis or high temperature steam cracking from new small modular nuclear reactors. This is sometimes described as "pink" rather than green hydrogen but is zero carbon.

Fuel switching to hydrogen
Conversion of existing facilities to hydrogen is not simple:

- Different gas densities, combustion properties and energy densities mean that burners will need to be modified or replaced. The radiative properties of hydrogen flames are also different, which may necessitate the replacement of industrial kilns and furnaces.
- Different combustion products are potentially a threat to downstream equipment (e.g. water droplet formation in gas turbines). NOx emissions may increase due to higher flame temperatures.
- No hydrogen distribution grid currently exists, so new or repurposed supply pipes will be needed for early users.
- Hydrogen production will need to match demand and storage will be needed to ensure no interruptions in supply.
- For hydrogen fuelled peak shaving power plants, large amounts of storage will be needed unless dedicated hydrogen production can rapidly respond. This could be particularly problematic as power demand shows both a high daily swing and seasonal swing. The original H21 Leeds City Gate Study[29] proposed blue hydrogen production operating at near maximum capacity in winter and at 70% in summer coupled with seasonal hydrogen storage in salt caverns. Recent stakeholder feedback from WWU report their studies showing 55% utilisation of blue hydrogen production facilities being optimal.

4.3.3 Electrification

Electrification is seen as a wide-ranging option for decarbonisation, and is seen as a preferred option by many.

- The UK will ban the sale of new combustion-engine vehicles by 2030 and are proposing to ban the sale of new hybrid cars by 2035 – it is expected that many private and light commercial vehicles will be replaced by Electric Vehicles (EVs) or Fuel Cell Electric Vehicles (FCEV's).
- Under UK Government current plans there will be a natural gas and oil boiler ban in new build homes from 2025.
- Light industrial sites, commercial premises such as shopping centres, food processors, public sector buildings such as schools and hospitals are expected to convert to electricity as their source of heat either through heat pumps or direct electric heating, and some heavier industries such as glass are considering electrification as a means of decarbonisation[30] though this may be in combination with fuel switching using hydrogen.

As with hydrogen, electricity can be produced from carbon-free sources (renewable and nuclear) or fossil fuels. The future electricity generation mix is expected to be a combination of:

- Nuclear (though the future of current large-scale projects is uncertain) which will run as baseload power. Small Modular Reactors (such as the potential site at Trawsfynydd) are however under development and are currently receiving financial support from the UK government
- Renewables (wind, wave, tidal. hydro, biomass) which will be favoured in the merit order when available.
- Gas fired CCGT which will run as needed but primarily in winter.
- Gas fired OCGT/gas engine peaking power plants.

The last two categories will at some point require CCS or fuel switching, potentially with blue hydrogen. In addition, any biomass power plants may choose to install CCS to take advantage of bioenergy with carbon capture and storage (BECCS) if it proves favourable, thus in the medium-term electrification may not decrease the need for CO_2 export infrastructure as much as expected.

4.3.4 Switching to Biomass/Biogas

There is a limited resource of biomass in the UK to be either used as fuel directly or fed to gasification or anaerobic digestor (AD) plants to produce low-carbon methane. Previous studies into the feasibility of biomass included:

- A report on the UK potential bioenergy feedstocks was conducted in 2017 for Cadent Gas by Anthesis and E4Tech[31].
- A subsequent report by Regen[32] states that analysis of the Cadent study by Wales & West Utilities suggests that the total renewable gas potential for Wales could, if fully exploited, reach as high as 7-8 TWh in the period from 2030 to 2040 - this was equivalent to 8.7% of energy usage in Wales in 2017.
- A further report by Regen for the Welsh Government[33] states that there were 46 anaerobic digestion (AD) projects in Wales in 2017 with total output of 18.9 MWe and 8.4 MWh. Assuming 35% electrical generation efficiency this is equal to about 62 MW of biogas or approximately 0.5 TWh/a.

On this basis, a further 6.5-7.5 TWh of energy could be supplied via biomass but the Biogas Action project[34] noted that:

29. NGN Leeds City Gate project https://www.h21.green/projects/h21-leeds-city-gate/
30 'Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Glass' Report by WSP and DNV for Department of Energy and Climate Change and the Department for Business, Innovation and Skills, March 2015
31. Anthesis, E4Tech: "Review of Bioenergy Potential: Technical Report for Cadent Gas Ltd" June 2017 https://cadentgas.com/nggdwsdev/media/media/reports/futureofgas/Cadent-Bioenergy-Market-Review-SUMMARY-Report-FINAL-amended.pdf
32. Regen for the Institute of Welsh Affairs 9Regen for the IWA: "Swansea Bay City Region: A Renewable Energy Future Energy system vision for 2035" April 2018
33. Energy Generation in Wales - Report by Regen for the Welsh Gov dated Oct 2018
34. https://www.fedarene.org/biogasaction-new-developments-wales-23030

- The most suitable agricultural sites for AD in Wales are dairy farms which are mostly located in the South and South West.
- In 2017 the average herd size would supply a plant generating 13 kWe, significantly lower than the 250 kW project size typically developed under FIT and RHI tariffs at that time.
- Growing crops for AD is now discouraged so cannot be used as a primary feedstock.

Imported biomass has been used extensively by Drax Power in the UK but questions have been raised about the overall environmental impact of this as an option[35].

4.3.5 Negative Emissions Technologies

"Negative emissions" is the term that describes removing CO_2 from the atmosphere beyond the natural cycle. Prime examples are afforestation and reforestation, bioenergy with carbon capture and storage (BECCS), which can be considered as offsetting projects, and direct air carbon capture and storage (DACCS). In March 2021 the Senedd agreed to set a 0% credit limit for the second carbon budget (2021-25), which means Wales must meet the carbon reduction budget through domestic action. This is in line with a recommendation from the Climate Change Committee. Therefore offsetting activities outside Wales would not be considered as negative emissions.

Afforestation/reforestation: in simple terms this means planting trees in new areas and/or replacing felled trees with as much forest as possible. The additional trees will store CO_2. The solution is easy to scale but cannot be scaled sufficiently for this to be the only solution.

BECCS: Burning wood is considered carbon neutral, because only the CO_2 that was captured when the plant was growing is released. If, in addition, CO_2 is captured from the burned wood and stored safely underground, then we remove carbon from the atmosphere. BECCS can be deployed via a range of technologies.

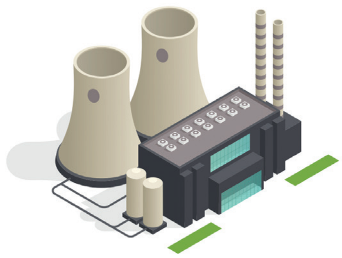
DACCS: Direct Air Capture removes CO_2 directly from the air and subsequently stores it underground. DACCS facilities can be located close to where the CO_2 is to be stored, thereby eliminating transport needs. The technology is unproven for all but laboratory-scale plants, and has the same challenges for Wales as BECCS regarding storage of CO_2. DACCS could be co-located at export hubs or major emitters however as an offset mechanism.

4.4 CCS Technology Options for Wales

4.4.1 Decarbonisation options

The main resource for this section of the report is the CCC Net Zero Technical Report (2019)[36] which investigates each sector of the UK economy in turn, breaks down each sector into separate source types, assesses levels of emissions from these sources and then identifies the most promising means of abating them. This section of the report is limited to power, industry, waste and business/building sectors relevant to Wales.

4.4.2 Decarbonisation of power generation



To meet the Welsh Government's CO_2 targets, all large CCGT power stations will need to be decarbonised. Other than decommissioning (which may be the option chosen for older power stations), the two main options for decarbonising power are CCS and fuel switching to hydrogen:

- CCGT generation with CCS:
  - Post combustion carbon capture – this approach would use an advanced amine (or possibly chilled ammonia) process to capture CO_2 from the CCGT flue gas.
  - Pre-combustion carbon capture – in this case, the fuel gas supply to the CCGT is passed first to a reformer where it is converted to hydrogen and CO_2. After separation, the hydrogen is used as fuel for the CCGT. Essentially this process is the same as fuel switching with hydrogen from a gas network.

- Hydrogen fired CCGTs.
  - Locally generated blue hydrogen.
  - Blue or green hydrogen delivered by the gas network.
  - Hydrogen imported by ship (possibly as ammonia or as a liquid organic hydrogen carrier (LOHC)).

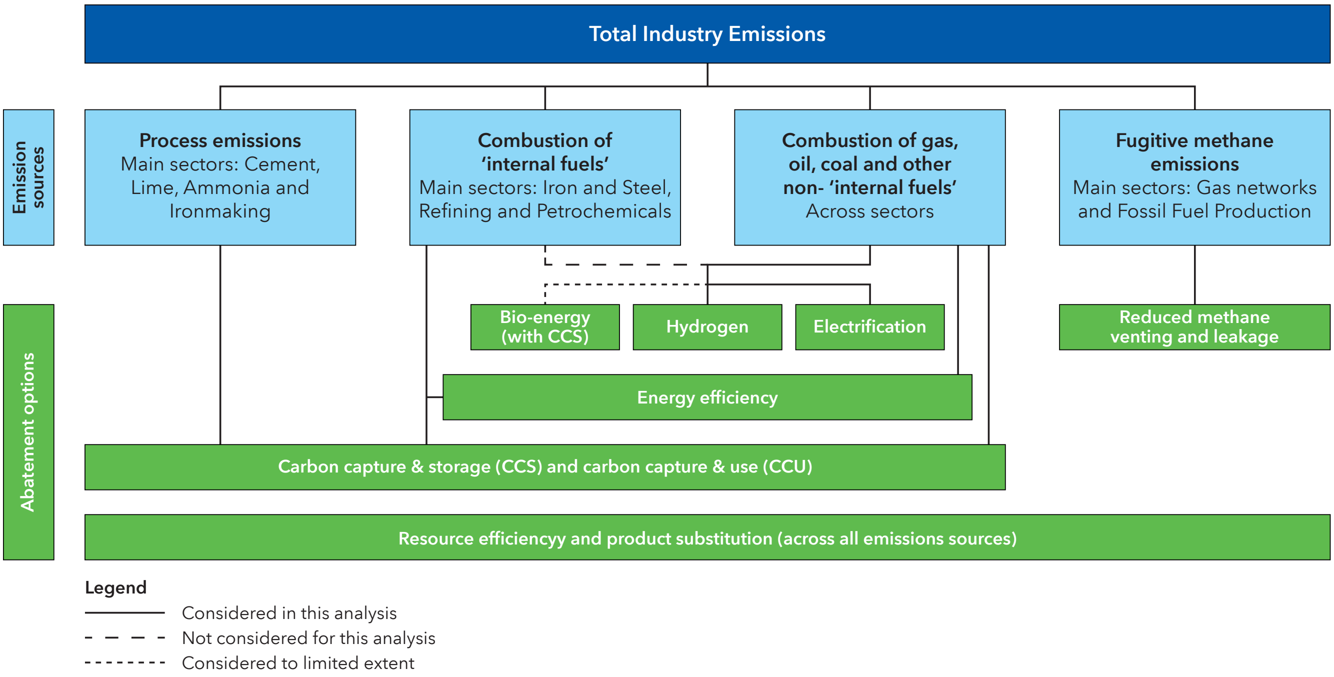
The choice between these two options depends on the available infrastructure (i.e. hydrogen supply by gas network and/or local hydrogen storage facilities or CO_2 transport and storage facilities), future gas prices and the load factor of the power station. Post combustion CCUS has the higher capital cost but exacts a lower efficiency

35. See, for example, an article in the Ecologist in 2017 https://theecologist.org/2017/apr/10/no-drax-theres-nothing-sustainable-about-big-biomass
36. CCC Net Zero Technical Report https://www.theccc.org.uk/publication/net-zero-technical-report/

penalty than the conversion of natural gas to hydrogen[37]. An ETI study[38] suggests that at high load factors, CCUS is the lowest cost option whilst at lower load factors, conversion to hydrogen (based around a continuously running ATR/SMR and hydrogen storage in caverns) is optimal. This was confirmed by stakeholder feedback during this project.

4.4.3 Decarbonisation of Industry

The CCC Net Zero Technical Report refers to BEIS 2018 fuel switching study[39] undertaken by Element Energy and Jacobs which identified types of processes rather than industries. An extension study was commissioned by the CCC[40] to look at decarbonisation of internal fuels which are produced from fossil fuel feedstocks as part of the manufacturing process and then combusted to produce heat (e.g. coke in ironmaking or hydrogen in refining). The conclusion was that full decarbonisation of stationary combustion in manufacturing is possible using hydrogen, CCS, BECCS and electrification as shown in the following schematic in Figure 4-5.



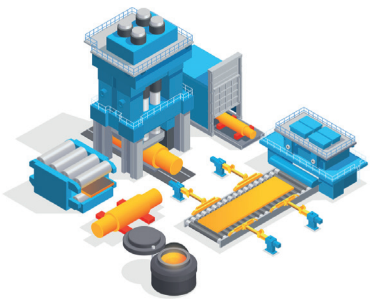
Notes: Combustion of gas, oil and coal includes off-road mobile machinery which can be abated with the fuel switching options. Fugitive CO_2 emissions are considered within process emissions above. The lines for CCS and CCU indicate the consideration of CCS; CCU has not been considered in this analysis. 'Internal fuels' are fuels produced by industry feedstock (blast furnace gas and coke oven gas in the iron-making sector, and some less valuable hydrocarbons in the refining and petrochemicals sectors).

Figure 4-5 Options for decarbonisation of industry (image credit CCC)

37. Bates, C. & Read, A. 'BEIS: CCUS Technical Advisory – Report on Assumptions' Uniper Technologies, September 2018
38. 'Hydrogen - The role of hydrogen storage in a clean responsive power system' Insights report by the Energy Technologies Institute, 2015
39. BEIS fuel switching study https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/824592/industrial-fuel-switching.pdf
40. Extension to the BEIS fuel switching study commissioned by CCC https://www.theccc.org.uk/wp-content/uploads/2019/05/Extension-to-Fuel-Switching-Engagement-Study-Assumptions-Log.pdf

4.4.4 CCS for Iron and Steel Production Processes

There are three main routes to steel production[41] as shown in Figure 4-6 and described below.



1. Conventional integrated steel production

Conventional integrated steelworks use a blast furnace (BF) followed by a basic oxygen furnace (BOF). Overall power usage per tonne of crude steel produced is reported (World Steel[42]) as 18.93 GJ. An IEAGHG study suggests that roughly 450 kg of carbon goes into the process for each tonne of hot metal produced. 85-90% of this carbon exits the process in flue gas from the power plant, furnace flares and heating stoves.

2. Electric Arc Furnace (EAF)

Recycled scrap steel and some flux/additives are placed into the EAF where carbon anodes are used to pass high currents through to melt the steel. The molten steel product is then tapped and sent direct to secondary steelmaking processes. Overall power usage per tonne of crude steel was reported (World Steel) as 7.33 GJ which is 38% of that used in the conventional route, albeit use of scrap steel eliminates the ironmaking step. Recycled steel produced in an EAF tends to be of lower quality than virgin steel because it retains contaminants that were present in the scrap steel, such as copper.

Nearly 30% of steel is made from EAF (about 50% in Europe). Production is limited by the availability of scrap steel, but recycling will increase as the world inventory of steel increases. Some Direct Reduced Iron (DRI-EAF) plants are now being built and the sponge iron that is produced is used as feedstock to the EAF.

3. Direct Reduction

Iron ore is directly reduced with a reducing gas (derived from any of a number of fuels including natural gas, coke, coal, refinery bottoms syngas) in a vertical furnace/reactor to produce a sponge iron. This can then be fed to an EAF for steel production[43].

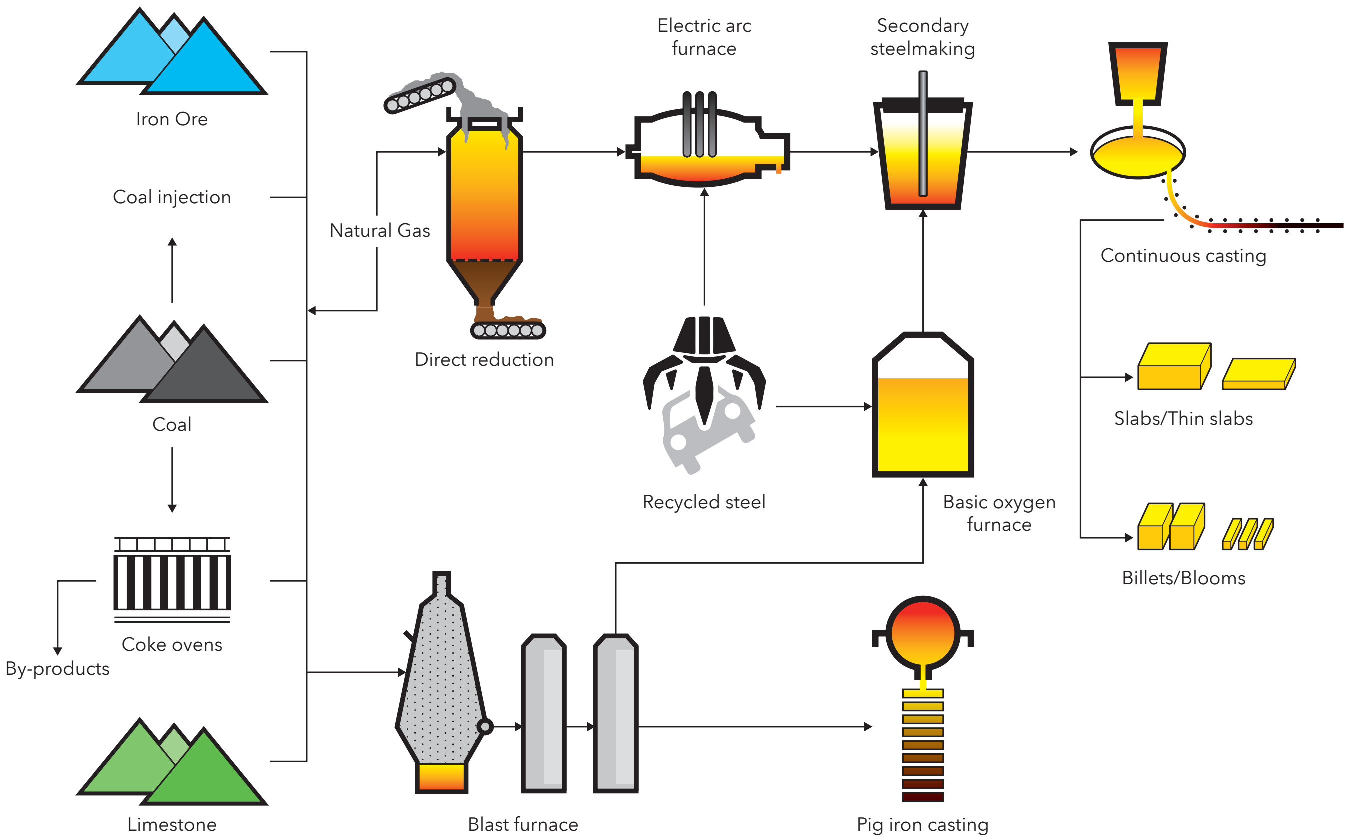


Figure 4-6 Options for steel production

41. 'Production routes for steel' and 'Ultra low CO2 steelmaking' pages at https://www.sustainablesteel.eu/default.asp
42. World Steel https://www.worldsteel.org/steel-by-topic/raw-materials.html
43. 'The MIDREX® Process - The world's most reliable and productive Direct Reduction Technology' Brochure downloaded from https://www.midrex.com/

4.4.5 HYBRIT

The HYBRIT process is a project under planning in Luleå in Sweden to pilot the use of hydrogen from electrolysis in a DRI-based steelmaking process[44]. It is a joint venture between SSAB, LKAB and Vattenfall. The production route is similar to existing DRI processes, except that H_2 reacts with iron oxides to form water instead of CO_2. HYBRIT's proposed DRI process is shown in Figure 4-7. The pilot concept is designed to have sufficient H_2 storage capacity to balance the H_2 demand for the DRI process and the hydrogen supply from intermittent power generation by, for example, wind or solar PV.

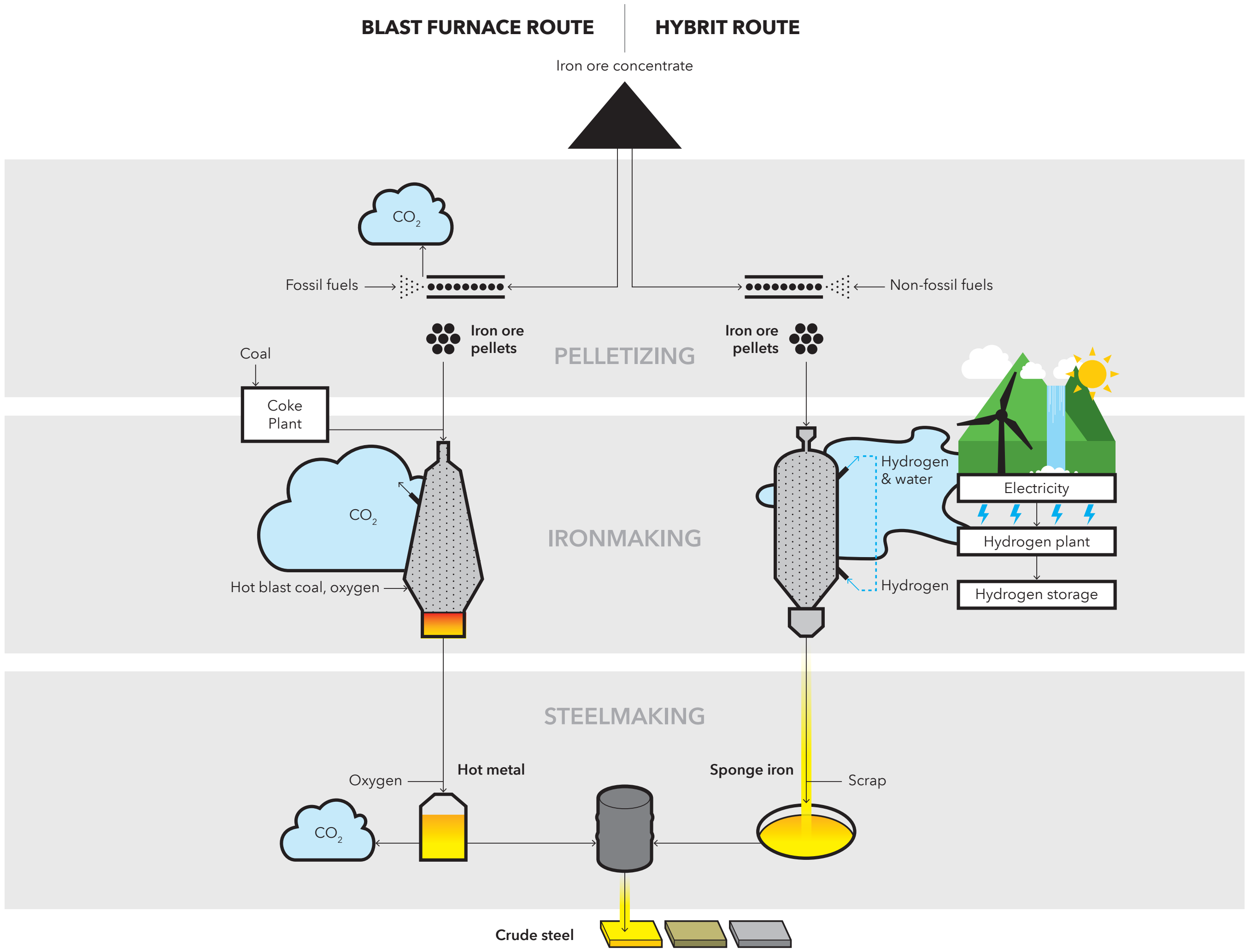


Figure 4-7 Schematic of the BF-BOF and HYBRIT processes. Source: Hybrit Development

4.4.6 Case study

As an example, for a large integrated steelworks, replacement of the blast furnaces with electric arc furnaces would significantly reduce direct carbon emissions:

1. Use of recycled scrap as feedstock eliminates the need for coke and the energy consumption and emissions associated with the ironmaking process.
2. The Basic Oxygen Furnaces would also no longer be needed, eliminating the need for oxygen supplies and the associated power demand. These two major duties would be replaced by the electrical power demand for the EAFs. As noted above this is equal to around 38% of the energy required for the BF-BOF process.

44. Summary of findings from HYBRIT pre-feasibility study 2016–2017', HYBRIT (2017). https://www.hybritdevelopment.com

3. If this load were all generated onsite then, assuming a CCGT generation efficiency of 55% and carbon intensities of 0.347 for coking coal and 0.184 for natural gas (BEIS, 2018), it would result in a CO_2 emissions reduction from the facility of approximately 60%. It is, however, likely that the EAFs would maximise their use of off-peak grid power. The 2015 WSP-DNV roadmaps report[45] quoted a carbon intensity for EAF steel of 0.6 tonnes/tonne which can be compared with 2.2 tonnes/tonne for the BF-BOF routes – this is equivalent to a 72% reduction in emissions.

This suggests that, even without CCS, the EAF option could dramatically reduce CO_2 emissions from a steelworks site and that in combination with CCS emissions could be reduced by over 95% from those at present. In this scenario, since much of the reduction arises from the process change, the CO_2 export capacity required would only be 25-30% of the present-day values.

Other new steelmaking routes (excepting electrolysis) require fossil fuels so are unlikely to result in bigger reductions in CO_2 unless they are accompanied by a significant reduction in site capacity.

4.4.7 Decarbonisation of other industrial processes

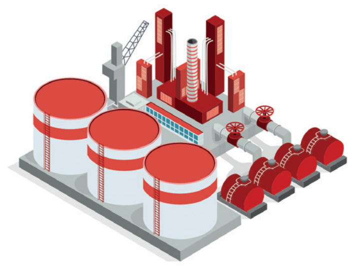
The data in this section was sourced from the 2015 WSP-DNV roadmaps report[46].

Cement – The primary flue gas stream for cement production is the exhaust gas from the kilns. Waste/biomass fuel is already widely used but the underlying chemical process releases CO_2 and this process-derived CO_2 forms over 60% of the emissions, so full abatement is impossible without CCS. The main options for decarbonization in the cement industry are:

- Switching to a low-carbon fuel to mitigate CO_2 emissions from fuel combustion.
- Applying CCS to the exhaust gases of cement kilns to prevent CO_2 emissions resulting from both fuel combustion and limestone calcination.
- Replacing limestone or clinker with other minerals, which could help reduce process emissions.

Glass and Ceramics – 80 to 90% of site CO_2 emissions arise from heating of kilns using natural gas. Capture may be possible with amine type processes but there are challenges due to aggressive components in the flue gas.

The glass industry is considering use of hydrogen but is also looking at electrification. Switching from natural gas to hydrogen may allow the use of existing furnaces and avoid major rebuilds, but all of this will be dependent on fuel costs.



Refining – A given site will have many CO_2 containing waste streams arising from heating loads and process sources.It is expected that refineries will implement a combination of CCS and fuel switching to hydrogen, which is already produced at scale as an intermediate feedstock. Augmented refinery hydrogen production with CCUS could be used to supply local industry. A general hydrogen grid including the Essar Stanlow refinery is proposed as the basis of the HyNet[47] industrial cluster in North West England.

Chemicals – Chemical sites will be similar to refineries in having a combination of flue gases arising from heating duties and process derived CO_2 emissions. Decarbonisation of waste streams is likely to be with amine or other solvent type processes plus electrification and fuel switching to hydrogen.

Manufacturing – The majority of these sites will be emitting flue gases from relatively low temperature heating duties and can be decarbonised by electrification. Some plants may require partial refuelling with hydrogen or another decarbonised fuel – for example, engine works with foundries.

Papermills – There are several papermill sites in the South and North East of Wales. Integrated works are partly fuelled with waste biomass derived from the process. CCUS on these sites may be attractive options for BECCS.

45. 'Industrial Decarbonisation and Energy Efficiency Road Maps' WSP and DNV for DECC and BIS, 2015
46. Ibid
47. HyNet is a project proposing to use blue hydrogen in NW England. https://hynet.co.uk/

4.4.8 Decarbonisation of buildings

CCUS on emission sources of the scale of domestic properties (currently 1-2 tonnes of CO_2 per year) and even larger commercial properties is not considered to be viable due to the cost and the nature of the infrastructure required.

For some properties this combination of technologies can eliminate or greatly reduce CO_2 emissions:

- Energy saving through insulation and efficiency gains (39% reduction in commercial building usage was identified, 21% in domestic)
- Low carbon district heating systems– ideally need a large anchor load.
- Electrification – either through direct electric heat, or a heat pump. Stakeholder feedback from Wales & West Utilities was that use of hybrid heat pumps could reduce the gas usage in suitable properties by >70%.
- Switch to hydrogen as a fuel for heating and cooking.

For the purposes of this report, it is assumed that these measures accompanied by gas grid decarbonisation and electrification will be the decarbonisation solution rather than small scale CCS.

4.4.9 Decarbonisation of Waste and Waste Processing

Key sources of waste emissions are:

- Methane from the decomposition of biodegradable waste in landfill sites – this has declined by 70% since 1998 due to less biomass to landfill and improved use/handling of landfill gas.
- Emissions produced from treatment of wastewater.
- Emissions from biological treatment (MBT), composting and incineration of municipal waste (MSW).

MSW emissions are surprisingly low, possibly because they are CO_2 rather than the methane generated by MBT and composting.

4.4.10 Decarbonisation of hydrogen production

Hydrogen will be produced using a combination of fossil fuel reforming plant and electrolysis. Due to the energy losses involved in production, use of fossil-derived hydrogen as a fuel effectively increases CO_2 emissions unless the CO_2 is captured, so it is expected that all such plants will be CCS equipped. Nearly all the CO_2 emissions from a reformer will be captured in the stream separated from the product hydrogen using a physical solvent technology as part of the hydrogen purification process.

4.5 Existing Infrastructure in South Wales

Ports

The existing port infrastructure for South Wales is summarised in Table 4-3.

Port	Max Ship Size L x B x D	Max Ship Dwt	Dock Area	Proximity to town	Notes
Units	m	tonnes	acres		
Newport	244 x 30.1 x 10.4 (South Dock)	40,000	685	1 km+	Uskmouth B, steelworks and Solutia opposite docks on River Usk Cement, steel, and ore/coal currently handled
Cardiff	198 x 27 x 10	35,000	852	100-200 m	Includes a liquid bulk terminal and an oil storage depot. Adjacent to BOC SMR site and 1-2 km from Cardiff steelworks
Barry	178 x 19.2 x 9	23,000	531	400 m (Dock 2)	Currently handles liquid chemicals. Dow Corning and Cabot Carbon adjacent to dock
Port Talbot	300 x * x 16.5 Tidal Basin *unlimited beam	170,000	845	1 km+ Tidal Basin	Coking coal, minerals and ores Adjacent to Port Talbot steelworks
Swansea	200 x 26.x x 9.9	30,000	521	400 m	Handles cement, minerals, agribulks, aggregates, and dredged sand Development land available for offshore wind industry
Llanelli	No longer used commercially				
Milford Haven	17m draft	Very large	Very large	-	Serves Valero refinery, Puma Energy oil terminal, South Hook and Dragon LNG with dedicated jetties. Also contains Pembroke Port and is adjacent to Pembrokeshire Power Station

Table 4-3 Existing port infrastructure in South Wales

Gas Pipelines

The National Transmission System in Wales is owned and operated by National Grid Gas. In South Wales it runs from the LNG terminals at Milford Haven to a connection point in the Midlands. Customers in South Wales are supplied by offtakes at Gilwern, Dowlais and Dyffryn Clydach. In North Wales, the National Transmission System runs two sets of pipelines from North West England. The first runs to Connah's Quay and Deeside power stations and the second runs to Maelor. Wales and West Utilities runs the local distribution systems in Wales with gas supplied from four offtakes from the National Transmission System. Large industrial users and power stations in Wales are directly connected to the National Transmission System which can supply the large flow rates required. A map of the gas transmission and distribution pipelines in Wales and the percentage of homes on the gas grid is shown in Figure 4-8[48]

Oil and other pipelines in Wales

There is a 16" multi-products (kerosine etc.) pipeline running North East from Milford Haven to Seisdon and a disused 18" oil pipeline from Milford Haven to the Llandarcy Refinery (near Junction 43 of the M4 between Swansea and Port Talbot). The refinery closed in 1998 and was demolished in 2009. See Figure 4-9 for an illustration of the pipeline and electricity transmission network in South Wales.

There is also a disused (decommissioned in 1990) twin 36" crude oil pipeline from Rhosgoch on Anglesey to the Essar Refinery at Stanlow.

PERCENTAGE OF ON-GAS HOMES BY LOCAL AUTHORITY AREA IN WALES, 2017

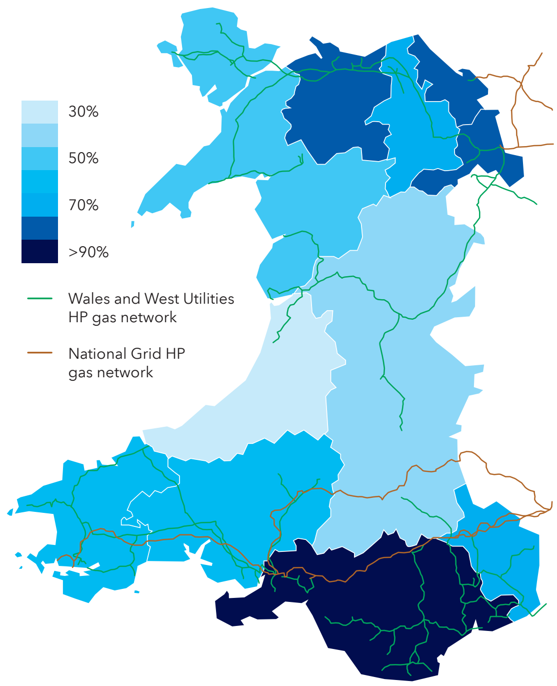


Figure 4-8 Gas pipelines and percentage of Welsh homes connected to the gas network in Wales (Image credit Welsh Government)

Power Lines

400 kV transmission lines run from Milford Haven (largest gas fired power station in Europe) to South Wales and England.

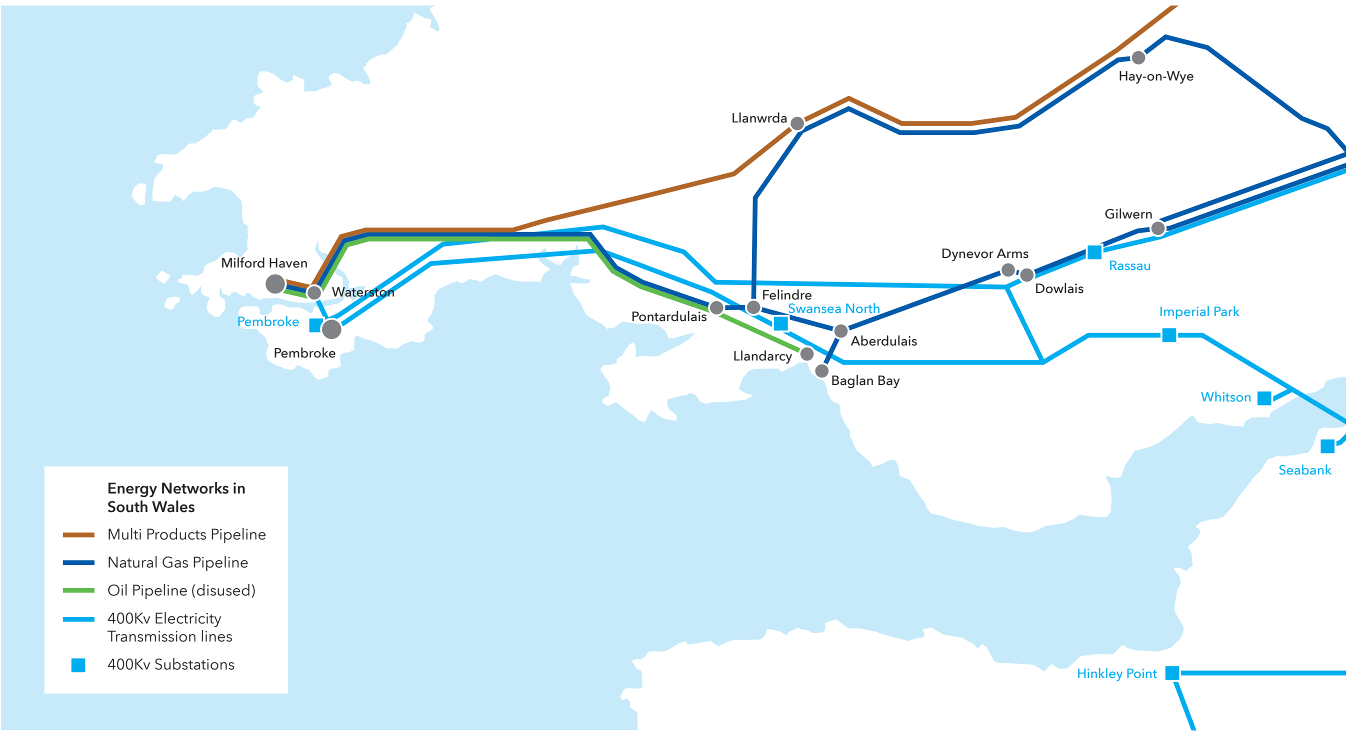


Figure 4-9 South Wales major pipelines and electricity transmission lines. Image courtesy of the Port of Milford Haven.

48. Welsh Government Report 2018 https://gov.wales/sites/default/files/publications/2020-06/energy-use-in-wales-2018.pdf

4.6 CO_2 Export Options

Table 4-4 summarises the potential destinations for CO_2 captured in Wales.

Option	Storage Location and Type	Storage Capacity	Developers	Timescales	Issues/ comments
Wales Onshore Footnote[49]	Onshore storage via local pipelines and injection into South Wales coal deposits.	Estimates range from 70.1 Mt (proven) to 152 Mt (possible) i.e. 5-10 years of storage.	None at present		Concerns over public reaction means that this option is very unlikely to be permitted.
Wales Offshore Footnote[50]	Central Irish Sea Basin, North and South Celtic Sea Basin.	BGS report concluded potential for storage is low. Some potential in South Celtic Basin.	None	No existing infrastructure - all facilities, pipelines etc. would be new build.	
East Irish Sea - Hamilton field Footnote[51]	CO_2 stored in depleted Hamilton gas field with infrastructure re-use. Pipeline from North Wales CO_2 & shipping from South Wales. Possible future phases in Morecambe fields.	2025 - 400,000 t/a from industry and blue hydrogen production. 2027/8 - 3-4 Mt/a from further blue hydrogen. 2030 - 10 Mt/a capture, 1 Mt from industry, the rest from blue hydrogen.	HyNet partner ENI (operator of the Hamilton) has a licence from OGA for appraisal work. A further licence would be required for storage. Morecambe Bay fields are operated by Spirit Energy.	Gas production is expected to cease in 2027, earliest possible injection start-up 2029.	Obvious route for NE Wales from the Point of Ayr Gas Terminal. HyNet in discussion with NE Wales CO_2 sites & SWIC. CO_2 import by ship is mentioned but unclear if capacity is available for South Wales.
Ireland Offshore Footnote[52]	Depleted gas fields (Kinsale Head, Ballycotton, SW Kinsale, Seven Heads) produced via Kinsale Head platform.		Proposals to use these fields for CO_2 sequestration. Ervia are undertaking a feasibility study for CCUS in Ireland, due to report at the end of 2022.	Long term. Existing fields were due for decommissioning in 2020.	SW Kinsale considered as a store, but likely that Ireland will adopt a ship export solution, possibly to Northern Lights[53].

49. Sarhois, V., Hosking, L.J. Thomas, H.R. 'A Preliminary Evaluation of the Carbon Sequestration Potential of Deep Lying Coal Seams in the South Wales Coalfield' Geoenvironmental Research Centre, Cardiff School of Engineering, Cardiff University, CF24 3AA
50. Bentham M, Williams J & Hannis S. 2014. Appendix 1: An assessment of the potential for subsurface CO_2 storage in two regions of the Central Irish Sea Basin. British Geological Survey Internal Report, CR/14/128., C J Vincent, K L Kirk and T C Pharaoh 2014. An assessment of the potential for subsurface CO_2 storage in the Celtic Sea Basin. British Geological Survey Commissioned Report, CR/14/134., Bentham, M.. 2015. 'Irish Sea Carbon Capture and Storage project, final report' British Geological Survey, 2015
51. Unlocking Net Zero for the UK' HyNET NW Vision Document, October 2020.
52. 'Assessment of the Potential for Geological Storage of CO_2 for the Island of Ireland' Report Prepared by CSA Group for Sustainable Energy Ireland, Environmental Protection Agency, Geological Survey of Northern Ireland, Geological Survey 2008
53. Memorandum of Understanding between Ervia and Equinor https://www.ervia.ie/news/ErviaEquinorMOUonCCS/

Option	Storage Location and Type	Storage Capacity	Developers	Timescales	Issues/ comments
Southern North Sea – Net Zero Teesside and Humber, Northern Endurance Footnote[54]	Northern Endurance Partnership plans to develop offshore CO_2 transport and storage infrastructure primarily aimed at Teesside and Humber hubs in the Endurance aquifer.	Total sequestration capacity in the formation is expected to be around 520 Mt but further aquifers are available nearby.	Examined by Don Valley CCS project, then taken further by White Rose Project. National Grid, Equinor and BP are partners in the OGA licence for development. Initial storage capacity about 53 Mt with pipelines from Teesside (145 km) and Easington (45 km).	2020s - hydrogen demonstrator near Drax. 2027-2030 CO_2 capture on Drax biomass fired units. Feed from Teesside expected first, ramping up to 10 Mt/a by 2028. Humber follows with 17 Mt/a by mid-2030's. Potential capture from Humber region of 44 Mt/a by 2040.	
Southern North Sea – Humber Zero, V Net Zero Footnote[55]	Dense phase CO_2 to be piped from Immingham to Theddlethorpe for injection into two depleted SNS gas fields.	Not disclosed.	The V Net Zero consortium comprising Chrysoar, Vitol and Philips 66 linked to Humber Zero. Plans to export dense phase CO_2 from Immingham to Theddlethorpe for two depleted Southern North Sea gas fields.	Awarded two licences by OGA, but do not yet have a storage lease (from Crown Estate). Aiming for full design package at end of this year. Earliest injection is 2026 but realistic aim is 2028 - 3-4 Mt/a. Pipeline to Theddlethorpe for up to 30 Mt/a.	May have advantage over other consortia as injecting into well documented & understood geological structures. Imported CO_2 at Immingham would be dense phase.
Northern North Sea – Acorn Footnote[56]	The Acorn Project is planned around an onshore facility located at the St Fergus gas terminal and proposes to use existing pipeline infrastructure to export CO_2 for injection into various depleted gas fields, the Captain aquifer and the Mey storage field.	Phase 1 Goldeneye reservoir has 30 Mt storage capacity.	Chrysaor, Shell and Total are project partners. Initially CO_2 from processing import gas at St Fergus terminal but further potential CO_2 from industry at Grangemouth, a possible hydrogen reformer at St Fergus and CO_2 shipped from Teesport, Rotterdam and Norway are expansion options with CO_2 import rate of up to 16 Mt/a.	2024 – 340 ktonne/a CO_2 from the St Fergus gas terminal. 2025 – 400 ktonne/a CO_2 storage required for Acorn hydrogen project. Phase 2 proposes to import CO_2 by ship to Peterhead and by pipeline from Scotland's central belt.	

54. https://www.zerocarbonhumber.co.uk/news/northern-endurance-partnership/, https://www.netzeroteesside.co.uk/
55. Acorn - A Low-Cost, Low-Risk Catalyst for Clean Growth - Pale Blue Dot Energy, SCCS, Dec 2018. The Acorn Project - Timeline https://theacornproject.uk/timeline/
56. CO_2 reduction through storage beneath the North Sea - Porthos ' https://www.porthosco2.nl/en/

Option	Storage Location and Type	Storage Capacity	Developers	Timescales	Issues/ comments
Dutch North Sea - Porthos Footnote[57]	Depleted gas fields in the Dutch sector of the N. Sea		CO_2 from Port of Rotterdam exported via 20 km pipeline to P18-A platform in Dutch sector of the North Sea for sequestration in disused P18-2,4 and 6 gas fields. JDA signed with Air Liquide, Air Products, ExxonMobil and Shell. Hope to sign transport and storage agreement 2021.	Expecting to get FID in 2022 and have a system storing up to 2.5 Mt/a CO_2 operational by 2024.	
Dutch North Sea - Athos Footnote[58]			Port of Amsterdam, Tata Steel, Gasunie and EBM planning a project like Porthos. Main source of CO_2 from Tata Steel Netherlands. Project includes CO_2 network, storage, CCU and CCS by export to depleted aquifer or oil or gas field.	Expect network to be operational by 2026.	
Norway – Northern Lights Footnote[59]	CO_2 will be shipped from Oslo to a terminal at Oygarden on the West Coast of Norway from where a 110 km pipeline will send it offshore for injection into a formation SW of the Troll field complex.	Maximum storage expected at this stage to be 100 Mtonne CO_2.	The Norwegian Government proposes to partly fund carbon capture at Norcem's cement factory in Brevik and at Fortum Oslo Varme's waste incineration facility in Oslo (a total of 0.8 Mtonne/a CO_2 but will require other funding (private or EU). Northern Lights (Equinor, Shell and Total) are handling the transportation and storage of CO_2.	Phase 1 with a capacity of 1.5 Mtonne/a CO_2 could be operational by 2024. Second phase of up to 5 Mtonne/a CO_2 is a possibility.	Northern Lights is actively looking for CO_2 suppliers to meet their planned 0.7Mtonne/a of spare capacity. Equinor has signed a Memorandum of Understanding with Ervia.

Table 4-4 Summary of CCS options potentially available to the Welsh Government

57. The Athos project https://athosccus.nl/project-en/
58. Porthos - Longship – Carbon capture and storage' Meld. St. 33 (2019–2020) Norwegian Ministry of Petroleum and Energy report to the Storting (translated version)
59. Estimation of travel distances using data from https://www.searates.com/services/distances-time/

Timescales published by the various consortia developing CO_2 storage projects have been combined in Figure 4-10 to provide an indication of the potential CO_2 injection capacity available up to 2050.

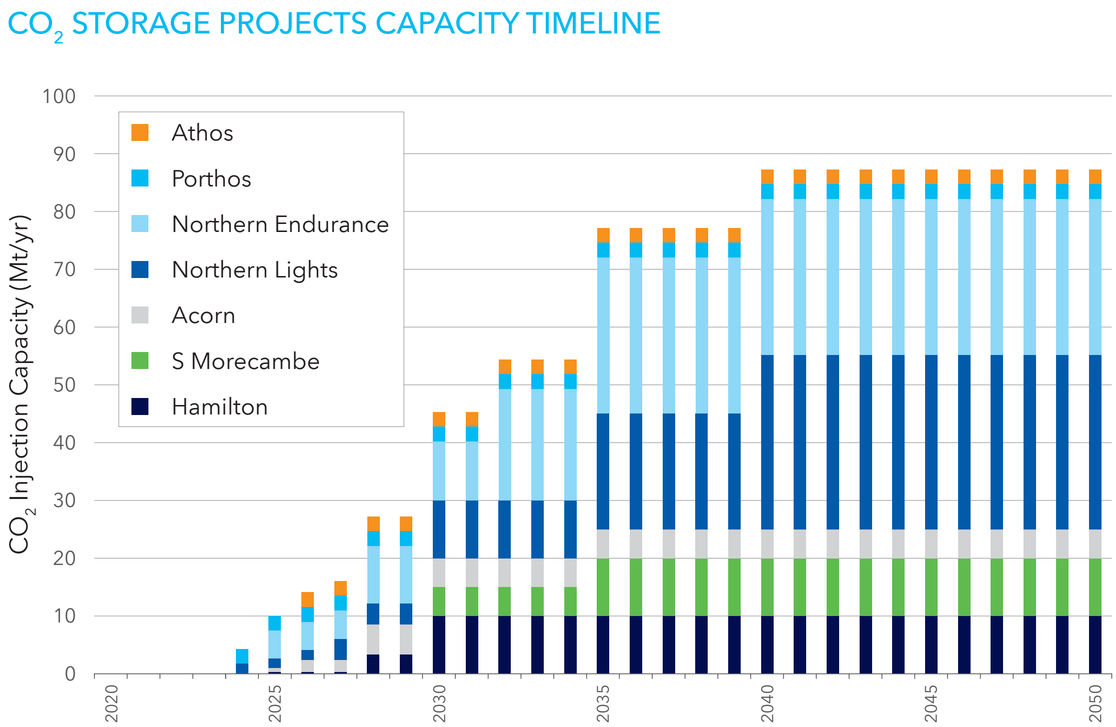


Figure 4-10 Combined timescales and capacities for proposed CCS projects that could be suitable for Wales

Whether this capacity is developed on the timescales indicated will be dependent on funding and on the development of matching supplies of captured CO_2 to the actual permitted injection rates. A summary of the possible routes and distances to these CO_2 injection hubs is given in Figure 4-11. An accompanying summary of voyage distances and one-way travel times is given in Table 4-5. Travel distances[60] are approximate and the full voyage cycle will require time for hook-up in port, loading and unloading the cargo and travel and manoeuvring in and out of port.

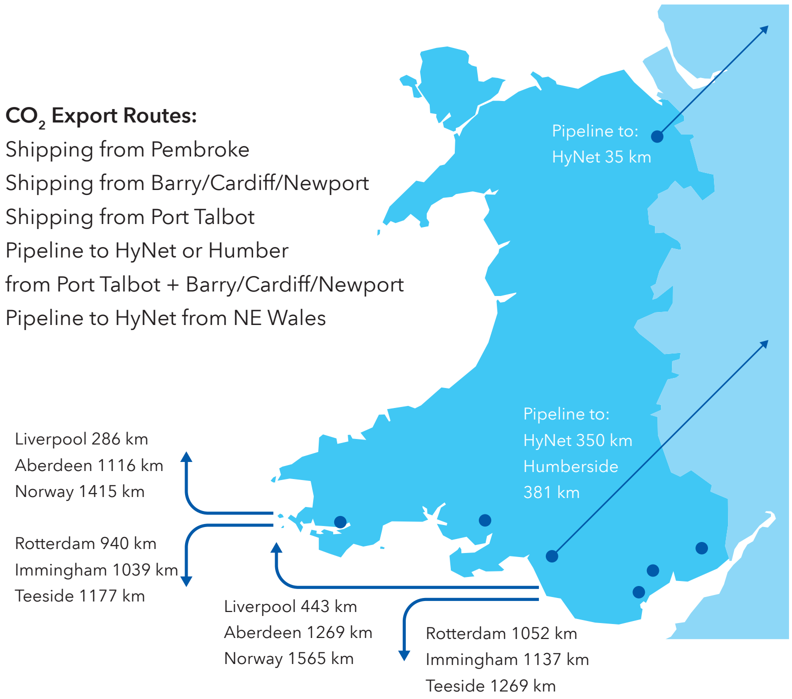


Figure 4-11 Summary of options and routes for CCS from Wales

Destination	Newport		Milford Haven	
	Nautical Miles	One-way travel time at 15 knots (hours)	Nautical Miles	One-way travel time at 15 knots (hours)
Liverpool (HyNet)	240	16.0	155	10.3
Rotterdam (Porthos)	570	37.9	507	33.9
Immingham (N. Endurance)	616	41.0	563	37.5
Teesside (N. Endurance)	688	45.7	636	42.4
St Fergus (Acorn)	688	45.7	603	40.2
Oygarden (Northern Lights)	848	56.4	763	51.0

Table 4-5 Summary of voyage distances and one-way travel times to CCS sites

60. Estimation of travel distances using data from https://www.searates.com/services/distances-time/

4.7 Scenario Identification

4.7.1 CCS Demand Scenarios

Based on the baseline investigations and stakeholder feedback, the following scenarios for CCS demand in Wales have been generated. The Port Talbot steelworks have been identified separately in each scenario due to the size of their emissions and the corresponding sensitivity of results to the future strategy for Port Talbot steelworks. No assumption for the future strategy for the steelworks is implied in these cases, they are intended to allow the Welsh Government to understand the impacts of different options:

MINIMUM CCS CASE

- Only those industries which require CCUS for decarbonisation of processes adopt it.
- No CCUS is assumed to take place on power plants.
- All other industry is assumed to decarbonise through fuel-switching or electrification.
- Any hydrogen used for decarbonisation is assumed to be either green or imported.
- The steel works at Port Talbot is assumed not to use CCUS.

MEDIUM CCS CASE

- Assumes the Minimal CCS case plus:
- Other industries which are amenable to decarbonisation via CCUS (on account of the processes involved and/or their proximity to essential CCUS users) use CCUS.
- All large-scale power generation (including biomass and energy from waste) is decarbonised by fuel-switching to Welsh produced hydrogen. The "blue" fraction of that hydrogen requires CCUS.
- The steel works at Port Talbot is assumed to not use CCUS.

HIGH CCS CASE

- Assumes the Medium CCS case plus:
- Port Talbot Steelworks is converted to a hydrogen and electrically fuelled steelmaking process. This is assumed to generate a CCUS demand (via hydrogen) of 25% of that for the existing steelworks.

MAXIMUM CCS CASE

- Assumes the Medium CCS case plus:
- Port Talbot Steelworks is refurbished to operate with the conventional Blast Furnace - Basic Oxygen Furnace route with decarbonisation via a combination of CCUS, hydrogen, and electrification.

Table 4-6 summarises the general assumptions on the decarbonisation methods for each case.

Table 4-7 details the timescales assumed for decarbonisation of each industry sector and Table 4-8 provides the assumptions regarding hydrogen production.

Emitter	Case 1 Minimum CCS	Case 2 Medium CCS	Case 3 High CCS	Case 4 Maximum CCS
Port Talbot Steelworks	No CCS	No CCS	50% Electrification 50% hydrogen	CCS on existing steelworks
Other Steelworks	50% CCS 50% Electrification			
Cement Works	100% CCS			
CCGT Power Generation	No CCS	Hydrogen Fuel Switch	Hydrogen Fuel Switch	Hydrogen Fuel Switch
Waste & Biomass Power generation	No CCS	CCS for BECCS	CCS for BECCS	CCS for BECCS
Milford Haven LNG terminals	Fuel switch to hydrogen			
Milford Haven refinery	50% CCS and 50% refuel with hydrogen			
Chemical sites	Electrification / import hydrogen if needed	CCS and hydrogen fuel switch	CCS and hydrogen fuel switch	CCS and hydrogen fuel switch
Paper mills	Fuel switch with biomass No CCS	CCS for BECCS	CCS for BECCS	CCS for BECCS
Car plants	Electrification except Toyota which has 50% hydrogen			
Small power generators	Fuel switch to hydrogen if near a CCS hub			
Small/remote industrial sites	Electrification or fuel switching			
Large public service sites, e.g. NHS	Electrification and gas grid decarbonisation			
Hydrogen Production	Mix of green and blue in the medium term, possibly other sources including nuclear in the longer term			

Table 4-6 Alignment of industry sectors with the four CCS cases

Emitter	Percentage Decarbonised					
	2025	2030	2035	2040	2045	2050
Port Talbot Steelworks, case 3 - High	0	50	100	100	100	100
Port Talbot Steelworks, case 4 - Maximum	0	25	50	100	100	100
Other Steelworks	0	25	50	100	100	100
Cement Works	0	0	50	100	100	100
CCGT Power Generation, cases 2,3 & 4	0	0	50	100	100	100
Waste & biomass power generation, cases 2,3 & 4	0	0	50	100	100	100
Milford Haven LNG terminals	0	0	0	100	100	100
Milford Haven refinery	0	0	50	100	100	100
Chemical sites	0	0	50	100	100	100
Paper mills, cases 2,3 and 4	0	0	0	50	100	100
Car plants	0	0	100	100	100	100
Small power generators	0	0	0	100	100	100
Small/remote industrial sites	Assumed these sectors to decarbonise by 2050 with a combination of electrification, efficiency gains, fuel switching and gas grid decarbonisation					
Large public service sites, e.g. NHS						

Table 4-7 Timeline assumed for each industrial category and CCS case where applicable

Hydrogen production all cases	2025	2030	2035	2040	2045	2050
Percentage of green hydrogen production	0	20	35	50	50	50
Balance is 80% efficient blue hydrogen with 95% CCS						

Table 4-8 Timeline for hydrogen production

4.7.2 CCS Demand Scenario Analysis

The estimated CO_2 demands from each source, grouped according to the nearest potential CCS export hub are shown in Figure 4-12 to Figure 4-15. Note that the scale for CO_2 tonnage for export varies between plots, and that these numbers include CO_2 export demand that arises from production of blue H_2 as well as that arising from industrial decarbonisation. Care must therefore be taken when comparing against emission quantities from other references.

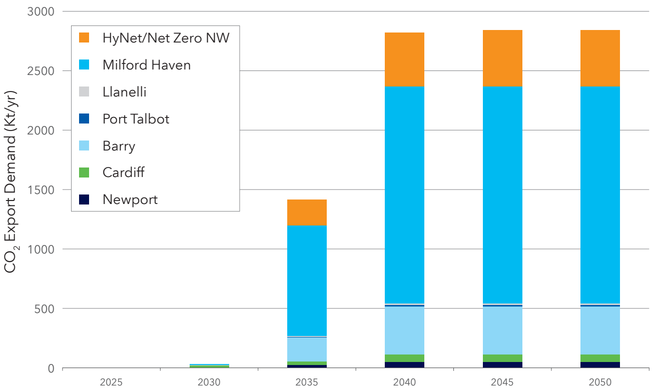


Figure 4-12 CO_2 Export Demand - Minimum CCS Case.

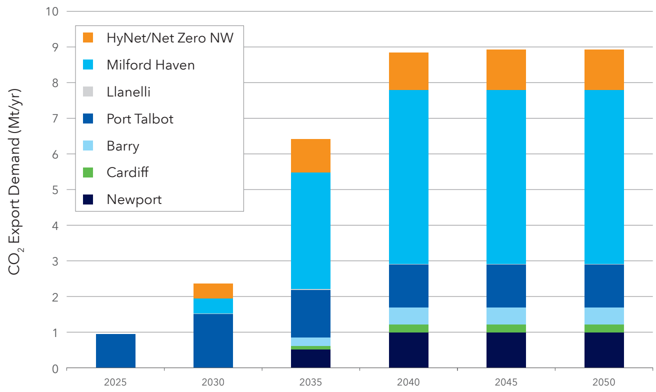


Figure 4-14 CO_2 Export Demand - High CCS Case

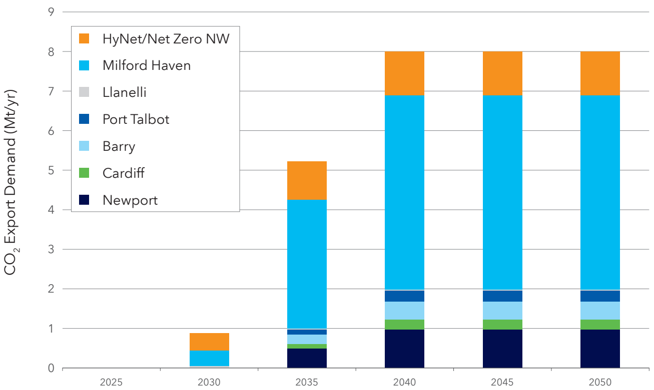


Figure 4-13 CO_2 Export Demand - Medium CCS Case

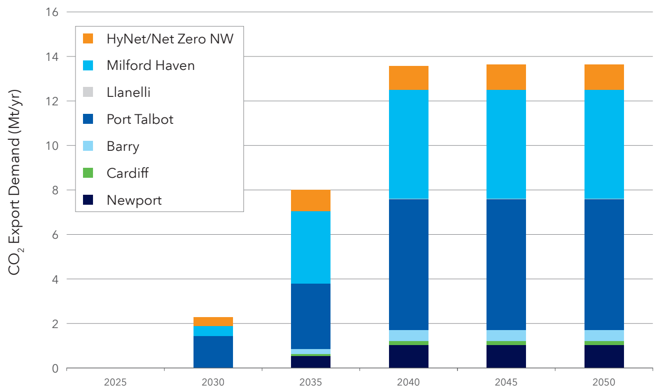


Figure 4-15 CO_2 Export Demand - Maximum CCS Case

4.7.3 Conclusions for each export scenario

Table 4-9 summarises the expected demand at each hub for CO_2 export for each of the scenarios. Note that these numbers include CO_2 export demand that arises from production of blue H_2 as well as that arising from industrial decarbonisation.

2040 CCS demands Mt/a	NE Wales (HyNet)	Milford Haven	Llanelli	Port Talbot	Barry	Cardiff	Newport	Total demand
Minimum	0.5	1.8	0.01	0.01	0.4	0.1	0.04	2.8
Medium	1.1	4.9	0.03	0.2	0.5	0.2	1.0	8.0
High	1.1	4.9	0.03	1.2	0.5	0.2	1.0	8.9
Maximum	1.1	4.9	0.03	5.9	0.5	0.2	1.0	13.6

Table 4-9 Expected CO_2 demand at each potential Welsh hub

Milford Haven is clearly a key location for CCUS infrastructure in all scenarios, as is NE Wales where the proximity of the proposed HyNet NW hub offers a low-cost export route for captured CO_2.

Hubs along the rest of the South Wales are more complicated to assess. Barry has a moderate demand for CO_2 export in the Minimum case and the potential for CCUS equipped power generation at Newport increases the demand at that hub in the Medium case.

Port Talbot is more complex. Without assumed demand from the steelworks (and its associated power and processing plant) demand is low and is limited to that from the Baglan power generation plant in the Medium case. However, Port Talbot offers the largest port on the South coast and has the prospect of extensive local development land, so it provides an attractive export hub option nevertheless.

Llanelli has very limited potential for CO_2 export and, as noted in an earlier section does not currently have a commercial harbour. As a result, it is not considered further in this report as a viable hub.

5 Feasibility of CCUS options for Wales

5.1 CCUS Network Cases

Basic costs for a CCUS infrastructure in Wales have been developed for each of the four Demand Cases outlined in Section 4.7.1 and summarised in Figure 5-1.

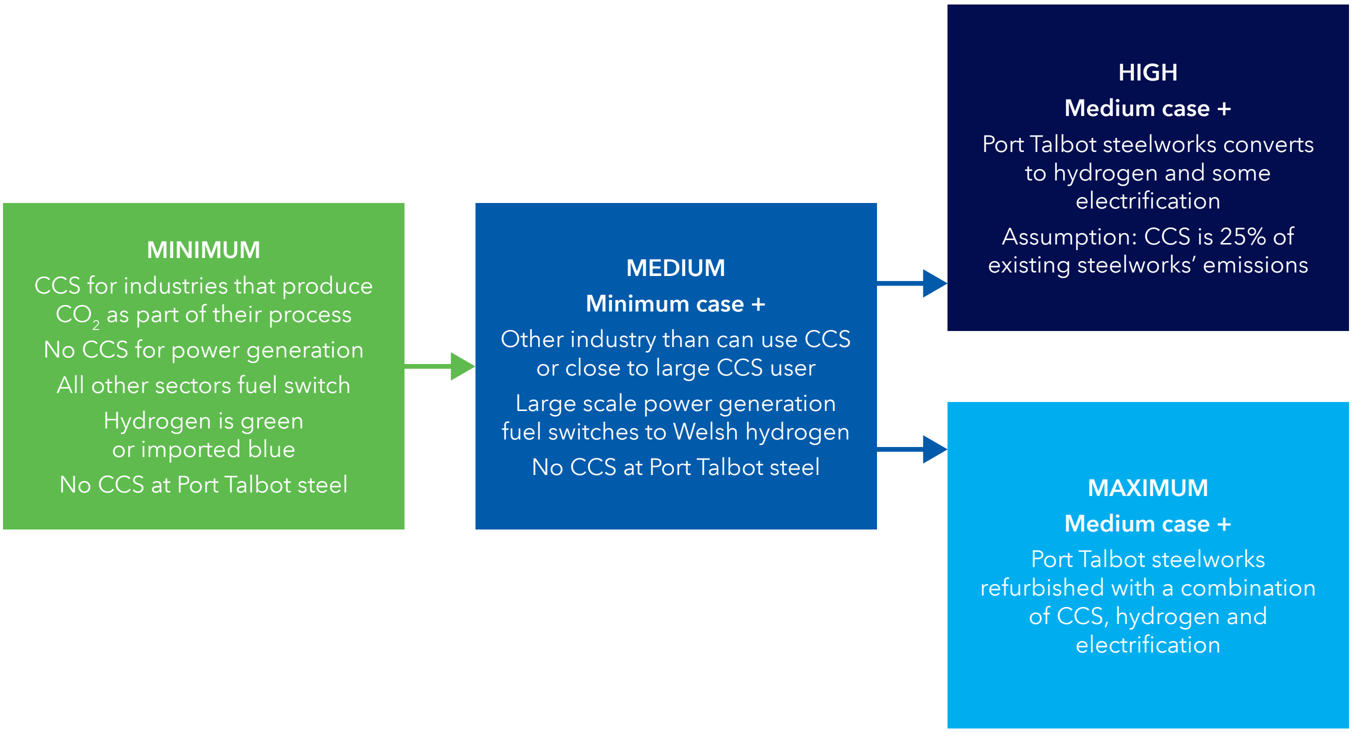


Figure 5-1 Summary of the four CCS demand cases

The following assumptions are made regarding the CCS network:

1. The network is optimised for CCS and we have not quantified utilisation opportunities.
2. S Wales CO_2 export hubs will be established at Newport, Barry, Port Talbot and Milford Haven.
3. CO_2 will be captured at the emitters and piped at medium pressure (20 bar) to their local hub.
4. Emitters in NE Wales are assumed to tie in to the HyNet/NW Zero cluster. CO_2 is captured at each site and exported via a pipeline at 20 bar.
5. The hub facilities at Newport, Barry. Port Talbot and Milford Haven comprise a liquefaction plant, liquefied CO_2 storage and loading facilities.
6. Local CO_2 storage is sized at 150% of the relevant ship volume.

5.2 CO_2 Capture Modelling

CO_2 capture at each of the sites has been modelled using a modified version of the techno-economic modelling in the 2014 DECC and BIS Industrial CCS study[61]. The cost of capture for each comprises:

The cost of carbon capture for each site is a combination of:

a) A gathering system – the cost of this is related to the number of CO_2 streams on the site. E.g. a chemicals site or refinery will have many flues necessitating a complex gathering system whilst a power station or cement works will have one or two major flues.
b) Compression of the flue gas – the existing vent streams are typically at atmospheric pressure and a flue gas blower is required to drive the gathered flue gases through the capture process.
c) A CCS plant – for this model it was assumed that an advanced amine process would be used for all sites. The cost and power consumption for this plant scaled from data in the DECC 2014 study. These scaled cost and power parameters were adjusted further with a factor to allow for the greater ease of removing CO_2 higher concentration flue gases (typical for blast furnace gas and cement kiln flue gas).
d) CO_2 compression – compression to an export pressure of 20 bar was assumed using a 3-stage compressor with intercooling.
e) Export pipeline – a pipeline was sized to transport the captured CO_2 to the nearest hub. The length of the pipeline was based on a study of the local topography, a route being selected to as far as possible avoid built up areas, river crossings and other major features.
f) Where reasonable it was assumed that neighbouring industrial sites would share a carbon capture facility and export pipeline.
g) It was assumed that industrial sites in Cardiff would export to the Newport hub via a shared 16km pipeline and that the two sites in Llanelli would export via a shared 36km pipeline to a hub at Port Talbot.

5.3 CO_2 Capture Modelling Results

The following tables summarise the modelling results for the various cases.

a) Cost of carbon capture ranges from £63 to £292 per tonne. The cost of compression and export to a local export hub increases this to £75 to £307 per tonne.
b) As would be expected, larger emissions sources have significantly lower costs whilst small sites, remote from the export hubs, have very high costs in comparison.
c) Shared export lines give small export savings for some sites, but it is the grouping of emissions from adjacent, compatible sites which offer large savings.
d) No allowance has been made in the costs for offsetting of capture costs by BECCS. This may be possible at several sites (e.g. papermills and EfW sites) where a portion of the captured CO_2 is likely to be of biogenic origin.
e) The costs produced by the model are comparable to those in the case studies derived for the 2014 industrial decarbonisation study undertaken by Element Energy for BIS and DECC
f) The costs are based on use of an advanced amine technology for carbon capture using as a baseline the 2025 cost figures for this type of technology in the Element Energy report[62]. No allowance has been made for further reductions in technology costs. The Element Energy study suggests that introduction of calcium looping might offer significant cost reductions in capture costs for some industries but, as noted earlier in this report, this technology is complex and has still only been implemented at a small demonstration scale.

The total capture costs for each of the four cases are shown in Table 5-1. The low price achieved in the first case is because the CO_2 capture is dominated by large sites where capture costs are relatively low. The cost drops for the final two cases because of the very large volume of CO_2 that can be captured relatively cheaply at Port Talbot. It is important to note these costs do not include the cost of CO_2 processing and storage at each hub, the costs of shipping the CO_2 away from each hub and the costs of sequestration of the CO_2. They are addressed later in the report.

To illustrate the effect of emission size against capture cost, the graph in Figure 5-2 shows how costs drop as capture quantities rise.

61. 'Demonstrating CO_2 capture in the UK cement, chemicals, iron and steel and oil refining sectors by 2025: A Techno-economic Study' Final Report for DECC and BIS by Element Energy & others, 30th April, 2014
62. 'Demonstrating CO_2 capture in the UK cement, chemicals, iron and steel and oil refining sectors by 2025: A Techno-economic Study' Element Energy for DECC and April 2014

Case	Total Installed CAPEX (£m)	Total CCS OPEX (£m)	Total CO_2 Captured (Mt/a) (excludes CCS for blue hydrogen)	Levelized cost of Capture (£/ tonne)	Overall Levelized cost delivered to hub (£/tonne)
1 - Minimum	764	90	1.97	83	99
2 - Medium	1375	195	3.29	93	108
3 - High	1812	270	4.7	89	103
4 - Maximum	2539	482	8.9	74	88

Table 5-1 Total CCS levelized costs for each of the four cases

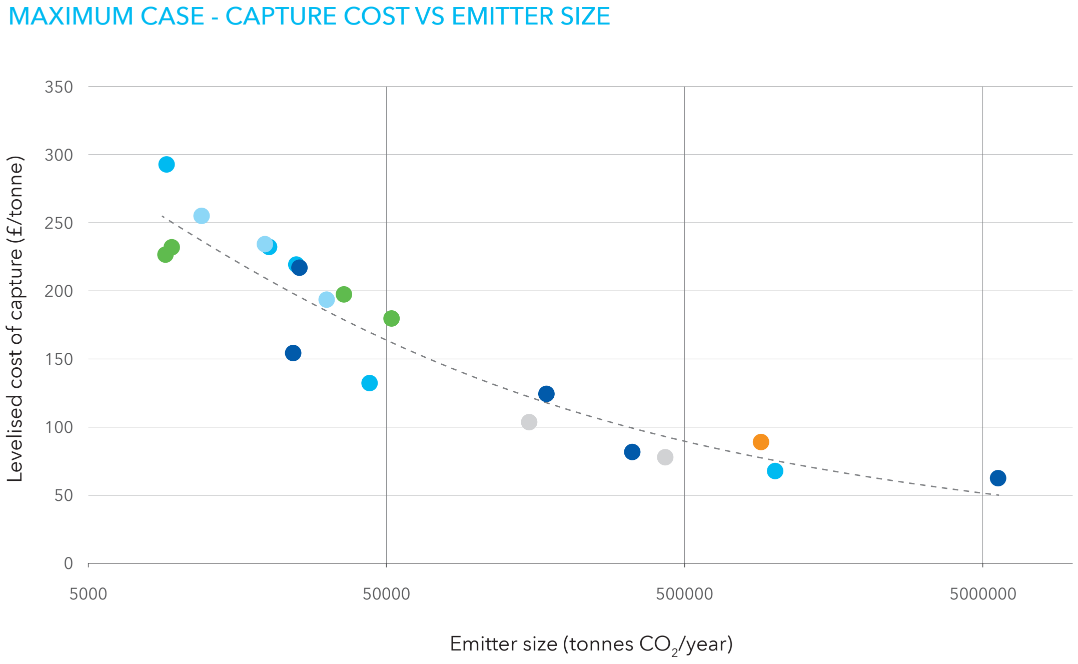


Figure 5-2 Capture Cost vs Emitter Size (Maximum Case)

Alternative Export of CO_2 from Sites to Hub by Road or Rail

As discussed earlier in this report, small remote sites in Wales which require CCS might consider use of batch transport of liquid CO_2 by road or rail as an alternative to installing a pipeline to the nearest CO_2 export hub. To examine this approach, liquefaction plant CAPEX was estimated for two sites:

- Road example - A local liquefaction plant (1.15 tonnes/hr) plus storage (25 tonnes) would cost approximately £4.2 million. This is significantly higher than the estimated cost of an export pipeline (£1.74m).
- Rail example - A local liquefaction plant (2.55 tonnes/hr) would cost approximately £6.0 million. It is assumed that CO_2 storage can be accommodated in rail tanker wagons as they are loaded. This is significantly higher than the estimated cost of an export pipeline (£3.6m).

In both cases the liquefaction facilities outweighed the estimated pipeline costs and would impose much higher fixed and variable OPEX costs. In addition, there would be costs and charges for road and rail loading facilities and transport, so it is concluded that in both cases an export pipeline is to be preferred.

5.4 CO_2 Hub and Shipping Modelling

To assess the best options for shipping and the infrastructure costs associated with it, a simplified CO_2 shipping model has been developed. The following assumptions have been made:

1. The CO_2 hubs are Newport, Barry, Port Talbot and Milford Haven. As noted earlier in this report, CO_2 emissions from Cardiff are assumed to be sent to the hub at Newport and emissions sites in Llanelli are sent to Port Talbot.
2. CO_2 captured in NE Wales is exported into the CO_2 system being proposed by HyNet/NetZero NW
3. Each shipping hub comprises a CO_2 liquefaction plant, liquid CO_2 storage and CO_2 loading facilities.

Two recent data sources were used to develop the hub and shipping cost models. These were from BEIS[63] and an internal study undertaken by DNV in 2018[64]. The DNV study modelled storage and shipping of liquid CO_2 at 7-8.5 bar and -50 °C which are essentially the same as those used in the existing Yara (now Praxair) CO_2 storage facilities[65].

For the hub costs in this study, the DNV study costs, generated by a specialist cost consultant and based on process modelling of the hub systems, were preferred. These costs were significantly higher than those from the BEIS study which were taken from a variety of online data sources.

5.5 South Wales Offshore CO_2 Pipeline

In general, subsea pipelines are expected to cost significantly more than onshore pipelines. An IEAGHG study reproduced US costs suggesting that a mile of subsea pipelines cost 7 times the same length of onshore pipeline. This figure seems extreme and a review of recent projects such as the Greece-Italy gas pipeline suggests that the subsea sections are closer to twice the cost per mile of the onshore parts.

To estimate the effect on CO_2 export costs of using a subsea trunk line, calculations were undertaken for Case 4 with a 120 bara offshore pipeline to Milford Haven and with a 120 bara offshore pipeline to Newport and 120 bara onshore pipeline to Immingham. For these simple step-outs it was assumed that the offshore pipelines cost twice as much per km as an onshore pipeline and that the route length was increased by 10km between each hub. For the first of these cases the overall levelized cost of shipping was increased by £4.5 per tonne of CO_2 and for the latter the cost increased by £5.4/tonne.

63. 'Shipping CO_2 – UK Cost Estimation Study' Final Report by Element Energy and others for Business, Energy and Industrial Strategy Department (BEIS), November, 2018 82.
64. 'Techno economic evaluation of CO2 shipping value chain' DNV Report for a Confidential Client, April 2018
65. Haugen, H.A., Eldrup, N.H., Fatnes, A.M. and Leren, E. 'Commercial capture and transport of CO_2 from production of ammonia' 13th Intl. Conf. on Greenhouse Gas Control technologies, GHGT-13, Lausanne. 14-18 November 2016.

5.6 Export Option Modelling Summary

Table 5-2 summarises the cost estimates for the export options discussed above.

Case	Description	CAPEX (£m)	OPEX (£m/a)	Levelized cost of CO_2 Shipping (£/t)
1	Direct Shipping to Immingham from all hubs	517	42	43
	Milford Haven ships to Immingham, other hubs ship to Milford Haven	481	41	41
	20 bara land-based pipeline to Milford Haven	576	42	46
2	Direct Shipping to Immingham from all hubs	1,029	95	31
	Milford Haven and Newport to Immingham. Barry and Port Talbot ship to Newport	994	93	31
	Direct Shipping to Liverpool from all hubs	838	85	27
	20 bara land-based pipeline to Milford Haven	886	89	28
	120 bara land-based pipeline to Milford Haven	837	70	25
3	Direct Shipping to Immingham from all hubs	1,147	107	31
	Milford Haven, Newport and Port Talbot ship direct to Immingham. Barry ships to Newport	1,150	106	31
	20 bara land-based pipeline to Milford Haven	945	99	27
4	Direct Shipping to Immingham from all hubs	1,550	156	27
	Milford Haven, Newport and Port Talbot ship to Immingham. Barry ships to Port Talbot	1,550	155	27
	20 bara land-based pipeline to Milford Haven	1,245	151	24
	120 bara land-based pipeline to Milford Haven	1,228	132	22
	20 bara land-based pipeline to Newport and 120 bara pipeline to Immingham	1,336	131	23
	120 bara land-based pipeline to Newport and 120 bara pipeline to Immingham	1,127	107	19

Table 5-2 Summary of the cost estimates from the modelling

In general, the pipeline options appear to offer significant cost savings over both short distance and long-distance shipping, but it must be emphasized that these are extremely high-level estimates.

1. The cases with higher export rates of CO_2 offer lower overall shipping costs.
2. Coastal shipping to larger ports offers negligible reductions in CO_2 export costs for all but the Minimum CO_2 export case.
3. Shipping to Liverpool rather than Immingham is about 10% cheaper for the Medium case.
4. A low-pressure S Wales Coast CO_2 land-based pipeline offers a 10% reduction in export costs for the High and Maximum cases, a small reduction for the medium case and increased costs for the Minimum case.
5. A high-pressure S Wales Coast land-based pipeline to Milford Haven is approximately 20% cheaper than a low-pressure system for the Medium and Maximum cases. This is mainly due to the smaller diameter of a higher-pressure pipe, with less steel in construction.
6. A cross-country high-pressure pipeline from S. Wales to Immingham lowers costs for the Maximum case. This option is still lower when the cost is doubled as a sensitivity case.

Comparison with Other Studies

These costs show similar patterns to the 2018 BEIS shipping costs study[66] in that pipelines are favoured at higher flowrates and that local shipping between hubs can offer advantages in some cases. However, our estimates of the overall costs for ship-based options are 2-3 times higher than those in the BEIS study. This is primarily due to the costs for CO_2 liquefaction, liquid CO_2 storage and the jetty and loading facilities at each port being 5-10 times higher than those used in the BEIS study. Further factors are that in this study a discount rate of 10% was assumed whereas the BEIS study used a 0% discount rate and assumed a smaller storage requirement at the hubs in relation to ship size (120% vs 150%). Inserting these factors (reduced CAPEX at the hub, smaller storage and 0% discount) into our spreadsheet model for the Medium CO_2 export case gave an overall shipping cost of £14.7 per tonne, approximately half our original figure.

An older (2004) study of CO_2 shipping is by Mitsubishi Heavy Industries (MHI) for IEAGHG[67]. After adjustment for inflation and currency differences the costs for liquefaction given by MHI were slightly higher than those used by the BEIS study and the storage costs were approximately double those of the BEIS study. MHI used a discount rate of 9%.

In conclusion the costs given above are conservative compared to earlier work and should be regarded as indicative and used for comparison between options.

Shipping Hub Plot Sizes

As the availability and cost of land could be a key to the development of a shipping hub, an indicative plot size for the liquefaction and storage facilities has been estimated for the direct shipping cases:

1. Tanks have been assumed to be spheres. Note that all hubs have two tanks, so each holds 50% of the stored volume.
2. An additional 2 m has been added to the sphere diameter to allow for shell and insulation.
3. Sphere plot area has then been estimated as the square of this diameter plus 10m safety/access on each side.
4. Relative liquefaction plant plot area has been estimated based on throughput and a scaling exponent of 0.65. The baseline size was a 260 m^2 for a 100 t/h liquefaction plant.

66. 'Shipping CO_2 – UK Cost Estimation Study' Final Report by Element Energy and others for Business, Energy and Industrial Strategy Department (BEIS), November, 2018
67. 'Ship Transport of CO_2' MHI report PH4/30 for IEAGHG, July, 2004

Results are summarised in Table 5-3 below:

Hub	Estimated Plot Area (m^2)			
	Minimum Case	Medium Case	High Case	Maximum Case
Newport	2,500	4,300	4,300	4,300
Barry	3,600	3,200	3,200	3,200
Port Talbot	1,800	3,200	4,300	7,000
Milford Haven	4,900	6,400	6,400	6,400

Table 5-3 Estimated Plot Areas For Liquefaction Plant at Each Hub

CO_2 Emissions from Shipping

Whereas the CO_2 emissions arising from capture and onshore transport and processing of CO_2 can be themselves captured or otherwise avoided, those from shipping are more challenging to handle. Nevertheless, they need to be considered. Estimates of the CO_2 emissions from the various shipping scenarios were derived from the estimated fuel usage of the vessels (as used to estimate shipping OPEX) and the UK Government 2020 Conversion Factors[68], and are shown in Table 5-4.

Case	Shipping CO_2 emissions kg/t CO_2 transported
Minimum	26
Medium	15
Medium shipping to Liverpool	7
High	15
Maximum	11

Table 5-4 Shipping Emissions for Each Case

68. 'UK Government Conversion Factors for Company Reporting' Department for Business, Energy and Industrial Strategy and Department for Environment Food and Rural Affairs, Standard Set 2020, Version 1.0, June 2021

5.7 Overall CO_2 Value Chain Results

Table 5-5 below summarises the model outcomes for the entire value chain costs per tonne of CO_2 for the major emitters in Wales, based upon the maximum case. The table shows the costs associated with either ship or pipeline export options for each site.

Hub	Total CO_2 Captured (tonnes/yr)	Based on Maximum Case, shipping via named hub, pipeline is HP pipeline to Newport and onto Immingham							
			Levelized Costs (£/tonne CO_2)						
			Capture only	Delivered to hub	Hub	Shipping	Total (sea)	Pipeline	Total (land)
Newport	977868	Average	96.0	108.9	27.2	11.4	148	19.2	128
		Minimum	89.0	101.5	27.2	11.4	140	19.2	121
		Maximum	292.0	306.8	27.2	11.4	345	19.2	326
Cardiff	221559	Average	136.8	153.6	27.2	11.4	192	19.2	173
		Minimum	124.0	140.8	27.2	11.4	179	19.2	160
		Maximum	178.7	195.4	27.2	11.4	234	19.2	215
Barry	479128	Average	88.5	103.0	34.2	19.6	157	19.2	122
		Minimum	81.7	96.8	34.2	19.6	151	19.2	116
		Maximum	103.4	116.5	34.2	19.6	170	19.2	136
Port Talbot	5684054	Average	64.2	77.3	18.0	6.2	102	19.2	97
		Minimum	62.5	75.5	18.0	6.2	100	19.2	95
		Maximum	233.8	262.2	18.0	6.2	286	19.2	281
Llanelli	29420	Average	232.0	268.2	18.0	6.2	292	19.2	287
		Minimum	231.7	267.8	18.0	6.2	292	19.2	287
		Maximum	232.2	268.3	18.0	6.2	293	19.2	288
Milford Haven	998112	Average	68.4	82.4	18.3	7	108	19.2	102
NE Wales	523126	Average	98.6	116.5	-	-	-	-	117
		Minimum	77.4	96.1	-	-	-	-	96
		Maximum	253.3	268.3	-	-	-	-	268

Table 5-5 Summary of the modelling of the costs across the whole CO_2 value chain

6 Practicalities

This section evaluates practical considerations for the development of a CCUS network in Wales:

- How it will be funded and commercialised through business models from the UK Government.
- How industrial clusters will be sequenced, which will impact on the timing of possible development in both South and North East Wales.
- The economic opportunities from CCUS roll-out, including supply chain.
- The need for skills development.

6.1 Funding a CCUS roll-out – UK Government business models and cluster sequencing

6.1.1 Business models overview

The UK Government's Ten Point Plan, published in November 2020, set an ambition for CCUS to be established in four clusters by 2030, capturing up to 10 million tonnes of CO_2 per year, and for CCUS to be developed alongside hydrogen to "create these transformative "SuperPlaces" in areas such as the heart of the North East, the Humber, North West and in Scotland and Wales"[69]. It is worth noting that the UK Government's ambition for CCUS increased during the course of last year, from an original ambition for two CCUS clusters by 2030,[70] and that the Ten Point Plan also set out an ambition for 1 GW of low carbon hydrogen production by 2025 and 5 GW by 2030.[71]

In order to achieve this goal, the Department for Business, Energy and Industrial Strategy (BEIS) is developing business models to provide an investible framework for CCUS, and a £1 billion CCUS Infrastructure Fund will provide additional grant support to the capital funding of some early industrial carbon capture and CO_2 transport and storage (T&S) networks.[72] Business models and the Infrastructure Fund are currently in development, within the following timetable as set out in the Ten Point Plan:

- *"2021: Execute a process for CCUS deployment, working in collaboration with industry, and set out further details of a revenue mechanism for industrial carbon capture and hydrogen projects.*
- *"2022: New CCUS business models finalised.*
- *"2030: Two clusters operational by the mid-2020s, subject to relevant value for money and affordability considerations, and a further two clusters operational by 2030."*[73]

69. HM Government, The Ten Point Plan for a Green Industrial Revolution, November 2020, p.22 https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution
70. HM Treasury, Budget 2020, March 2020 p.6 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/871802/Budget_2020_Print.pdf
71. HM Government, The Ten Point Plan for a Green Industrial Revolution, November 2020, pp.10-11 https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution
72. BEIS, Carbon Capture, Usage and Storage: An update on business models for Carbon Capture, Usage and Storage, December 2020, p.73 https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-business-models
73. HM Government, The Ten Point Plan for a Green Industrial Revolution, November 2020, p.23 https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

In December 2020, BEIS published a detailed update setting out the Government's preferred options for CCUS business models, covering carbon capture in power, carbon capture in industry, CO_2 transport and storage, and, with less detail, hydrogen production.

6.1.2 Likely features of the business models

The December 2020 update set out the following key business model features for the various parts of the CCUS value chain. These are subject to change as the business models are refined over the next year, but changes will not be material in our view. Ensuring value for money for taxpayers and consumers will however remain critical.

Power capture – Dispatchable Power Agreement (DPA)
The DPA is being designed to support flexible mid-merit power generation (coming behind renewables and nuclear in the merit order, but ahead of unabated gas) covering CCUS technology applied directly to a thermal power plant, including pre-combustion, post-combustion and oxy-fuel technologies. It will encompass both new-build and retrofitted CCUS plants, potentially hydrogen power generation, depending on the hydrogen business model development.

The DPA is based on the contract for difference (CfD) framework for renewable generation, although it would comprise an availability payment as well as a variable payment for electricity generated:

- The availability payment would provide a regular payment for making the capacity available and would be reduced in the event of outages or poor carbon capture performance.
- The variable payment would incentivise the plant to run ahead of an unabated equivalent plant when demand cannot be met by renewables and nuclear. It will be calculated by taking into account the higher gas costs, lower carbon costs, T&S fees and other higher costs faced by the CCUS plant, ensuring that its overall short run marginal costs are less than those faced by an equivalent unabated plant.

The DPA would be established between the power CCUS project company and the Low Carbon Contracts Company (LCCC), which currently fulfils the same counterparty role for renewable generation:

- The power plant would provide dispatchable, low carbon power at the market price in the wholesale and balancing markets and ancillary services to the Electricity System Operator.
- The generator would pay the CO_2 T&S company the T&S fees for captured carbon.
- The DPA would then provide the generator with the availability and variable payments.
- As per CfDs for renewable generation, the DPA payments would be funded from electricity consumers in general.

Industrial carbon capture (ICC)
The ICC business model is designed to incentivise existing industrial facilities to decarbonise, while maintaining their international competitiveness, and encourage investment in new industrial facilities in the UK. It will be supported by capex co-funding, but only for initial projects.

The commercial framework will be based on the CfD framework, and utilisation will be out of scope unless it leads to permanent abatement of CO_2:

- The counterparty will most likely be the LCCC.
- The ICC contract will have an overall duration of 15 years: an initial 10-year period will cover operational expenses, T&S fees and a rate of return on capital investment, and the remaining 5 years will cover operational expenses and T&S fees only.
- For early projects the reference price for the ICC contract will be a fixed carbon price trajectory, and emissions trading system (ETS) free allowances will be forfeited. Over time the reference price will evolve to a market-driven carbon price.
- The strike price will be negotiated bilaterally for initial projects, based on expected costs of carbon capture, T&S fees, and a return on CAPEX investment, moving to a competitive allocation process over time. As per renewables CfDs, the difference between the reference price and the strike price would be paid to the industrial facility (or paid by the industrial facility if the reference price is higher).

Construction and CO_2 leakage risks at the capture facility would be the responsibility of the industrial facility. Capture rates would be expected to be at least 90%, although modular carbon capture technology would be eligible – industrial facilities fitting carbon capture onto one, but not all, of their emissions sources may therefore be covered, but this is still subject to confirmation.

CO_2 transport and storage (T&S)
The Transport and Storage Regulatory Model (TRI Model) is based on an economic regulation model, which aims to provide stable and predictable returns within a bounded range. It envisages that a Transport and Storage Company (T&SCo) will be responsible for the development, construction, financing, operation, maintenance, expansion and decommissioning of the T&S network. T&SCo's key roles will be:[74]

74. BEIS, Carbon Capture, Usage and Storage: An update on business models for Carbon Capture, Usage and Storage, December 2020, p.15 https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-business-models

- **Asset Owner:** T&SCo will own the onshore and offshore network, and obtain the licence for the storage site; and
- **System Operator:** T&SCo will operate the T&S network to ensure the operational parameters are within specified limits, manage network access, perform network planning, and administrate sector specific tasks (such as relevant connection codes).

The business model is designed to balance the need to oversize infrastructure initially to enable new users to connect, and the economic attractiveness of the network to the early users. The model will seek to incentivise T&SCo to attract more users to their network. There are three elements to the model.

- **Revenue model.** The User Pays revenue model will see T&SCo's revenue stream made up of payments from those who use the T&S network, with contingent recourse to consumer and/or taxpayer support to ensure the revenue stream is predictable. The User Pays model can be extended to cover the import of CO_2 from external sources (paying to inject CO_2 at a T&S network access point) and reuse of CO_2 (paying to offtake CO_2).
  The T&S fees will be determined under the economic regulatory regime (described below) and will likely include a connection fee for a given capture plant, a capacity fee for the shared use of the T&S asset, and a volumetric fee based on the amount of CO_2 transported and stored.
- **Economic Regulatory Regime (ERR).** The ERR provides the framework to manage the annual allowed revenue to the T&SCo. Similar to gas and electricity network regulation, an Economic Regulator would be established to set periodic price controls and determine the allowed revenue to fund T&SCo's activities.
- **Government support package (GSP).** The GSP would offer protection to investors for specified high impact low probability risks that the private sector may not be able to bear. These risks would include leakage of the CO_2 from storage facilities, and stranded assets. The GSP may act as an insurer of last resort.

Hydrogen production

Hydrogen production business models are much less advanced in their development, and will interact with other support mechanisms, including the Renewable Transport Fuel Obligation (RTFO) for transport fuels, CfDs for renewable generation (relevant to green hydrogen) and business models for CCUS (relevant to blue hydrogen). Key aims for BEIS are to avoid double-subsidy and establish shared hydrogen infrastructure to connect multiple producers and users.
The two most likely options are for a contractual or regulatory framework to be developed for hydrogen production:

- A contractual framework would probably be similar to a CfD.
- A regulatory framework would operate in a similar manner to the existing Regulated Asset Base (RAB) funding mechanism for gas and electricity networks.

BEIS has expressed a preference for a contractual framework, stating that it "would be more appropriate than a regulatory framework, recognising the asset life of hydrogen production assets, the likely investor profile, and our long-term aim of a subsidy free market for low carbon hydrogen".[75] However, in our view, the development of hydrogen pipelines would likely be better suited to a regulatory framework, as per existing gas pipelines, and so we expect that the eventual hydrogen business models may contain some elements of both.

It is also worth noting that separate "buckets" for blue and green hydrogen are likely, reflecting their different cost profiles, and the larger cost reduction potential of green hydrogen. Business models may also differ between large centralised projects and small-scale distributed projects. A further consultation is planned for Q2, 2021.

6.1.3 CO_2 shipping

Within the business models update paper, CO_2 shipping is conspicuous by its absence. It is mentioned just once in the document, which states that the ERR for T&SCo "would be designed to have sufficient flexibility to allow for future CO_2 market expansion (potentially including shipped CO_2) whilst ensuring affordability and value for money for the users".[76]

There are several questions that we think the business models need to answer for shipping, including:

- The T&SCo model is based on a single owner of the pipeline and storage assets. For shipping, there are likely to be multiple owners, including the pipeline or other transport from the capture plant to the port, the port handling and intermediate storage facilities, the ships, and potentially the receiving port. How can the T&SCo model be adapted for multiple owners of CO_2 transport infrastructure?
- If the T&SCo model is not adapted for multiple owners, how can shipping be reliably incentivised, including the construction of pipelines to ports and the port infrastructure?
- The ERR could allow CO_2 to be received by T&SCo via ship, but this is in addition to the main pipeline assets. If shipping is the only option for a whole region, how is the flexibility in the ERR relevant?

Ultimately, a separate business model for CO_2 transport (not storage) by ship may be needed. In this case, the storage element is covered by the existing T&SCo model, with a fee being paid to inject CO_2 from elsewhere into the T&SCo network.

6.2 Timing of a CCUS roll-out – cluster sequencing

6.2.1 Cluster sequencing

On 10 February 2021, BEIS published its draft approach to the sequencing of CCUS clusters, alongside a consultation which ran until 10 March 2021.[77] The sequencing of industrial clusters is designed to meet the ambition to have two clusters operational by the mid-2020s and a further two by 2030, although the document notes that all clusters will need to decarbonise. The draft process is as follows:

Track 1 clusters – Phase 1: Provisional Cluster Sequencing

Cluster eligibility: Clusters will need to submit a cluster CCUS plan. The cluster will firstly be determined for eligibility, and will need to meet the following criteria: "We define a CCUS cluster as a T&S network (incorporating the onshore and offshore network and offshore storage facility) and an associated first phase of carbon capture projects."[78] Note that CO_2 shipping is not mentioned in the BEIS definition.

This would restrict entry only to those clusters that can demonstrate a coordinated, full chain proposal, and is designed to ensure that more than one storage location is developed in Track 1. This effectively rules out South Wales from Track 1, although capture sites in North East Wales could be included as part of the HyNet cluster, which would likely be eligible.

Cluster evaluation: Secondly, the CCUS plans of eligible clusters will be evaluated against a set of criteria, including deliverability, emissions reduction, cost, economic benefits, and learning and innovation. The highest scoring two clusters will be put onto Track 1, with potentially an additional two reserve Track 1 clusters. It is also possible that more than two clusters will be included on Track 1.

75. BEIS, Carbon Capture, Usage and Storage: An update on business models for Carbon Capture, Usage and Storage, December 2020, p.76 https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-business-models
76. BEIS, Carbon Capture, Usage and Storage: An update on business models for Carbon Capture, Usage and Storage, December 2020, p.18 https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-business-models
77. BEIS, Carbon Capture Usage and Storage: Market Engagement on Cluster Sequencing, February 2021 https://www.gov.uk/government/consultations/carbon-capture-usage-and-storage-market-engagement-on-cluster-sequencing
78. BEIS, Carbon Capture Usage and Storage: Market Engagement on Cluster Sequencing, February 2021, p.24 https://www.gov.uk/government/consultations/carbon-capture-usage-and-storage-market-engagement-on-cluster-sequencing

Track 1 clusters – Phase 2: Final Project Selection

This phase would determine which individual projects within the cluster would be selected and allocate support to these projects:

- For T&S, this would be composed of negotiation and due diligence.
- For capture projects, there would be an open process where individual projects would be invited to submit applications. Capture projects would need to be able to connect to the cluster T&S infrastructure, and this could include capture projects outside of those mentioned in the cluster plan – this would have relevance to North East Wales. It could also include capture projects that have a credible plan to transport CO_2 (including by ship) to the Track 1 cluster – but no additional support would be provided.

The support package would then include:

- For T&S, an economic licence to grant the licensee a regulated revenue stream, access to part of the £1 billion CCUS Infrastructure Fund, if required, and the Government Support Package (GSP) to manage remote risks. This would be determined by bilateral negotiation.
- For power, support would consist of the DPA, which would be agreed by bilateral negotiations for the early projects (with competitive auctions coming later).
- For industrial capture, support would consist of an ICC contract, and CAPEX co-funding through part of the CCUS Infrastructure Fund, if required. Like power, this would be agreed by bilateral negotiations for the early projects (with competitive auctions coming later).
- For hydrogen, more details will be forthcoming, but support could include a hydrogen business model and access to part of the £240 million Net Zero Hydrogen Production Fund, agreed through bilateral negotiation.

We think that this approach, by considering cluster projects together, will help to mitigate cross-chain risk, ensuring that cluster projects are appropriately matched to T&S infrastructure, with business model and grant support also included.

Track 2 clusters

BEIS envisage naming up to two reserve clusters in Track 1, but without finalising the two clusters for Track 2 at that stage. BEIS will continue to engage with potential Track 2 clusters and projects and will publish an allocation process for Track 2 clusters in October 2021.

Eligibility for Track 2 is also likely to be relaxed, with a cluster storage proposal not being required (although a credible storage solution, including shipping to another cluster, would be necessary). This would mean that South Wales would be eligible to be considered for Track 2.

Draft timeline

The draft timeline for the process is as follows:

- April 2021 – Phase 1 call for cluster CCUS plans.
- July 2021 – Deadline for Phase 1 cluster plans to be submitted to BEIS.
- August 2021 – Phase 1 eligible clusters announced AND Phase 1 call for capture projects in eligible clusters.
- October 2021 – Track 1 clusters and Track 1 reserve clusters named AND Deadline for Phase 2 capture project applications.
- November 2021 onwards – Phase 2 project assessment, negotiation and due diligence.

6.3 Economic Opportunities for Wales

CCUS presents several economic opportunities – safeguarding of existing industry and jobs as much of the world decarbonises; and the creation of new jobs and supply chain opportunities.

6.3.1 Safeguarding of Existing Industry

Wales has a high dependence on energy intensive industry:

- Carbon intensive processes make up 29% of total emissions, or 14 $MtCO_2$ per year in 2016.[79]
- As a share of the economy, manufacturing accounts for 17% of Welsh gross value added (GVA), the highest proportion of any UK region.[80]
- Around 10% of Welsh employment is in manufacturing (almost 150,000 jobs) well above the UK average of 7%.[81]

Overall, the UK has seen too much emissions reduction through offshoring of heavy industry, and is now the largest per-capita importer of CO_2 emissions in the world.[82] To give one example, the closure of Redcar steelworks in late 2015 led to 2,000 job losses, but caused nearly half the fall in industrial emissions in 2016.[83]

CCUS offers the opportunity to safeguard existing industry, through providing a network to enable decarbonisation, including of processes that cannot be electrified – in the context of a growing share of global emissions falling under varying net zero targets, including the EU, US and China.

6.3.2 Supply Chain Opportunities, Jobs and Economic Value Added

The benefits of developing a CCUS infrastructure network will also extend to the supply chain responsible for providing the resources to construct and maintain such a network. The Energy Industries Council (EIC)[84] has a database of over 3,600 supply chain companies to all energy sectors in the UK of which 225 are affiliated to Wales. This can be filtered to the supply of products which could benefit from CCUS initiatives such as Ports and Logistics, Pipeline design and manufacture, Transmission and substations, Tank design and manufacture. This lists nearly 100 energy industry suppliers who are likely to both support and in doing so benefit from CCUS initiatives. These suppliers could currently be serving a range of energy industries including oil and gas, offshore wind and nuclear.

Many of these potential suppliers are also located close to the major emitting sites in South and North East Wales, providing further opportunities for local economic development.

The Energy Innovation Needs Assessment (EINA) on CCUS[85] provides a comprehensive assessment on the potential economic benefits of developing a strong CCUS market in the UK. It highlights the resources and expertise available to the UK which can allow it to become highly competitive in a CCUS export market providing an estimated £4.3 billion of GVA to the UK economy per year by 2050.

CCUS will also support a significant number of jobs across the UK. The EINA estimates that as soon as 2030, 50,000 jobs could be supported by CCUS, of which 45,000 is expected to support a large export market and 5,000 domestically. This peaks at nearly 70,000 jobs overall in 2040 and these trends are shown in Figure 6-2 below. Successful implementation of CCUS in Wales would allow Wales to see a significant share of the jobs benefit. As there are limited studies on the scale of economic benefits from CCUS in Wales specifically, data based on the UK as a whole can be interpolated to estimate the share of jobs which can be allocated to Wales. Depending on the topic of the data, various key coinciding datasets can be used to provide a rough estimate.

79. Wales Industry Sector Emissions Pathway Factsheet February 2021: https://gov.wales/sites/default/files/publications/2019-06/industry-sector-emission-pathway-factsheet.pdf
80. Office for National Statistics, Regional gross value added (balanced) by industry: all NUTS level regions, December 2019 https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/nominalandrealregionalgrossvalueaddedbalancedbyindustry
81. Office for National Statistics, JOBS05: Workforce jobs by region and industry, December 2020 https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/datasets/workforcejobsbyregionandindustryjobs05
82. Office for National Statistics, The decoupling of economic growth from carbon emissions: UK evidence, October 2019, Figure 11 https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/compendium/economicreview/october2019/thedecouplingofeconomicgrowthfromcarbonemissionsukevidence
83. Cooper SJG and Hammond GP, Decarbonising UK industry: towards a cleaner economy, Institution of Civil Engineers paper 1800007, May 2018, p.3; See https://www.gazettelive.co.uk/news/teesside-news/redcar-steelworks-closure-contributes-sharp-12696855
84. EIC Supply Chain Mapping https://www.the-eic.com/MarketIntelligence/EICSupplyMap
85. Energy Innovation Needs Assessment on CCUS https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/845655/energy-innovation-needs-assessment-ccus.pdf

Jobs: For an estimate of jobs supported by CCUS in Wales, the percentage of the UK working population in Wales can be used from Workplace Employment by Industry in Wales 2016[86]. This value can then be scaled using data to identify the share of the working population in potentially CCUS relevant industries such as Manufacturing, Construction, Electricity, gas, steam & air conditioning, Professional, scientific & technical activities in Wales compared to the UK average. Taking the EINA forecast for the UK as a whole, this scales to approximately 2,000 directly related CCUS jobs by 2030 in Wales.

GVA: GVA forecasts provided by the EINA on CCUS can also be scaled for Wales by interpolation in a similar respect based on GVA added by each industry in 2018[87]. Firstly, split by Wale's share of UK wide GVA and then scaled by the share of GVA in potentially CCUS relevant industries in Wales compared to the UK average such as those listed below.

- Manufacture of coke, refined petroleum and chemicals
- Rubber and plastic products
- Basic metals and metal products
- Machinery and equipment not elsewhere classified
- Electricity, gas, steam and air-conditioning supply
- Construction
- Architectural and engineering activities

A multiplier of 0.041 was applied to the EINA estimates of GVA from CCUS by 2050 – this multiplier accounts for the Welsh share of UK GDP scaled up by 18% due to the increased industrial presence in Wales compared to the UK average. This provided an estimated GVA from CCUS in Wales of approximately £148m per year by 2050 from the export market and £35m domestically per year.

6.4 Skills Required to Implement a CCUS Network

It is not possible to deliver a CCUS network without skilled people and, as identified by the Committee on Climate Change's Net Zero Report, there are emerging skills gaps. Today, the energy sector directly employs 144,000[88] people across the UK and hundreds of thousands more across the supply chain.

6.4.1 The Human Resource Challenge

Losing Existing Talent

The Energy & Utility Skills Partnership has identified two factors that will shrink the energy sector workforce over the next decade:

- It is estimated that around 20% of the Energy Sector Workforce are set to retire by 2030.
- Employees choosing to leave the Sector permanently following a career break. Energy & Utility Skills' research reports that in excess of 75% of women who leave engineering following maternity leave are put off returning due to inflexible working hours and practices.

Competition for Talent

Like all other sectors in the engineering industry, the energy sector must compete to attract the best STEM qualified talent. Unfortunately, the sector loses out on this talent to other industries each year. For example, more than 40% of physics graduates opted for careers in banking, finance or technology.

86. Workplace Employment by Industry in Wales 2016
https://gov.wales/sites/default/files/statistics-and-research/2019-03/workplace-employment-by-industry-2001-to-2016.pdf
87. Wales GVA by each industry 2018
https://statswales.gov.wales/Catalogue/Business-Economy-and-Labour-Market/Regional-Accounts/Gross-Value-Added-GDP/gvainwales-by-industry
88. National Grid – Building the Net Zero Energy Workforce 2020
https://www.nationalgrid.com/stories/journey-to-net-zero/net-zero-energy-workforce

STEM Pipeline Challenge
Research carried out by YouGov for National Grid found that a lack of relevant qualifications was cited as the biggest hurdle to a career in combatting climate change. As the figures below will show, this 'pipeline problem' starts at school and runs right through to degree level:

- **STEM Uptake in Schools** – In 2019, 37,000 students took Physics A Level[89] and 91,000 completed Maths A Level. Research carried out by Development Economics for the National Grid found that increases of 24% for Physics and 19% for Maths were needed in order for Britain to maintain the pipeline of qualified talent it needs to build the net zero workforce.
- **Apprenticeships** – Between 2016 and 2017, England's apprenticeship starts in engineering fell from 91,000 to 75,000. This came about as a result of the ongoing uncertainty about the future operation and management of the Apprenticeships Levy (a tax on UK employers to fund apprenticeship training).
- **Degree Qualifications** – In 2017/18, c. 42,000 undergraduates studied degrees in engineering and technology courses. Development Economics estimates that this number must grow by 14,000 over the next 30 years to at least 56,000 annual enrolments.

Lack of Diversity
A diverse workforce in a supportive environment drives success through different perspectives, new ideas and greater creativity. The under-representation of women in the engineering workforce therefore means that the energy sector is missing out on a full-strength workforce capable of maximising success. Indeed, it is estimated that only 12% of engineering industry employees are women:

- **STEM Uptake in Schools** – Of the 37,000 students to have taken A Level Physics in 2019, only 22% were women.
- **Apprenticeships** – Only 8% of apprenticeship starts in engineering were attributed to women.
- **Degree Qualifications** – Of the 42,000 individuals who studied engineering and technology degrees in 2017/18, just 15% of these were women.

6.4.2 Bridging the Gap

Universities and Colleges must work together with companies in the industry to highlight the opportunities of vocational training to school leavers and offer specific courses aimed at catering for net zero[90]

The Skills Required
Operating and maintaining an increasingly decentralised energy system on ever greener power and gas will require a whole range of skills across a variety of experienced workers:

- **Digital and Data skills** – Digital skills and data analytics will form the core skills for the net zero energy sector workforce, with large amounts of data required for network planning, more efficient maintenance and improving risk mitigation.
- **Designing and Implementing new Technologies** – The net zero energy workforce will require highly skilled scientists, engineers and designers to design, test and maximise the potential for new technologies such as efficient CCUS.
- **Industry communication and change management skills** – The pace and scale of change means organisations behind the net zero drive will not be able to do it by themselves. Expert communicators will be required to smooth out the introduction of collective technical advancements.

The Role of the Oil and Gas Industry
The skills required for CCUS are virtually the same as those utilised in the exploration, production and procession of hydrocarbons. Current experience of production, transportation and injection of CO_2 in Enhanced Oil Recovery projects shows minimal difference between this reservoir characterization, well drilling, facilities design and operations and those required to safely inject CO_2 into the ground.[91]

Broader Energy Sector Skills Development
For the development of the CCUS Sector and other net-zero initiatives to become a reality, these skills must be harnessed in a timely manner. Aligning training and standards between energy sectors, including oil and gas, wind, hydrogen and other renewables, will help to streamline the training landscape. This is being actioned through the establishment of the Energy Skills Alliance.

89. National Grid – Building the Net Zero Energy Workforce 2020
https://www.nationalgrid.com/stories/journey-to-net-zero/net-zero-energy-workforce
90. Jobs, Skills, Zero Emissions – The Economic need for Carbon Capture by Drax
https://www.drax.com/energy-policy/jobs-skills-zero-emissions-the-economic-need-for-carbon-capture-by-drax/
91. Achieving Net Zero Emissions Requires the Knowledge and Skills of the Oil and Gas Industry
Frontiers | Achieving Net Zero Emissions Requires the Knowledge and Skills of the Oil and Gas Industry | Climate (frontiersin.org)

7 Conclusions

The Conclusions and Recommendations are shown in section 1 as part of the Executive Summary.

8 Glossary

Term or abbreviation	Meaning
ABP	Associated British Ports
Acorn	A CCS project operating from the St Fergus gas terminal and aiming to offer CCS in the depleted North Sea gas fields such as Golden Eye
AD	Anaerobic Digestor – a method of producing biogas from organic feedstock which is a low-carbon fuel
BECCS	Bioenergy with Carbon Capture and Storage (a form of negative carbon emissions)
BEIS	UK Government Department for Business, Enterprise and Industrial Strategy
BF	Blast Furnace – used in steel making
BFOG	Blast Furnace Off Gas
BioSNG	Biological Synthetic Natural Gas
BOF	Basic Oxygen Furnace – used in steel making
CCC	Climate Change Committee
CCGT	Closed Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Storage
CfD	Contracts for Difference
CO2	Carbon dioxide
COG	Coke Oven Gas produced from coal and used in steel making
DNV	The consultancy company that undertook this study for the Welsh Government
EAF	Electric Arc Furnaces used for reclaiming scrap steel
EIC	Energy Industries Council
EOR	Enhanced Oil Recovery
ERR	Economic Regulatory Regime
EV	Electric Vehicle
FIT	Feed-In Tariff
FLEXIS	Consortium of strategic partners – Cardiff University, Swansea University, The University of South Wales, Neath Port Talbot Borough Council and Tata Steel UK
GHG	Greenhouse gases

Term or abbreviation	Meaning
GSP	Government Support Package
GVA	Gross Value Added
H2	Hydrogen
HP	High Pressure
HyNet	A low carbon project in NW England aiming to use the depleted Hamilton field for CCS
IEAGHG	International Energy Agency Greenhouse Gas
LOHC	Liquid Organic Hydrogen Carrier
LP	Low Pressure
LPG	Liquid Petroleum Gas – usually a mixture of propane and/or butane
MBT	Mechanically Biologically Treated waste
MP	Medium Pressure
MSW	Municipal Solid Waste
Net Zero NW	A project in NW England aiming to use the depleted Hamilton field for CCS.
NDC	Nationally Determined Contribution
Northern Endurance	A CCS partnership of BP, Eni, Equinor, National Grid, Shell and Total in the North East of England
Northern Lights	A CCS project in Norway run by Equinor
OCGT	Open Cycle Gas Turbine
OGA	Oil and Gas Authority
OHC	Organic Hydrogen Carrier
RHI	Renewable Heat Incentive
Spirit Energy	Operator of the Morecambe Bay gas fields
SWIC	South Wales Industrial Cluster
T&SCo	Transport and Storage Company
TGR	Top Gas Recycling in a blast furnace
Zero Carbon Humber	An initiative to create a carbon neutral industrial cluster in the Humber region.

Appendix A
Key documents reviewed

Source	Title
CCC	Net Zero, The UK's Contribution to Stopping Global Warming
	Net Zero Technical Report
	Building a Low Carbon Economy in Wales-Setting Welsh Climate Targets
	Sixth Carbon Budget 2020
	Advice Report: The path to a Net Zero Wales 2020
	Progress Report – Reducing emissions in Wales 2020
Welsh Government	Low Carbon Delivery Plan
	Industry Sector Emission Pathway Factsheet
	Prosperity for All Economic Action Plan
	Energy Use in Wales
	Energy Generation in Wales
	Well-being of Future Generations (Wales) Act 2015
	Future Wales: the national plan 2040 - Our National Development Framework, setting the direction for development in Wales to 2040.
BEIS	Response to CCUS Business Models Consultation
	CCUS deployment at dispersed industrial sites
	UK National Atmospheric Emissions Inventory (NAEI)
	The Energy Innovation Needs Assessment CCUS (EINAs)
	Shipping CO_2 – UK Cost Estimation Study
	Energy Consumption in the UK (ECUK) 1970 to 2018
Frontier Economics	Business models for low carbon hydrogen production
Element Energy	Hydrogen Development in Wales
	Deep Decarbonisation Pathways for UK Industry
Global Carbon Capture & Storage Institute	Global Status of CCS 2019
DNV	Recommended Practices and CCUS Studies
EIC	CCUS UK Supply Chain Capabilities
Net Zero Clusters	Drax CCS: Delivering Jobs, Clean growth and Levelling up the Humber

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