Assessment of the Feasibility of CCS for Deployment in Ireland

15 December 2021

Contents

Scope and Context of Report

As required by the Government's Climate Action Plan 2019[1] (Action 33), a Carbon Capture and Storage (CCS) Policy and Project Feasibility Steering Group (CCS SG) was established and led by the Department of the Environment, Climate and Communications (DECC) to examine and oversee the feasibility of the utilisation of CCS in Ireland; reporting to the Oireachtas Standing Committee on Climate Action, as appropriate.

As requested by the CCS SG, Ervia has prepared this report to assess the feasibility of CCS for deployment in Ireland against the four criteria, and sub-criteria, developed by the CCS SG (listed in Appendix 1).

Executive Summary

As outlined in the Scope and Context of Report section, this report has been prepared for the Government's CCS SG in line with the criteria set by the Group to inform the Assessment of the Feasibility of CCS for Deployment in Ireland. The four key high-level criteria under which the feasibility of CCS for deployment in Ireland was assessed, are:

1. Environmental Issues: The potential role of CCS in Ireland meeting its climate targets.
2. The technical feasibility of the deployment of the technology in Ireland.
3. Financial viability of CCS.
4. EU, National and Other Relevant Regulatory Issues.

This assessment of the feasibility of CCS for deployment in Ireland under these criteria and sub-criteria has been carried out within the context of achieving Ireland's commitment to net-zero emissions by 2050 at the latest, and the need for negative emissions to achieve same[2].

Our approach consisted of drawing on Global, European, United Kingdom (UK) and Irish energy research, focussing on credible Irish and international energy modelling of scenarios which achieve net-zero emissions by 2050. In addition, this report also examines existing Global, EU, UK and Irish Government-led policies and strategies in relation to achieving net-zero and the role that CCS can play.

Furthermore, the report goes beyond energy research and modelling and the identification of relevant policies and strategies by identifying verified plans, commitments and real time projects that taking place today, across the EU and the UK, to develop and deploy CCS. It is within this context that this report assesses the potential for CCS to help Ireland achieve its climate ambitions.

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[1] https://assets.gov.ie/25419/c97cdecddf8c49ab976e773d4e11e515.pdf

[2] https://www.epa.ie/publications/research/climate-change/Research_Report_354.pdf

The main conclusions of this report, set against each of the headline criteria, are outlined below:

1. **Environmental Issues: The potential role of CCS in Ireland meeting its climate targets.**
    - Credible energy modelling has identified a potential role for CCS in decarbonising the Irish economy and helping Ireland achieve its net-zero climate ambitions.
    - 2050 climate targets cannot be achieved without Carbon Dioxide (CO_2) Removal (CDR) solutions which are based on CCS technologies; and interim (2030) targets may be much harder to achieve without CCS technologies.
    - Irish industry and stakeholder groups recognise the potential role for CCS to enable their decarbonisation.
    - CCS has the potential to reduce Ireland's 40$MtCO_{2(eq)}$ non-agriculture emissions from 6 to 16.6 $MtCO_{2(eq)}$ per annum.
    - Based on the current available information and analysis, export of CO_2 would be the recommended option for Ireland to develop CCS. Monitoring and assessment of the CO_2 to ensure permanent geological storage would be the responsibility of the host country where the store is located.

2. **The technical feasibility of the deployment of the technology in Ireland.**
    - The maximum Technology Readiness Levels (TRLs) for capture (post- and pre-combustion), transport (by pipeline and ship) and storage of CO_2 (in saline aquifers) are all 9, i.e. all aspects of the export storage option are in commercial operation. CCS for industry decarbonisation, power decarbonisation and negative emissions is well proven.
    - There are numerous existing International Organisation for Standardisation (ISO) standards, and a multitude of guidance documents, for CO_2 capture, transport and storage.
    - In terms of a roadmap to export CO_2 for storage in Europe, a number of developers in Norway, the UK and the Netherlands have stated that they will be available to store CO_2 from other countries from the mid-2020s.
    - It has been demonstrated in Norway (since 1996) that saline aquifers are suitable to receive and store CO_2. Further research would be required to fully assess the suitability of indigenous stores.
    - Detailed risk assessments would be carried out as part of any project development. Current CCS developers believe that the risks could all be adequately mitigated.

3. **Financial Viability of CCS**
    - CCS could play a significant role in decarbonising Ireland via its use in electricity generation, industry, low-carbon hydrogen production, and negative emissions sources (via bioenergy with CCS (BECCS)).
    - Based on an Enhanced LCOE basis, modelling indicates that CCS would be cheaper than onshore wind, offshore wind and solar energy by 2035 in the UK.

- Subsidies for CCS would be heavily dependent on carbon price. As carbon price increases, less subsidies would be potentially required.
- Deploying CCS to the electricity sector in Ireland would save c. €2.2bn versus the alternative of not utilising it[3].
- International experts agree that CCS would significantly reduce the cost of achieving net zero in each of the countries examined.
- A broad range of funding models for CCS are emerging as project developments progress across Norway, UK and the Netherlands.
- There are no potential liabilities for Ireland for storage of CO_2 if the export option is used.

4. EU, National and Other Relevant Regulatory Issues

- High-level overviews of the existing and required regulatory frameworks for the export and indigenous storage options are provided within this report. The framework required for the export model is by far the least complex.
- There is no long-term liability for the State with the export storage option.
- If Ireland needs or decides to pursue CCS to help it reach its legally binding 2030 targets, then, with policy support, a CCS regulatory regime could be developed for an export model by the late 2020s.
- There have been significant CCS developments at Member State level in recent years with the Netherlands, Denmark, Belgium and Sweden progressing projects. Candidate PCI projects for the 5th list also include France, Germany and Poland.
- In a wider European context, Norway, the UK and Iceland are at the forefront and have all stated that they will be available to import CO_2 from European countries.

Ervia's assessments to date have focused largely on the potential to decarbonise Ireland's electricity sector with CCS. Information from credible sources has been provided to address, as much as possible, the criteria set out by the Government CCS Committee and to extend, where possible, to the consideration of industry, low-carbon hydrogen and negative emissions (via BECCS). It is recommended that the new Government CCS Research Group (as per the Interim Climate Actions 2021) broaden its research to also include those three other sectors.

Report Structure

This report generally adheres to the structure of the criteria document received from the CCS SG in January 2021. There is a section on each of the four main criteria with the relevant sub-criteria shown in dark or light blue boxes dependent on the level on sub-criteria. In general, references in the text are shown as footnotes and references in tables are given in the bibliography.

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[3] Baringa, 2020. The role for CCS in Ireland's net zero electricity capacity mix.

1. Environmental Issues: The Potential Role of CCS in Ireland Meeting its Climate Targets

a. Demonstration (including credible energy modelling) of the need for CCS for Ireland to meet its Climate targets.

The response below provides evidence from MaREI, Baringa, the Climate Change Advisory Council (CCAC) and the Environmental Protection Agency (EPA) to demonstrate the need for Ireland to utilise CCS. Reference is also made to other EU and international studies that are of relevance.

MaREI / University College Cork (UCC)

MaREI/UCC recently published[4] a journal publication on Marginal Abatement Cost Curves (MACCs) and energy system analysis for Ireland. Some of the key findings in relation to CCS are:

- It is impossible to reach carbon neutrality (now Ireland's legally binding commitment) without negative emissions technologies such as Bioenergy with CCS (BECCS) – which relies on CCS technology.
- Electricity generation can be further decarbonised by gas CCS plants.

The results show that without BECCS (and therefore CCS), Ireland cannot achieve 100% emissions reduction – and therefore net-zero.

Further modelling by UCC/MaREI[5] identifies a role for CCS not only in achieving net-zero by 2050, but also being needed much earlier than this, possibly playing a role by 2030. This indicates that gas fired Combined Cycle Gas Turbine (CCGT) power stations coupled with CCS (or another form of dispatchable low or zero emissions electricity) could support the achievement of the 7% emissions reductions per annum by 2030 (51%) as set out in the Programme for Government and now legally binding. This analysis seems to be consistent with EirGrid's recent statement[6] about requiring new, clean dispatchable generation by 2030.

EirGrid

In EirGrid's 2019 document, Tomorrow's Energy Scenarios[7], CCS plays a key role in the only scenario that meets or puts Ireland on a pathway to full decarbonisation. In the only scenario where CCS is not an option (delayed transition), climate targets are neither met

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[4] https://www.sciencedirect.com/science/article/pii/S0306261920309685

[5] https://www.tandfonline.com/doi/full/10.1080/14693062.2018.1464893

[6] Shaping our electricity future 2021

[7] Eirgrid Tomorrow's Energy Scenarios 2019

nor on a full decarbonisation pathway. CCS is installed on up to 1.5GW of gas fired power generation in the scenario that puts Ireland on a pathway to full decarbonisation.

Climate Change Advisory Council

According to the CCAC's 2020 Annual Review[8], "consistency with Paris temperature goals will require CO_2 removal (negative emissions) technologies" and that "Bio-energy with carbon capture and storage (BECCS) is one such negative emission technology".

Environmental Protection Agency (EPA)-funded research by Dublin City University (DCU) & Trinity College Dublin (TCD)

The EPA recently published a study[9] carried out by DCU and TCD exploring Negative Emissions Technologies (NETs) and their potential for Ireland. It clearly identifies the potential for CCS to reduce emissions as well as its role in negative emissions. It states that "*CCS should be deployed on existing fossil fuel electricity generation sites*", noting "*CCS could already contribute significantly to mitigation of existing gross CO_2 emissions in Ireland*" and that "*there is a clear national interest in progressing fossil fuel CCS proactively*".

The EPA's report calls directly for the Government's CCS Steering Group to "*address all existing and potential high-concentration point sources of CO_2*", and that "*its work should be accelerated as much as possible*". The report further calls for the Steering Group to "*critically assess the case for more rapid CCS deployment (specifically including potential retrofitting of existing unabated point sources), facilitated by exporting of CO_2 for geo-storage in other jurisdictions*".

Baringa

A recent report by Baringa into 'The role for CCS in Ireland's net-zero electricity capacity mix' found that, while achieving net-zero in the electricity sector without CCS is possible, "*CCS can reduce the cost of meeting a 2050 net-zero emissions target by over €2bn over the period 2030-2050*".

International Energy Agency

In its recent report published in May 2021, 'Net Zero by 2050 – A Roadmap for the Global Energy Sector'[10], the International Energy Agency states that "*CCUS can facilitate the transition to net-zero CO_2 emissions by: tackling emissions from existing assets; providing a way to address emissions from some of the most challenging sectors; providing a cost-effective pathway to scale up low-carbon hydrogen production rapidly; and allowing for CO_2 removal from the atmosphere through BECCS and DACCS.*"

European Commission

[8] http://www.climatecouncil.ie/councilpublications/annualreviewandreport

[9] https://www.epa.ie/pubs/reports/research/climate/Research_Report_354.pdf

[10] https://www.iea.org/reports/net-zero-by-2050

At EU level, the European Commission is currently developing new rules to allow hydrogen and renewable gases to flow through the gas networks across Europe. The 'Hydrogen and Gas Markets Decarbonisation Package'[11] is currently under development but its ambition clearly sets out a key role for CCS in achieving the EU's decarbonisation targets. The consultation states that gases currently comprise 22% of Europe's energy. By 2050 they will comprise 20% but they will be decarbonised: 2/3 renewable gas (hydrogen, biomethane etc.) and 1/3 abated (i.e. CCS).

The EU's Hydrogen and Energy Sector Integration strategies[12] were launched simultaneously on 8 July 2020 by the European Commission. Some key points identifying the potential for CCS and hydrogen taken from these strategies include:

- Future (clean) energy systems will be built upon renewable electricity and zero-carbon gas networks.
- CCS is needed to support deep decarbonisation.
- CCS can address hard-to-abate emissions.
- CCS will be needed to produce low-carbon hydrogen until such time as renewable hydrogen is available at scale (produced by renewable electricity within the EU and/or via import).
- Clear role identified for CCS to create much needed negative emissions.

UK Government

In the UK, the Government recently announced plans to deploy CCUS to abate 10Mtpa CO_2 by 2030, as part of its 'Ten Point Plan for a Green Industrial Revolution'[13]. Referring to CCUS, the Plan states that "*this technology will be globally necessary*". It adds "*CCUS will help decarbonise our most challenging sectors, provide low carbon power and a pathway to negative emissions*".

UK National Grid

UK's National Grid published its Future Energy Scenarios 2020[14] (FES), (similar to EirGrid's Tomorrow's Energy Scenarios). It found that:

- Reaching net-zero is achievable but not without negative emissions from BECCS
- Hydrogen and CCS must be deployed for net-zero.
- Industrial scale projects need to be in operation this decade.

- **An assessment of the levels of Carbon Dioxide Removal (CDR) solutions Ireland will require to meet it climate targets to 2050 and the potential role for CCS in this regard.**

[11] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12911-Gas-networks-revision-of-EU-rules-on-market-access/public-consultation

[12] https://ec.europa.eu/energy/topics/energy-system-integration_en

[13] https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

[14] https://www.nationalgrideso.com/future-energy/future-energy-scenarios

CDR refers to the process of removing CO_2 from the atmosphere. Since this is the opposite of emissions, practices or technologies that remove CO_2 are often described as achieving 'negative emissions'.

There are two main types of CDR: either (1) enhancing existing natural processes that remove carbon from the atmosphere (e.g. by increasing its uptake by trees, soil, or other 'carbon sinks') or (2) using chemical processes to, for example, capture CO_2 directly from the ambient air and store it elsewhere (e.g. underground) or capture CO_2 from a process using biomethane or biomass.

Ervia has not assessed the quantum of total CDR required for Ireland. There are however a number of studies which acknowledge the need for CDR to allow Ireland to achieve net-zero emissions. These reports, from the EPA and MaREI/UCC, are summarised below.

Separately, the Government assessed long-term climate strategies out to 2050 as part of its preparation for the Climate Action Plan (CAP) 2019.

Action 1 in the CAP 2019 committed Ireland to evaluate the steps necessary for the country to achieve net zero by 2050 and publish a Long-term Study. Publication of this study, and its submission to the European Commission, has been delayed. When published, this study may provide an estimate of total CDR required to enable the country to achieve net zero by 2050.

Action 1 of the CAP 2019 states "*Evaluate in detail the changes required to adopt a more ambitious commitment of net zero greenhouse gas emissions by 2050, as part of finalising Ireland's long-term climate strategy by the end of 2019 as per the advice of the Intergovernmental Panel on Climate Change and the recommendation of the Joint Oireachtas Committee on Climate Action.*"

Completion of this action has been delayed by the rounds of observations (Ministerial and Departmental) and public consultation necessary.

Action 3 of the 2021 Interim Climate Actions stated: "*Prepare Long-Term Climate Strategy to meet requirements of EU and the Climate Action and Low Carbon Development (Amendment) Bill 2021.*" The latest update states "*Long-term Climate Strategy will be prepared in Q3 (2021) once Climate Action Bill is in force and Climate Action Plan 2021 is completed.*"

EPA-funded research by DCU/TCD

The EPA recently published a study by DCU/TCD exploring NETs and their potential for Ireland. It clearly identifies the potential for CCS to reduce emissions as well as its role in negative emissions.

The study indicates that Ireland will use up its fair quota of $391MtCO_2$ by c. 2028 and thereafter will accumulate hundreds of millions of tonnes of CO_2 debt i.e. the total quantity of emissions that Ireland can emit to play its part in ensuring global warming does not increase over 1.5ºC is $391MtCO_2$. (Ireland currently emits c. $60MtCO_{2(eq)}$ pa). CDR technologies are the only technologies which will be able to erase such debt.

MaREI/UCC

MaREI/UCC recently published[15] a journal publication on MACCs and energy system analysis for Ireland which shows the critical need for CDR technology in Ireland in order to meet climate ambitions. Please refer to section (a) above for more details.

Developments in the UK may also give an indication of the level of CDR required in Ireland.

UK Royal Academy of Engineering and the Royal Society

A joint report by the UK Royal Academy of Engineering and Royal Society[16] has found that for the UK to reach net-zero greenhouse gas emissions around 2050 an estimated 130MtCO_2 of negative emissions will be required per annum, even with stringent reductions in emissions.

The UK Government published its Net Zero Strategy[17] on 19 October 2021. This document sets out the roadmap to demonstrate how each sector will be addressed to achieve net zero overall. The table below, from the strategy, shows UK residual emissions (MtCO_2) in 2050. It can be noted that the UK will require over 75 million tonnes per annum of greenhouse gas removals i.e. negative emissions to achieve net zero.

Table 1 UK Residual Emissions (MtCO_2) in 2050 (UK Government Net Zero Strategy, 2021)

Sector	MtCO_2
Power	3.0
Industry	3.2
Fuel Supply and Hydrogen	0.2
Heat and Buildings	0.0
Domestic Transport	2.6
International Aviation and Shipping	34.9
Agriculture and LULUCF	19.6
Waste and F-Gases	12.3
Greenhouse Gas Removals	-75.4

This is 16% of the current UK annual emissions (c. 468Mtpa in 2019). Applying the same percentage to Ireland's total emissions of c. 60 Mtpa (in 2019) would equate to 9.5 Mtpa of negative emissions of CDR required for Ireland by 2050.

15 https://www.sciencedirect.com/science/article/pii/S0306261920309685

16 https://www.raeng.org.uk/news/news-releases/2018/september/greenhouse-gas-removal-could-make-the-uk-carbon-ne

17 https://www.gov.uk/government/publications/net-zero-strategy

- **Assessment of the sectors and sub-sectors in which CCS may be appropriately used in Ireland in order to remain consistent with decarbonisation goals.**

Sectors where CCS can potentially play a role in helping to decarbonise include electricity generation, industry, heating and transport (via decarbonised hydrogen) and right across the whole economy via negative emissions.

Table 2 below shows Ervia's estimates of the potential emissions reductions across these sectors utilising CCS:

Table 2 Annual Potential emissions reductions using CCS (Ervia)

Sector	$MtCO_2$	Comment
Gas-fired Power Generation	1-3	Depending on policy and ambition for decarbonisation in the power sector, CCS can provide different levels of decarbonisation if applied to either existing or new gas fired combined cycle gas turbine (CCGT) power stations. In 2020 total emissions from Ireland's eight CCGTs was c. $5MtCO_2$.
Industry		
Cement	1 - 2.5	Approx. 70% of a cement plant's emissions are from its process. CCS is a suitable technology to decarbonise this sector. There are five cement plants in Ireland which emitted c. $2.5MtCO_2$ in 2020.
Alumina	Up to 1.2	There is one Alumina plant in Ireland which emitted c. $1.2MtCO_2$ in 2020.
Oil Refinery	Up to 0.3	Large point source emissions at Ireland's oil refinery (Irving Oil) could be decarbonised with CCS. Total emissions in 2020 was c. $0.3MtCO_2$.
Agri-food Processing	Up to 0.3	Assumes a number of the larger agri-food processing facilities could be decarbonised either with post-combustion CCS or with low-carbon hydrogen.
Low Carbon Hydrogen		
Heating	0.5-3	Assumes conversion of the existing gas connected homes and businesses to hydrogen
Transport	0.5-3	Assumes use of hydrogen in heavy goods vehicles and buses.
Negative Emissions		
BECCS	3-6	Estimate based on availability of bio-resources
Total	6-16.6	

b. Large emitters/Industry representative bodies recognise potential role of CCS(U) for their decarbonisation and as a feedstock.

References and brief summaries are provided below for a broad range of industrial sectors in both Ireland and abroad supporting the need for CCS.

Cement

Emissions from cement production in Ireland accounted for 2.7MtCO_2 in 2020, according to verified EU ETS data[18], and 3.2Mt in 2019. Cement production accounts for approximately 5% of Ireland's annual emissions.

Emissions in cement production have increased by over 80% since 2011 and are projected to increase further under both of the EPA's modelled scenarios[19]. About 70% of a cement plant's emissions are related to process rather than fossil fuel consumption.

Cement Manufacturers Ireland (CMI) has three members in the Republic of Ireland: Breedon Cement, Irish Cement and Mannok Cement, and an associate member in Northern Ireland - Lafarge Cement.

CMI has stated that its member companies are committed to achieving climate neutrality along the construction value chain by 2050 in line with Cembureau (European Cement Association) Roadmap[20]. The roadmap is clear: the current pilot and demonstration CCUS projects in European cement factories must become commercially viable and be made mainstream throughout the industry. In addition, State investment in CCUS transport networks and infrastructure together with the right policy framework will be essential if CCUS is to contribute to a climate neutral Europe by 2050.

Oil Refining

Oil refining is an inherently energy-intensive activity. Refineries require energy, in the form of heat and motive power, to transform crude oil into commercial products. CCS is needed for carbon-intensive industries because fuel switching is often not an option, and/or process-related emissions cannot be avoided.

Ireland's only oil refinery (operated by Irving Oil at Whitegate) supplies c. 40% of our fuel needs with a throughput of over 2 million tonnes of product per annum. This leads to a large single source of emissions on the Island in which CCS could play a vital role in its decarbonisation.

Irving Oil is a member of the EU funded REALISE[21] project to research how to achieve efficiencies in the operation of CCUS in oil refineries. REALISE is a 3-year research project

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[18] Verified EU ETS data for 2020

[19] EPA Ireland

[20] https://www.cembureau.eu/library/reports/2050-carbon-neutrality-roadmap/

[21] The REALISE (Demonstrating a **RE**finery-**A**dapted c**L**uster-**I**ntegrated **S**trategy to **E**nable full-chain CCUS implementation) project will involve the deployment of a small pilot carbon capture unit at Irving oil refinery in Cork and a study of how to optimally integrate it into a wider carbon capture cluster.

with 17 partners worldwide, involving the installation of a pilot carbon capture unit at the Irving Oil refinery in Cork. The Irish element of the project is being led by Ervia, alongside Irving Oil, ESB, Bord Gáis Energy and UCC.

Electricity Association of Ireland (EAI)

According to the EAI's recent 'Our Zero E-Mission Future'[22], deploying CCS to a single, existing gas-fired generator would reduce emissions from the 2030 Base scenario from 6.3Mt to 5.2Mt. The EAI also states that "*Carbon Capture and Storage (CCS) is a uniquely important technology*".

The report further notes that "*In fact, all modelled future scenarios that meet the 1.5 °C target share a number of robust findings for the electricity sector, including a growth in the share of energy derived from low-carbon-emitting sources, a steep decline in the overall share of fossil fuels without Carbon Capture and Storage (CCS).*"

Wind Energy Ireland

In March 2021, Wind Energy Ireland and MaREI published 'Our Climate Neutral Future – Zero by 50'[23] in which the potential for CCS to play a role in further decarbonising electricity and producing negative emissions is clearly identified. The report states "*For peripheral EU countries like Ireland with limited geographical spread for interconnection options, some form of mass energy storage or decarbonised conventional generation is required to cover energy balancing over a number of days and weeks. Options such as conventional power plant with carbon capture, hydrogen as a fuel, and Bio-energy with carbon capture and storage (BECCS), are required to keep the energy system operating in a reliable and robust manner*".

Regarding negative emissions, the report states that "*their role is uniquely important in terms of emissions reduction and in reaching Net Zero*".

Ibec

In December 2020 Ibec formed a dedicated group to assess CCS as a potential technology to decarbonise large industry. The kick-off meeting was attended by 14 industry players including Aughinish Alumina, Irving Oil, Cement Association, Dairy Industry Ireland, ESB, SSE Airtricity, Energia and Bord na Mona.

Ibec recognises the potential for CCS to support the decarbonisation of industry. In its 2019 report 'Building a low carbon economy'[24], it stated that CCS "*could help with certain energy intensive sectors like cement and chemical production to reduce emissions without negatively affecting production. CCS will also be required if CO2 emissions from biomass-based energy and industrial plants are to be captured and stored to create negative emissions in a carbon neutral scenario or for the production of carbon free hydrogen.*" Ibec further warned that failure to deploy CCS "*could force these energy intensive sectors to move operations to locations with CCS and/or alternative fuel options*".

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[22] https://eaireland.com/our-zero-e-mission-future-report-published-today/

[23] MaREI – Our Climate Future

[24] IBEC – Ireland needs to build a new low carbon economy

National Competitiveness Council (NCC)

More generally according to Ireland's NCC 2020 report[25], "*within Ireland there are a cohort of industrial companies that have no available means of decarbonisation*".

The Council report notes that "*Ireland's enterprise sector (particularly industry) is currently heavily reliant on natural gas, considerably more so than in competitor countries, and certain firms are unable to transition to zero-carbon energy alternatives. Accordingly, decarbonising the gas network will be critical for enterprise to achieve carbon neutrality in the longer term*". CCS offers a solution to both decarbonise the energy these large emitters use as a fuel, and to capture the CO_2 emitted as part of their industrial processes.

European Commission

The European Commission has, in 2021, made two very strong statements regarding support for CCS and belief in its need for Europe's future.

On 10 February 2021 the European Commission published an Evaluation Roadmap for a 'Hydrogen and Gas markets Decarbonisation Package'. The Commission stated "*Gaseous fuels account for roughly 22% of total EU energy consumption today. According to the relevant scenarios used by the Climate Target Plan Impact Assessment, the share of gaseous fuels to total EU energy consumption in 2050 would be about 20%. Biogas, bio-methane, renewable and decarbonised hydrogen as well as synthetic methane would represent some 2/3 of the gaseous fuels in the 2050 energy mix, with fossil gas with CCS/U representing the remainder*." i.e. CCS will be used to decarbonise over 7% of Europe's energy needs by 2050.

On 11 October 2021, EU Commissioner Kadri Simson spoke at the Carbon Capture, Utilisation and Storage Forum[26]. Here are some of her key statements:

"*I am convinced that we should double our efforts to deploy CCS and CCU value chains in Europe and I know that we have all the tools to do so. The timing is also right.*

CCS and CCU are key to achieve our climate goals. Our models consistently show that they are very powerful mitigation technologies and that without them our decarbonisation task will be very difficult. In some of our scenarios, we see up to 600 million tonnes of CO_2 captured in 2050, more or less half of this amount could be stored permanently underground and half could be reused in industry.

In the European Commission, we believe that this time around the conditions are there for the successful deployment of CCS and CCU."

UK

Within the UK there is also strong support for CCS:

Confederation of British Industry

[25] http://www.competitiveness.ie/publications/2020/ireland's%20competitiveness%20challenge%202020%20.html

[26] https://ec.europa.eu/commission/commissioners/2019-2024/simson/announcements/speech-commissioner-simson-carbon-capture-utilisation-and-storage-forum_en

In a letter to the Secretary of State for Business, Energy and Industrial Strategy, Britain's largest business group has set out a series of priorities to decarbonise the UK economy and has called on the Government to scale up carbon capture technology and infrastructure to reach the Government's target of net-zero greenhouse gas emissions by 2050[27].

SSE

According to SSE[28] (the UK's third largest electricity generator) "*In achieving a net zero economy, CCS technology will be vital in decarbonising power generation, heavy industry and hard-to-reach sectors while protecting and creating thousands of high-quality jobs across the UK's industrial regions*".

UK Government

The UK is in the early stages of developing a CCUS industry, with ambition to deploy four clusters and capture at least 10MtCO_2 annually by 2030.

In November 2020, the UK Government published its 'Ten Point Plan for a Green Industrial Revolution'[29]. The plan states that "*CCUS technology will be globally necessary*" and sets out plans to "*establish CCUS in two industrial clusters by the mid-2020s, and an aim for four of these sites by 2030, capturing up to 10Mt/CO_2 per year*".

On 19th October 2021 Greg Hand, UK Minister of State for Energy, Clean Growth and Climate Change confirmed that the UK Government had selected two large projects (Hynet and East Coast Clusters) as track 1 clusters to be potentially developed in the mid-2020s and as such will be taken forward into Track-1 negotiations[30].

BEIS

In May 2021, the UK's BEIS published 'CCUS Supply Chains: a roadmap to maximise the UK's potential'[31]. The strategy document states that "*Carbon Capture, Usage and Storage (CCUS) is integral to the UK's Green Industrial Revolution*".

The Committee on Climate Change UK (CCC)

The CCC[32] has long been clear that the development of UK-based carbon capture and storage technology is essential to reducing greenhouse gas emissions across the economy, and to meet the UK's climate change targets.

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[27] Confederation of British Industry – Statement

[28] https://www.sse.com/news-and-views/2021/03/major-boost-for-ccs-projects/

[29] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf

[30] https://questions-statements.parliament.uk/written-statements/detail/2021-10-19/hcws325

[31] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/984308/ccus-supply-chains-roadmap.pdf

[32] Net Zero The UK's contribution to stopping global warming

The technology can play a key role in removing emissions from industry, in electricity generation, in producing low-carbon hydrogen and by opening up pathways for greenhouse gas removals more broadly.

Carbon Capture Storage Association (CCSA)

The CCSA sees CCUS as essential to achieving net zero by 2050 in the UK and its latest report states that all 2030 net zero scenarios clearly show that CCUS needs to significantly scale up in the 2020s. To do that, it states that the UK should introduce a long-term funding mechanism for CCUS, like that introduced ten years ago for renewable power. In both scenarios analysed in the CCSA's latest report[33], significant economic impacts are forecast, with growth in both jobs and GDP. Significantly, these are 'net jobs', including supply chain and multiplier effects.

- **The potential contributions of CCS for the decarbonisation of large emitter/industry including energy, cement, transport and heating.**

CCS can contribute significantly to decarbonisation in Ireland's energy and industrial sectors, with potential benefits also for the heat and transport sectors. In Table 2 above, an estimate of the potential contribution of CCS is shown for each sector.

- **The potential utilisation of CCUS, including clustering.**

Based on location, emissions and proximity to potential export facilities, Ervia and Arup's analysis indicates that there is potential for up to 5 clusters in Ireland which encompass post-combustion CCS.

The map in Figure 1 shows the potential locations for each of the 5 clusters encompassing post-combustion CCS.

Table 3 Potential for CCS Clusters in Ireland with respective emissions in Kilotonnes (Kt) (Arup/Ervia)

Cluster	Location	CO_2 Emitters	Current annual emissions (Kt) in each potential cluster area
1	Dublin	North Wall Generating Station; Dublin Bay Power Plant; Dublin Waste to Energy (WtE) Plant; Poolbeg Power Plant	Dublin Bay Power – 750Kt Dublin WtE – 745Kt Poolbeg CCGT – 540Kt
2	Dublin /Louth	Lagan Cement; Indaver Waste to Energy Meath; Irish Cement Limited (Platin Cement); Premier Periclase	Lagan Cement – 350Kt Indaver – 250Kt Platin Cement – 1,000Kt Premier Periclase – 80Kt

[33] CCSA – Economic Analysis of UK CCUS

Cluster	Location	CO_2 Emitters	Current annual emissions (Kt) in each potential cluster area
3	Cork	Whitegate Power Plant; Aghada Power Plant; Whitegate Oil Refinery; Indaver Waste to Energy (in planning)	Whitegate CCGT – 765Kt Aghada CCGT – 675Kt Irving Oil Refinery – 300Kt
4	Shannon	Moneypoint Power Plant; Tarbert Power Plant; Aughinish Alumina; Irish Cement Limited (Limerick Works)	Moneypoint – 870Kt Tarbert – 195Kt Aughinish – 1,250Kt Irish Cement – 575Kt
5	Waterford	Great Island Generating Station and nearby smaller emitters	Great Island CCGT – 800Kt

Outside Ireland, clusters are being recognised as an important mechanism to allow the CCS sector to develop i.e. through enabling economies of scale and the shared use of transport and storage infrastructure.

The UK Government has recognised the benefits of CCS clusters. In November 2020 the British Prime Minister launched a 10-point plan for a green industrial revolution. Within that plan was a commitment to deploy CCUS in a minimum of two industrial clusters by the mid-2020s, and four by 2030 at the latest, with an aim to use CCUS technology to capture and store 20-30 $MtCO_2$ per year by 2030. On 19 October 2021 the UK Government announced that it had just selected its first two clusters[34]: Hynet[35] on the West coast and East coast cluster[36] on the East coast and stated that *"CCUS will be crucial for industrial decarbonisation, low carbon power, engineered greenhouse gas removal technologies and delivering our 5GW by 2030 low carbon hydrogen production ambition."*

The Hynet cluster team recently spoke with Ervia (26 Oct 2021) and stated that they hope that at least two capture projects will be funded in the first round: an ammonia plant and a blue hydrogen plant based on a refinery serving other local industrial partners. It is hoped that these will then be followed by additional projects for carbon capture at the refinery, a waste to energy plant, a cement plant and negative emission plants.

The Dutch Government is also supportive of the development of CCS via clusters. In June 2021 it awarded €2.1bn to what will be one of the largest CCS projects in the world, Porthos[37]. This project is being developed by a consortium that includes Shell, ExxonMobil, Air Liquide and Air Products and aims to capture emissions from factories and refineries and store them in depleted gas fields in the North Sea.

[34] https://questions-statements.parliament.uk/written-statements/detail/2021-10-19/hcws325

[35] https://hynet.co.uk/

[36] https://eastcoastcluster.co.uk/

[37] https://www.offshore-energy.biz/dutch-govt-awards-over-2-5-bln-to-porthos-carbon-capture-project/

- **CCS and synthetic fuels.**

Synthetic fuel or synfuel is a liquid fuel, or sometimes gaseous fuel, obtained from syngas, a mixture of carbon monoxide and hydrogen, in which the syngas was derived from gasification of solid feedstocks such as coal or biomass or by reforming of natural gas. Figure 2 below shows the processes involved. Where natural gas is used as the feedstock, CCS can be used to capture the carbon output from the Steam Methane Reformation to provide a low-carbon Syngas as input to the Synfuel process. This process is also called Gas-to-Liquids (GTL).

It is unclear at this stage what the future market could be for GTL. On one hand it is expensive to produce, as referenced from a Massachusetts Institute of Technology (MIT) article below, but on the other hand it may be the key solution for very hard to decarbonise sectors such as aviation, as highlighted in a recent Financial Times article[38] (27 October 2021).

In a 2017 paper from MIT, 'Is there a future for gas-to-liquids technology?'[39] it was stated that "*GTL…… has barely penetrated the energy market, with fewer than 10 industrial-scale plants currently in operation around the world*" and "*GTL is unlikely to emerge as a profitable industry in the coming decades. Without dramatic efficiency improvements and cost reductions, GTL will remain too expensive to make liquefied natural gas competitive with refined crude oil in the transportation sector (the primary determinant of crude oil pricing). This conclusion holds regardless of whether restrictions are placed on carbon emissions—limits that would bolster GTL's profitability.*"

According to the article in the Financial Times, the global airline industry will require 450,000 million litres of sustainable aviation fuel by 2050. However, this is 4,500 times more than current global production of 100 million litres per annum.

It should be noted that development of a Synfuel industry in Ireland via the above method would require development of gas reforming to produce low-carbon hydrogen. Alternatively, synthetic fuel could also be obtained from a mixture of CO_2 (captured via CCS) and green hydrogen.

[38] https://www.ft.com/content/c41864fc-2b78-4220-91d8-5a4f43fb12b0

[39] https://globalchange.mit.edu/news-media/jp-news-outreach/there-future-gas-liquids-technology

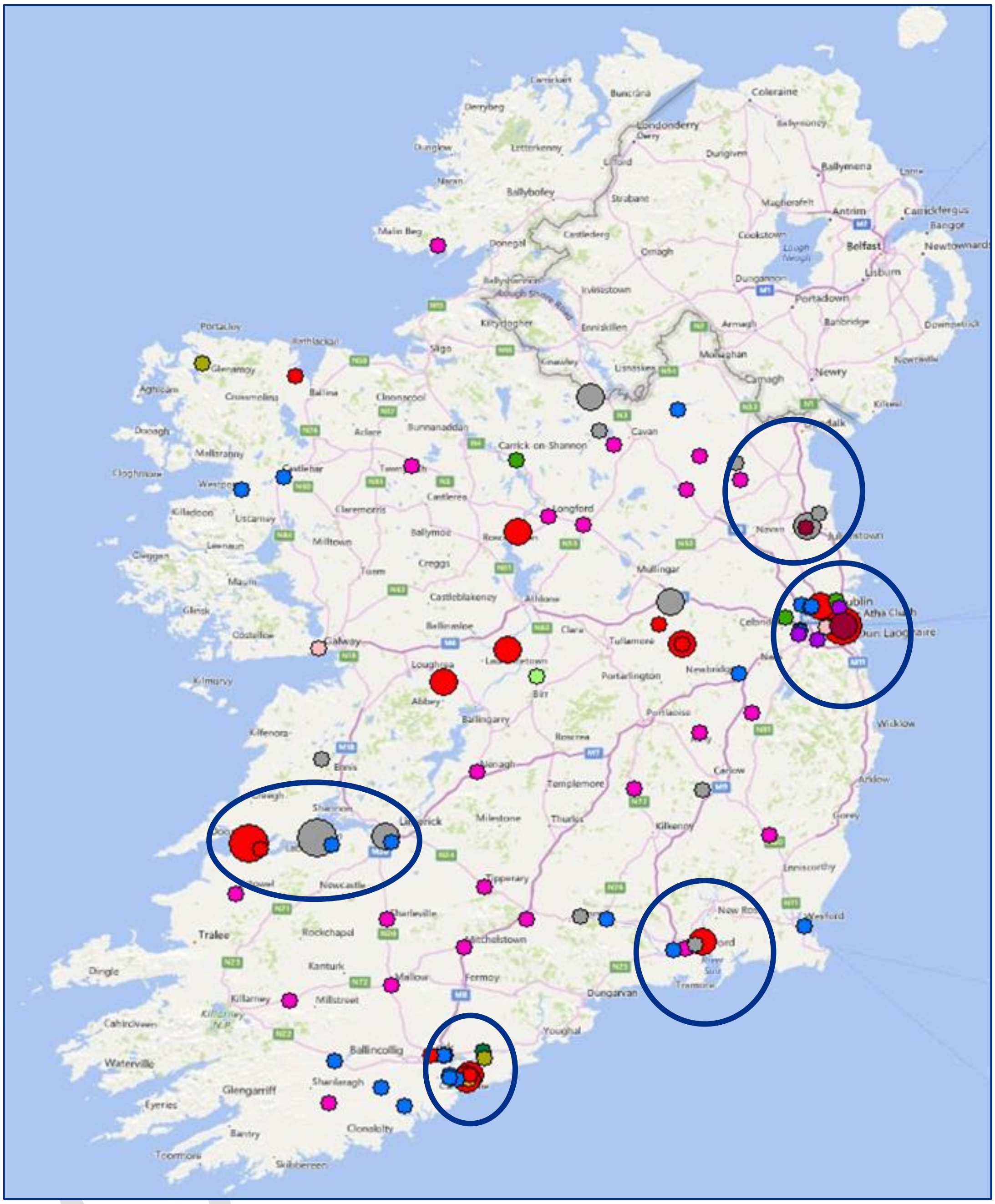
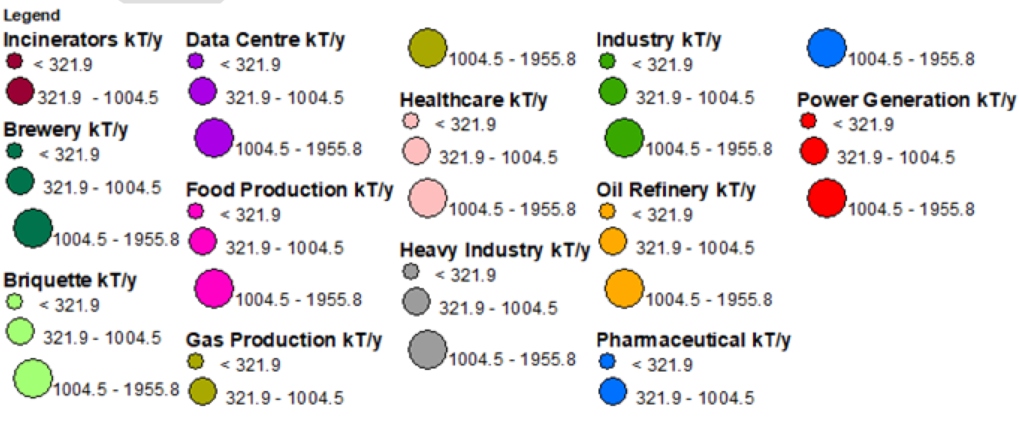


Figure 1 Potential locations for clusters (Arup, 2020)



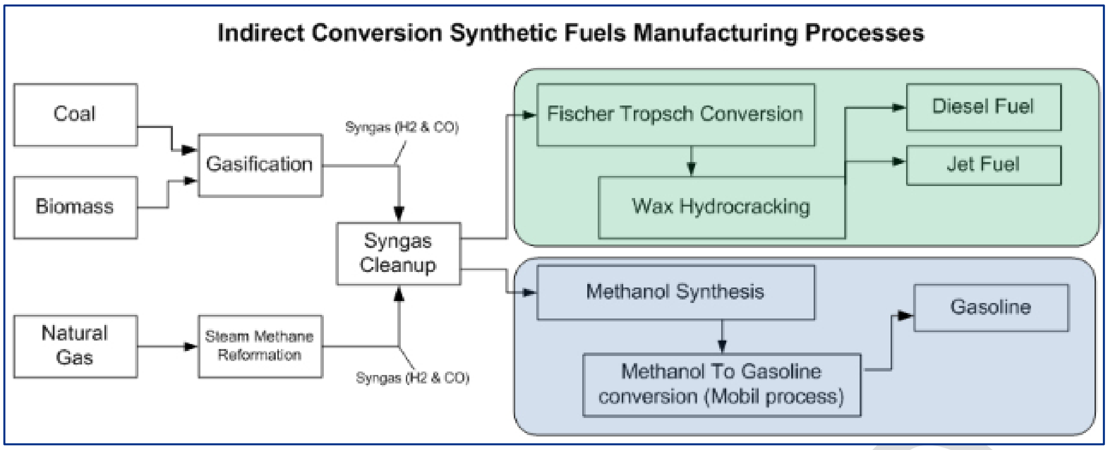


Figure 2 Indirect Conversion Synthetic Fuels Manufacturing Processes[40]

In assessing current direct demand in Ireland for CO_2, which is used for food packaging, carbonation of drinks and slaughtering animals, current national demand is c. 40 $KtCO_2$pa according to conversations with key players in the industry. Total demand for CO_2 in Ireland is therefore a very small proportion of what could be captured with CCS. As such most CO_2 capturable would need to be exported for permanent storage.

c. Material decarbonisation potential of CCS for Ireland.

- **CCS should have the potential to decarbonise a material amount of Ireland's non-agriculture-related emissions of c.40 Million tonnes per annum.**

In 2019 Ireland's total emissions were c. 60$MtCO_{2(eq)}$[41] and non-agriculture emissions were c. 40 $MtCO_{2(eq)}$.

As per Table 2 the total potential decarbonisation with CCS in Ireland is within the range 6-16.6 Mtpa which as a percentage of non-agriculture emissions is 15 – 42 %.

d. Health and Environmental impacts of CCS for Ireland.

Assess the monitoring and assessment that is required in relation to carbon capture and storage to ensure that carbon dioxide streams are retained permanently in geological formations, and evaluate any significant adverse consequences for the marine environment, human health and other legitimate users of the maritime area to inform future developments and to minimise environmental risk. *(Note this focuses on the geological storage; health and environmental impacts of the transport of CO_2 will also need to be outlined).*

If indigenous CCS is developed in Ireland in the future then the Monitoring, Measurement &

[40] https://thomaspmbarnett.com/globlogization/2012/3/7/the-displacement-effect-of-all-that-new-us-natural-gas.html

[41] Ireland's Provisional Greenhouse Gas Emissions 2019 (EPA, November 2020)

Verification (MMV) requirements in the EU CO_2 Storage Directive[42] would apply as discussed later in the report.

However, development of an indigenous permanent store for CO_2 in the depleted Kinsale Head Gas Field (KHGF) is not recommended at this stage considering the complex consenting challenges that would arise for a project developer and the possible long term liabilities that would arise, initially for the developer, but ultimately for the State.

Instead, Ervia believes that export of CO_2 should be the first avenue for CCS in Ireland and as such the monitoring and assessment to ensure permanent containment of CO_2 will be the responsibility of the storage facility developer and Government elsewhere in Europe and therefore would not be a matter for the Irish State.

CO_2 has been stored in other jurisdictions without any adverse effects on the marine environment, human health and other legitimate users of the maritime area for decades. For example, Equinor have been storing CO_2 in two geological formations at Sleipner and Snøhvit in Norway for over 20 years with no environmental impacts[43].

CO_2 Transport and Interim Storage

Ervia is currently carrying out a detailed assessment of the technical and financial aspects of transport and interim storage of CO_2 in Ireland. This work is part funded by the EU Connecting Europe Facility (CEF) fund. The assessment is due to be completed by the end of 2022.

Areas for Additional Research

If Ireland wishes to progress an indigenous store, then additional research would be required on the health and environmental impacts of CCS for an Irish indigenous store.

Environmental Issues - Conclusions

- ✓ Credible energy modelling has identified a potential role for CCS, in decarbonising the Irish economy and helping Ireland achieve its net-zero climate ambitions.
- ✓ 2050 climate targets cannot be achieved without CDR solutions which are based on CCS technologies. Meeting interim (2030) targets may be much harder to achieve without CCS technologies.
- ✓ Irish industry and stakeholder groups recognise the potential role for CCS to enable their decarbonisation.
- ✓ CCS has the potential to reduce Ireland's 40Mt$CO_{2(eq)}$ non-agriculture emissions by up to 6-16.6Mt$CO_{2(eq)}$ per annum.
- ✓ Export of CO_2 would be the recommended option for Ireland to develop CCS. Monitoring and assessment of the CO_2 to ensure permanent geological storage would be the responsibility of the host country where the store is located.

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[42] Directive 2009/31/EC of the European Parliament and of the Council the 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006 Directive 2009/31/EC. EC. 23 April 2009, Brussels.

[43] Insights from 22 years of Saline Aquifer Storage (Norway)

2. The Technical Feasibility of the Deployment of the Technology in Ireland

a. Technology Readiness Levels for carbon capture, transport and storage technologies for its potential roles.

Technology Readiness Levels (TRLs) are used to assess technology maturity levels. Originally developed by the US National Aeronautics and Space Administration (NASA)[44], they have been used by the EU's Horizon 2020 research framework as part of the requirements in its funding calls[45]. The standard scale used in the EU's Horizon 2020 framework, and in this summary, ranges from 'TRL 1 – basic principles observed' to 'TRL 9 – actual system proven in operational environment' with the full scale and definitions given in Table 4.

Table 4 TRL scale used by Horizon 2020

Technology Readiness Levels	
TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validity in a lab
TRL 5	Technology validated in relevant environment
TRL 6	Technology demonstrated in relevant environment
TRL 7	System prototype demonstration in an operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment

In 2021, from a general global technology readiness perspective, there were 27 commercial CCS facilities in operation (with the majority in the USA for Enhanced Oil Recovery (EOR)), four under construction and 58 in advanced development. The operating facilities can capture and permanently store around 37MtCO_2pa[46]. In Europe, there are two large-scale projects in operation in Norway, i.e. Sleipner (since 1996) and Snøhvit (since 2008), with several projects due to commence in the mid-2020s in the UK and the Netherlands.

[44] https://www.nasa.gov/topics/aeronautics/features/trl_demystified.html

[45] https://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2016_2017/annexes/h2020-wp1617-annex-g-trl_en.pdf

[46] https://www.globalccsinstitute.com/

Globally there are more than 8,000km of CO_2 pipelines[47]. Transport of mainly food-grade CO_2 by ship has taken place for decades with approx. 3Mtpa transported in Europe [48]. There are plans to scale up CO_2 ships using the learnings from Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG) ships.

Storage of CO_2 in saline aquifers has been happening in Norway since 1996. In terms of CO_2 storage in depleted oil and gas reservoirs, a number of demonstration projects have taken place in Australia, the Netherlands and China.

In its 2021 technology progress report, DNV stated "*CO_2 capture technologies are mature and commercially available for large scale projects in all industrial sectors*"[49]. Recently, regarding Norway's Longship project (described later), Gassnova[50] stated that "*developing a CCS chain with CO_2 capture, transport by ship and geological storage is technically feasible and safe*.[51]"

TRLs - Carbon Capture and potential roles of CCS

Carbon capture technologies can be divided into three broad categories:

- Post-combustion carbon capture, where following combustion of fuel in a power plant or industrial site the exhaust is diverted into a chemical plant which can capture 90%+ of the CO_2[52]. Recent research indicates that 99% CO_2 capture is possible for little increase in cost.[53]
- Pre-combustion carbon capture, where methane (generally natural gas) is split into its two chemical constituents, CO_2 and hydrogen (H_2), commonly via a process called steam methane reforming (SMR)[54]. CO_2 is captured directly from the methane reforming process.
- Oxyfuel capture is a process whereby oxygen (O_2) is separated from the air before being combusted directly with natural gas. The resulting exhaust gas is a mixture of CO_2 and water vapour only. This simplifies the carbon capture process. The resulting exhaust gas can be taken directly to compression and conditioning stage.

For further background descriptions of carbon capture technologies see section 3.1 of Ervia's 2019 report [55] for the CCS SG. The maximum TRLs[56] for each of the three carbon

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[47] https://iea.blob.core.windows.net/assets/181b48b4-323f-454d-96fb-0bb1889d96a9/CCUS_in_clean_energy_transitions.pdf

[48] https://doi.org/10.1016/B978-008044704-9/50369-4

[49] https://eto.dnv.com/technology-progress-report-2021#TPR2021-top

[50] Gassnova was established by the Norwegian authorities to further the development of technologies and knowledge related to CCS.

[51] Gassnova – Developing Longship

[52] https://www.sciencedirect.com/science/article/pii/S2211467X18300634

[53] https://www.carboncapturejournal.com/news/amine-technology-capable-of-99-co2-capture/4723.aspx?Category=all

[54] Steam methane reforming is a mature production process in which high-temperature steam (700°C–1,000°C) is used to produce hydrogen from a methane source, such as natural gas.

[55] Ervia, 2019. Carbon Capture and Storage for Ireland: Initial Assessment.

[56] Maximum TRL is used as there may be a range of technologies within each category.

capture technologies are set out in Table 5.

Table 5 TRLs for carbon capture technologies. (Global CCS Institute, 2021) (Bui, et al., 2018)

Capture technology	Maximum TRL	Comment
Post-combustion	9	Amine-based version of this technology has been widely applied for decades, e.g. fertiliser, natural gas processing (Sleipner, Snøhvit), power generation (Boundary Dam since 2014) and soda ash.
Pre-combustion	9	Widely applied to natural gas processing.
Oxyfuel	6-7	Allam-Fetvedt cycle with 50MW demonstration plant in La Porte (Texas).

As both post-combustion (amine-based) and pre-combustion capture technologies are currently deployed at scale worldwide, these are assessed further in terms of highest TRLs for CCS's potential roles, i.e. power generation decarbonisation, industry decarbonisation, negative emissions, decarbonised hydrogen and CO_2 utilisation.

Table 6 TRLs for CCS's potential roles. (Global CCS Institute, 2021), (Bui, et al., 2018), (IEA, 2020), (E4tech, Energy Institute UCL & Kiwa Gastec for UK CCC, 2015), (Consoli, C., 2019).

CCS potential role	Max TRL	Comment
Power generation decarbonisation	9	Post-combustion carbon capture (amine) applied to power stations is technically operating.
Industry decarbonisation	9	Post-combustion carbon capture (amine) widely applied to fertiliser and ethanol production.
Negative emissions **(i) BECCS**	7	There are more than ten facilities capturing CO_2 from global bioenergy production at various scales. CO_2 capture from bio-ethanol production and biomass-based power production are the most advanced. The largest facility is the Illinois Industrial Facility with a capture capacity of 1Mtpa and dedicated geological storage.
(ii) Direct air capture with storage	6-7	Direct Air Capture (DAC) is the physical or chemical separation and concentration of CO_2 directly from the air, combined with permanent storage. Several small-scale commercial facilities are in operation using Climeworks (Switzerland) and Carbon Engineering (Canada) technology.

CCS potential role	Max TRL	Comment
Decarbonised hydrogen	8	Steam methane reforming (SMR) has been in operation at commercial scale in industry for decades and has a TRL of 9. SMR plants with CCS are under development or in operation in several countries and have TRL of 8.
CO_2 utilisation	9	TRL 9 for urea and cement. Other applications such as methanol, synthetic methane and liquid hydrocarbons have TRLs ranging from 5 to 8.

Transport TRLs

Currently CO_2 is transported mainly by pipeline and ship. However smaller volumes are also transported by road and rail. Highest TRLs for CO_2 transportation methods are listed in Table 7 below.

Table 7 TRLs for CO_2 transport technologies. (Global CCS Institute, 2021), (Bui, et al., 2018), (IEA, 2020) and as stated in Table.

Transport technology	Max TRL	Comment
Pipeline	9	More than 8,000km of CO_2 pipelines globally, mainly in the US and Canada, operating for decades. There are over 200km in Norway and the Netherlands combined (IEA, 2020).
Ship	9	Shipping has taken place for over 30 years mainly for food-grade CO_2. Approximately 3Mtpa is transported by ship in Europe (Brownsort, 2015) generally in small-scale ships 800-1,800m^3 (Global CCS Institute, 2021) or c. 2,000t (IEAGHG, 2020). Northern Lights project plans on 7,500m^3 ships (Shell, Equinor and Total, 2019). Injection from the ship to an onshore terminal (like Northern Lights) has TRL 9 (Global CCS Institute, 2021).
Road	9	Suitable for small-scale applications.
Rail	9	Suitable for small-scale applications.

Storage TRLs

The Highest TRLs for CO_2 storage are listed in Table 8 below.

Table 8 TRLs for CO_2 storage options. (Global CCS Institute, 2021), (Bui, et al., 2018) *and as stated in Table.*

Storage options	Max TRL	Comment
Saline formations	9	Successful permanent storage in Sleipner (Norway) since 1996 storing 1Mtpa. Four more operating commercially and numerous demonstration projects have commenced.
Depleted oil & gas reservoirs	7	A number of demonstration projects have taken place, e.g. in Australia (CO2CRC Otway Project), K12-B (The Netherlands – offshore) and DF-1 South China Sea Gas field (Cao, et al., 2020)
Mineralisation	3-6	Small-scale operation, e.g. Carbfix (Iceland) (Carbfix Iceland ohf, 2021) (JRC, 2013).
EOR	9	Applied for decades with over 40 in operation mainly in the USA.

A visual overview of TRLs from 2018 is shown in Figure 3.

b. ISO standard (or similar) for the carbon capture, transport and storage elements

It is important that a range of technical standards and guidance is available to ensure appropriate design and operation of CCS technologies. The tables below contain a list of published International Organization for Standardization (ISO) standards and those which are under development as well as several codes and guidance documents.

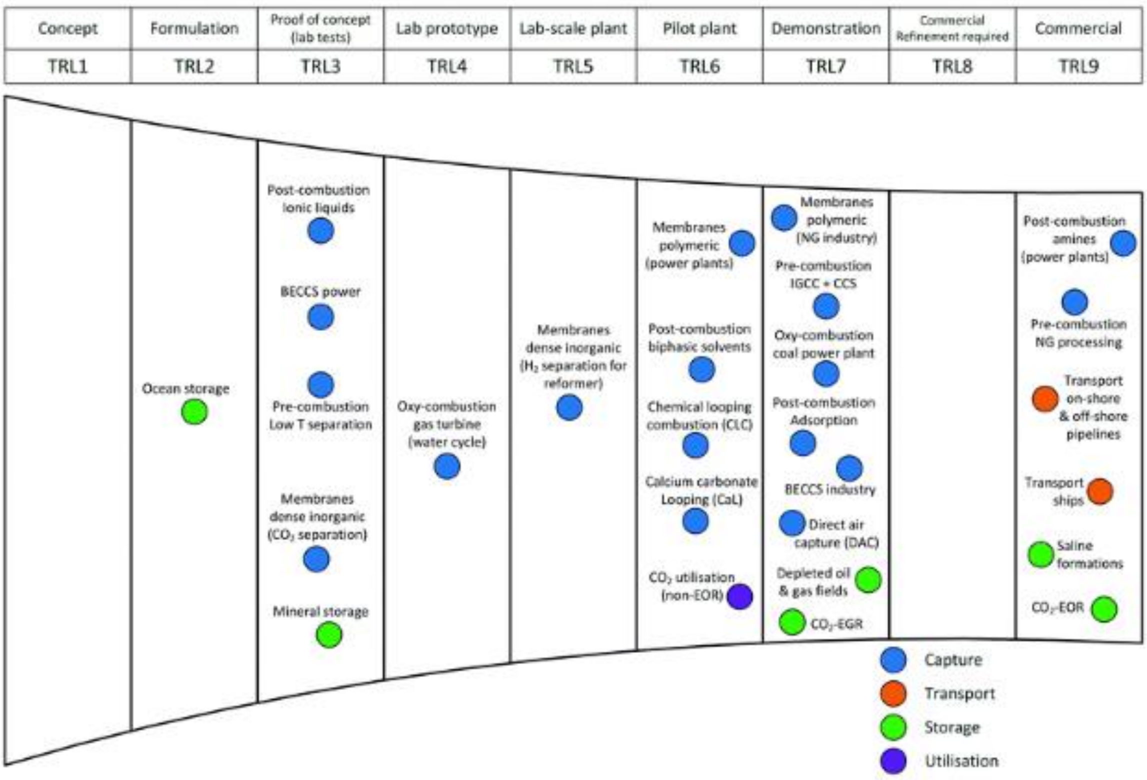

Figure 3 Development progress of carbon capture, storage and utilisation technologies in terms of TRL as at 2018. BECCS = bioenergy with CCS, NG = natural gas, IGCC = integrated gasification combined cycle, EGR = enhanced gas recovery, EOR = enhanced oil recovery. Note: CO_2 utilisation (non-EOR) reflects a wide range of technologies, most of which have been demonstrated conceptually at the lab scale. The list of technologies is not intended to be exhaustive (Bui, et al., 2018).

Table 9 ISO standards for carbon capture, transport and storage elements. (ISO, 2016-2021)

ISO standard	CCS Element(s)
ISO Technical Report (ISO/TR) 27912:2016 Carbon dioxide capture - Carbon dioxide capture systems, technologies and processes	Capture
ISO/TR 27919-1:2018 Carbon dioxide capture – Part 1: Performance evaluation methods for post-combustion CO_2 capture integrated with a power plant	Capture
ISO/TR 27922:2021 Carbon dioxide capture — Overview of carbon dioxide capture technologies in the cement industry	Capture
ISO 27913:2016 Carbon dioxide capture, transportation, and geological storage - Pipeline transportation systems	Transport
ISO 27914:2017 Carbon dioxide capture, transportation, and geological storage - Geological storage	Storage
ISO 27916:2019 Carbon dioxide capture, transportation, and geological storage - Carbon dioxide storage using enhanced oil recovery (CO_2-EOR)	Storage (EOR)

ISO standard	CCS Element(s)
ISO/TR 27915:2017 Carbon dioxide capture, transportation, and geological storage - Quantification and verification	All
ISO 27917:2017 Carbon dioxide capture, transportation, and geological storage - Vocabulary - Cross cutting terms	All
ISO/TR 27918:2018 Lifecycle risk management for integrated CCS projects	All
ISO/TR 27921:2020 Carbon dioxide capture, transportation, and geological storage - Cross Cutting Issues - CO_2 stream composition	All

All the above standards, excluding ISO/TR 27915, have been adopted by the British Standards Institute (BSI)[57].

Table 10 ISO standards under development. (ISO, 2021)

ISO standard	CCS Element(s)
ISO/FDIS 27919-2 Carbon dioxide capture - Part 2: Evaluation procedure to assure and maintain stable performance of post-combustion CO_2 capture plant integrated with a power plant	Capture
ISO/DTR 27923 Carbon dioxide capture, transportation, and geological storage - Geologic storage of carbon dioxide - Injection operations, infrastructure and monitoring	Storage
ISO/AWI TS 27924 Risk management for integrated CCS projects	All

The BSI is also progressing the above standards for the UK[58].

There are codes, recommended/best practice and technical guidance documents related to carbon capture, transport and storage elements and some of the key ones are listed in the table below (non-exhaustive list).

Table 11 Guidance/best practice/code documents for CCS. (Sources: See table).

Document	Document type	CCS Element(s)
Energy Institute - Technical guidance on hazard analysis for onshore carbon capture installations and onshore pipelines (2010) (Energy Institute, 2010). (Updated version expected in 2021).	Guidance	Capture & transport
Energy Institute - Good plant design and operation for onshore carbon capture installations and onshore pipelines (2010)	Guidance	Capture & transport

[57] https://standardsdevelopment.bsigroup.com/committees/50234265#published

[58] https://standardsdevelopment.bsigroup.com/committees/50234265#in-progress

Document	Document type	CCS Element(s)
(Energy Institute, 2010). (Updated version expected in 2021).		
Energy Institute - research report for hazard analysis for offshore carbon capture installations and offshore pipelines (Energy Institute, 2013) (2013)	Guidance	Capture & transport
DNVGL-RP-F104 – Design and operation of carbon dioxide pipelines (2021) (DNVGL, 2021)	Recommended practice	Transport
Guidance on conveying carbon dioxide in pipelines in connection with carbon capture and storage projects (2021) (HSE UK, 2021)	Guidance	Transport
ASME Code B31.4 - 2019: Pipeline transportation systems for liquids and slurries (CO_2 chapter) (ASME, 2019)	Code	Transport (liquid CO_2 only)
CSA Z662:19 Oil and gas pipeline systems (refers to CO_2) (CSA, 2019)	Code	Transport
The International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk (IBC code) (includes CO_2) (IMO, 2007)	Code	Transport
International Code of the Construction and Equipment of Ships Carrying Liquified Gases in Bulk (IGC code) (includes CO_2) (IMO, 2016)	Code	Transport
2012 Specific Guidelines for the Assessment of carbon dioxide for disposal into sub-seabed geological formations (IMO, 2012)	Guidance	Storage
DOE/NETL-2017/1846 Risk Management and Simulation for Geologic Storage Projects (2017) (DOE/NETL, 2017)	Best Practices	Storage
DOE/NETL-2017/1848 Operations for Geologic Storage Projects (2017) (DOE/NETL, 2017)	Best Practices	Storage
WRI Guidelines for Carbon Dioxide Capture, Transport and Storage (2008)	Guidance	All

For an extensive list of pipeline and subsurface storage codes and standards applied to CCS, see Tables 3.1-3.4 in the IEAGHG's 2003 report[59].

The UK Health and Safety Executive (UK HSE) has a section on CCS on its website[60] and its guidance on CO_2 conveying (referred to above) references DNVGL's and the Energy Institute's documents and also refers to appropriate existing codes and standards, e.g. BS PD 8010: 2004 Part 1 - Steel pipelines on land, BS PD 8010: 2004 Part 2 - Subsea pipelines, BS EN 14161: 2011 - Petroleum and Natural Gas Industries, Pipeline Transportation Systems, Institute of Petroleum Pipeline Code IP6 and DNV OS-F101 - Submarine Pipeline Systems (2012), etc. Many of the pipeline-related guidance documents listed in the table were reviewed in the UK Health and Safety Laboratory (UK HSL) 2013 document.[61]

In terms of the shipping of CO_2, it is currently covered by general shipping codes, i.e. IBC and IGC codes (see Table 11) which include CO_2. In July 2021, Zero Emissions Platform (ZEP) formed a working group focussed on the shipping of CO_2 which was well attended by the shipping industry.

c. Roadmap to export CO_2 for storage in Europe

Equinor, along with Total and Shell, is developing the Northern Lights project to accept CO_2 from carbon emitters across Europe. Northern Lights is the transport and storage element of the Longship project. The Longship project is the Norwegian Government's full-scale CCS project, being developed by Gassnova, that will capture CO_2 from the cement industry and from a waste-to-energy facility and transport it by ship to an offshore geological storage site.

The Northern Lights/Longship project reached FID in 2020 and the Norwegian Government confirmed that the state's share of the costs is estimated to be NOK16.8 billion (€1.6bn). This means that the state covers around two thirds of the costs of the project. It plans to start operations and importing CO_2 from 2024 onwards.

Several other European projects, at various phases of development, have stated that they plan on importing CO_2 from other European countries. They include the following:

Table 12 European projects with plans to import CO_2 (Ervia)

Project	Location	Operational Date
Northern Lights	Norway	2024
Porthos	The Netherlands	2024
Acorn	UK	2024

59 https://ieaghg.org/docs/General_Docs/Reports/Barriers%202%20%20Rules%20and%20standards%20for%20trans%20and%20storage.pdf

60 https://www.hse.gov.uk/carboncapture/index.htm

61 https://www.hsl.gov.uk/media/396859/co2pipehaz_goodpracticeguidelines.pdf

Project	Location	Operational Date
HyNet	UK	2024
Aramis	The Netherlands	2026
Greensand	Denmark	2028
Carbfix	Iceland	2025[62]
Endurance	UK	2026

The above projects are described in Criteria 4 (c) regarding CCS Developments and a visual overview of these projects is shown in Figure 4 below.

In terms of technical challenges to be addressed for CO_2 export from Ireland, the key one is scale-up of ship size, but a lot can be learned from LPG and LNG industries[63]. Longship has designed ships (very similar to LPG design) with a capacity of up to 7,500m^3 [64]. Two Danish companies, Evergas and Ultragas, have formed Dan-Unity CO_2 (a CCS-specific shipping entity) which has a partnership with Carbfix and together they plan to offer CO_2 transport and storage services from 2025[65]. Zero Emissions Platform (ZEP)[66] has also initiated a CO_2 Shipping Standards working group.

In addition, cross-border CO_2 networks are recognised by the European Commission's Project of Common Interest (PCI) initiative with the following achieving PCI status on the 4th list (2019), with many affiliated with each other so that they can provide storage, and back-up storage, for each other:

Table 13 4th PCI list in cross-border CO_2 networks (European Commission, 2019)

PCI	Location
CO_2 Sapling Project (transport component of Acorn Project)	UK
CO2TransPorts	The Netherlands and Belgium
Northern Lights	Norway
Athos	The Netherlands
Ervia Cork	Ireland

[62] https://inews.co.uk/news/iceland-europe-co2-pollution-carbon-dustbin-uk-buried-bedrock-1238059

[63] https://doi.org/10.1016/j.apenergy.2021.116510.

[64] https://ccsnorway.com/wp-content/uploads/sites/6/2020/11/Gassnova-Developing-Longship-FINAL.pdf

[65] https://dan-unity.dk/press-release-copenhagen-may-19-2021/

[66] ZEP is the technical adviser to the EU on the deployment of CCS and CCU – a European Technology and Innovation Platform under the Commission's Strategic Energy Technologies Plan.

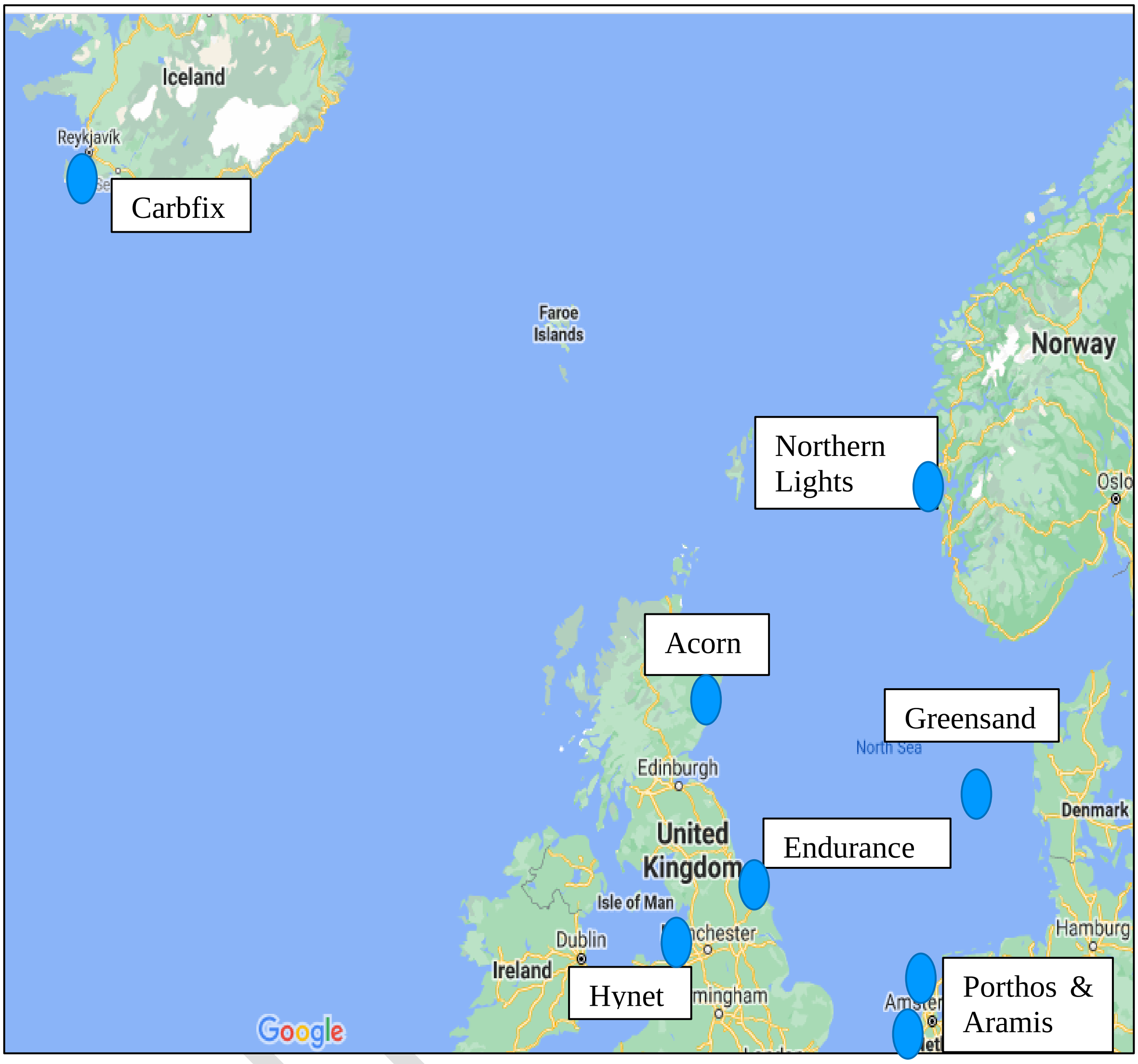

Figure 4 Map of European CCS projects that are expected to be operational and ready to import CO_2 this decade. (Ervia)

The following applied for inclusion on the 5th PCI list in which six projects were successful in achieving PCI status[67].

Table 14 5th Candidate PCIs in cross-border CO_2 networks (European Commission)

Candidate PCI	Location	Successful Applicant?
CO2TransPorts	The Netherlands and Belgium	Yes
Northern Lights	Norway	Yes
Athos (now cancelled) *	The Netherlands	Yes
Aramis	The Netherlands, Belgium, France & Germany	Yes

[67] https://ec.europa.eu/energy/sites/default/files/fifth_pci_list_19_november_2021_annex.pdf

Candidate PCI	Location	Successful Applicant?
Dartagnan	France & the Netherlands	Yes
Poland EU CCS	Poland	Yes
Wilhelmshaven	Germany	No
CO2 Pipeline Hastedt-Bremen	Germany	No

*Note: Athos project cancelled as the anchor emitter in the region, Tata Steel, is no longer considering post-combustion capture of carbon and is instead preparing to utilise zero carbon hydrogen as an input to the steel plant.[68]

It is clear from the wide range of countries involved in the 2021 applications that there is recognition across Europe of the need to progress CCS in order to reach net zero.

Regulatory issues associated with the export of CO_2 from Ireland are described in Criteria 4(a) but a recent IEAGHG report on the status and challenges of CO_2 shipping infrastructure states that "*A review of the legal instruments (international treaties, EU law & Norwegian Law), that relate to the movement of CO_2, shows that there are no evident showstoppers to the international shipment of CO_2*".[69]

d. Suitability of a geological reservoir to receive and store the volume of CO_2

The suitability of a geological reservoir for CO_2 storage is site-specific to local geological conditions and must be demonstrated in addition to the general technology readiness level of injection and well technologies. Criteria for the characterisation and assessment of a potential storage site are set out in Annex 1 of EU Directive 2009/31/EC

Export Storage

From the previous section, it is clear that European export storage options will be available from the mid-2020s. This would be prior to any indigenous storage option being developed for Ireland so, in the first instance, the suitability of an export geological reservoir to receive and store the volume of CO_2 is described. A CO_2 store in another EU jurisdiction would have to meet the requirements of Annex 1 of EU Directive 2009/31/EC in order to obtain a Storage Permit from its regulator(s). Non-EU European countries, such as Norway and the UK, generally have requirements similar to that of the Directive.

The European projects who are stating that they will import CO_2 are listed in Table 15 together with the current status regarding the suitability of their reservoirs to receive and store CO_2. Well injection TRLs are also provided.

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[68] https://www.gasunie.nl/en/news/athos-project-ends-after-tata-steel-decision

[69] https://ieaghg.org/ccs-resources/blog/new-ieaghg-report-the-status-and-challenges-of-co2-shipping-infrastructures

Table 15 Current status of European reservoirs to receive and store CO_2. (Maersk Drilling, 2020) (Clark, et al., 2020)

Project	Reservoir name & type	Suitability	Potential max. capacity (Mt)	Well injection TRL
Northern Lights	Aurora - saline aquifer	Exploitation licence since 2019. Verification well drilled confirming reservoir suitability.	≥100	9 – saline aquifer injection in operation in Norway since 1996
Porthos	P18A - depleted gas field	Storage permit application submitted	37	6-7 – injection at demonstration scale taking place in the Netherlands (offshore) since 2003 in K12-B[70]
Acorn	Goldeneye – depleted gas field	Exploration licence	250	6-7
HyNet	Hamilton - depleted gas field	Exploration licence	130	9
Aramis	Multiple fields in North Sea	Early feasibility	400	6-7 or 9 (dependent on field type)
Greensand	Nini – depleted gas field	Statement of Feasibility (from DNV-GL)	1,000	6-7
Carbfix	Hellisheiði geothermal field – mineralisation	Small-scale capture in operation since 2014.	2,430	N/A. TRL for mineralisation technology = 3-6.

As part of the reporting requirements of the CO_2 Storage Directive, Member States that intend to allow storage in their territory have to carry out assessments of their available storage capacity. The European Commission's 2019 implementation (of the Directive)

[70] CO_2 Injection at K12-B, the final story.

report has been used to provide most of the information in Table 16 below. For reference, Ireland's non-agriculture-related emissions are c. 40Mtpa.

Table 16 Theoretical CO_2 storage capacity in key European jurisdictions. (Sources in table.)

Country	Theoretical CO_2 storage capacity (Mt)	Comment
Norway	c. 83,000	2011 CO_2 storage atlas estimated 70Gt capacity in the Norwegian part of the North Sea. 2019 CO_2 storage atlases estimated up to 5.5Gt capacity in the Norwegian Sea and 7.2Gt in southern Barents Sea (Norwegian Petroleum Directorate, 2019).
UK	77,600[71]	Currently 87 sites located across five geological basins in the offshore sector assessed. 90% saline aquifers.
The Netherlands	1,700	Mainly depleted gas fields (European Commission, 2019).
Denmark	24,000	22Gt (saline aquifers) and 2Gt (hydrocarbon fields) (European Commission, 2019).
Germany	95-190,000	20-115Gt (saline aquifers) and 75Gt (gas fields). 80% of aquifers in states that ban storage (European Commission, 2019).
Iceland	953-2,470	Potential of basaltic rocks and oceanic ridges (Snæbjörnsdóttira, et al., 2014)

The European Commission provides guidance on characterisation of CO_2 storage complexes in one of the documents which supports the CO_2 Storage Directive[72]. In addition, the verification body, DNV, offers a service where it certifies storage sites and projects for geological storage of CO_2[73]. For example, in November 2020, DNV certified Denmark's Nini West reservoir (Project Greensand)[74]. The mineralisation storage technology in Iceland is interesting as it binds the CO_2 to pores within the underground basalt rock.

Indigenous Storage

[71] Global Storage Resource Assessment

[72] https://ec.europa.eu/clima/sites/default/files/lowcarbon/ccs/implementation/docs/gd2_en.pdf

[73] https://rules.dnv.com/docs/pdf/DNV/SE/2017-10/DNVGL-SE-0473.pdf

[74] https://www.maerskdrilling.com/news-and-media/press-releases/project-greensand-north-sea-reservoir-and-infrastructure-certified-for-co2-storage

In terms of indigenous storage options, initial studies were carried out for Ireland which indicated that the KHGF had the best potential for CO_2 storage with a theoretical capacity of 330Mt[75]. Schlumberger carried out CO_2 storage reservoir studies for KEL[76]. These were built on by further desktop studies for Ervia. The full area of the KHGF is c. 550km^2. Ervia contracted with a specialist geological consultancy, CGG, to perform a desktop review of existing seismic data for a c. 100km^2 section of the reservoir to assess the reservoir's suitability to store CO_2.

The assessment identified three secondary caprock intervals. A secondary caprock is a requirement in the EU Directive for CO_2 storage permitting for depleted oil/gas reservoirs.

CGG believes that the KHGF remains a suitable candidate for CO_2 storage and has high confidence in the ability of the KH structure to provide long-term containment due to the following reasons:

1. The field has held gas for an estimated several million years and there is no evidence of escape features like gas chimneys.
2. Despite rapid production of gas from 1981 to 2020, no failure of the caprock seal was ever detected. It is thought, therefore, that the geological storage volume remains capable of safely holding injected CO_2 over the long term.
3. The field is at approximately 2,700 feet (823 metres) depth and has primary and secondary caprock intervals, then chalk formations.
4. Existing well penetrations and abandonment well integrity are identified as risks and should be evaluated after abandonment as they are man-made leak paths.
5. New injector wells and a new platform (if a platform is required) would minimise the risk.
6. Monitoring strategies at the depth of this field exist and are feasible, therefore corrective measures on wells are possible.

CGG has recommended that any subsequent phase should assess the remaining 450km^2 and include a detailed analysis of reservoir dynamic behaviour and storage capacity. It also recommends that a new seismic survey is conducted prior to any project execution.

CGG estimates that it would take approximately 18 months (excluding procurement) to address the majority of the criteria in Annex 1 for KHGF. The likely approach to progress studies regarding the 'suitability of a geological reservoir' could be via relevant funding calls.

In terms of the general technology readiness level of injection and well technologies for indigenous storage options, they are in line with those presented in Table 15. EC guidance and DNV's certification scheme are expected to be part of the methodology used to demonstrate the suitability of the reservoir to receive and store the volume of CO_2.

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[75] Assessment of the Potential for Geological Storage of CO_2 for the Island of Ireland. https://www.seai.ie/publications/Assessment-of-the-Potential-for-Geological-Storage-of-CO2-for-the-Island-of-Ireland.pdf

[76] Schlumberger/Kinsale Energy, 2011. Kinsale Head field CO_2 Storage Evaluations.

e. Risk factors, including, but not limited to security of powergen with CCS, potential dependence on overseas storage sites, physical risk to CCS infrastructure and its environment, climate and weather extremes, to include potential for leakage, etc.

In general, Ervia interprets the term ‘risk factor’ as ‘risk’ where risk is defined by ISO 31000:2018 as the effect of uncertainty on objectives.

Table 17 Risk factors outlined in CCS SG criteria (Ervia)

Risk factor	Mitigating measures	Comment
Security of powergen with CCS	If CCS plant is not running, power generation plant can run independently.	If there are issues with the carbon capture plant, then power can continue to be generated but there would be CO_2 emissions (if the capture plant was not running).
Potential dependence on overseas storage sites	Address in commercial terms of agreement. A number of European developers have stated that they will provide overseas storage so should not be reliant on one site.	It is noted that aim of cross-border CO_2 networks PCI is for EU stores to provide back-up to each other.
Physical risk to CCS infrastructure and its environment	Full technical studies, including environmental and safety risk assessments, to be completed for infrastructure suitability, to ensure that the design mitigates the risk and ensures that the system operates safely. Employ similar measures to those used in the oil and gas industry to protect the infrastructure and its environment.	Risks are similar to those for oil and gas infrastructure so it is expected that they would need to be managed similarly.
Climate and weather extremes	Full technical studies to be completed for infrastructure suitability. Design infrastructure in accordance with relevant codes, standards and guidance.	Risks are similar to those for oil and gas infrastructure so it is expected that they would need to be managed similarly.
Potential for leakage	Full technical studies to be completed for infrastructure	CO_2 is heavier than air and if released in large concentrations could act as an asphyxiant.

Risk factor	Mitigating measures	Comment
	suitability for capture plant, pipeline and storage facilities. Design CCS infrastructure to relevant codes and standards. Employ leak detection tools. For reservoirs, ongoing MMV required as part of the Directive.	CO_2 is not flammable, so CO_2 leakage risk is similar to, or less than, the risk associated with natural gas.

Additional high-level risks covering areas such as technical, business case, policy and stakeholders are outlined in Section 5.5 of Ervia's 2019 CCS for Ireland: Initial Assessment and in Section 7 of Arup's CCS in Ireland – Onshore Technical Study Summary where high-level risks and mitigating measures associated with a potential site-specific project are described. Detailed risk assessments would be carried out as part of any potential CCS project development. The Risk Reports for the cancelled UK Peterhead[77] and White Rose[78] Projects are on the UK Government's website and illustrate the thorough analyses carried out for those projects.

Areas for Additional Research

Ervia envisages that the export storage option would be the recommended CCS route for Ireland in the first instance and Gassnova has stated that this option is technically feasible for the Northern Lights/Longship project.

If Ireland wishes to progress the development of indigenous stores in parallel then further research would need to be carried out to address the CCS SG criteria related to the suitability of the reservoir to receive and store the volume of CO_2 and meet the requirements of the CO_2 Storage Directive.

Technical Feasibility - Conclusions

- ✓ The maximum TRLs for capture (post- and pre-combustion), transport (by pipeline and ship) and storage of CO_2 (in saline aquifers) are all nine, i.e. all aspects of the export storage option are in commercial operation. CCS for industry decarbonisation, power decarbonisation and negative emissions is well proven.
- ✓ There are numerous existing ISO standards, and a multitude of guidance documents, for CO_2 capture, transport and storage.
- ✓ In terms of a roadmap to export CO_2 for storage in Europe, a number of developers in Norway, the UK and the Netherlands have stated that they will be available to store CO_2 from other countries from the mid-2020s.

[77] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/531405/11.023_-_Risk_Management_Plan_and_Risk_Register.pdf

[78] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/531411/K06_Full_chain_FEED_risk_report.pdf

- ✓ It has been demonstrated in Norway (since 1996) that saline aquifers are suitable to receive and store the very large volumes of CO_2. Further research would be required to demonstrate the suitability of indigenous stores.
- ✓ Detailed risk assessments would have to be carried out as part of any project development. Current CCS developers believe that the risks could all be adequately mitigated.

3. Financial Viability of CCS

The financial viability should demonstrate the need, or not, for CCS based on a bottom up analysis of the cost of deploying CCS in Ireland relative to the counterfactual, no CCS *(over what time line, based on what sort of deployment and the state of development of the technology).*

Where possible, all inputs should be derived from Irish evidence to reflect Ireland's position as an energy importer with limited interconnection, difficulties in planning and higher Levelised Cost of Energy (LCOEs) relative to European averages.

Ervia's main focus in assessing CCS has been for power generation with some insights into specific industrial emitters. In addressing the criteria listed in this section Ervia will provide data from its own studies and use external studies where relevant. In addressing the criteria as they apply to industry, low-carbon hydrogen and Bioenergy with CCS (BECCS), Ervia will also reference credible external studies.

a. CCS Financial Inputs

- **Define all potential roles for CCS in Ireland (i.e. domestic storage and export for industry and powergen etc.)**

To achieve cost-effective net-zero emissions there are several ways and a number of industries in which CCS developments and CCS investment can contribute, and in some cases are already contributing, internationally. These can be categorised as:

- CCS for power generation.
    - CCS can be deployed on existing, or as part of new, gas-fired power plants capturing 90%+ of CO_2 emissions for safe, permanent underground storage. With a small percentage of biomethane added to the natural gas, emissions from the power plant can be net zero.
- CCS for hard to abate industries.
    - CCS can be deployed in industries which emit CO_2 as part of their process such as:
        - Cement and lime manufacturing sectors
        - High process emissions industries such as the agri-food sector and oil refining
        - Brewing and distilling
        - High heat (natural gas) dependant
- CCS for low-carbon hydrogen production at scale.
    - CCS can be deployed with natural gas reformer technology such as Steam Methane Reforming (SMR), Gas Heated Reformer (GHR) or Auto Thermal Reforming (ATR) to separate out natural gas into decarbonised hydrogen and CO_2. The decarbonised hydrogen can be utilised to decarbonise multiple sectors including power generation, transport and heating. The CO_2 emissions

    - captured as part of this process would be removed for safe, permanent, underground storage.
- CCS for delivering negative emissions.
    - When Biomethane is used in a facility with CCS this provides BECCS (Bioenergy with Carbon Capture & Storage) which gives Negative Emissions. CO_2, which has been already removed from the atmosphere and is temporarily stored within the crops used to produce the Biomethane, is then captured again in the CCS facility.
- Direct Air Capture (DAC)
    - DAC is a process that separates CO_2 emissions directly from the air[79]. The source of the captured CO_2 makes DAC distinct from Carbon Capture, Use and Storage (CCUS) technologies that trap CO_2 emissions directly at the point of emissions (from flue gases). DAC involves separating CO_2 from ambient air. The captured CO_2 can either be used directly (for example, in the beverage industry or to produce synthetic aggregates or synfuels) or stored geologically.

- **Key inputs for the financial evaluation should consider, again not limited to;**
    - **An indicative timeline for deployment of various technology and sectoral options**

In order to indicate timelines across which CCS could potentially be deployed in Ireland, the report provides planned dates for deployment in the UK and EU across four sectors: power generation, large industry, low carbon hydrogen and negative emissions. With strong policy support **it may be possible to deploy CCS in any of these sectors in Ireland within a few years of deployment in either the UK or EU.**

Table 18 Potential deployment dates for CCS (Ervia)

Potential Deployment Dates			
Sector	**UK[80]**	**EU**	**Ireland**
Power Generation	Mid 2020s	Mid 2020s	c. 2030
Industry	Mid 2020s	Mid 2020s	c. 2030
Low Carbon Hydrogen	Late 2020s	Late 2020s	Mid 2030s
Negative Emissions	Mid 2020s	Mid 2020s	Mid 2030s

In 2019, Ervia commissioned Baringa to assess the benefits or otherwise of deploying CCS into the electricity market in Ireland and its impact on other technologies and overall system

[79] https://itemsweb.esade.edu/research/EsadeGeo_Event_Brief_DAC_EN.pdf

[80] https://questions-statements.parliament.uk/written-statements/detail/2021-10-19/hcws325

costs to the State. In its models Baringa assumed that CCS would be available for deployment in Ireland by 2030.

- **Project costs, most likely LCOEs, for CCS and other low / zero carbon technologies.**

In this section costs will be provided for power generation based on a Baringa study commissioned by Ervia Baringa. Costs will also be provided from a recent UK Government study from BEIS. For industry, low-carbon hydrogen, and negative emissions reference will be made to external, credible sources.

Power Generation

In 2020 Ervia commissioned Baringa to assess the benefits or otherwise of deploying CCS into the electricity market in Ireland and its impact on other technologies and overall system costs to the State.

The Baringa study examines the Irish electricity system over the period 2030 – 2050 with an assumed target of attaining net-zero emissions in 2050. The Baringa study starts at 2030 and **models that the system has achieved 70% renewables electricity production. Notably, by 2030 and with 70% renewables, this results in the emissions in the electricity system reducing by 2.6Mtpa from the current level of 9Mtpa. This leaves a further 6.4Mtpa of CO_2 to be removed from the electricity system post 2030.**

The tables below set out some key assumptions used in the study.

Table 19 Demand & CO_2 Target Assumptions (Baringa, 2020)

Scenario Assumptions	Unit	2031	2040	2050
Demand	GWh	52,470	59,262	61,335
Emissions Target Absolute	Mt CO_2	6.4	3.9	0
Emissions Intensity	gCO_2/KWh	122	66	0

Table 20 Commodity Prices assumed (Baringa, 2020)

Commodity Prices		2031	2040	2050
Carbon	€/Tonne	46	48	53
Gas	€/GJ TWA	8	8	9
Biogas	€/GJ TWA	19	17	14
H_2 Electrolysis (Inc. storage)	€/GJ	37	36	34
H_2 Methane Reformation (Inc. storage)	€/GJ TWA	27	27	28

The Technology Capex figures are set out in Table 21 below.

Table 21 Technology Capex €/kW (Baringa, 2020)

Technology Capex	2031 €/kW	2040 €/kW	2050 €/kW
CCGT	797	779	760
OCGT	611	597	582
Solar	672	623	561
Onshore Wind	1,261	1,127	989
Offshore Wind	2,033	1,700	1,016
CCGT with CCS	1,632	1,632	1,632
H_2 OCGT	672	657	640
H_2 CCGT	877	857	836

The Baringa report concludes that the electricity system cost to meet a net-zero emission target in 2050 would conservatively be **€2.2bn less if CCS is included versus CCS not being included**. The reason for stating 'conservatively' here is that the study is restricted to the system costs and does not take into account cost savings in energy balancing, system constraints or network upgrades by using CCS.

Three core scenarios were modelled:

- A scenario with a 2050 net-zero emissions target in Ireland, with CCS as part of the Irish electricity capacity mix **(With CCS)**.
- A scenario with a 2050 net-zero emissions target in Ireland, but where Ireland meets this target without investment in CCS **(No CCS)**.
- A scenario with a 2050 net-zero emissions target in Ireland, but introducing negative emissions CCS technology, such as BECCS **(CCS with BECCS) which is discussed later**.

The cost saving of €2.2bn (by using CCS versus not using it) can be explained by two key factors

- Not using CCS results in over capacity on the system.

  Following the achievement of 70% renewables in the electricity system the total CO_2 emissions are 6.41 Mtpa., and the CO_2 intensity is 122 gCO_2/kWh. These emissions can be abated by building out an increased amount of renewables in all scenarios with the primary differences between models being the volume of **total capacity needed to meet net zero (~50% greater without CCS) and the technology deployed to provide** firm dispatchable power.

  Baringa's report states the following:

  - ***"CCS****: Combined Cycle Gas Turbines (CCGTs) with CCS are part of the least cost capacity mix capable of delivering net zero by 2050. To meet net zero without CCS, a further 6.7GW of wind and solar would have to be built. The study shows that the least cost route to meet net zero includes investment in CCS in the early 2030s. CCS capacity deployment increases to 1.4 GW by 2035 and 4.7GW by 2050."*

    - ***"Wind and solar:*** *Wind and solar capacity investment is significant in all scenarios – ranging from 17GW additional capacity alongside CCS to an additional 24GW without CCS. This compares to around 5.5GW of wind on system in 2020 (based on EirGrid's analysis)."*

- Thermal Power without CCS, i.e. using green hydrogen, is more expensive.

  Thermal Power is required by the system in all scenarios. Where CCS is not deployed, CCGTs fuelled with green hydrogen provide this firm power function. Although the capital and operational costs for CCGTs with CCS are higher, the fuel costs are significantly lower. See Table 22 below.

In conclusion, all Baringa model results show thermal power plant in the capacity mix in 2050. Where CCS is included this tends to result in higher use of CCGT-CCS. Where CCS is excluded as an option there is a greater amount of (green) hydrogen CCGT and OCGT on the system. Importantly, when both options are compared, the option including CCS is the cheaper option by €2.2bn. Furthermore, where CCS is excluded the required capacity demand is met by a much higher level of offshore wind and solar production. Using variable renewables, even with battery technology, is more expensive than CCS with conventional power plant.

Table 22 Cost comparison, with and without CCS

Scenario	Discounted Total System Cost € billions 2030 -2050
Emissions Target with CCS	€25.682
Emissions Target without CCS	€27.874
Emissions Target with CCS + Negative Emissions	€25.010

Arup/Uniper Technology Study for Ervia, 2020

Arup and Uniper were appointed by Ervia to undertake an Onshore Technical Study into the feasibility of utilising CCS to contribute to the decarbonisation of the Irish economy. The study involved a high-level assessment of

- Capturing carbon at a CCGT power station in Dublin and exporting that CO_2 to Norway.
- Capturing carbon at a CCGT in Cork and storing that in the depleted Kinsale gas field.

The lowest total estimated capital cost for the Cork CCS Project Option (excluding the new-build CCGT and excluding all costs associated with the offshore gas field – which is expected to cost in the hundreds of millions) is €643m, based on indigenous permanent storage at the depleted Kinsale Head reservoir. The lowest total estimated capital cost for the Dublin CCS Project Option (excluding the new-build CCGT) is €737m, based on exporting CO_2 via a jetty at Poolbeg for permanent storage overseas. Capital cost estimates are expected to reduce as the technology matures and deployment increases.

Depending on the operating load factor of the plant, the required carbon price to make this abated CCGT and CCS plant competitive against a new build unabated unit estimated in this study is in the range of €99-€162/tCO_2. This is highly dependent on the annual running hours and the capital cost of the capture unit (which will reduce as the technology matures). The capital cost estimates developed in this study include a significant degree of conservatism, considering close to first-of-a-kind cost estimates rather than n^{th}-of-a-kind, and therefore would be expected to reduce over time with further design development. The case studies concluded that both CCS projects would be a potentially economic method of abating CO_2 in the Irish economy. The capital cost has a greater influence on this carbon parity point between abated and unabated cases at lower load factors due to the more limited potential annual generation available to achieve payback. Without considering the cost of carbon, the cost of electricity varies between €82-€109/MWh.

UK Enhanced Levelised Costs

In addition to the Irish costs, it is worth looking at the **UK view** regarding the competitiveness of post combustion CCS. In the UK, CCS is forecast to be competitive with unabated gas in 2025 and cheaper thereafter as the price of emitting carbon rises. Levelised cost estimates (£/MWh) for CCS have recently been significantly reduced by BEIS in the UK in its Electricity Generation Cost Report 2020[81].

Traditionally, LCOE has been used to compare alternative generation technologies but in recent years there is consensus that this metric does not take account of the additional system costs that renewable technologies add to the electricity system such as upstream grid reinforcement, batteries, back-up needed for when there is little wind etc.

BEIS (in UK) recently released its report on ‘Electricity Generation Costs 2020’. The report outlines, for the first time, assessment by BEIS of the costs of a range of electricity generation technologies on an ‘Enhanced Levelised Cost’ basis.

Enhanced LCOE takes into account the relative impacts of different technologies to the system (upstream network reinforcement, grid stability etc). It can therefore be deemed to be a more suitable method of comparison of studies taking into account wider system costs beyond the individual wind farm or power station technology costs. Enhanced LCOE also accounts for wider system impacts between technologies due to differences in the timing of their generation, their location and other characteristics. This results in a fairer comparison between technologies.

For example, the figures in Table 23 published by BEIS demonstrate enhanced LCOE ranges for plants commissioning in 2025 across six low-carbon generation scenarios. It can be seen in BEIS’s report estimates for 2035 that **the enhanced levelised costs for CCGT with post-combustion CCS are significantly lower than either onshore or offshore wind.** See Figure 5.

In Figure 5 the ‘dots’ represent a technology’s enhanced levelised cost, made up of the original levelised cost ‘bar’, the technology’s wider system impact and its ‘other’ impacts, including unpriced carbon and lower than maximum load factors, with the latter being

81 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/911817/electricity-generation-cost-report-2020.pdf

particularly important for dispatchable technologies or those that get curtailed. The range of the blue dots represent different scenarios of how much this technology is deployed.

Table 23 Enhanced levelised cost ranges for plants commissioning in 2035, £/MWh (BEIS, Electricity Generation Cost Report, 2020)

2035 £/MWh	Unabated CCGT Plant	Post Combustion CCS Plant	Onshore Wind	Large-Scale Solar	Offshore Wind
Original Levelised Cost(A)	112	78	42	33	41
Wider System Impact (Excl. Transmission network and other impacts) (B)	-201 to -80	-81 to -47	1 to 14	8 to 9	12 to 22
Other impacts (C)	68 to 119	22 to 43	6 to 23	1 to 11	1 to 7
Transmission System Impacts (D)	-1 to 2	-2 to 0	6 to 9	0	5 to 11
Enhanced Levelised Cost (A+B+C+D)	27 to 127	38 to 61	60 to 87	45 to 61	59 to 79

Please note these values are in £ sterling.

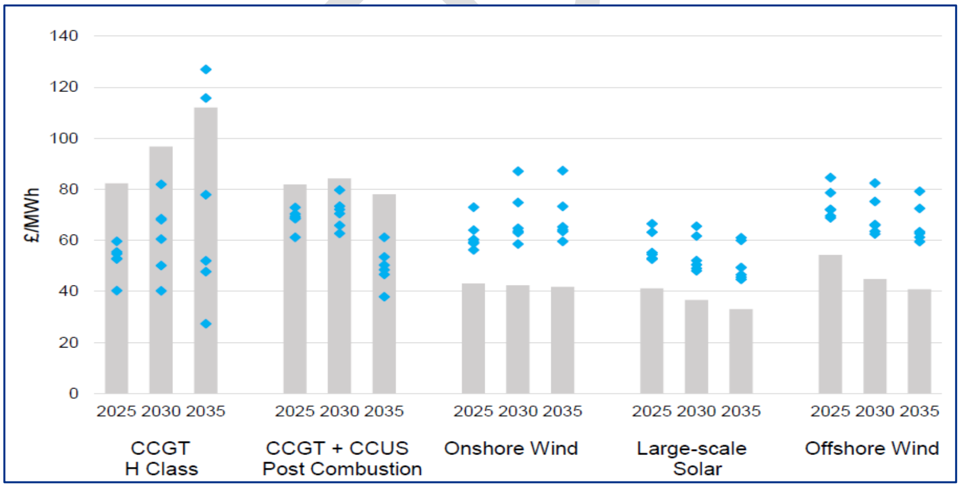

Figure 5 Enhanced levelised cost for plants commissioning in 2025, 2030 and 2035 across three scenarios with varying amounts of low carbon, £/MWh. (BEIS Electricity Generation Cost Report, 2020)

Industry

Norway

A report was prepared for the Norwegian Ministry of Energy and Petroleum in 2020 entitled ‘The role of Carbon Capture and Storage in a Carbon Neutral Europe - Assessment of the Norwegian Full -Scale Carbon Capture and Storage Project’s Benefits’. The aim of the report was to demonstrate a novel CCS value chain with carbon capture at one or two Norwegian industrial facilities, transport of CO_2 by ship and offshore pipeline, and long-term CO_2 storage in a saline aquifer offshore.

The analysis focussed on the potential role of CCS in six key sectors and in hydrogen production. The analysis concluded that:

"*CCS is the principal solution for achieving deep cuts in emissions from cement and waste-to-energy. Other sectors have abatement alternatives which makes the scope for CCS more uncertain and sensitive to the direction of technology improvements and costs, as well as EU and national policies*"**.**

In terms of scale the report suggested that "*applying carbon neutrality for cement production and waste-to-energy generation would require capture and storage in the range of 90–170 million tonnes (Mt) of CO2 per year*". CCS therefore has a significant role to play in decarbonising certain industrial sectors.

The report provides very useful benchmark abatement costs for CCS in the sectors analysed, as referenced in Figure 6 below.

Sector	Emissions $MtCO_2$ (2017)	Capture by 2050 ($MtCO_2$) Carbon neutral Europe (*)	Abatement costs – current estimates (EUR/tCO_2) (**)
Manufacturing industries			
Iron and Steel	115	11-71 (***)	70-95
Chemical/petrochemical	102	30-39 (***)	39-113
Refineries	130	10-30 (***)	40-359
Cement	122	57-105	60-120
Energy generation			
Waste-to-energy	68	36-60	150-200
Power	1007	0-218	70-105

(*) The low and high estimates reflect the use of CCS versus alternative abatement option. Further, data from different sources with different assumptions have been used, also creating variations in estimates.
(**) All estimates include capture, transport and storage. Estimates vary because of differences in methodologies and underlying data and because different emission sources within each sector have different abatement costs.
(***) Not all emissions are technically capturable

Figure 6 CO_2 emissions, range of potential for capture and abatement costs for key sectors (Norwegian Ministry of Energy and Petroleum, 2020)

Global CCS Institute

The Global CCS Institute in its 2017 CCS cost update report[82] highlighted that "*the cost of CCS on several industrial applications is far below what many would expect given the repeated claims that CCS is 'too expensive*'". The lowest cost applications for CCS include natural gas processing, ammonia and bio-ethanol production. Higher cost industrial applications for CCS include iron and steel production, and cement. Their benchmark abatement costs for cement are in the range $103-$124/T, roughly equivalent to €85-€103 (using 0.83 dollar to euro rate).

[82] https://www.globalccsinstitute.com/archive/hub/publications/201688/global-ccs-cost-updatev4.pdf

In May 2019 a report from the International Energy Agency[83] concluded that **CCUS is one of the most cost-effective solutions** available for large-scale emissions reductions

- CCUS **reduces the cost and complexity** of industry sector transformation.
- The development of CO_2 transport and storage networks for industrial CCUS hubs can reduce unit costs through economies of scale.

CCS for low-carbon hydrogen production at scale

Natural gas with CCUS is one of the most cost-effective ways to produce low-carbon hydrogen presently. It is expected to remain the lowest cost option in regions where large amounts of affordable renewable electricity (for hydrogen production) is not available and fossil fuel prices are low. This may give rise to potential for import of hydrogen to Ireland as a carbon free fuel in place of some of the hydrocarbons that are currently used. While Ireland has potential to produce green hydrogen at scale in the future, it should be borne in mind that to transition from hydrocarbons to green hydrogen, there may be an intermediate requirement to facilitate the transition by introducing industrial production of hydrogen for a period of time.

CCS, in conjunction with Steam Methane Reforming (SMR), Gas Heated Reforming (GHR), or Auto Thermal Reforming (ATR), could produce hydrogen while at the same time abating CO_2 at scale. Moreover, CCS for decarbonised hydrogen production in this scenario is competitive versus green hydrogen production. The table below shows the price differential in the period 2030 to 2050 and indicates that for the period up to 2050 decarbonised hydrogen is more cost effective even when compared to the emerging low-cost sources of hydrogen from Solid Oxide Electrolysis (SOE).

Table 24 Hydrogen Prices (BEIS Hydrogen Production Costs, 2021[84])

Hydrogen Source	2030 £/MWh	2040 £/MWh	2050 £/MWh
SMR 300 MW with CCUS	64	64	66
ATR 300 MW with CCUS	66	66	65
SOE 10MW Grid electricity: Industrial LRVC (Baseload)	115	109	106
SOE 10 MW Dedicated Offshore (at Offshore LF)	91	73	69

CCS for delivering negative emissions

There are three main pathways to achieve BECCS.

- Combust biomethane in a gas-fired power station fitted with CCS.
- Combust biomethane in a SMR fitted with CCS to produce negative emissions Hydrogen.
- Combust biomass in a power station fitted with CCS.

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[83] IEA, May 2019. Transforming Industry through CCUS

[84] Hydrogen Production Costs 2021

No referenceable costings have been carried out for the first two i.e. biomethane based BECCS. These, incidentally, are possibly the two options most suited to Ireland (as Ireland does not have large-scale biomass potential). It is recommended that further research is carried out to determine the costs of these two options.

In the UK, costs for BECCS have been analysed on behalf of BEIS, 'Analysing the potential of bioenergy with carbon capture in the UK to 2050'[85]. This study assesses BECCS via utilisation of biomass only (and therefore may not be directly applicable to Ireland) and it assesses a number of different infrastructure processes to utilise the fuel.

LCOEs estimated for the BECCS plants range from £138/MWh for chemical looping technology to £204/MWh for the IGCC plant. The two most significant contributions to LCOE are capex cost and fuel costs.

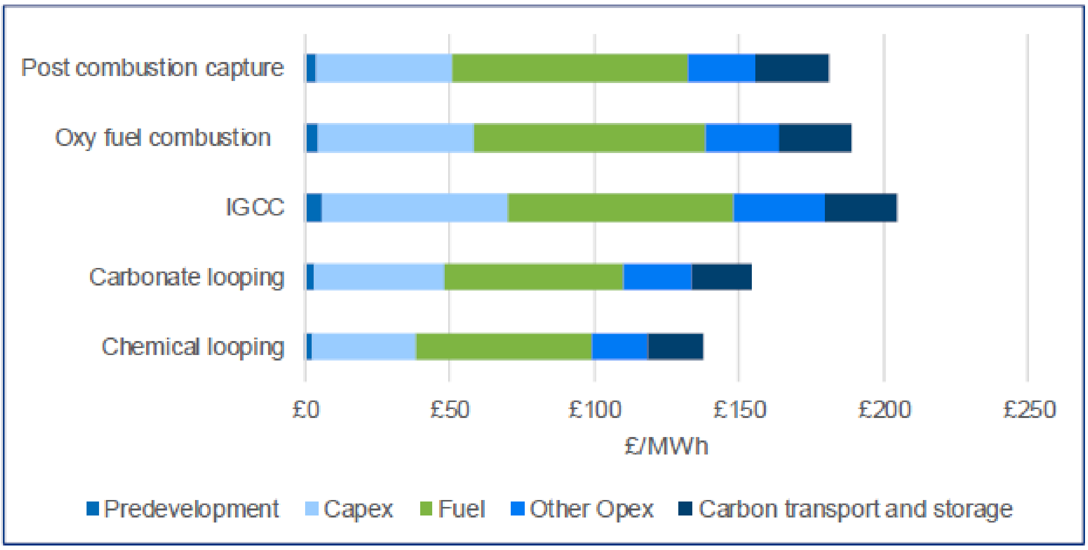

Figure 7 Breakdown of LCOE costs for central biomass fuel price – NOAK (BEIS, 2018)

○ Learning curves for CCS and other low / zero carbon technologies

When considering the full investment costs of projects, the impact of technology learning and development must be considered. In other words, how the first of a kind (FOAK) installation costs will develop as the technology becomes widely deployed and understood, i.e. reaches an n^{th} of a kind (NOAK) cost level.

There are two key metrics used to assess how costs may drop over time as a technology is deployed:

- Learning Curves, which are the ratio of the prices on doubling of capacity and progress ratio.

85 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/911268/potential-of-bioenergy-with-carbon-capture.pdf

- Learning Rate, which is a percentage cost reduction for each doubling of experience.

In the 'Global Status of CCS 2019' report[86], the GCCSI analysed the cost trajectory of CCS on existing operating plants with the help of estimated costs from a range of feasibility and front-end engineering design (FEED) studies. It shows that the cost of capture reduced from over $100 per tonne in 2012 to below $65 per tonne CO_2 just three years later.

BEIS view on maturity timeframe

In 2020 BEIS produced a report on the levelized cost estimates for different electricity generation technologies. The information included for both a FOAK and NOAK gas fired CCGT with post combustion CCS. There was no change in the NOAK cost from 2035 to 2040, suggesting BEIS expects post combustion CCS to be a mature technology by 2035.

Similarly Baringa in its study on the electricity system in Ireland, with and without CCS, does not assume any further cost reductions post 2030 for CCGT with CCS – please refer to Table 21 above.

To understand how learning curves or learning rate might apply for CCS in industry, it is useful to consider an example from a similarly complex technology such as Flue Gas Desulphurisation (FGD). This technology was initially deployed in the 1970s with the first large scale units being deployed in the United States. Through the 1980s the FGD capacity slowly increased in Japan and in the mid-80s a substantial increase occurred in Germany. Through the 1990s and into the millennium there was a continued increase in these countries and the rest of Europe as environmental legislation tightened (analogous to what is being experienced with carbon reduction targets being set in developed economies).

According to Rubin (2004 a&b)[87] FGD capital costs learning rate reduction was 11% (reduction per doubling in capacity) and operating costs learning rate 22%.

The learning rate for CCS capex used by Rubin et al[88] and McKinsey & Co (2008)[89] is 11% and 12%, respectively. That is to say they expect learning rates similar to that of FGD, McKinsey also note that this learning rate has been observed in the LNG business.

Rubin also uses a learning rate for operation and maintenance (O&M) expenditure of 22%, the same as found for FGD. For post combustion capture in particular, savings in operation will largely derive from reducing the energy consumed in solvent regeneration and compression.

In conclusion, assuming there is a no rapid price reduction for CCS, such as that seen in the area of PV deployment, then **learning curve adjustments of 10-12% capital reduction per doubling of capacity** seem appropriate for CCS.

[86] https://www.sustainablefinance.hsbc.com/carbon-transition/carbon-capture-and-storage-global-status-report-2019

[87] https://seeds.lbl.gov/wp-content/uploads/sites/29/2018/02/Rubin-Taylor-Yeh-Hounshell-Energy-29-9-10.pdf

[88] https://doi.org/10.1016/j.enpol.2015.06.011

[89] McKinsey & Company. (2008). Carbon Capture and Storage: Assessing the Economics.

In its report on BECCS for the UK Government, Ricardo has stated that the LCOE for FOAK plant has been estimated from the cost of NOAK plant, assuming that the capex cost of CCS related elements in NOAK plant will be 25% lower than in FOAK plant for technologies using post combustion capture, and 20.5 % lower for technologies using pre-combustion capture (i.e. blue hydrogen).[90] The capex cost of carbon transport and storage is assumed to be 25% higher for FOAK plant than for NOAK plant. Overall, this means that the LCOE for FOAK plant are likely to be about 15% higher than those for NOAK plant.

- **EU ETS forecasts/Carbon tax/Shadow price of carbon**

The table below shows a broad range of forecast carbon prices out to 2050. The forecasts range from a low of €30/t up to a high of €250/t in 2030 and a low of €53/t to a high of €800/t in 2050. As at October 2021 carbon prices have hit a high of €65/t demonstrating the level of uncertainty associated with such forecasts.

Table 25 Range of Forecast Carbon Prices to 2050 (Sources: See table)

Carbon Curve	2030 €/t	2050 €/t
Baringa Study	46	53
EIB 2015 (Base Case)	50	120
EU Reference Scenario 2016[91]	35	90
EU Reference Scenario 2020[92]	30	150
DPER 2019 Shadow Price (ETS sector)[93]	33.5	88
IEA Net Zero by 2050 (2021)	116	223
EIB 2020[94]	250	800

The criteria listed recommends the use of the DPER shadow price of carbon which is €33.5/t for 2030 and €88 for 2050. It is Ervia's view that the shadow prices listed are too low (based on current carbon price and based on the latest forecasts from the International Energy Agency (IEA) and the European Investment Bank (EIB)) and will not provide meaningful results if used for modelling future energy costs or supports necessary in Ireland.

[90] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/911268/potential-of-bioenergy-with-carbon-capture.pdf

[91] https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

[92] https://op.europa.eu/en/publication-detail/-/publication/96c2ca82-e85e-11eb-93a8-01aa75ed71a1/language-en/format-PDF/source-219903975

[93] https://assets.gov.ie/45078/b7dbf515ad694c3e8b2c37f1094b7dca.pdf

[94] https://www.eib.org/attachments/general/reports/sustainability_report_2020_en.pdf

- **System balancing/ enforcement costs e.g. grid infrastructure, port infrastructure etc.**

Ervia has not assessed grid or port infrastructure costs as part of its studies. The cost of achieving electricity carbon reduction targets with CCS versus without CCS has been assessed in a number of other studies as referenced below: Irish Academy of Engineers in 2016, Baringa in 2020 and BEIS in 2020. In all of these studies, the cost with CCS is significantly less than without CCS and this is due, in part, to the reductions in grid infrastructure costs associated with CCS compared to development of new infrastructure for wind power etc.

Where CCS is to be located at existing CCGT power generation sites, then little or no new electricity grid infrastructure would be required to accommodate low or zero carbon, dispatchable electricity onto the national grid. This provides a very significant saving to Irish energy users versus building new zero carbon power generation with the requirement to develop associated electricity grid infrastructure to transfer that power into the national grid.

BEIS

BEIS in the UK recently released its report on 'Electricity Generation Costs 2020'. As stated earlier, the report assesses the costs of a range of electricity generation technologies on an 'Enhanced Levelised Cost' basis.

Enhanced LCOE takes into account the relative impacts of different technologies to the system (upstream network reinforcement, grid stability etc). It can therefore be deemed to be a more suitable method of comparison of studies taking into account wider system costs beyond the individual wind farm or power station technology costs.

The figures published by BEIS provide enhanced LCOE ranges for plants commissioning in 2025 across six low-carbon generation scenarios. It can be seen in BEIS's report estimates for 2035 that **the enhanced levelised costs for CCGT with post-combustion CCS are significantly lower than either onshore or offshore wind.** This was previously referenced in Table 23 and Figure 5.

The costs for port infrastructure for the transport of CO_2 from Ireland will be assessed as part of Ervia's current CEF study into the feasibility of transporting CO_2 by pipeline from large emitters in Dublin and Cork – for either export to a permanent CO_2 store in Norway or for indigenous storage. This CEF study will be completed in 2022.

For background information, in 2020 Ervia successfully obtained PCI status for its assessment of CCS in Cork. This allowed Ervia to apply for CEF funding to study the technical and economic aspects of CO_2 transport in Ireland. The total cost of the study is €1.7million with 50% being provided by the EU CEF fund.

Irish Academy of Engineers

In 2016 the Irish Academy of Engineers (IAE) produced an estimate of the investment cost for Ireland to achieve an 80% reduction in carbon intensity in the electricity sector from 1990 levels by 2030.[95] The estimate for the base case, with just more wind power and associated infrastructure, was €10.8 billion. A separate scenario where CCS is utilised on some CCGT power stations to achieve the same reduction in carbon intensity would cost €8.7 billion i.e. €2.1 billion lower cost due to lower wind power and grid infrastructure costs.

Baringa

Similarly the Baringa study assessed the benefits or otherwise of deploying CCS into the electricity market in Ireland and its impact on other technologies and overall system costs to the State.

The Baringa study examines the Irish electricity system over the period 2030 – 2050 with an assumed target of attaining net-zero emissions in 2050. The study starts at 2030 and models that the system has achieved 70% renewables electricity production.

The Baringa report concludes that the electricity system cost to meet a net-zero emission target in 2050 would conservatively be **€2.2bn less if CCS is included versus CCS not being included**. The reason for stating "conservatively" here is that the study is restricted to the system costs and does not take into account cost savings in energy balancing, system constraints or network upgrades by using CCS. If these had been included, then the savings associated with using CCS would be greater again.

b. Financial Comparison of CCS and no CCS options

- **The comparison should highlight the need, or otherwise, for CCS.**

Power Generation

A broad range of studies demonstrate that the cost of achieving decarbonisation targets in both the electricity sector and in the wider economy are significantly lower when CCS is included as part of the mix. A number of these studies are referenced in the preceding sections.

The Baringa report concludes that the electricity system cost to meet a net-zero emission target in 2050 in Ireland would conservatively be €2.2bn less if CCS is included versus CCS not being included.

The IAE report shows that for Ireland to achieve an 80% reduction in carbon intensity in the electricity sector by 2030 (from 1990 levels), it would cost €2.1 billion less where CCS is utilised versus the base case of just more wind power and associated infrastructure.

Further work is required to assess the financial comparison of CCS versus no CCS in Ireland for industry, low-carbon hydrogen and BECCS.

[95] http://iae.ie/wp-content/uploads/2017/07/IAE_Report__Irelands_2030_Greenhouse_Gas_Emissions.pdf

Internationally a lot of studies have been published which clearly demonstrate the financial benefit of utilising CCS versus a scenario where CCS is not used. Some of these are as referenced below:

- A report from the IEA shows that without CCS, the cost of meeting a 50 per cent global CO_2 reduction target by 2050 would increase by 40 per cent[96].
- In the UK, the Energy Technologies Institute concludes that the cost of delivering a UK low carbon energy mix in 2050 would increase by one per cent of GDP (or £30bn–40bn per year) if CCS were not included[97].
- The IPCC found that it would be "*138 per cent more expensive to reach global climate goals without the deployment of CCS*"[98].
- A June 2020 study for Eurogas on the importance of gas concluded that "*continued use of gaseous energy resulted in €130 billion in annual savings by 2050*"[99]**.** This study cited CCS as an indispensable technology for the decarbonisation of the power and manufacturing sectors with capacity of 1048 million tonnes of CO_2 sequestered per year in 2050.
- Portugal recently updated its 2050 decarbonisation roadmap to reflect the clear benefits that come from repurposing gas distribution networks to support deployment of biomethane, hydrogen and CCS clusters. A report prepared by Pöyry estimated that "*the conversion of Portuguese gas distribution networks could save up to €9bn to the Portuguese economy when compared to a pathway where zero-carbon gases are not allowed*"[100].

- **To establish an unbiased evaluation, the shadow cost of carbon should be used where there is a difference in timing of carbon emissions.**

The Baringa study, which examined CCS in a future electricity market in Ireland, assumed carbon prices of €46/tonne in 2030 rising to €53/tonne in 2050. These carbon prices were based on 2019 projections of the spark price needed to ensure that all gas plants in Ireland were economically dispatched ahead of coal plants. This is why the price of carbon (€53/tonne) in 2050 is lower than all of the other forecast carbon prices.

The criteria listed recommends the use of the DPER shadow price of carbon which is €33.5/t for 2030 and €88 for 2050. It is Ervia's view that the shadow prices listed are too low (based on current carbon price and the latest forecasts from the IEA and EIB) and will

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[96] IEA – Net Zero by 2050

[97] https://es.catapult.org.uk/reports/still-in-the-mix-understanding-the-role-of-carbon-capture-usage-and-storage/

[98] https://epic.awi.de/id/eprint/37530/1/IPCC_AR5_SYR_Final.pdf

[99] https://eurogas.org/website/wp-content/uploads/2020/06/DNV-GL-Eurogas-Report-Reaching-European-Carbon-Neutrality-Full-Report.pdf

[100] https://afry.com/sites/default/files/2020-03/the_role_of_portuguese_gas_infrastructure_in_the_decarbonisation_process.pdf

not provide meaningful results if used for modelling future energy costs or supports necessary in Ireland.

Using higher carbon prices increases the financial benefit of deploying CCS and reduces any subsidies that might be required. The Baringa electricity market model demonstrates that even with a relatively low projection of carbon prices there is still a net financial benefit of CCS in comparison to other decarbonisation technologies.

c. Project and Subsidy Evaluation

- **Estimates of the likely project costs for each use of CCS technology (i.e. storage and export for industry and powergen).**

The subsidies necessary will vary across different parts of the CCS supply chain and are considerably dependent on carbon price, among other factors. As noted earlier, carbon prices are difficult to forecast with any certainty on the horizon to 2050.

BEIS commissioned Wood to assess CO_2 capture technologies. The study, published in 2018, 'Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology'[101], evaluated the cost reduction potential and competitiveness of novel UK carbon capture technologies that may be implemented over the next thirty years. Three case studies within the report are of direct interest:

- Case 0 – Reference Case – Unabated natural gas CCGT.
- Case 1 – Natural gas CCGT with post-combustion carbon capture.
  This case consists of a natural gas fired combined cycle power plant with heat recovery steam generator (HRSG), steam turbine and post-combustion carbon capture system (using an amine-based solvent).
- Case 2 – Natural gas reformation with pre-combustion carbon capture. This case consists of a natural gas fed integrated reforming combined cycle (IRCC) power plant. Natural gas is first reformed in an ATR to separate the CO_2 from the hydrogen. The CO_2 is captured. The hydrogen is then fed as the fuel into a CCGT.

Table 26 below provides key project and financial information on the three cases.

Table 26 Project and Financial Data on three case studies (BEIS, 2018)

	Case 0	Case 1	Case 2
Total Gross Installed Capacity	1229 MW	1144 MW	919 MW
CO_2 Capture Rate	---	90.8 %	90.4%
Total Project Cost	£672m	£968m	£1256m

101 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/864688/BEIS_Final_Benchmarks_Report_Rev_4A.pdf

	Case 0	Case 1	Case 2
Levelised Cost of Electricity (LCOE)	£74.2/MWh	£69.9/MWh	£100/MWh
Cost of CO_2 Avoided (including carbon price)	---	- £14.5/tCO_2	£91.9/tCO_2
LCOE (zero carbon price)	£45.4/MWh	£67.1/MWh	£96.2/MWh
Cost of CO_2 avoided (zero carbon price)	---	£73.1/tCO_2	£178.9/tCO_2

Although the unabated CCGT case, Case 0, has the lowest overall investment cost, it does not result in the lowest overall LCOE. The lowest overall LCOE is provided by Case 1, the CCGT plant with state-of-the-art post-combustion carbon capture. Case 0 features a significant proportion of LCOE arising from the penalty paid for emitting CO_2, which is included in the financial analysis for this study, demonstrating the importance of the carbon price as a potential tool for encouraging low carbon investments in power plant. Please note, in Table 26 above, there are two cost of avoided CO_2 metrics: one that includes the effect of a carbon price, and one that doesn't include a carbon price. The cost of avoided CO_2 metric that is of relevance to UK (and other countries / regions with a price on CO_2) is the one that includes the effect of a carbon price.

Based on the quality of the report prepared for BEIS, as above, Wood was also commissioned by Ervia to develop a high-level model for internal assessment of CCGT + CCS costs and subsidies. For indicative purposes only, subsidies required for two projects deploying CCS on power generation in Ireland are provided below. Costs assessed relate to deployment of CCS onto a gas fired CCGT in Cork with (a) the CO_2 being shipped to Norway and (b) the CO_2 being stored in the Kinsale gas field.

For this analysis the forward price of carbon used was the European Investment bank (EIB) carbon forecast (2015) ranging from €50/tonne in 2030 to €120/tonne in 2050. Following a review of the latest carbon price information, this was deemed to be a more appropriate measure than the lower EU Reference Scenario 2016 price and the DPER 2019 shadow price of carbon.

The model shows the following subsidy level required for Export and Indigenous Cork projects assuming a 60% CCGT Load Factor as given in Table 27 and Figure 8 and Figure 9 below.

Table 27 Subsidy required for Cork CCS Powergen under both export and indigenous storage scenarios assuming medium 60% load factor (Wood, 2020)

	Cork Export Scenario	Cork Indigenous Storage Scenario
Capex (1 CCGT) €m	€444m	€868m
Lifetime Total Support €m	€760	€ (935)

	Cork Export Scenario	Cork Indigenous Storage Scenario
Peak Support Payment €m	€97	€27
Ave Support Payment €mpa	€30	€ (37)

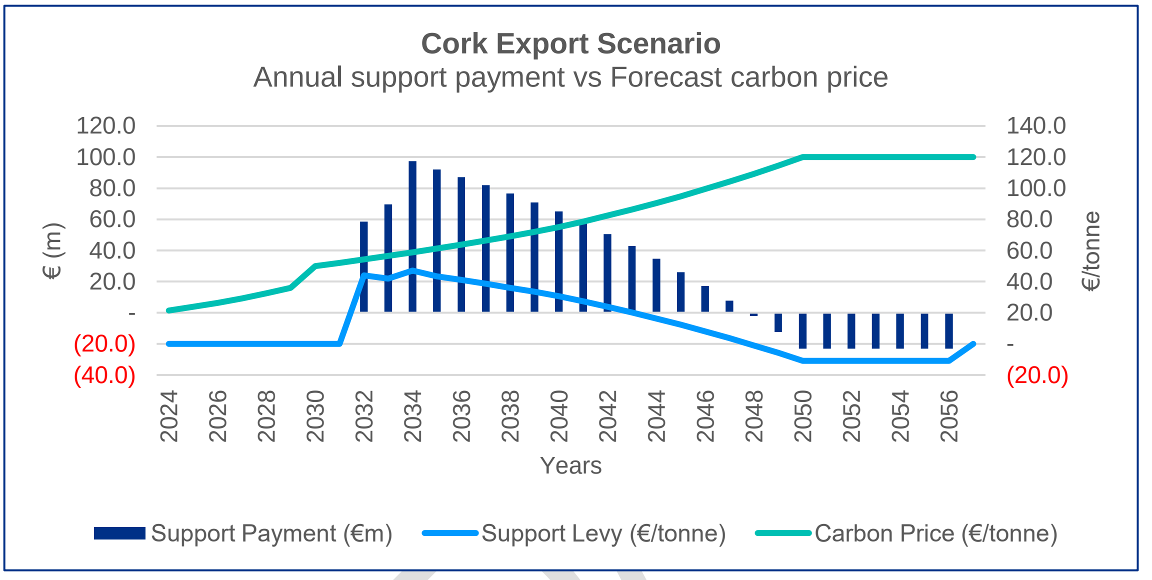

Figure 8 Support Payment profile for Cork export scenario over the life of the Project assuming 60% Load Factor (Wood, 2020)

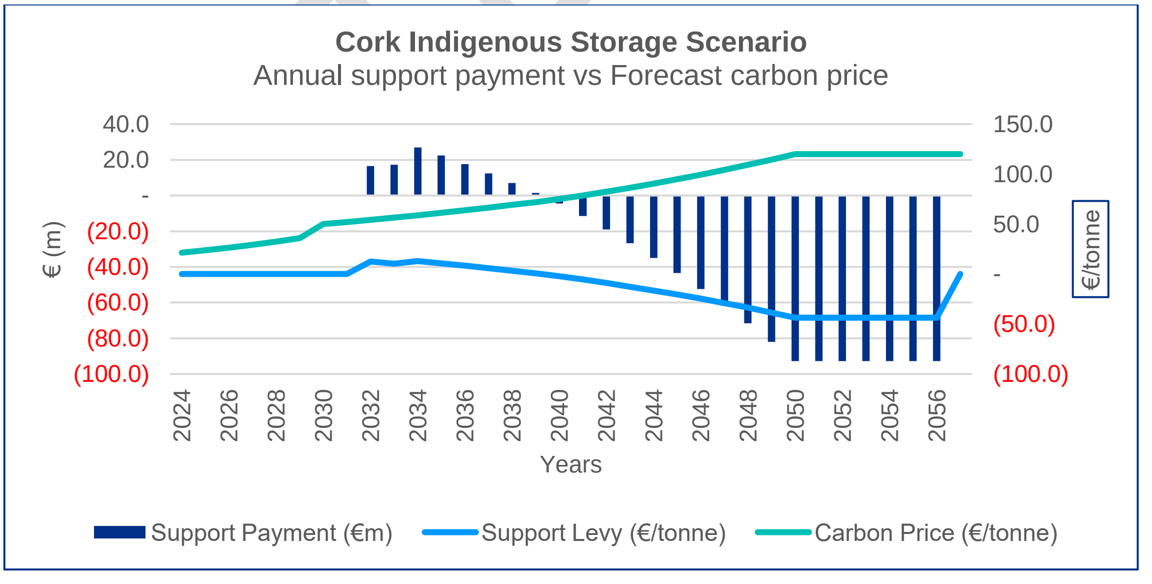

Figure 9 Support Payment profile for Cork indigenous Storage scenario over the life of the Project assuming 60% Load Factor (Wood, 2020)

The table and figures above show two very different subsidy requirements for CCS depending on the scenario selected. The export scenario has lower Capex than the indigenous scenario but then has a much higher annual Opex over the lifetime of the project. The total lifetime subsidy of €760m equates to an average payment of €30m per annum with a peak year subsidy requirement of €97m which occurs in 2034.

By contrast, the subsidy requirement under the indigenous storage scenario over the lifetime of the project is actually a net negative €935m. It has a subsidy requirement in the early years up to 2041 but from 2042 onwards does not require a subsidy. It is theoretically in a negative subsidy requirement position. This net negative figure does not however consider the total long-term liability to the Irish State for CO_2 stored within its geographical territory and possible cost impacts due to planning delays in developing large scale offshore infrastructure in Ireland.

Subsidy sensitivity to the market price of carbon

The key sensitivity for subsidies that may be required for CCS is directly related to the market price of carbon. In both Figure 8 and Figure 9 above it can be seen that subsidies are required when the price of carbon is still low and climbing. As the market price of carbon increases, CCS becomes more economic. Both Figure 8 and Figure 9 show where the economics of both cases match the carbon forward curve. For the indigenous storage scenario, it happens in 2041 whereas in the export scenario it happens in 2049. The base case market carbon price forecast assumes a market price of €50/tCO_2 in 2030 rising to €120/t by 2050. It should be noted that the market price of carbon in October 2021 was already at €65/t and, as such, that would greatly reduce the subsidies required for CCS in both scenarios.

Table 28 illustrates the subsidy required at the alternate low and high case forward curves for carbon discussed above.

Table 28 Subsidy Required at Low and High Case Forward Curves (Ervia)

	Base case (low)	Base Case (high)	DPER 2019 (low)	DPER 2019 (high)	IEA 2021 (low)	IEA 2021 (high)	EIB 2020 (low)	EIB 2020 (high)
	Cork Export Scenario	Cork Indigenous Storage Scenario	Cork Export Scenario	Cork Indigenous Storage Scenario	Cork Export Scenario	Cork Indigenous Storage Scenario	Cork Export Scenario	Cork Indigenous Storage Scenario
Lifetime Total Support €m	€760	€ (935)	€1,331	€ (269)	€ (2,202)	€ (4,104)	€ (18,664)	€ (20,933)
Peak Support Payment €m	€97	€27	€107	€40	€12	€ -	€ -	€ -
Ave Support Payment €mpa	€30	€ (37)	€53	€ (11)	€ (88)	€ (164)	€ (747)	€ (837)

It is recommended that further research is carried out to assess the level of subsidies required for CCS for industry, low-carbon hydrogen and BECCS.

- **Evaluate the range of state financial support mechanisms that may be required to commercialise CCS technology in Ireland.**

In order to evaluate the range of state financial support mechanisms that may be required to commercialise CCS technology in Ireland, the approach taken in the UK, the Netherlands and Norway is summarised below.

UK

BEIS has produced proposed CCUS revenue mechanisms to support the UK Government's ambition to capture 10MtCO_2pa by 2030[102]. These include business models for Transport and Storage (T&S), power and Industrial Carbon Capture (ICC).

A proposed T&S model was published in December 2020 and updated in May 2021 and is based on a Regulated Asset Value (RAV) basis, which would provide long-term index linked revenue to market operated through an independently regulated regime following the existing economic regulation in the UK which will be adjusted for CCUS specific elements. The T&S charges would be made up of the following fees:

- Connection fee: Payments related to the costs of the specific and sole use of infrastructure required to connect a given capture plant to the T&S network.
- Capacity fee: Payments related to the costs incurred by T&S operator for shared network assets, i.e. infrastructure that cannot be solely attributed to a single user.
- Volumetric fee: Payments related to the costs incurred by T&S operator that are linked to the volume of CO_2 being transported and stored.

The proposed business model for power CCUS plants is based on a Dispatchable Power Agreement (DPA) and was published in December 2020, with updates in May and October 2021. The objective is to develop a business model which enables power CCUS to play a mid-merit role in the generation mix. The proposed DPA is based on the framework for the standard Contract for Difference (CfD), amended to ensure it addresses the identified challenges. It is proposed that the DPA would be established between the power CCUS project company and a Low Carbon Contracts Company (LCCC), a government company. The October version provided updates on legal and contractual aspects and on the payment mechanisms.

The proposed business model for Industrial CCUS plants was published in December 2020 with updates in May and October 2021. The most recent update states that capital grant support will be available to initial industrial projects to fill any funding gaps, after industry has raised as much private capital as possible. It is exploring the transport and storage fee being paid by the emitter or by the industrial carbon capture contract counterparty. It continues to consider options around opex costs. The October update provided clarity

[102] https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-business-models

regarding eligibility criteria along with updates on risk allocation, capture-as-a-service model and the legal and contractual framework.

BEIS has also recently consulted on business models for low-carbon hydrogen[103] and is currently reviewing feedback received.

The UK Government issued an update on the design of the CCUS Infrastructure Fund in May 2021, indicating that there will be a two-track approach. In October 2021 it was announced that the Hynet and East Coast Cluster were selected as the two industrial clusters and will have the first opportunity to be considered for receipt of any necessary support under the government's CCUS Programme.[104] These projects are profiled in the next section (see CCS Developments).

The Netherlands

The incentivisation scheme used in the Netherlands is the stimulation of sustainable energy production and climate transition (SDE++). The aim of the scheme is to reduce greenhouse gas emissions by 49% by 2030 (compared to 1990 levels) in the most cost-effective way. The scheme is technology neutral and technologies compete on the amount of CO_2 and other greenhouse gases that have been avoided. The technologies need to meet certain eligibility criteria in terms of readiness, viability and scalability. CCS is eligible for SDE++ support. The scheme involves an operating grant to subsidise the difference between the cost price of the technology and the market price of the avoided CO_2 and is financed via a levy on the use of electricity and gas. The Netherlands has a number of other schemes for technologies which are ineligible for SDE++.

In addition, the Netherlands introduced a carbon tax in January 2021 which will increase from €30/t in 2021 to €125/t in 2030 to act as a disincentive to greenhouse gas emissions.

Regarding the SDE++ scheme, Bellona published a paper recently on the Industrial CCS Support Framework in the Netherlands[105] and the Netherlands Enterprise Agency has produced a brochure[106] on its SDE++ scheme. The scheme provides a 15-year CfD-like subsidy and CCS applications will be ranked in order of subsidy intensity, i.e. subsidy requirement per tonne of CO_2 avoided. The scheme has a cap on the maximum amounts of CO_2 which will be captured and stored from industry and electricity per year by 2030. In May 2021, the Dutch Government awarded €2bn in SDE++ subsidy to six projects to capture CO_2 and remunerate Porthos for the operation of the transport and storage aspect.

Norway

The Norwegian Government introduced a carbon tax for the oil and gas industry in 1991. This stimulated the development of the Sleipner (1996) and Snøhvit (2008) CCS projects.

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103 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011469/Consultation_on_a_business_model_for_low_carbon_hydrogen.pdf

104 https://www.gov.uk/government/publications/design-of-the-carbon-capture-and-storage-ccs-infrastructure-fund

105 https://network.bellona.org/content/uploads/sites/3/2021/07/2021-The-Industrial-CCS-Support-Framework-in-the-Netherlands.pdf

106 https://english.rvo.nl/sites/default/files/2021/10/SDEplusplus_oktober_2021_ENG.pdf

The Norwegian Government has also supported research, development and demonstration programmes (such as the current CLIMIT programme) and provided direct subsidies and co-financing along with industry to develop CCS.

It set up Gassnova, a state enterprise, to further the development of technologies and knowledge regarding CCS. Gassnova is the entity developing the Longship Project which is estimated to cost NOK25.1bn with the Norwegian Government estimating its cost contribution as NOK16.8bn (or approximately two-thirds of the overall costs equivalent to c. €1.6bn)[107].

Norway is exploring new business models related to the Longship project, as outlined by Zero Emission Resource Organisation (ZERO)[108], which include a tax on waste incineration without CCS, tax on concrete, and green public procurement, among others.

Earlier this year the Norwegian Government announced plans to increase its carbon tax to c. €200/t by 2030.

Ireland

In its modelling of the Irish electricity system, Baringa proposed that the RESS should be extended to other low-carbon technologies such as CCS.

- **The evaluation should take into account European funding as well as the level and type of support required for debt and equity financing.**

It is anticipated that the development of CCS in Ireland would benefit from financial grant support from multiple EU sources. The funding would be drawn down over a phased basis from: initial feasibility and offshore studies; Front End Engineering and Design (FEED) phase; Construction phase; and Operation phase. The funding sources identified include:

- **EU ETS Innovation Fund.** This fund covers the period 2020 to 2030. It is being funded from the sale of €450m EU ETS allowances (on an annual basis, c. €45m p/a). Grant aid of up 60% of relevant project costs will be awarded to successful applicants. Ervia attended multiple round table stakeholder consultations in Brussels, hosted by DG Clima, to seek input from potential beneficiaries of the fund. CCS is a technology that is being supported by the Innovation Fund. However, CCS related funding is likely to be awarded to CO_2 capture costs rather than CO_2 transportation or storage.
- **Connecting Europe Facility (CEF).** The CEF is an EU fund to support Projects of Common Interest (PCIs). PCIs are cross border gas and electricity infrastructure projects that provide improved energy security of supply, or sustainability benefits across at least two EU member states. PCIs can apply for grant aid both for studies, and/or for works. The regulation underpinning the PCIs includes support for cross border CO_2 transportation

[107] https://www.regjeringen.no/en/historical-archive/solbergs-government/Ministries/smk/Press-releases/2020/the-government-launches-longship-for-carbon-capture-and-storage-in-norway/id2765288/

[108] https://zero.no/wp-content/uploads/2019/09/rapport-eng-ccs-v6.pdf

- **Horizon 2020/Europe** are EU research and innovation funds totalling €175m available between 2014 and 2020, and 2021 to 2027 respectively. Ervia was granted €400K for Project REALISE, which is demonstrating a refinery-adapted cluster-integrated strategy to enable full-chain CCUS implementation.
- **Structural Funds** such as the European Regional Development Fund (ERDF) or the European Energy Programme for Recovery (EEPR) may provide support for CCS. The ERDF is part of 'Cohesion Policy 2021 – 2027' and has a total fund of €392 billion. ERDF can cover up to 50% of project cost.

In order to understand what supports are required to enable both debt and equity financing to enter the CCS market, a number of excerpts from key reports are provided below:

Global CCS Institute, UNLOCKING PRIVATE FINANCE TO SUPPORT CCS INVESTMENTS, 2021[109]

"The need for CCS in the IEA-SDS translates to an estimated 70-100 CCS facilities built per annum, for which we estimate the total capital requirement to be between US$655 bn and US$1280 bn. To achieve this, the private sector must be incentivised to invest in CCS because the capital requirement far outstrips what governments are willing to pay in the timeframe required. This means most of the funding for CCS is to come from debt, capital markets, and other sources such as sovereign wealth funds, which currently do not directly fund CCS at a meaningful scale.

Thus far, the 28 commercial CCS facilities around the world have mostly been financed on the books of state-owned enterprises and large corporations (through corporate finance), and, in most cases, these projects have relied on the commercial value of CO_2. What is clear is that if there is a business case for CCS, the private sector will invest in and deliver CCS projects. However, for CCS to be deployed at scale, governments can support the deployment of CCS in two ways. Firstly, they can create climate-based policies to provide a reliable source of revenue for CCS projects. Secondly, smaller emitters with more constrained balance sheets cannot invest in CCS through the corporate finance model. Instead, they will require support to enable their investments through project finance.

To enable project finance, governments can mandate specialist financiers such as multilateral agencies (MLAs) and export credit agencies (ECAs) to support CCS investments. Support from these specialist financiers will allow the participation of commercial lenders in CCS projects as they can fund the most high-risk areas of projects.

As CCS deployment accelerates, sustainable finance has an important role to play, whether through innovative lending instruments such as sustainability linked loans (SLL's) or through capital markets, for example, bond markets."

Global CCS Institute, Insight, June 2019[110].

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109 https://www.globalccsinstitute.com/resources/publications-reports-research/unlocking-private-finance-to-support-ccs-investments/

110 https://www.globalccsinstitute.com/news-media/insights/14285/

To date, investment in CCS projects have typically been supplemented by capital grants from public funds, with returns relying heavily on revenues from enhanced oil recovery (EOR). Although this arrangement has significantly contributed towards learning rates, an essential driver of cost reductions, it cannot be sustained at scale. The large-scale deployment of CCS will, therefore, require significant investments from the private sector i.e. banks.

However, a range of barriers and risks are limiting private sector investment in CCS. In the absence of EOR, there is an insufficient value on carbon dioxide to generate the revenues required for a sufficient return on investment. In addition, hard to reduce risks, namely cross chain and liability related risks, drive up the cost of capital. Since CCS facilities are capital intensive, this represents a significant material cost to projects, further reducing their economic viability.

Under these conditions, banks cannot qualify CCS projects for debt financing. As such, government has an important role to play in de-risking CCS investments.

- *Firstly, a material value must be placed on carbon dioxide, which can be in the form of a carbon price or a financial reward for CO2 storage. This value must be sufficient to incentivise investment in CCS.*

- *Secondly, the cross chain (or counter party) risk must be addressed. This risk emerges from single source, single sink CCS projects, whereby only one capture facility sells carbon dioxide to a storage operator across a pipeline. The possibility of either the capture plant or the storage facility becoming unavailable presents itself as a significant risk to the overall project.*

- *Moving towards a hub and cluster model reduces the risk of either counter party being unable to deliver or accept carbon dioxide. It utilises a transport and storage (T&S) network, connecting clusters of capture facilities together. In addition, this arrangement also reduces the unit cost of CO2 transportation through economies of scale.*

- *Investing in T&S networks is, however, challenging for the private sector. The initial investment will be exposed to all the costs and risks of a single source, single sink model until other facilities join the network. This presents a significant barrier unless guarantees are provided for revenue during the early stages of deployment. This can be achieved through the Regulated Asset Base (RAB) model, which recovers costs from consumers — by way of long-term tariffs — under regulation. In this way, the consumers cover the risks, making it possible for the private sector to invest.*

- *Where the balance of risk and return is insufficient to initiate private sector investment in the T&S network, government can take on the role of first investor. It could make the initial investment, establishing a T&S network for an anchor customer. Over time, more customers are able to join the network until such time that the business becomes an attractive investment. At this point, government can then choose to sell this mature business to the private sector for a profit.*

- *Finally, addressing the liability risk, specifically long-term storage liability, is the last piece of the puzzle to ensure sufficient de-risking of CCS to attract private investments. If there are no limitations on liability, the storage operator will be liable for any leakage that occurs at any time in the future. To mitigate this risk, it is critical for governments to implement a well-characterised legal and regulatory framework that clarifies storage operators' potential liabilities. Therein, it may be that the storage operator bears the risk of short-term liability during the operational period, as has been implemented by the Australian Government, which then goes on to accept the long-term risk. Each government will choose the path that best suits its circumstances.*

De-risking will attract debt financing to projects, which can initially be blended with grant funding to reduce the cost of capital. Over time, as the market develops and there is more experience from successfully implementing more and more CCS projects, costs will plateau. Risks will be well understood, reduce or disappear, and grant funding will no longer be needed to incentivise and support investments. The CCS market will attract significant debt funding at pricing comparable to other infrastructure projects, allowing deployment to reach the numbers required. Projects will eventually come to rely exclusively on equity and debt for funding, and acceptable returns will be achieved through diminished costs and the increased value of CO_2*.*

Deployment of an industrial Carbon Capture and Storage cluster in Europe: A funding pathway, Element Energy, August 2017.

Enabling the deployment of strategically important industrial CCS clusters in Europe will require a variety of coordinated funds and subsidies including grants for storage appraisal and construction; loan guarantees to unlock private investment; operational subsidies; and operational guarantees and sharing storage liability to de-risk the cluster. Key requirements of a typical industrial CCS project vary for the pre-FID (pre-Final Investment Decision), Construction, Operation and Post-closure phases.

Private investment options for industrial CCS can be broadly categorised under the following two categories:

- *Debt: Loans and other debt instruments from the European Investment Bank and commercial banks with long maturity (e.g. ~10-year) and low-interest rate (e.g. 3%) might be available for bankable CCS projects. Most first-of-a-kind CCS projects are likely to require government loan guarantees to become bankable;*
- *Equity: Depending on balance sheet capacity, it could be obtained from industrial shareholders or 3rd party sponsors; however, high cost of equity (target Return on Equity (ROE) of 10%-15%) means that, for each €1 invested, €2 of public funds might be needed. Private investment can be leveraged with the right incentives and guarantees; however, both equity and debt should be paid back. Industrial emitters, for instance, might typically require very short payback period for their capital investment (e.g. 3-5 years); however, repayment length for debt might be ~10 years depending on the guarantees in place. Private investors and equity providers would also require returns on investment depending on the risk profile of the project.*

EIB Taxonomy

Funding may also be possible from the European Investment Bank[111] subject to certain criteria as set out in Figure 10.

Activity	EU Taxonomy criteria for substantial contribution to climate mitigation
Carbon Capture and Storage (applies to manufacturing and energy projects)	Capture: Carbon capture is currently eligible provided that: • it enables the economic activity to operate under its respective threshold; and • it shows that the captured CO_2 will be offloaded to a Taxonomy-eligible CO_2 transportation operation and permanent sequestration facility. Transport: Transport modes that contribute to the transport of CO_2 to eligible permanent sequestration sites are eligible, only if the asset operates below the leakage/tonne of CO_2 threshold <0.5%. Storage: Operation of a permanent CO_2 storage facility is eligible if the facility complies with ISO 27914:2017 for geological storage of CO_2.

Figure 10 EIB Funding Criteria

d. Evaluation of State Liability (if storing in Ireland)

- **Evaluation of the cost of transfer of liability from project sponsor to the State. At a minimum this will require 30 years of monitoring post transfer (according to slides from the previous session).**

The liability associated with CO_2 storage would only apply to Ireland for the indigenous storage option. For the export storage option, the liability would be with the export storage location.

Article 18 of the CO_2 Storage Directive deals with the Transfer of Responsibility and is supported by the EC's guidance regarding the Criteria for Transfer of Responsibility to the Competent Authority.[112] It is clear from both the Directive and the guidance document that transfer of responsibility will only occur if the following conditions have been met:

a. all evidence indicates that the CO_2 will be completely and permanently stored.
b. a minimum period of no shorter than 20 years has elapsed.
c. the financial obligations referred to in Article 20, i.e. Financial Mechanism, have been met (where the operator makes a financial contribution prior to the transfer of responsibility and will, at least, cover the costs of monitoring for a period of 30 years).
d. the site has been sealed and the injection facilities have been removed. After the minimum period of at least 20 years has elapsed, the operator prepares and submits a transfer report to the competent authority.

[111] https://www.eib.org/attachments/thematic/eib_group_climate_bank_roadmap_en.pdf

[112] https://ec.europa.eu/clima/system/files/2016-11/gd3_en.pdf

Only if the competent authority is satisfied that the report demonstrates that there is complete and permanent containment does it issue a draft decision which is submitted to the EC who may issue a non-binding opinion. When the competent authority is satisfied that the conditions a - d listed above have been met, it shall finally approve the transfer of responsibility.

As stated above, the first 30 years of monitoring costs post transfer will be covered by the financial contribution made by the operator (prior to the transfer taking place). Thereafter monitoring costs would need to be covered by the Member State. A preliminary high-level estimate indicates that this would be of the order of €40m over a 50-year period (which is significantly higher than the €1-10m estimate for 30 years quoted by the article relating to CCS in the Netherlands which can be found later in this section).

It is noted that the operator covers the costs of monitoring for a period 50 years (20 years post-closure followed by 30 years post-transfer (via financial contribution)) before any monitoring costs accrue to the state. Table 29 below summarises this. In addition, the competent authority can recover leakage costs from the operator if they are a result of negligence.

Table 29 Party responsible for costs of MMV and additional liabilities (Ervia, 2021)

	Monitoring Measurement & Verification	Repair Leak	Pay carbon price at time of a leak
CO_2 injection (c. 20 years)	Developer	Developer	Developer
Post Closure (EU recommends at least 20 years)	Developer	Developer	Developer
Post Transfer (In perpetuity)	Developer (via financial contribution) (For first 30 years) Then Member State only.	Member State	Member State

The key liability that may arise is the long-term CO_2 leakage liability. Before assessing this in more detail some further background information in relation to this risk is provided below.

A properly selected and competently managed storage site could experience a level of leakage that is "*much less than 0.1 per cent in even 1 million years*"[113]. This is because CCS technology mimics analogous geological processes using the same natural trapping mechanisms which have already kept huge volumes of oil, gas and CO_2 underground for millions of years. Therefore, while the risk of leakage exists, with appropriate management it is expected to be very low. In terms of evaluating the liability, the determined volume of CO_2 leaked would be subject to the purchase of emissions allowances. It must also be

[113] The EU Legal Liability Framework for Carbon Capture and Storage, ASLR Vol6 Dec 15 32.56 Pop, Page 37

taken into account that the volume of CO_2 stored increases during the injection period and the cost of emissions allowances are also expected to increase over time.

Views have been sought from Insurance providers as to the prospects and the potential costs of providing insurance against this risk. Following discussions on the risks it was suggested that an annual insurance premium could be made available where the liability would be capped at the maximum value each year to which the price of carbon could rise. This would have to be renewed on an annual basis. The remaining liability could be indemnified by a bond which could be horizontally geared at 20/80 where the site operator would be liable for 20% of the total cost of leakage up to the known value, beyond which it would be covered by the annual insurance policy.

Determining the cost of this liability would be a matter for actuarial determination and as outlined in the next section it is expected that progress will be made in this area with the materialisation of a number of European CCS projects by the mid-2020s.

Along with the liability to purchase emissions allowances there are also other potential liabilities associated with a leak:

- Administrative liability arising under the provisions of the CCS Directive itself (as transposed within national law).
- Liability in relation to environmental harm.
- Liability under delict/tort and other laws at national level.

In reality these three liabilities could apply to any project involving the transportation of gas and have been managed for many years in the natural gas industry in very similar circumstances.

Once again, long-term liability for CO_2 leakage only applies to Ireland if CO_2 is stored here. Where CO_2 is being exported for storage in another country then the liability is with that country.

- **Potential funding options for this.**

Liabilities for CCS and how to manage them have been a long-standing issue and concern for the development of projects, particularly in the EU. To date no long-term insurance products or shared insurance pools across Member States supporting CCS have been developed. It is expected that the manner in which long-term liabilities associated with the risk of CO_2 leakage will be addressed may emerge over the next 2 – 3 years as Member State and European projects materialise.

There is a considerable body of research into the issue and challenges of liabilities for CCS development. Many of these reports highlight how liabilities can arise and also the low risk of actual leakage of CO_2 in a well-regulated and operated CO_2 storage site. Some reports with key points and excerpts have been included as below.

Global CCS Institute, Lessons and Perceptions: *Adopting a commercial approach to CCS liability*, 2019[114]

Some key points/excerpts include:

- *"Insurance policies are to be viewed as a key element in guarding against expenses and liabilities associated with injection and storage operations. The scope of this insurance will be necessarily broad and, in many instances, encompass the expense of complying with a regulator's directions with respect to clean-up, or to remedy the effects of a CO_2 escape.*
- *Operators seeking to undertake storage operations will be required to self-insure or seek third-party products, to address liabilities throughout the project lifecycle.*
- *Overall there is a low risk of leakage: A recent article, published in Nature Communications by* Alcalde *et al., discussed the findings of the Storage Security Calculator (SSC) that aims to determine the global security and longevity of geological CO_2 storage.*[115] *"For regional implementation of CO_2 storage in a realistically well-regulated industry, with a moderate density of legacy wells, our program calculates a 50% probability that more than 98% of the injected CO_2 will remain trapped in the subsurface over 10,000 years."*
- *The incorporation and recognition of CCS activities within a national or regional greenhouse gas trading scheme and the liabilities created, continue to be highlighted as problematic for operators and investors.*
- *Project proponents and insurers have similarly confirmed that there are still, currently no available 'off-the-shelf' insurance products to address these liabilities.*
- *One potential option considered to manage liabilities for a storage facility operator would be to cap an operator's liability, in line with the total financial gain received from the ETS scheme throughout the storage period of the project lifecycle.*
- *Respondents to questions from the Global CCS Institute suggested breaking the CCS process into its component parts and considering the likely liability and insurance implications for the capture, transport and storage aspects separately. When examining the CCS process in this manner, it was thought that the capture and transport elements would be considered relatively low-risk and underwriters would be confident in developing products to address them. Ultimately, the storage aspect of the process was considered perhaps the more problematic element to insure, particularly when considering the novel requirements of CCS-specific regulatory frameworks. Notwithstanding these reservations, representatives from the insurance sector offered a more prosaic outlook on the future development of CCS-specific products. It was thought that current uncertainties could be readily overcome and that the risks posed by CCS activities were far less significant than those of other industry sectors – many of which have been successfully insured for years. The expansion of the CCS industry would ultimately provide greater impetus*

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[114] https://www.globalccsinstitute.com/wp-content/uploads/2019/08/Adopting-a-Commercial-Appraoch-to-CCS-Liability_Thought-Leadership_August-2019.pdf

[115] https://aura.abdn.ac.uk/bitstream/handle/2164/10624/Estimating_geological_CO2_storage_security_to.pdf;sequence=1

to develop CCS-specific products. Further dialogue between insurers, project proponents and regulators, would be a critical factor in ensuring that fit-for-purpose products were made available.

- *A close and robust dialogue, between project proponents and regulators will prove essential as projects seek to navigate the regulatory process and management of CCS-specific liabilities."*

Financial precautions, carbon dioxide leakage, and the European Directive 2009/31/EC on carbon capture and storage (CCS), 2020[116].

Some key points/excerpts include:

- *"It should be noted that within the EU CO_2 Storage Directive the main condition enabling a transfer of responsibility is that "all available evidence indicates that the stored CO_2 will be completely and permanently contained (CCS Directive, Article 18(1))," which shall be demonstrated by the operator by reporting "the conformity of the actual behavior of the injected CO_2 with the modeled behavior, the absence of any detectable leakage", and by reporting "that the storage site is evolving towards a situation of long-term stability (CO_2 Storage Directive, Article 18(2)(a)&(b)&(c))." In other words – before the Member State takes over control and responsibility for a CO_2 storage site, the Developer/Operator must have demonstrated that there are no issues with that site including any leakage.*
- *This paper makes reference to the German and Hungarian approaches to financial precautions for CCS such that 3% to 6% of a CCS operator's emission-related revenues should be diverted into a financial precaution fund when the storage site is being operated to address climate-related costs, i.e., the costs to surrender emissions allowances at the time of CO_2 leakage.*
- *The intent behind Article 19 Financial Security (FS) of the CCS Directive is to ensure that the costs related to monitoring, safety, environmental and other obligations are covered and thus do not impose financial risks on the taxpayer if CCS operators are unable to fulfill these obligations. A combination of deposits, irrevocable trust funds, escrow accounts, payment or performance bonds, bank guarantees or letters of credit, EU emissions allowances, and insurance solutions were discussed as FS instruments.*
- *Notwithstanding the financial contribution (FC) must finance at least the anticipated cost of monitoring for a period of 30 years, FC amounts may be determined on basis of the full costs borne by the Competent Authority (CA) in the post-transfer period, accounting for (i) longer monitoring periods than 30 years, (ii) corrective measures, (iii) the surrender of allowances in the event of leakages.*
- *Hungary has set an amount of 200 million Hungarian Forint (HUF) as minimum FS, based on existing national regulation for mining (around €647,000). Germany specified in its CCS Act that the operator must pay 3% of the emissions-related revenues, i.e., the revenues that stem from the saved emissions certificates, at the end of each year into an interest-bearing deposit account."*

[116] https://link.springer.com/article/10.1007/s10584-020-02904-1

Different This Time? The Prospects of CCS in the Netherlands in the 2020s, May 2021[117].

Some key points/excerpts include:

- *"Liability for damages to the environment is dealt with by means of the Directive on Environmental Liability (Directive 2004/35/CE, 2004) and damage to health and property is dealt with at the Member State level.*
- *After closure all legal responsibilities for the site, including monitoring and corrective measures, can be transferred to the CA after a period of 20 years. However, this is only possible in the case where the CA is convinced the CO_2 is stored safely and a financial contribution by the operator has been made (Article 18). This includes a financial contribution for monitoring efforts for at least 30 years, which contribution lies between €1million and 10 million. Operators are therefore, at least for a period of 50 years, responsible for monitoring. After this period, the responsibility is taken over by governmental authorities. The Dutch Minister can moreover recover any costs resulting from a leakage from the permit holder beyond the 20 years in case the operators has not acted carefully (Article 31k under 5)."*

Areas for Additional Research

It is recommended that additional research is carried out to assess all financial aspects related to CCS for industry, low-carbon hydrogen and BECCS for indigenous and export storage options.

Financial Viability of CCS - Conclusions

- ✓ CCS could play a significant role in decarbonising Ireland via electricity, industry, low-carbon hydrogen and negative emissions (via BECCS).
- ✓ Based on an Enhanced LCOE basis, CCS is cheaper than onshore wind, offshore wind and solar energy by 2035.
- ✓ Subsidies for CCS would be heavily dependent on carbon price. As carbon price increases, less subsidies would be required.
- ✓ There is study evidence that deploying CCS to the electricity sector in Ireland would save c. €2.2bn versus the alternative of not utilising it.
- ✓ International experts agree that CCS would significantly reduce the cost of achieving net zero.
- ✓ A broad range of funding models for CCS are emerging as project developments progress across Norway, UK and the Netherlands.
- ✓ There would be no potential liabilities for Ireland for storage of CO_2 if the export option is used.

[117] https://www.frontiersin.org/articles/10.3389/fenrg.2021.644796/full

4. EU, National and Other Relevant Regulatory Issues

a. Identification of relevant existing and required regulatory frameworks

- **Further transposition of CCS Directive**
- **OSPAR Decisions 2007/1, 2007/2 and OSPAR Agreement 2007-12 and ongoing developments**
- **Environmental planning and permitting**
- **Mechanism to provide credit for CO_2 exports to emitter**
- **Transport of CO_2 by Ship (e.g. London Protocol issues)**
- **Long term leakage liability**
- **ETS legislative amendments if any; Environmental Liability legislative amendments; and other legislation (marine side) as listed at the first meeting of the Steering Group; and there may be other legislation e.g. IPPC and EIA**

In this section the regulatory framework for a potential CCS project is outlined as follows:

- EU and Other Regulatory Frameworks.
- Existing National Regulatory Framework.
- Required National Regulatory Framework.

Where the regulatory framework needs to be changed, or a new permitting system introduced, this is noted. A summary of consent regimes required for a potential CCS project with indigenous storage (offshore Ireland) and one with export storage is then presented. Please note that a high-level overview of key consents is presented, and further research would be required to identify all consents required.

This section ends with other topics referenced in the criteria, i.e.

- A mechanism to provide credit for CO_2 exports to emitter.
- ETS legislative amendments.
- Long term leakage liability.

EU and Other Regulatory Frameworks

1996 London Protocol[118] (relevant to Transport of CO_2 by ship)

The London Convention[119] was developed to control pollution of the sea by dumping and to encourage regional agreements supplementary to the Convention. It covers the deliberate

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118 https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/PROTOCOLAmended2006.pdf

119 https://www.gc.noaa.gov/documents/gcil_lc.pdf

disposal at sea of wastes or other matter from vessels, aircraft, and platforms. It does not cover discharges from land-based sources such as pipes and outfalls, wastes generated incidental to normal operation of vessels, or placement of materials for purposes other than mere disposal, providing such disposal is not contrary to aims of the Convention.

The 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (the 1996 London Protocol) effectively replaced the 1972 London Convention by requiring a precautionary, preventive and risk management approach, with the parties agreeing to move from controlled dispersal at sea of a variety of land-generated wastes towards integrated land-based solutions for most, and controlled sea disposal of few, remaining categories of wastes or other matter. The Protocol prohibits dumping of wastes or other matter at sea and in the sub-seabed except those specified in its Annex 1, and these require permitting with extensive impact assessments, conditions and monitoring. Examples of wastes or other matter which may be dumped include dredged material, fish waste, inert, inorganic geological material.

Ireland is a contracting party to the 1996 London Protocol.

In 2006, the Contracting Parties to the 1996 London Protocol adopted amendments to the Protocol. The 2006 amendment provided for the disposal of CO_2 streams in sub-seabed geological formations. This amendment allows and regulates the storage of CO_2 streams from CO_2 capture processes in geological formations under the seabed.

Prior to the 2009 amendment, Article 6 of the Protocol stated that "*Contracting Parties shall not allow the export of wastes or other matter to other countries for dumping or incineration at sea*." Article 6 was amended by the addition of the following text:

"*2 Notwithstanding paragraph 1, the export of carbon dioxide streams for disposal in accordance with Annex 1 may occur, provided that an agreement or arrangement has been entered into by the countries concerned. Such an agreement or arrangement shall include:*

- *2.1 confirmation and allocation of permitting responsibilities between the exporting and receiving countries, consistent with the provisions of this Protocol and other applicable international law; and*
- *2.2 in the case of export to non-Contracting Parties, provisions at a minimum equivalent to those contained in this Protocol, including those relating to the issuance of permits and permit conditions for complying with the provisions of annex 2, to ensure that the agreement or arrangement does not derogate from the obligations of Contracting Parties under this Protocol to protect and preserve the marine environment.*

A Contracting Party entering into such an agreement or arrangement shall notify it to the Organization."

In October 2019, the London Protocol Parties at their annual meeting (LC41/LP14) approved a Resolution for Provisional Application of the 2009 CCS Export Amendment. This Provisional Application allows countries to agree to export and receive CO_2 for offshore geological storage provided there is a bilateral agreement between both the exporting and importing countries. This means that CO_2 can be transported across international borders to offshore storage. The Netherlands, Norway and the UK prepared this proposal.[120]

London Protocol applies to the export storage option only.

OSPAR Convention[121]

The Oslo Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft (1972) was developed to control the dumping of harmful substances from ships and aircraft into the sea. It covered parts of the Atlantic and Arctic Oceans. The Convention prohibited the dumping at sea of a variety of waste materials including substances considered to be 'persistent' or carcinogenic. It applied restrictions and required a permit for the dumping of a variety of substances, metals and bulky wastes, and defined the considerations to be made by each State in the issuing of dumping permits.

The Oslo Convention was broadened by the Paris Convention for the Prevention of Marine Pollution from Land-Based Sources of 1974. This Convention outlined measures to control the pollution of the sea from land-based sources, namely rivers, pipes or structures, to further protect the marine environment from pollution.

The OSPAR Convention, concluded in 1992, combines and updates the Oslo and Paris Conventions.

The EU and Ireland are contracting parties to the OSPAR Convention.

In 2007 the Contracting Parties to the OSPAR Convention adopted amendments to the Annexes to the Convention to allow the storage of CO_2 in geological formations under the seabed, a Decision to ensure environmentally safe storage of CO_2 streams in geological formations, and OSPAR Guidelines for Risk Assessment and Management of that activity[122]. They also adopted a Decision to prohibit placement of CO_2 into the water-column of the sea and on the seabed, because of the potential negative effects.

EU CO_2 Storage Directive

EU Directive 2009/31/EC established a legal framework for the environmentally safe geological storage of CO_2. The directive applies to a storage capacity of greater than 100Kt. The directive provides for the establishment of a permitting regime for the exploration, to identify geological storage sites, and for the operation of geological storage sites. The permitting requirement does not extend to the carbon capture installation or the pipeline network, which transports the CO_2 to the storage site.

In Article 3.3, storage site is defined as:

"*'storage site' means a defined volume area within a geological formation used for the geological storage of CO_2 and associated surface and injection facilities;*"

[120] https://ieaghg.org/ccs-resources/blog/positive-result-on-the-london-protocol-s-ccs-export-amendment

[121] Sintra Statement Paper (ospar.org)

[122] https://www.ucl.ac.uk/cclp/pdf/OSPAR2007-Annex-4.pdf

Article 5.1 states:

“*Where Member States determine that exploration is required to generate the information necessary for selection of storage sites pursuant to Article 4, they shall ensure that no such exploration takes place without an exploration permit.*

“Where appropriate, monitoring of injection tests may be included in the exploration permit.”

Article 6.1 states:

“*Member States shall ensure that no storage site is operated without a storage permit, that there shall be only one operator for each storage site, and that no conflicting uses are permitted on the site*.”

Environmental Impact Assessment Directive (2011/92/EU[123] amended by Directive 2014/52/EU[124])

A directive for Environmental Impact Assessment (EIA) has been in force since 1985, with the adoption of Council Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment. The EIA directive of 1985 was amended three times. It was ultimately codified and repealed by Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment. This directive was amended in 2014 by Directive 2014/52/EU.

In summary, the Directive applies to a wide range of public and private projects which are listed in Annex I and II, as follows:

- EIA is mandatory for all projects listed in Annex I. These projects are considered as having significant effects on the environment and require an EIA; and
- Projects where the discretion of Member States applies. These projects are listed in Annex II. For these projects the Member State may set thresholds/criteria for the requirement for an EIA or decide on a case-by-case examination. Authorities are required to consider the criteria laid down in Annex III as part of this process.

Annex I includes:

“*16. Pipelines with a diameter of more than 800 mm and a length of more than 40 km:*

(a) for the transport of gas, oil, chemicals;

(b) for the transport of carbon dioxide (CO_2) streams for the purposes of geological storage, including associated booster stations.”

“22. Storage sites pursuant to Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide.

[123] Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment (codification)

[124] Directive 2014/52/EU of The European Parliament and of the Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment

23. Installations for the capture of CO_2 streams for the purposes of geological storage pursuant to Directive 2009/31/EC from installations covered by this Annex, or where the total yearly capture of CO_2 is 1,5 megatonnes or more."

Annex II includes:

"*3. Energy Industry*

(j) Installations for the capture of CO_2 streams for the purposes of geological storage pursuant to Directive 2009/31/EC from installations not covered by Annex I to this Directive."

Habitats Directive (92/43/EEC) and Birds Directive (2009/147/EC)

EU Directive 92/43/EEC on the Conservation of natural habitats and of wild flora and fauna, as amended by Directive 97/62/EC, commonly known as 'the Habitats Directive', was adopted in 1992 and has become the single most important piece of legislation governing the conservation of biodiversity in Europe. The main aim of the Habitats Directive is to achieve and maintain favourable conservation status for habitats and species which are considered at risk. This is to be achieved by designating key sites as 'Special Areas of Conservation' (SACs), and by introducing protective measures for species considered at risk.

Directive 2009/147/EC on the conservation of wild birds, known as the 'Birds Directive', seeks to protect, manage and regulate all bird species naturally living in the wild including their eggs, nests and habitats, and to regulate the exploitation of these species. Special measures for the protection of habitats are adopted for certain bird species identified by the Directives (Annex I) and migratory species and the Directive establishes a network of Special Protection Areas (SPAs) to protect migratory species and species which are rare, vulnerable, in danger of extinction, or otherwise require special attention.

SACs and SPAs form a pan-European network of protected sites known as Natura 2000 sites. The Habitats Directive sets out a unified system for the protection and management of SACs and SPAs. Article 6(3) and 6(4) of the Directive set out key elements of the system of protection including the requirement for Appropriate Assessment of plans and projects as follows:

Article 6(3): "*Any plan or project not directly connected with or necessary to the management of the site but likely to have a significant effect thereon, either individually or in combination with other plans or projects, shall be subject to appropriate assessment of its implications for the site in view of the site's conservation objectives. In the light of the conclusions of the assessment of the implications for the site and subject to the provisions of paragraph 4, the competent national authorities shall agree to the plan or project only after having ascertained that it will not adversely affect the integrity of the site concerned and, if appropriate, after having obtained the opinion of the general public.*"

Article 6 (4): "*If, in spite of a negative assessment of the implications for the site and in the absence of alternative solutions, a plan or project must nevertheless be carried out for imperative reasons of overriding public interest, including those of a social or economic nature, the Member State shall take all compensatory measures necessary to ensure that the overall coherence of Natura 2000 is protected. It shall inform the Commission of the compensatory measures adopted*".

Industrial Emissions Directive 2012/75/EU[125]

The Industrial Emissions Directive lays down rules on integrated prevention and control of pollution arising from industrial activities. It also lays down rules designed to prevent or, where that is not practicable, to reduce emissions into air, water and land and to prevent the generation of waste, in order to achieve a high level of protection of the environment, taken as a whole. For the industrial installations, combustion plants, incineration plants and co-incineration plants, to which the Directive applies, member states must implement a permitting regime. The activities, which must be subject to the permitting regime, are listed in Chapters II to VI of the Directive. Annex 1 lists the industrial activities which are covered by Chapter II of the directive. These include

"*4.2. Production of inorganic chemicals, such as:*

(a) gases, such as ammonia, chlorine or hydrogen chloride, fluorine or hydrogen fluoride, carbon oxides, sulphur compounds, nitrogen oxides, hydrogen, sulphur dioxide, carbonyl chloride;"

"*6.9. Capture of CO_2 streams from installations covered by this Directive for the purposes of geological storage pursuant to Directive 2009/31/EC*"

Waste Framework Directive 2008/98/EC[126]

The Waste Framework Directive has been effective since 12 December 2010. The new Directive repealed the codified Directive 2006/12/EC on Waste, the Hazardous Waste Directive (91/689/EEC) and the Waste Oils Directive (75/439/EEC). The Waste Framework Directive was amended by Directive 2015/1127/EU.

The Directive seeks to include in Community legislation the provisions of the Basel Convention, sets out the basic concepts and definitions related to waste management, and lays down the following waste management principles:

- The 'polluter pays principle' which requires costs of waste management to be borne by the original waste producer or by current or previous waste holders; and
- The 'waste hierarchy' which is a five-step hierarchy of waste management options which must be applied by Member States when developing their national waste policies, as follows:
  - Waste prevention (preferred option)
  - Re-use
  - Recycling
  - Recovery (including energy recovery), and
  - Safe disposal, as a last resort.

The Directive defines 'waste' as "*any substance or object which the holder discards or intends or is required to discard*" (Article 3 (1)). The Directive also has the concept of by-product and end-of-waste.

[125] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (Recast)
[126] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

The European Commission has produced guidance on the interpretation of the concepts in the Waste Framework Directive[127].

The guidance states that:

"*The CJEU has recognised a need for flexibility in adopting a case-by-case approach as well as a need to consider all the specific factual circumstances involved. Furthermore, the Court has held that in view of the aims and objectives pursued by the WFD, the concept of waste cannot be interpreted restrictively.*

The following non-exhaustive clarifications regarding the concept of discarding were provided by the CJEU:

- *Discard applies to both recovery and disposal of waste. However, it should be noted that this does not mean that any substance which undergoes a recovery/disposal operation as listed in the WFD Annexes is waste per se, but it might be regarded as evidence for being waste;*
- *Discard can involve a positive, neutral, or negative commercial value. No distinction is made based on whether the substance/object is marketable or not;*
- *Discard can be intentional/deliberate on the part of the holder or unintentional / involuntary / accidental (see also 1.1.2.4 below) or even can occur with or without the knowledge of the holder;*
- *The storage location of a material does not influence whether it is a waste or not.*

It must be noted that no single factor or indicator is conclusive. It is always necessary to consider all the circumstances. Hence, none of the examples provided in the following paragraphs are intended to take precedence over real-life cases, since the circumstances of those cases may lead to other results.

1.1.2.2 Practical examples for the three alternatives of 'discarding'
Discard:

- *An item is thrown into a waste bin;*
- *A company transfers material to a waste collector.*

Intention to discard:

- *In its decommissioning plan in the event of future closure, an operating site indicates that it will send off-site for appropriate disposal or recovery any of its stock of raw materials that cannot be returned;*
- *The holder of leftover quarried stone which has been stored for an indefinite length of time to await possible use discards or intends to discard that leftover stone'.*

Requirement to discard:

- *Any oil containing PCBs above 50 ppm must be discarded under the provisions of EU PCB/PCT Directive 96/59/EC and is therefore to be considered waste;*
- *Stockpiles of banned pesticides must be discarded and therefore be managed as waste.*"

The long-term storage of CO_2 for an indefinite period may be regarded as a waste activity. Article 23 of the Directive specifies that Member States shall require any establishment or

[127] Guidance on the interpretation of key provisions of Directive 2008/98/EC on waste (EC June 2013)

undertaking intending to carry out waste treatment to obtain a permit from the competent authority. Treatment is defined in Article 3 (14) as *"recovery or disposal operations, including preparation prior to recovery or disposal".*

Decision 2000/532/EC establishing a list of wastes was amended by Commission Decision 2014/955/EU. This Decision establishes the classification system for wastes, including a distinction between hazardous and non-hazardous wastes, and is linked to Annex III of the Waste Framework Directive, as amended.

Regulation 1013/2006 on Shipments of Waste[128]

Regulation 1013/2006 on shipments of waste (as amended) establishes procedures and control regimes for the shipment of waste, depending on the origin, destination and route of the shipment, the type of waste shipped and the type of treatment to be applied to the waste at its destination. The regulation specifies the conditions under which waste can be shipped between/through Member States and to or from other countries. Its aim is to strengthen and simplify procedures for controlling waste shipments to improve environmental protection and reduce the risk of uncontrolled shipments. The Regulation addresses all types of wastes, with the exception of radioactive waste or waste types subject to separate control regimes, and reduces the number of waste shipment control procedures from three to two as follows:

- The 'Green listed' procedure applies to non-hazardous waste intended for recovery; and
- The 'Amber list' notification procedure applies to shipments of all waste, intended for disposal, and hazardous waste intended for recovery.

The long-term storage of CO_2 for an indefinite period may be regarded as a waste activity. In which case, this regulation would apply to any shipment of waste.

Environmental Liability Directive 2004/35/EC[129]

Directive 2004/35/EC, known as the 'Environmental Liability Directive,' was adopted in 2004. It establishes a framework for environmental liability based on the 'polluter pays' principle, with a view to preventing and remedying environmental damage.

The Environmental Liability Directive was amended four times through Directive 2006/21/EC on the management of waste from extractive industries, Directive 2009/31/EC on the geological storage of CO_2 and amending several directives, Directive 2013/30/EU on safety of offshore oil and gas operations and amending Directive 2004/35/EC, and through Regulation (EU) 2019/1010 on the alignment of reporting obligations in the field of legislation related to the environment. The amendments broadened the scope of strict liability by adding the "*management of extractive waste*" and the "*operation of storage sites pursuant to Directive 2009/31/EC*" to the list of dangerous occupational activities in Annex III of the Environmental Liability Directive. The Offshore Safety Directive, containing an amendment to the Environmental Liability Directive (extension of the scope of damage to

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[128] Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste

[129] Directive 2004/35/EC on environmental liability with regard to the prevention and remedying of environmental damage

marine waters), was adopted in June 2013. The Reporting Alignment Regulation adapted the reporting requirements to the need to create a better evidence base.

Under the terms of the Directive, environmental damage is defined as:

- Direct or indirect damage to the aquatic environment covered by Community water management legislation; and
- Direct or indirect damage to species and natural habitats protected at Community level by the Birds Directive or by the Habitats Directive; and
- Direct or indirect contamination of the land which creates a significant risk to human health.

Article 3 specifies:

"*1. This Directive shall apply to:*

(a) environmental damage caused by any of the occupational activities listed in Annex III, and to any imminent threat of such damage occurring by reason of any of those activities;

(b) damage to protected species and natural habitats caused by any occupational activities other than those listed in Annex III, and to any imminent threat of such damage occurring by reason of any of those activities, whenever the operator has been at fault or negligent."

The activities listed in Annex III, as amended, include:

"*14. The operation of storage sites pursuant to Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide*"

The 'polluter pays' principle makes an operator that causes environmental damage legally and financially liable for the damage caused and subsequent remediation. It also affords the opportunity to put right environmental damage in a civil framework thereby avoiding the need for a criminal prosecution.

Environmental damage may be remedied in different ways depending on the type of damage:

- For damage affecting the land, the Directive requires that the land concerned be decontaminated until there is no longer any serious risk of negative impact on human health; and
- For damage affecting water or protected species and natural habitats, the Directive is aimed at restoring the environment to how it was before it was damaged. For this purpose, the damaged natural resources or impaired services must be restored or replaced by identical, similar or equivalent natural resources or services either at the site of the incident or, if necessary, at an alternative site.

COMAH III (Seveso III) Directive

Directive 2012/18/EU on the control of major-accident hazards involving dangerous substances is referred to as the COMAH III or Seveso III Directive.

The Directive applies to establishments, in which the dangerous substances, listed in the Directive, are stored in quantities which equal or exceed the specified thresholds. In addition to the quantities of named substances, the quantities of substances, which fall into certain hazard categories, are summed to determine if an establishment falls under the Directive. There are two classes of establishment, upper tier and lower tier.

The Directive specifies the general duties, and the requirements for notification and the preparation of major accident prevention plans and safety reports, which must be imposed by Member States on the operators of the establishments, to which the Directive applies.

The Directive does not apply to the transport of dangerous substances by road, rail, internal waterways, sea or air, or pipeline, or to the underground offshore storage of 'gas' (type of gas not specified).

The installation for carbon capture may include the storage of dangerous substances and may be an establishment to which the Directive applies.

Existing National Regulatory Framework

Industrial Emissions Licence

The industrial emissions directive 2012/75/EU was transposed into Irish law by the Environmental Protection Agency Act, 1992, as amended, and associated regulations. Part IV of the Act requires the activities listed in the First Schedule of the Act to have a licence in order to operate.

Carbon capture for the purposes of geological storage is listed in the First Schedule of the Environmental Protection Agency Act 1992, as amended. An activity which captures CO_2 , for the purposes of geological storage, requires an industrial emission licence in order to operate.

"*13.5 The capture of CO_2 streams from installations to which Part IV applies for the purposes of geological storage pursuant to Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide.*"

The Environmental Protection Agency is the competent authority for industrial emissions licensing.

Environmental Impact Assessment

The EIA Directive is implemented in Irish law through the Local Government Planning and Development Act, 2000 (No. 30 of 2000), as amended, and associated regulations, including the Planning and Development Regulations, 2001 (S.I. No. 600 of 2001), as amended and the European Commission (Environmental Impact Assessment) Regulations (S.I. 349 of 1989), as amended. The European Communities (Environmental Impact Assessment) Regulations 1989 were the regulations which transposed the original EU environmental impact assessment directive into Irish legislation.

Section 176 of the Planning and Development Act 2000, as amended, provides that any reference in an enactment to the classes of development specified under Article 24 of European Communities (Environmental Impact Assessment) Regulations 1989 (S.I. No. 349 of 1989) shall be deemed to be a reference to a class of development prescribed under that section. Section 176 has the effect that the classes of development, requiring an environmental impact assessment under a range of legislation, such as the Gas Act 1976, the Petroleum and Other Minerals Developments Act 1960 and the EPA Act 1992, are the same as the classes under the Planning and Development Act 2000, as amended.

The classes of development which require an environmental impact assessment are specified in Section 172 of the Planning and Development Act 2000, as amended. The classes of development, listed in Parts 1 and 2 of Schedule 5 of the Planning and

Development Regulations 2001, as amended, and developments which would not exceed the thresholds specified in Schedule 5, but which would be likely to have significant effects on the environment, require an environmental impact assessment.

Classes 16, 22 and 23 in Part 1 of Schedule 5 are relevant to a CCS project:

"*16 "Pipelines with a diameter of more than 800mm and a length of more than 40km:*

— for the transport of gas, oil, chemicals, and,

— for the transport of carbon dioxide (CO_2) streams for the purposes of geological storage, including associated booster stations."

"*22. Storage sites pursuant to Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide".*

"23. Installations for the capture of CO_2 streams for the purposes of geological storage pursuant to Directive 2009/31/EC from installations covered by this Part, or where the total yearly capture of CO_2 is 1.5 megatonnes or more."

Classes 3(k) and 10(i) of Part 2 of Schedule 5 are also relevant to a potential CCS project.

"*3(k) Installations for the capture of CO_2 streams for the purposes of geological storage pursuant to Directive 2009/31/EC from installations not covered by Part 1 of this Schedule."*

"10(i) Oil and gas pipeline installations and pipelines for the transport of CO_2 streams for the purposes of geological storage (projects not included in Part 1 of this Schedule)."

Schedule 5 does not distinguish between onshore and offshore pipelines or works.

Installations for the capture of CO_2, pipelines for the transport of CO_2 and geological storage sites for CO_2 are specified as classes of development requiring an environmental impact assessment. Consequently, no element of a CCS development, which will involve works or a material change of use, is exempted from the requirement to obtain planning permission.

It is noted that the Large Combustion Plants Regulations 2010, S.I. 371 of 2010, make provision for carbon capture on sites of combustion plants of 300MW or more. In considering whether to grant a licence to such an activity, the EPA must ensure that the applicant undertakes an assessment to determine if

i. "suitable storage sites are available;
ii. transport facilities are technically and economically feasible; and
iii. it is technically and economically feasible to retrofit for CO_2 capture."[130]

If these conditions are met, the EPA must ensure that suitable space on the installation site for the equipment necessary to capture and compress CO_2 is set aside.

Appropriate Assessment under the Habitats Directive

The Habitats Directive and the Birds Directive are transposed into Irish law by the Wildlife Acts 1976 – 2010, the European Communities (Birds and Natural Habitats) Regulations,

[130] Article 4 of S.I. 371 of 2010

2011 (S.I. No. 477 of 2011), as amended. This legislation provides the legislative framework for the establishment of Natura 2000 sites in Ireland.

Developments, for which a statutory consent is sought, must be screened by the competent authority, on a case-by-case basis, for the requirement for an appropriate assessment (of the effects on a European site, which is a site designated under the Habitats Directive 92/42/EEC or Birds Directive 2009/147/EC). The requirement applies to a very wide range of statutory consents, not just planning consent. There is no list of developments or activities which require assessments.

Foreshore Licence

Under the Foreshore Acts[131], the 'Foreshore' means the bed and shore, below the line of high water of ordinary or medium tides, of the sea and of every tidal river and tidal estuary and of every channel, creek, and bay of the sea or of any such river or estuary. The outer limit of the Foreshore is the 12 nautical mile limit of the territorial seas.

A foreshore consent - a lease or licence - is required by any person proposing to place any material or to place or erect any articles, things, structures, or works in or on foreshore or to get and take any minerals in foreshore or to use or occupy foreshore for any purpose unless exempt under other legislation or due to existing rights.

Any part of a potential CCS project, which is to be located on the Foreshore, would require a Foreshore consent. The Foreshore Section of the Department of Housing, Local Government and Heritage is the competent authority under the Foreshore Acts.

The consent regime under the Foreshore Acts is due to be replaced by a new marine area consent regime, which is outlined in the Maritime Area Planning Bill published in 2021. The Maritime Area Planning Bill is described later.

Continental Shelf Act

The continental shelf is the area of sea and seabed between the 12 nautical mile limit (the outer limit of the foreshore) and the 200 nautical mile limit. An offshore CCS project may involve installing or altering objects or material on and under the seabed of the continental shelf.

The Continental Shelf Act no 14 of 1968 is the legislative regime which applies to the continental shelf.

The Continental Shelf Act 1968 was amended by article 5 of the Energy Miscellaneous Provisions Act no 35 of 1995. Section 2 of the 1968 Act, as amended, imposes the requirement to obtain consent from the Minister for the Marine to "*construct, alter or improve any structure or works in or remove any object or material from a designated area*."

The Continental Shelf Designated Areas Order 1993 S.I. 92 of 1993 defines the 'designated area' as follows: "*The area set out in paragraph 1 of the Schedule to this Order is hereby designated as an area within which the rights of the State outside the territorial seas over the sea bed and subsoil for the purpose of exploring such sea bed and subsoil*

[131] Foreshore Acts no. 12 of 1933, no. 17 of 1992, no. 54 of 1998, no. 11 of 2011

and exploiting their natural resources are exercisable." The Schedule provides a list of points, defined by latitude and longitude, to specify the Irish Continental Shelf.

The Geoscience Regulatory Office of the Department of the Environment, Climate and Communications is the competent authority under the Continental Shelf Act, as amended.

The consent regime under the Continental Shelf Act is due to be replaced by a new marine area consent regime, which is outlined in the Maritime Area Planning Bill published in 2021. The Maritime Area Planning Bill is described later.

Environmental Liability Directive

The Environmental Liability Directive (2004/35/EC) has been transposed into Irish law through the European Communities (Environmental Liability) Regulations[132], 2008 and subsequent amendments[133]. The regulations apply to the activities listed in Schedule 3. Schedule 3 was amended by S.I. 307 of 2011 with the inclusion of the operation of storage sites pursuant to Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide. The definition of water damage was amended by S.I. 293 of 2015 to include the environmental status of marine waters.

The EPA is the competent authority under the regulations.

COMAH (Seveso) III

The Chemicals Act (Control of Major Accident Hazards Involving Dangerous Substances) Regulations, S.I. 209 of 2015, implement the Seveso III Directive.

The Regulations apply to establishments, in which the dangerous substances, listed in the Regulations, are stored in quantities which equal or exceed the thresholds specified in the Regulations. In addition to the quantities of named substances, the quantities of substances, which fall into certain hazard categories, are summed to determine if an establishment falls under the Regulations. There are two classes of establishment, upper tier and lower tier.

The Directive does not apply to the transport of dangerous substances by road, rail, internal waterways, sea or air, or pipeline, or to the underground offshore storage of 'gas' (type of gas not specified).

The installation for carbon capture may include the storage of dangerous substances and may be an establishment to which the Regulations apply.

The Health and Safety Authority (HSA) is the competent authority for regulatory control of sites to which the Directive 2012/18/EU, applies.

Waste Management

The provisions of the Waste Framework Directive have been transposed into Irish Law through the Waste Management Act, 1996 (No. 10 of 1996) 'as amended' and associated regulations. The legislation on the classification of waste was consolidated in Ireland by the Environmental Protection Agency through the publication of the document entitled 'Waste

[132] S.I. 547 of 2008 European Communities (Environmental Liability) Regulations 2008

[133] S.I.307 of 2011 European Communities (Environmental Liability) (Amendment) Regulations 2011 and S.I. 293 of 2015 European Communities (Environmental Liability) (Amendment) Regulations 2015

Classification - List of Waste and Determining if Waste is Hazardous or Non-hazardous'[134]. For the waste activities, which are listed in First Schedule of the Environmental Protection Agency Act 1992, the requirement, under the Waste Framework Directive, for a permit, is met by an industrial emissions licence. If CCS was deemed a waste activity, an industrial emissions licence would meet the Waste Framework Directive requirements.

Transport of CO_2 Overseas for Export Storage

Regulation 1013/2006 on shipments of waste was transposed into Irish legislation by the Waste Management (Shipments of Waste) Regulations, 2007 (S.I. No. 419 of 2007). If the captured CO_2 was determined to be a waste and was to be shipped overseas, the aforementioned Waste Regulations would apply.

Required National Regulatory Framework

Permit(s) under Directive 2009/31/EC for the Geological Storage of Carbon Dioxide

A permitting regime for exploration for and operation of geological storage of CO_2 is not in place in Ireland. It would need to be established before indigenous CO_2 storage could proceed.

The permitting regime specified by the Directive covers approval of the physical properties of the storage site but does not appear to cover the construction works and the installation of equipment required to establish the geological storage site. A permitting regime would also be required for these.

European Communities (Geological Storage of Carbon Dioxide) Regulations 2011 (S.I. No. 575 of 2011)

Ireland is one of several countries that have applied at least temporary restrictions on CO_2 geological storage. The European Communities (Geological Storage of Carbon Dioxide) Regulations 2011[135] (S.I. No. 575 of 2011) transpose Directive 2009/31/EC into Irish legislation.

Section 4 of the Regulations, Selection of Storage Sites, prohibits storage of CO_2 in amounts greater than 100,000 tonnes.

"*Section 4: Selection of Storage Sites*

4(1) The storage of CO_2 in a storage site in part or in the whole of the area referred to in Regulation 3(2) is not permitted.

(2) The storage of CO_2 in a storage site with a storage complex extending

beyond the area referred to in Regulation 3(2) is not permitted.

(3) The storage of CO_2 in the water column is not permitted."

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[134] https://www.epa.ie/publications/monitoring--assessment/waste/national-waste-statistics/2019--FULL-template.pdf

[135] Department of Communications, Energy and Natural Resources, European Communities (Geological Storage of Carbon Dioxide) Regulations 2011. DCENR, 18/11/2011, Dublin.

Regulation 3(2) states:

"*These Regulations apply to the geological storage of CO_2 in the territory of the State, its exclusive economic zone and on its continental shelf within the meaning of the United Nations Convention on the Law of the Sea.*"

The explanatory note accompanying this Statutory Instrument, recognises the potential value of CCS and states that the restriction will be kept under active review.

"*CCS is a new, emerging and valuable technology with significant potential as a mitigation technique for carbon emissions. Ireland considers it appropriate to await developments and progress by key players in this field, and the more advanced Member States who have committed substantial resources both financial and human to the implementation of the regulatory framework underpinning this technology.*

Accordingly, Ireland has exercised its right, in accordance with Article 4 of the Directive, not to allow for any storage in part or in the whole of the State and therefore there is currently no area of Irish territory that would be free to be used for CO_2 storage. However, this issue will be kept under active review."

The regulation is still in place.

European Communities (Geological Storage of Carbon Dioxide) (Amendment) Regulations, S.I. 279 of 2014

The 2011 regulations were amended by the European Communities (Geological Storage of Carbon Dioxide) (Amendment) Regulations SI 279 of 2014. The 2014 regulations amend article 4 of the 2011 regulations by inserting a new article 4A. However, the prohibition on the storage of CO_2 in article 4 of the 2011 regulations is not removed. Article 6 of the 2014 regulations has the effect of making the Commission for Regulation of Utilities the competent authority with respect to the 2011 and 2014 regulations.

Consent to Construct and Operate a Pipeline Transporting CO_2

The Gas Act 1976, as amended, defines natural gas as follows:

"*'natural gas' means any gas derived from natural strata (whether or not it has been subjected to liquification or any other process or treatment) and in this Act, a reference to natural gas may also be construed as including, where the Commission considers it appropriate and where, in the opinion of the Commission, such gas may be technically and safely injected into, and transported through, the natural gas system, biogas, gas from biomass and other types of gas"*[136].

The Gas Act does not apply to CO_2. Currently there is no consent regime in place to regulate the construction and operation of a pipeline transporting CO_2.

The consent process under the Gas Act 1976, as amended, provides for an application for consent to construct and operate such a pipeline, subject to the requirement for an environmental assessment and appropriate assessment (of effects on Natura 2000 sites) in

[136] Substituted by European Communities (Internal Market in Natural Gas) (No. 2) Regulations 2004, S.I. 452 of 2004, section 4

certain circumstances. It also provides for powers to enter land to undertake surveys and for compulsory acquisition of wayleaves, subject to certain conditions.

The Commission for Regulation of Utilities is the competent authority under the Gas Act 1976, as amended, for downstream gas pipelines. The Department of the Environment, Climate and Communications is the competent authority for upstream gas pipelines.

A regime similar to the consent process under the Gas Act 1976, as amended, would be required for CO_2 pipelines. It would be difficult to design and construct a new CO_2 pipeline in the absence of the power to enter land to undertake surveys and to acquire wayleaves compulsorily.

Safety Regulation of Operation of the CCS Project

The Petroleum (Exploration and Extraction) Safety Acts 2010 and 2015 established a regulatory regime for petroleum activity owners and operators. In the Acts the definition of petroleum is very broad but does not include CO_2 captured in an industrial process which is not linked to a petroleum production process.

Under the Acts a person shall not carry on a designated petroleum activity without a permit. The Acts impose general duties on petroleum owners and operators, including that the activity shall be designed, constructed and operated in such a manner as to reduce any risk to safety to a level that is as low as reasonably practicable. The petroleum operator must prepare a safety case.

The Commission for the Regulation of Utilities (CRU) is the competent authority for the Petroleum (Exploration and Extraction) Safety Acts 2010 and 2015.

It is expected that a regime for the regulation of safety in the design, construction and operation of CCS projects, similar to that in place under the Petroleum (Exploration and Extraction) Safety Acts 2010 and 2015, may be established.

Planning on Land

Strategic Infrastructure Act - Seventh Schedule Development

The sections 37A to 37E of the Planning and Development Act 2000, as amended, make provision for certain developments, which are of a class listed in the Seventh Schedule of the Act, and which satisfy at least one of the three conditions listed in paragraph (a), (b) or (c) of section 37A(2) of the Act, to be classed as strategic infrastructure developments. The planning application for a strategic infrastructure development is made directly to An Bord Pleanála, with the Local Authority as a consultee.

CCS is not listed in the Seventh Schedule of the Act as a potential strategic infrastructure development.

Strategic Infrastructure Act - Strategic Gas Infrastructure

Sections 182C to 182E of the Planning and Development Act 2000, as amended, make provision for strategic gas infrastructure developments. Planning applications for strategic gas infrastructure, which An Bord Pleanála (ABP) is satisfied meets at least one of the three conditions listed in paragraphs (a), (b) or (c) of section 37A(2) of the Act, are to be made directly to ABP, with the Local Authority as a consultee.

Section 2 of the Planning and Development Act 2000, as amended, provides the following definitions:

"*'strategic gas infrastructure development' means any proposed development comprising or for the purposes of a strategic downstream gas pipeline or a strategic upstream gas pipeline, and associated terminals, buildings and installations, whether above or below ground, including any associated discharge pipe;*"

"*'strategic downstream gas pipeline' means any proposed gas pipeline, other than an upstream gas pipeline, which is designed to operate at 16 bar or greater, and is longer than 20 kilometres in length;*"

"*'strategic upstream gas pipeline' means so much of any gas pipeline proposed to be operated or constructed—*

(a) as part of a gas production project, or

(b) for the purpose of conveying unprocessed natural gas from one or more than one such project to a processing plant or terminal or final coastal landing terminal,

as will be situated in the functional area or areas of a planning authority or planning authorities;"

The three conditions listed in paragraphs (a), (b) or (c) of section 37A(2) of the Act are:

"*(a) the development would be of strategic economic or social importance to the State or the region in which it would be situated,*

(b) the development would contribute substantially to the fulfilment of any of the objectives in the National Spatial Strategy or in any regional spatial and economic strategy in force in respect of the area or areas in which it would be situated,

(c) the development would have a significant effect on the area of more than one planning authority."

The definitions of strategic gas infrastructure development and strategic downstream gas pipeline refer to 'gas', rather than 'natural gas', and thus potentially include development for gaseous CO_2. However, the procedures to be followed, set out in Sections 182C to 182E of the Act, when making an application for a strategic gas infrastructure development, refer to provisions of the Gas Act 1976, as amended.

Sections 182C to 182E of the Planning and Development Act 2000, as amended, would need to be amended to cover a CCS project. Under the Act, as it is currently, the developer of a CCS project would make a planning application to the relevant county council, since the development would not be strategic infrastructure.

The offshore elements of a CCS project are likely to fall under the Maritime Area Planning Bill.

Maritime Area Planning Bill[137]

The Maritime Area Planning Bill and explanatory memorandum were published in 2021. The new planning regime will operate in the maritime area that will extend from the high-

[137] https://data.oireachtas.ie/ie/oireachtas/bill/2021/104/eng/memo/b10421d-memo-1.pdf

water mark to the outer limit of Ireland's continental shelf and include the territorial seas and the Exclusive Economic Zone, thus covering the Foreshore and continental shelf. The new regime will establish a new agency Maritime Area Regulatory Authority (MARA) to undertake certain consenting and enforcement functions.

A primary focus of the Maritime Area Planning Bill is to establish a statutory marine spatial policy framework for the maritime area, which would have a similar status, in the consent process, to the County Development Plans and Regional Economic and Spatial Strategies on land.

The national marine forward planning framework aspect of the bill includes:

- Restatement of and additions to the marine forward planning provisions of the 2018 Planning and Development (Amendment) Act that will apply to future iterations of the National Marine Planning Framework.
- Providing a statutory basis for the Marine Planning Policy Statement.
- Making a Public Participation Statement a mandatory requirement in the preparation of all Marine Spatial Plans.
- Provision for sub-national planning: Designated Maritime Area Plans (DMAPs). A designated competent authority may develop a DMAP for a region, sector or locality.
- The establishment of a Maritime Authorisation Database to ensure visibility of all consents in the maritime area granted by public bodies.

The consenting regime established in the Bill comprises three distinct elements:

- Maritime Area Consent (MAC): -
  - sets the terms of occupation of the maritime area, including rehabilitation obligations,
  - governs the relationship between the MARA and the holder; and
  - acts as the gateway into the planning permission process. Failure to secure planning permission will terminate the MAC automatically.
- Licensing: specified maritime usages will be subject to a licensing regime and will not require a MAC or planning permission. Any activity that attracts an Environmental Impact Assessment requirement will not be licensable and will be subject to planning permission.
- Planning Permission (development consent).

- The terrestrial planning permission regime, augmented with marine specific considerations, will be extended to the entire maritime area.
- It is within this process that specific projects will be examined in detail including Environmental Impact Assessments and Appropriate Assessments.
- Local authorities will examine all other applications within their own designated "nearshore area" extending a maximum of 3 nautical miles from the shore.
- An Bord Pleanála will examine applications for specified infrastructural, all far offshore (i.e. outside three nautical miles) projects and those which cross more than one local authority nearshore area

It is expected that An Bord Pleanála would be the competent authority for offshore elements of a CCS project.

Summary of Consent Regimes

Arup has provided an overview of the Consent regimes for the indigenous and export storage options which is presented here.

Carbon Capture and Storage in Ireland (i.e. indigenous storage option)

The CO_2 capture equipment may be installed on existing industrial and/or power plant sites or a dedicated CO_2 capture facility developed. It is expected that the captured CO_2 would be transported by pipeline on land and subsea to an offshore storage facility.

Table 30 Relevant Existing and Required Regulatory Frameworks for Carbon Capture in Ireland and Storage Offshore Ireland (ARUP)

CCS Infrastructure	Existing Frameworks	Existing versus Required Frameworks
Capture plant	Planning permission (would be an application to the County Council)	Inclusion in Strategic Infrastructure Act preferable
	Environmental Impact Assessment and Appropriate Assessment (Habitats Directive)	Existing frameworks appear sufficient
	Industrial Emissions Licensing	Existing frameworks appear sufficient
	COMAH (Seveso III) Regulations (may be relevant)	Existing frameworks appear sufficient
	Waste Management Act (CO_2 capture may be deemed a waste activity)	Existing frameworks appear sufficient
Onshore CO_2 pipeline	Consent to Construct and Operate Gas Pipelines (Gas Act)	Amendment of Gas Act to include CO_2
Offshore CO_2 pipeline	Foreshore licence	Maritime Area Planning Bill preferable – to give a single consent
	Continental Shelf Act consent	
	Consent to Construct and Operate Gas Pipelines (Gas Act)	Amendment of Gas Act to include CO_2
Offshore Geological Storage	Continental Shelf Act consent (to install equipment on the continental shelf)	Maritime Area Planning Bill preferable
	-	Permit under Directive 2009/31/EC for the Geological Storage of Carbon Dioxide to

CCS Infrastructure	Existing Frameworks	Existing versus Required Frameworks
		explore, identify a site and operate a storage facility
All	Safety Case (for gas and petroleum)	Safety Case Framework similar to PEES Act may be required for CCS.
	Environmental Liabilities Regulations	Existing frameworks appear sufficient

Carbon Capture in Ireland and Export Overseas for Storage

The CO_2 capture equipment may be installed on existing industrial and/or power plant sites or a dedicated CO_2 capture facility developed. The captured CO_2 would be transported by pipeline on land to a seaport and new CO_2 loading jetty for export to an overseas storage facility.

Table 31 Relevant Existing and Required Regulatory Frameworks for Carbon Capture in Ireland and Export for Storage Overseas (ARUP)

CCS Infrastructure	Existing Frameworks	Existing versus Required Frameworks
Capture plant	Planning permission (would be an application to the County Council)	Inclusion in Strategic Infrastructure Act preferable
	Environmental Impact Assessment and Appropriate Assessment (Habitats Directive)	Existing frameworks appear sufficient
	Industrial Emissions Licensing	Existing frameworks appear sufficient
	COMAH (Seveso III) Regulations (may be relevant)	Existing frameworks appear sufficient
	Waste Management Act (CO_2 capture may be deemed a waste activity)	Existing frameworks appear sufficient
Onshore CO_2 pipeline	Consent to Construct and Operate Gas Pipelines (Gas Act)	Amendment of Gas Act to include CO_2
Bulk Interim Storage of Liquid CO_2	No specific consenting framework in place for non-	Further research required

CCS Infrastructure	Existing Frameworks	Existing versus Required Frameworks
	geological storage of liquid CO_2 (that Ervia is aware of)	
Jetty	Planning permission (would be an application to the County Council)	Inclusion in Strategic Infrastructure Act preferable
	Foreshore Licence	Maritime Area Planning Bill preferable - Planning Interest and Marine Area Consent
Shipping Overseas of CO_2	Waste Management (Shipments of Waste) Regulations, 2007 (the captured CO_2, for indefinite storage, may be deemed a waste)	Existing frameworks appear sufficient
	London Protocol (allows shipment overseas, subject to certain controls)	Existing frameworks appear sufficient
All	Safety Case (for gas and petroleum)	Safety Case Framework similar to PEES Act may be required for CCS.
	Environmental Liabilities Regulations	Existing frameworks appear sufficient

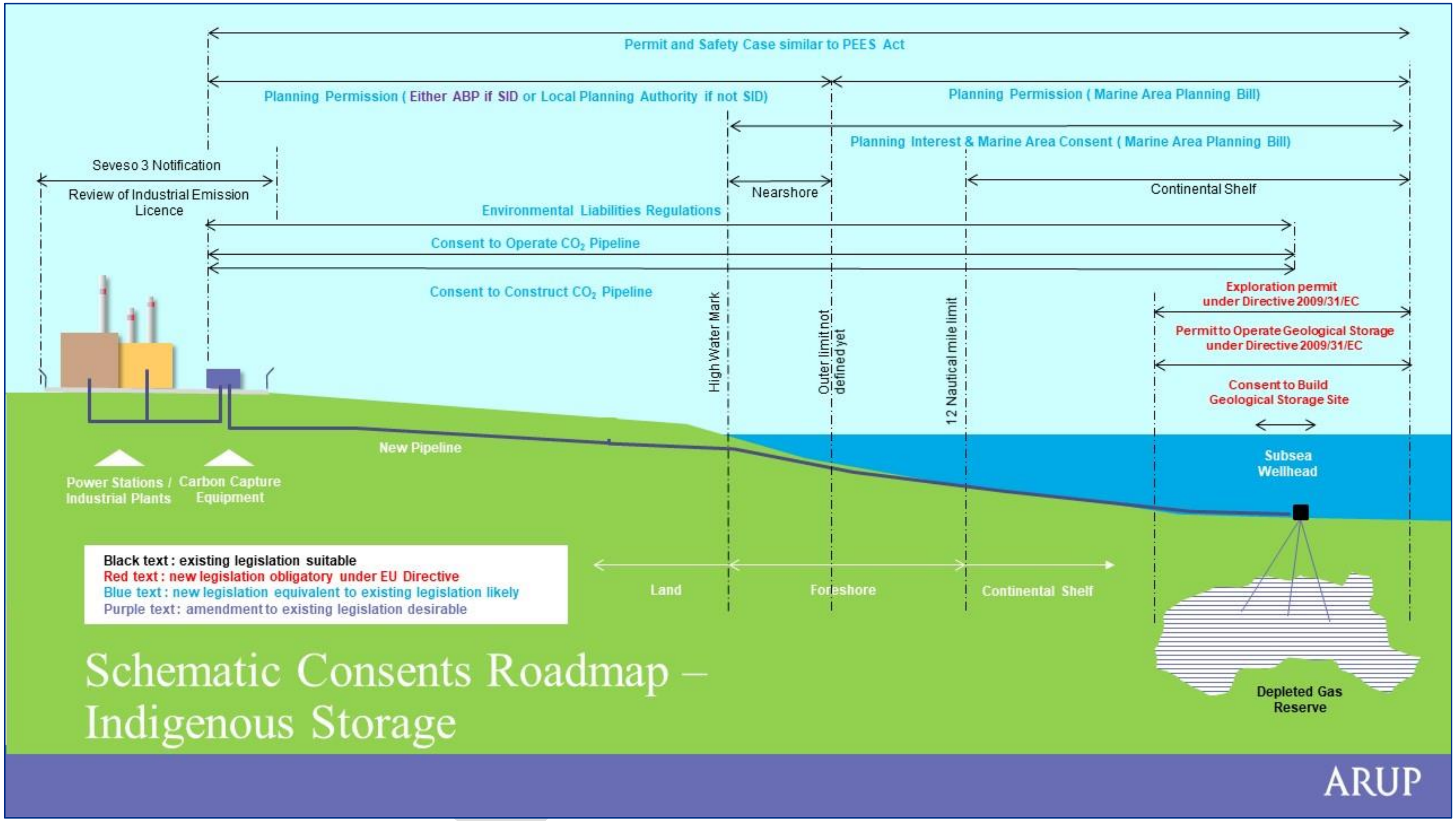

Figure 11 Schematic Consents Roadmap - Indigenous Storage (ARUP, 2021)

As part of its criteria, the CCS SG outlined a number of other aspects related to the identification of relevant existing and required regulatory frameworks. These are addressed below.

Mechanism to provide credit for CO_2 exports to emitter

The export of CO_2 between different countries is in its infancy, with the Northern Lights project being one example of 'open source' storage. In 2020, the Norwegian Government in a letter to DG CLIMA[138] raised the issue that, under the current EU ETS Directive, it is only transport by pipeline that falls within the term "transport network"[139].

From Ervia's membership of ZEP, Ervia was informed that later in 2020 the European Commission's DG CLIMA replied to Norway's Ambassador to the EU and confirmed the possibility to use ships, trains and trucks as means of CO_2 transport to the Northern Lights project in the EU ETS. This indicates that the EC is committed to resolving this issue.

ETS legislative amendments

In line with the EU CO_2 Storage Directive, carbon emissions captured, transported and stored will be considered as not emitted.

The European Commission publishes annual reports on the European carbon market and how it is functioning. The EU ETS is now in phase 4 and there have been two major reviews prior to both phase 3 and phase 4, with changes to the operational framework. It is expected that the same would occur for any changes to carbon export and storage. The Emissions Trading System Directive 2003/87/EC[140] stipulates that the system is kept under review based on the implementation of the Paris Agreement and the development of the carbon markets in other major economies. Any changes required would be made to the ETS Directive 2003/87/EC and the subsequent amendments. A full list of the legislation relating to the EU ETS can be found online.[141]

Long term leakage liability

With the storage of CO_2, the liability for leakage in the long term becomes an issue.

In relation to long-term liability for CO_2 storage activities, the EU approach provides for *transfer of responsibility* from the operator to the *competent authority* in accordance with the CO_2 Storage Directive. In the predominant model for managing liability, the liability is *transferred* to a public body after closure once a series of conditions have been met.

A transfer of responsibility may have *financial implications* for relevant authorities. The CO_2 Storage Directive requires a regulatory framework and where this framework envisages transfer of responsibility, then the framework also must appropriately manage the resulting risks for the relevant authority.

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[138] https://bora.uib.no/bora-xmlui/bitstream/handle/1956/21783/Vedlegg-til-masteroppgave--22CCS-in-the-EU-ETS-request-for-legal-clarification-22-i-originaltekst.pdf?sequence=2

[139] http://carbonneutralcities.org/wp-content/uploads/2020/01/Barriers-to-Transport-and-Storage-of-CO%E2%82%82-Within-the-EU.pdf

[140] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32003L0087&from=EN

[141] https://ec.europa.eu/clima/policies/ets_en#tab-0-1

The CO_2 Storage Directive requires that when a storage site has been *closed*, the operator remains responsible for the site for a *minimum of 20 years* after closure. After the 20-year period passes, liability for the CO_2 storage site is *transferred to the competent authority* on the condition that the operator has provided evidence that the CO_2 will be completely and permanently contained. Where operators are state-owned, clear separation of ownership may not be apparent and the issue of transferring responsibility may not arise. A properly selected and competently managed storage site could experience a level of leakage that is "*much less than 0.1 per cent in even 1 million years*".[142] It should be noted that if a storage site has been closed after withdrawal of a storage permit, the competent authority immediately becomes responsible and liable for the storage site.

The CO_2 Storage Directive requires surrender of emissions trading allowances for any leaked emissions or an equivalent financial security. Neither the EU CO_2 Storage Directive nor the published Guidance allows the simple estimation of the surrender allowances based on the likelihood of leakage[143]. This exposes the operator to the obligation to insure against the loss of the whole quantity of stored CO_2. This is both "*physically impossible*" and "*an unacceptable position for commercial businesses*".[144]

The *likelihood* of leakage is not factored into the calculation of financial provisions. In order to give an indication of the gap between the likely cost of leakage and the EU Directive provisions, reference can be made to a ZEP report compiled for the EU.

This ZEP report[145] examined CO_2 leakage, assessing probability, impact, duration, and cost implications of minor to major leakage from a storage site 2000-3000m deep with 100MtCO_2 injected over a period of 50 years. The site includes one injection well and one abandoned well. The probabilities of specific events are considered over a period of 500 years from commencement of injection. The analysis concludes the following: adding together the risked cost for all scenarios, and therefore assuming the possible simultaneous occurrence of mutually exclusive incidents, results in a total possible risked cost for one storage project of €840,650. This is several orders of magnitude less than the defined worst-case scenario cost of €589 million, for which owners and operators are required to set aside Financial Security in the EU CO_2 Storage Directive requirements.

As with any significant infrastructure project, the risks of leakage and long-term liability vary depending on timeframe and operational status. The following diagram is a simple illustration of the typical risk profile for a CCS project.

[142] The EU Legal Liability Framework for Carbon Capture and Storage, ASLR Vol 6 Dec 15 32.56 Pop, Page 37

[143] European Commission, 'Implementation of Directive 2009/31/EC on the Geological Storage of Carbon Dioxide Guidance Document 4: Article 19 Financial Security and Article 20 Financial Mechanism' (European Communities 2011) (Commission Guidance Document 4) 12 http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/docs/gd4_en.pdf

[144] Stuart Haszeldine, 'Geological Factors in Framing Legislation to Enable and Regulate Storage of Carbon Dioxide Deep in the Ground' in Ian Havercroft, Richard Macrory and Richard B Stewart (eds), Carbon Capture and Storage: Emerging Legal and Regulatory Issues (Hart Pub 2009) 19.

[145] CO2 Storage Safety in the North Sea: Implications of the CO2 Storage Directive, ZEP, Nov 2019

Figure 12 illustrates that the environmental risk profile of a reservoir reaches a plateau prior to cessation of injection, after which the risk decreases significantly with time.

The European Commission undertook a review of the CO_2 Storage Directive in 2015. While not universal, several stakeholder responses cited in the report highlighted the following aspects[146]:

- Potentially restrictive nature of liability provisions, in their aim to reduce all possible risks.
- Uncapped liabilities remain unacceptable to companies.
- Limited industry experience of the liability provisions within the Directive.
- Nature of the provisions which address potential liabilities associated with shared storage resources.
- Liability associated with an unpredictable carbon price.

In summary, the EU CO_2 Storage Directive currently places an unprecedented burden on any CCS development in relation to the long-term leakage liability and the requirement to provide financially for the worst-case scenario. This burden is a significant obstacle to CCS development in the EU. While subject to ongoing debate, there has been no indication to date that the EU is minded to revise the position.

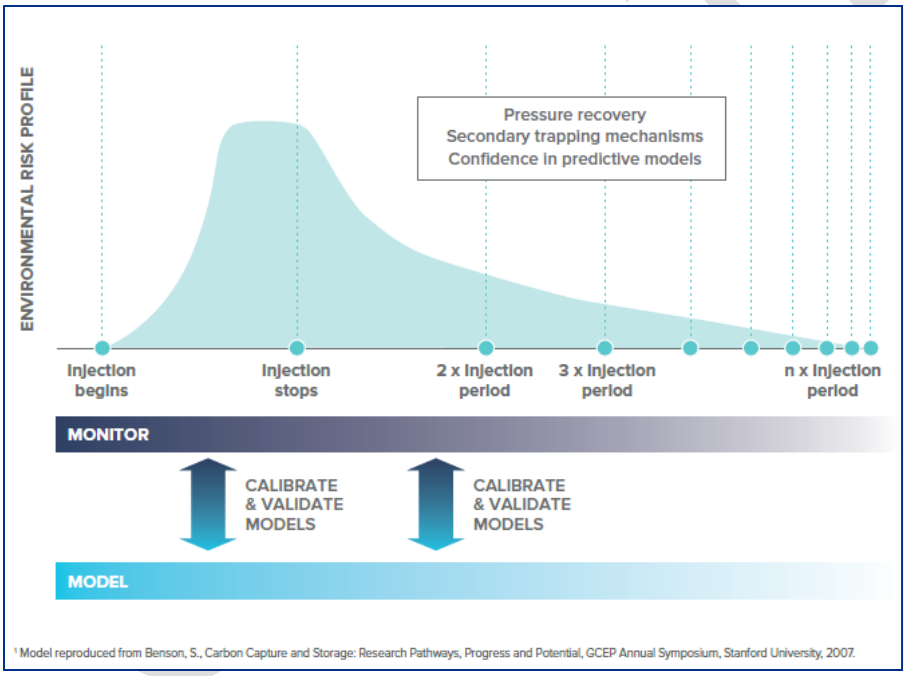

Figure 12 Lifecycle Risk Profile for CO_2 Storage[147]

[146] CO_2 Storage Safety in the North Sea: Implications of the CO_2 Storage Directive, ZEP, Nov 2019, p. 14

[147] Lessons and Perceptions: Adopting a Commercial Approach to CCS Liability, Ian Havercroft, GICCS, 2019, Page 7

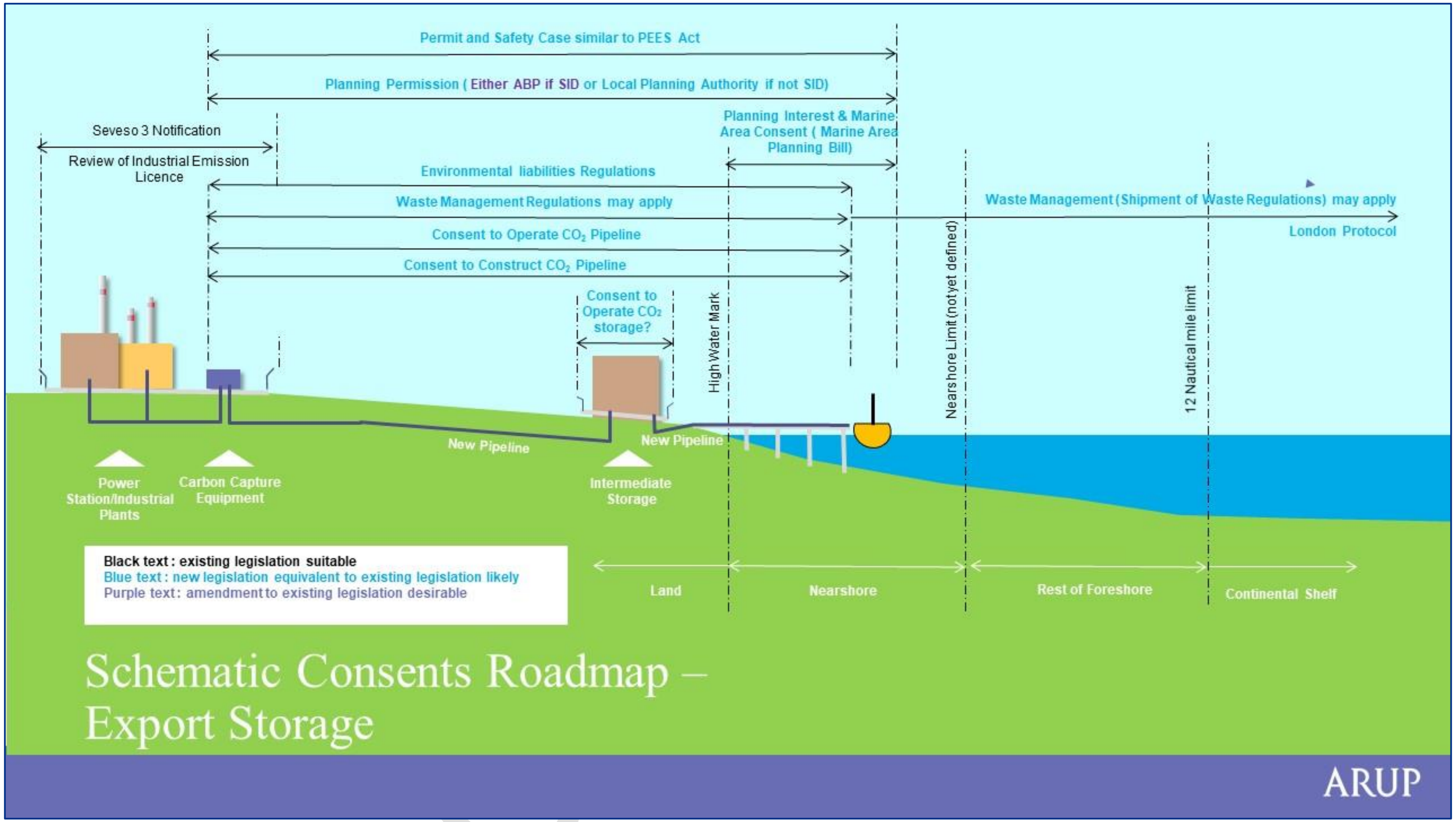

Figure 13 Schematic Consents Roadmap - Export Storage (ARUP)

Long-term leakage liability for the Irish Government would apply to the indigenous storage option only. Under the Directive currently, the Irish State would have no long-term leakage liability with the export storage option as the liability would be with the country storing the CO_2.This is a key factor in our recommendation that Ireland only consider export of CO_2 at this stage.

b. Required timeline for regulatory development, based on assessed CCS implementation

CCS will only be developed if there is an appropriate level of policy support and a clear outline of the proposed business model. The required timeline for regulatory development depends on whether the Government sees a need for CCS to help Ireland achieve its Climate Action 2030 and/or 2050 targets. If there is a national need for CCS to help achieve Ireland's 2030 targets, then regulatory development would need to begin immediately. Indicative timeframes for regulatory development are presented below for the export and indigenous storage options.

Export storage

As outlined in the previous section, the regulatory developments required for the export storage option would be far simpler that those for the indigenous storage option as transposition of the CO_2 Storage Directive would not be required.

The development of a plant for the large-scale capture of CO_2 and the development of a jetty, or the modification of a jetty, for the export of CO_2 could be consented under the existing planning legislation. The amendment of Schedule 7 of the Planning and Development Act, to include these types of development would be preferable and could be done relatively quickly. While the jetty could be consented under the Foreshore Act, the enactment of the Maritime Area Planning Bill would be preferable. The amendment of the Gas Act to provide a consenting regime for the construction and operation of pipelines to convey CO_2, could also be done quickly. Legislation to regulate the bulk interim storage of CO_2 and legislation, similar to the Petroleum Exploration and Extraction Safety Act, for the safety case framework for CO_2 activities would be required and would take longer to enact. Significant political and policy support would be required to deliver the required regulatory frameworks by the late 2020s.

Indigenous storage

The indigenous storage option would require regulatory changes, which are additional to those needed for the option of the export of CO_2 for storage. While the development of an offshore geological storage site could be consented under the Foreshore Act and/or Continental Shelf Act, the enactment of the Maritime Area Planning Bill would be preferable. Legislation establishing a permitting regime under Directive 2009/31/EC for the Geological Storage of Carbon Dioxide to explore, identify a site and operate a storage facility, is required.

The EC published indicative timeframes associated with the various CO_2 storage life cycle phases and milestones as part of its CO_2 Storage Life Cycle Risk Management Framework

Guidance document[148]. The time needed to go from 'assessment of storage capacity' to the commencement of CO_2 injection/operations ranges from 3.5 to 16 years. The document states that the timeframes are indicative only and depend on the storage option and local circumstances and that the lower timeframes relate to an oil and gas storage option not requiring exploration with a smooth and established regulatory approval system.

The development of an indigenous storage project would need to be preceded by the development of a regulatory regime for CO_2 storage. An Irish example of the timeframe associated with the development of a new regulatory regime is the Petroleum Safety Framework development[149]. In that case, the Petroleum (Exploration and Extraction) Safety Bill was published in January 2010 with the Act published in April 2010 (preceded by Bill drafting, regulatory impact analysis, etc.). Subsequently, a Petroleum Safety Framework, which included further regulations and significant associated guidance, was developed via a consultative process. The Framework was substantially complete at the end of 2013 giving a timeline of approximately four years for this particular regulatory development.

A comprehensive new marine consent regime, to replace the Foreshore Act, has been in process since at least 2013 and has not yet been enacted. The then Department of Environmental, Community and Local Government commenced public consultation on *A New Planning and Consent Architecture for Development in the Maritime Area* in early 2013. The *General Scheme of Maritime Area and Foreshore (Amendment) Bill 2013* was published in 2013. The most recent iteration, *Maritime Area Planning Bill*[150] was published in July 2021 and, at the beginning of November, is at the fourth stage[151] of an 11-stage process.

Assuming that all other required legislative amendments, regulatory and business model developments could proceed in parallel and be completed within the four-year timeframe of the PEES Act and that the more lengthy timeframe of the Maritime Area Planning Bill is avoided, then based on the combined indicative timelines outlined above it could be expected to take between 7.5 and 20 years to go from Bill stage to CO_2 injection for an indigenous field. Due to these lengthy timeframes, if a need for indigenous CCS is identified, then regulatory development should start as soon as possible.

[148] EC, 2011. https://ec.europa.eu/clima/sites/default/files/lowcarbon/ccs/implementation/docs/gd1_en.pdf

[149] CRU, 2021. https://www.cru.ie/professional/safety/petroleum-safety-framework-2/

[150] https://data.oireachtas.ie/ie/oireachtas/bill/2021/104/eng/initiated/b10421d.pdf

[151] https://www.oireachtas.ie/en/bills/bill/2021/104/?tab=bill-text

c. CCS developments at Member State level

Outline developments and progress by key players in this field at EU level including Member States (explanatory note from 2011 CCS Regs refers to *awaiting developments and progress by key players in this field, and the more advanced Member States who have committed substantial resources both financial and human to the implementation of the regulatory framework underpinning CCS technology*).

The development and the roll-out of CCS technology and projects varies throughout Europe and the wider world. What is evident however is that the pace of change is accelerating, and CCS across the EU is very much on an upward curve. This section considers the development and progress of key players and projects within the CCS sector. While the focus is on the EU level and member states, we also present the status of wider European (non-member state) developments as well as global case studies in order to help contextualise the EU picture within the global market.

At Member State Level

Every 4 years, the European Commission publishes a report on the implementation of the CO_2 storage Directive[152], based on input from Member States. The latest report refers to the significant theoretical CO_2 storage potential reported by Member States and Norway, noting that "despite the continuous lack of positive assessment for technical and economic feasibility for CCS retrofitting, power plants are nevertheless setting aside land should the conditions change in the future". The 2019 implementation report concluded "A considerable number of Member States and Norway continue to support or plan to support in the near future, through their national programmes or funds, research and demonstration activities on CCS. Furthermore, many countries are involved in a number of European research and collaborative projects"[153].

This subsection explores a number of projects and initiatives currently underway in the EU Member States of the Netherlands, Sweden, Denmark, and Belgium, an overview of which is provided in Table 32 below.

Table 32 Overview of projects and initiatives underway in EU Member States

Country	Project Name	Project Type	CO_2 Captured	Operational date	Status
The Netherlands	PORTHOS	Industrial Capture	5mtpa	2024	Construction

[152] European Commission, 2019. Implementation of the CCS Directive https://ec.europa.eu/clima/policies/innovation-fund/ccs/implementation_en

[153] European Commission, 2019. 3rd Implementation Report. https://ec.europa.eu/clima/sites/default/files/strategies/progress/docs/com_2019_566_en.pdf

Country	Project Name	Project Type	CO_2 Captured	Operational date	Status
The Netherlands	ATHOS	Industrial Capture	7.5mtpa	n/a	Cancelled
The Netherlands	Everest	CO_2 capture	5.5mtpa	2027	Early stage
The Netherlands	Aramis	Industrial capture	5mtpa	2026	Early stage
The Netherlands	H-Vision	Power and Capture	2.2-4.3mtpa	2026	Pre-FEED
Sweden	Preem CCS	Industrial capture, natural gas to H_2	0.5mtpa	2025	Pilot phase
Sweden	Stockholm Exergi Bio-CCS	Power and Capture	0.8mtpa	2025	Pilot phase
Denmark	Greensand	Capture Storage	0.5-1mtpa	2025	Feasibility study
Denmark	C4: Carbon capture Cluster Copenhagen	Power and capture, Storage	3mtpa	2025	Feasibility study
Belgium	Antwerp@C	Industrial capture	9mtpa	By 2030	Feasibility Study

From an EU policy perspective, the EU Green Deal has had a dramatic impact on the energy landscape across the EU[154]. Net-zero commitments means that almost all emissions will need to be abated by 2050 and for those residual emissions that remain (of which there will inevitably be some) negative emissions will be required. As highlighted earlier, CCS can be used to decarbonise hard-to-abate sectors. It will also be critical to delivering negative emissions. It is expected that hydrogen will also be able to play a valuable role in hard-to-abate sectors. The choice of CCS and/or hydrogen will be a matter for national policy makers and the energy dynamics of each country across the EU. Both hydrogen and CCS have received significant committed and future financial and policy support from the EU as outlined below.

The Netherlands

Over the last three years a number of significant CCS projects in the Netherlands have progressed from feasibility stage to full financial investment and construction. This progress

[154] The European Green Deal, European Commission, Dec 2019

is broadly due to the commitment of the CCS project developers and the emergence of national and EU financial and policy support for CCS within the Netherlands and EU.

In May 2021 the Dutch Government committed €2bn in support of the **PORTHOS** (**P**ort **o**f **R**otterdam CO_2 **T**ransport **H**ub and **O**ffshore **S**torage) **Project**, which is to become one of the largest CCS project in the world. Located around the port area of Rotterdam, the PORTHOS project will capture emissions from several high-emitting industrial sites. The CO_2 will be compressed and transported via a shared pipeline for offshore subsea storage in depleted gas fields in the North Sea.

PORTHOS is set to become operational in 2024 and is expected to be able to transport and store between 2 and 5Mtpa of CO_2.

The project is led by a consortium of State-owned entities that include the Port of Rotterdam, Gasunie (Dutch gas TSO) and Energie Beher Nederland (EBN).[155] In 2019, the PORTHOS project was awarded €102m of EU grant aid funding from the Connecting Europe Facility fund. In 2021, the Dutch Government announced a CCS subsidy scheme worth €5 billion, SDE++, which supports all low carbon/decarbonisation technologies. Specific subsidies of €2bn are being granted to the PORTHOS project, almost half of the total annual subsidy.[156]

A second large-scale CCUS project, the **ATHOS** project, has recently been cancelled in the Netherlands. The ATHOS project was based around the port area of Amsterdam and had similar ambitions to that of the PORTHOS project, seeking to capture emissions from numerous industrial sites for transport and storage offshore. The site was expected to have the potential to reduce CO_2 emissions by 7.5 Mtpa by 2030, when the site was planned to be operational. The ATHOS project was awarded €15m for detailed feasibility studies under the CEF in 2019.

The conceptual, technical and economic feasibility of the site was predicated on the expected CO_2 volume of one of the project partners; Tata Steel. The company recently decided however to develop a direct reduced iron process using hydrogen instead which meant the ATHOS project can't continue in its planned form.

Other projects of note in the Netherlands include:

- **Project Everest** – the project will utilise carbon monoxide and hydrogen by-products from Tata Steel's steel production for conversion into chemicals and also capture waste CO_2 for storage in North Sea gas fields. The project has the potential to capture 5.5 Mtpa of CO_2 but is still in early development.
- **Aramis** - a collaboration between Total Energies, Shell Netherlands, EBN and Gasunie, Project Aramis plans to develop CO_2 transport facilities to allow for offshore storage of the gas.

[155] Energie Beheer Nederland (EBN) is owned 100% by the Dutch state and is responsible for conducting exploration and extraction, planned management and the best possible sale of hydrocarbons in addition to advising the government on parts of the energy and climate policy.

[156] https://seekingalpha.com/news/3693886-huge-shell-exxon-carbon-storage-project-wins-2b-dutch-government-subsidies

- **H-Vision** – the project will capture the CO_2 from blue hydrogen production in the port of Rotterdam. The project is made up of a number of projects partners, and the Port of Rotterdam plans to achieve FID on the project later this year.

Sweden

In Sweden the largest test facility for carbon capture has begun operation at Preem's refinery in Lysekil, on the west coast of Sweden. Norwegian engineering firm Aker Solutions is providing its mobile test facility for the project. The project will analyse the whole value chain from carbon capture to storage off the Norwegian west coast. It also aims to enable more companies to utilise CCS technology and reduce their CO_2 emissions. The project is a collaboration between Preem, Aker Solutions, Chalmers University of Technology, Equinor and the Norwegian research institute SINTEF.

In 2020, the mobile test unit will capture carbon from flue gases coming from Preem's hydrogen gas plant at the Lysekil refinery. The goal is for the tests to form the basis for a full-scale CCS plant that can be operational by 2025 thereby reducing emissions from the refinery by 500,000t per annum.

Also in Sweden, energy utility Stockholm Exergi AB is planning to have a full-scale facility for BECCS in operation in 2025. The EU Innovation Fund has announced that the company is one of 70 applicants invited to submit a complete application for partial financing in stage two, which could be an important contribution to establishing the technology in Stockholm. If successful in its stage two application, Stockholm Exergi AB would receive a significant contribution to the costs of installation and operation of BECCS at Värtaverket. The proposed bio-CCS plant will capture CO_2 from biomass fuels that are already climate-neutral and will therefore be able to create a so-called carbon sink and remove up to 800,000t of CO_2 from the atmosphere per annum.

Denmark

In Denmark, **Project Greensand**, which aims to store CO_2 beneath the Danish North Sea, has cleared a first major hurdle. Injection and storage of CO_2 in the Nini West subsea reservoir has been certified feasible by independent certification body DNV GL.

The Nini West depleted oil reservoir is operated by INEOS Oil & Gas Denmark with Wintershall Dea (German based oil and gas company) as partner. With this certification DNV GL confirms that the reservoir is conceptually suitable for injecting c. 0.5 Mtpa CO_2 per well for a 10-year period, and that the subsea reservoir can safely contain the CO_2 in compressed form.

Wintershall Dea, INEOS Oil and Gas Denmark, Maersk Drilling and a research partner, the Geological Survey of Denmark and Greenland (GEUS), formed the Project Greensand consortium to reuse discontinued offshore oil fields for the permanent safe storage of CO_2 captured at onshore industrial facilities.

Project Greensand targets having the first well ready for injection from the Nini platform in 2025. The longer-term ambition is to develop capacity to store approximately 3.5Mtpa CO_2 before 2030.

Another project, **C4: Carbon Capture Cluster Copenhagen** represents a consortium of project partners looking to convert CO_2 into green fuels, as well as transportation and storage to depleted oil fields in the Danish North Sea. The project is at early feasibility stage but is hoped to be able to capture around 3 Mtpa of CO_2.

In addition to the above, Wintershall Dea is currently involved in projects including a feasibility study for CCS at Brage in Norway, and a methane pyrolysis (hydrogen) research partnership with the Karlsruhe Institute of Technology. The company established a Carbon Management and Hydrogen division earlier this year in order to further drive forward its work in these areas.

Belgium

Project partners Air Liquide, BASF, Borealis, ExxonMobil, INEOS, Fluxys, Port of Antwerp and Total joined forces at the end of 2019 under the name of Antwerp@C, to investigate the technical and economic feasibility of building CO_2 infrastructure to support future CCUS around the Port of Antwerp.

Antwerp@C is currently carrying out a feasibility study to investigate the possibility of building a central pipeline along the industrial zones, along with various shared processing units, a shared CO_2 liquefaction unit, interim storage facilities and cross-border transport of CO_2, both by ship and by pipeline. Subsidy applications for studies have been submitted under the CEF fund and the European Innovation Fund as part of the Green Deal.

EU Projects of Common Interest

Projects of Common Interest (PCIs) are key cross border infrastructure projects that link energy systems of EU countries. They are intended to help the EU achieve its energy policy and climate objectives. Projects that are awarded PCI status are afforded certain benefits, for example, accelerated planning and permit granting, a single national authority for obtaining permits, improved regulatory conditions, etc. In its 4th, and latest, list of PCI projects[157], the European Commission included five projects related to cross-border CO_2 networks - Project Acorn, transPorts, Northern Lights, ATHOS, and Ervia Cork. The Commission published its 5th list of PCIs in November this year and as expected six more CCS projects are now Projects of Common interest.

At wider-European level

Whilst not EU Member States, the experiences of Norway, Iceland and the UK help provide further detail and context around the development of CCS technology in Europe. Norway and the UK have a great deal of experience operating in the CCS market with many projects currently under development. An overview of relevant projects is provided in the table below.

Table 33 Overview of projects underway in non-EU Member States (Arup)

Country	Project Name	Project Type	CO_2 Captured	Operational date	Status
Norway	Sleipner CO_2	Industrial capture	1Mtpa	1996	Operational

[157] https://ec.europa.eu/energy/sites/ener/files/c_2019_7772_1_annex.pdf

Country	Project Name	Project Type	CO_2 Captured	Operational date	Status
Norway	Snøhvit CO_2	Industrial capture	0.7Mtpa	2008	Operational
Norway	Northern Lights	Industrial capture	0.8Mtpa	2024	FID
Iceland	Hellisheiði	Industrial capture	0.012Mtpa	Operational	Operational
Iceland	Orca	Direct Air capture	0.004Mtpa	2021	Operational
UK	Drax	Negative emissions power	4Mtpa	2024	FEED
UK	Humber	CO_2 Capture	9.5Mtpa	2024	FEED
UK	Northern Endurance Partnership	CO_2 Storage and transport	10Mtpa	2026	Carbon storage licence approved
UK	Acorn	Industrial Capture	0.2Mtpa	2027	Pre-FEED
UK	Hynet	Blue H2 production for industrial use with CCS		2024	FEED

Norway

Norway has 25 years' experience of CCS with the **Sleipner CCS** offshore project, the world's first industrial-scale CCS project for the purpose of carbon emission abatement and operating since 1996. It also operates the **Snøhvit CO_2** capture facility, using amine technology, which started in 2008.

Norway is currently developing the **Northern Lights/Longship projects**. Northern Lights is responsible for developing and operating CO_2 transport and storage facilities, open to third parties. It will be the first ever cross-border, open-source CO_2 transport and storage infrastructure network and offers heavy emitting industry and power generators across Europe the opportunity to store their CO_2 safely and permanently underground.

Phase one of the project will be completed in mid-2024 with a capacity of up to 1.5 million tonnes of CO_2 per year, largely supplied with CO_2 from the Longship project, the Norwegian Government's full-scale carbon capture and storage project. This project involves the capture of CO_2 from the Norcem Heidelberg cement plan in Brevik, and from the Fortum waste-to-energy plant in Oslo. The captured CO_2 will be shipped to an onshore terminal on the Norwegian west coast. From there, the liquefied CO_2 will be transported by pipeline to an offshore storage location subsea in the North Sea, for permanent storage.

Iceland

In Iceland a CCS project has been operating at the **Hellisheiði** geothermal power plant since June 2014. The Carbfix project mineralises the plant's CO_2 emissions, by first capturing CO_2 through its dissolution in water and then injecting it into subsurface basalt rock. The dissolved CO_2 reacts with the rocks and is mineralized within the rock, permanently storing it underground. To date over 0.67MtCO_2 have been stored through this facility. Basaltic rocks contain the metals and properties necessary for effectively and permanently immobilising CO_2 through the formation of carbonate minerals. They are often fractured and porous, providing storage space for the mineralised CO_2.

It has been estimated that the active rift zone in Iceland could store over 400GtCO_2. The theoretical storage capacity of the ocean ridges is significantly larger.

The Carbfix storage site has recently signed a partnership with Climeworks to install its direct air capture technology and store it at its site, as part of **Project Orca.** The project is actively seeking potential import of CO_2 from other European emitters to Iceland. The current costs of capture and storage from the geothermal plant are $24.8/t.

This project differs in that operations will be on land. It is anticipated that this may be the first large-scale geological storage project in Europe that is carried out onshore.

The preparation phase is beginning in 2021 with engineering and permitting processes. Drilling of the first well is to start in 2022, with the aim of starting operations in 2025 and reaching full-scale operations by 2030.

At full scale, it is expected to be able to provide an annual storage of 3Mt of CO_2. Total investment is estimated in the range of €190m-€220m, including operating expenses and capital expenditures.

United Kingdom

The UK Government's approach to carbon capture, usage and storage (CCUS) is laid out within its Clean Growth Strategy. The approach is designed to enable the UK to become a global technology leader for CCUS and ensure that the government has the option of deploying CCUS at scale by 2030. The UK government also established a CCUS Cost Challenge Taskforce to provide advice on the steps needed to reduce the cost of deploying CCUS in the UK.

In November 2020, the UK government announced funding of £1bn to support the development of four CCS hub and cluster projects across the UK by 2030. This funding initiative is part of a 10-point plan to reach net-zero climate targets by 2050 and it is estimated that it will secure 50,000 jobs within industrial clusters in the UK[158]. The most advanced CCUS projects in the UK include the Drax project, the Zero Carbon Humber Cluster, the Northern Endurance partnership and Acorn CCS.

- The **Drax[159]** project has, as a first step, modified an existing power station, transforming it from coal-fired to one firing on biomass. The addition of CCS will effectively generate negative emissions. Drax is targeting the capture of 4Mtpa of CO_2 from one of its four power generation units. Storage will be in the North Sea, with a proposed start date of 2024 (due to recent UK announcement). This project

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158 https://www.gov.uk/government/publications/design-of-the-carbon-capture-and-storage-ccs-infrastructure-fund/the-carbon-capture-and-storage-infrastructure-fund-an-update-on-its-design-accessible-webpage#fn:5

159 https://www.drax.com/about-us/our-projects/bioenergy-carbon-capture-use-and-storage-beccs/

is part of a larger program to eventually deploy CCS on all four of its bioenergy power units by the mid-2030s.

- In the **Humber**[160] area of North East England, a consortium including Equinor, Drax, National Grid, Associated British Ports, Centrica Storage, SSE Thermal and Uniper is planning to develop a major power/industry CCS cluster. Equinor has also announced a major hydrogen production project, **Hydrogen to Humber Saltend**[161]. Initially, the project will produce low-carbon hydrogen using a 600MW auto thermal reformer equipped with carbon capture – potentially the largest plant of its kind in the world.
- BP, Eni, Equinor, National Grid, Shell and Total announced the formation of the **Northern Endurance Partnership**[162]. With BP acting as Operator, the Group will develop offshore CO_2 transport and storage infrastructure in the UK North Sea to serve the Net Zero Teesside and Zero Carbon Humber industrial clusters. Storage will utilise the Endurance saline aquifer in the Southern North Sea, one of the UK's largest and most well understood CO_2 storage resources.
- Scotland's **Acorn project**[163] is positioned to grow quickly using nearby oil and gas infrastructure thereby minimising capital costs. The project aims to deliver both the CCS and hydrogen facilities essential to meeting Scottish and UK Government climate targets. With an established CO_2 storage licence in place, the project could be handling Scotland's CO_2 emissions from 2027 (due to recent UK Government announcement).
- **HyNet** North West is a low carbon and hydrogen energy project that is located in the North West of England and North Wales. The storage site will be in the Hamilton field in the Irish Sea. From 2024, HyNet will produce, store and distribute hydrogen as well as capture and store carbon from industry in the North West of England and North Wales. This revolutionary project has the potential to reduce CO_2 emissions by 10 million tonnes every year by 2030.

In October 2021, Hynet and the East Coast Cluster were selected as the two industrial clusters & the Scottish CCUS project as first reserve is line with the UK's Ten Point Plan for a Green Industrial Revolution. The East Coast Cluster will be enabled by the Zero Carbon Humber Cluster and the Northern Endurance partnership which includes emitters across the Humber and Teesside regions to secure offshore storage in the Endurance aquifer in the Southern North Sea.

Projects within the clusters sequenced onto Track-1 will have the first opportunity to be considered to receive any necessary support under the government's CCUS Programme. These will be considered under the different business models available to power and industrial customers which are all based on CfD styled contract.

At a Global level

160 https://www.zerocarbonhumber.co.uk/

161 https://www.equinor.com/en/what-we-do/h2hsaltend.html

162 https://www.netzeroteesside.co.uk/northern-endurance-partnership/

163 https://theacornproject.uk/

Globally there are 27 large-scale CCS plants that are currently in operation[164], most of which are in the Americas, and there are 62 commercial CCS facilities in construction and advanced development. CCS has been deployed in a range of industries including power generation, oil refining, hydrogen production, fertiliser production, natural gas processing, synthetic natural gas production, chemical production, ethanol production and Iron & Steel production. A summary of large-scale CCS developments globally is provided in the table below.

Table 34 2020 Summary Global CCS Developments – large-scale plants.[165]

	Operational	In Construction	Advanced Development	Total
# of facilities	27	4	58	89
Capture capacity (Mtpa)	36.6	3.1	46.7	86.4

Areas for Additional Research

Identification of relevant existing and required regulatory frameworks

A high-level overview of the relevant existing and required regulatory frameworks has been provided for the export and indigenous storage options. Significant further research is needed to identify all existing and required regulatory frameworks regarding the export and indigenous storage models.

Bulk Interim Storage of Liquid CO_2

Further research would be required regarding regulatory frameworks regarding the bulk interim storage of liquid CO_2 for the export storage option.

EU, National and Other Relevant Regulatory Issues - Conclusions

- ✓ High-level overviews of the existing and required regulatory frameworks for the export and indigenous storage options have been provided. The framework required for the export model is far simpler.
- ✓ There is no long-term liability for the State with the export storage option.
- ✓ If Ireland needs CCS to help it reach its legally binding 2030 targets, then, with policy support, a CCS regulatory regime could be developed for an export model by the late 2020s.
- ✓ There have been significant CCS developments at Member State level in recent years with the Netherlands, Denmark, Belgium and Sweden progressing projects. Candidate PCI projects for the 5th list also include France, Germany and Poland.

[164] https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Global-Status-of-CCS-Report-English.pdf

[165] https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Global-Status-of-CCS-Report-English.pdf

- ✓ In a wider European context, Norway, the UK and Iceland are at the forefront and have all stated that they will be available to import CO_2 from European countries.

Overall Conclusion

CCS can potentially play a very significant role in meeting Ireland’s decarbonisation targets, depending on how it is developed. It could be used to decarbonise electricity production, industry, produce low-carbon hydrogen for heating and transport, and it could be used to provide negative emissions.

There are two options for countries to consider regarding permanent storage of CO_2: export of CO_2 to another country which has an open access sequestration facility for CO_2; or permanent storage of CO_2 within one’s own jurisdiction (if suitable geological structures are available). It is Ervia’s recommendation that Ireland should only consider export of CO_2 for development of CCS at this stage. Export of CO_2 would be simpler to develop from a planning and infrastructure perspective and, most importantly, Ireland would not have any long-term liabilities related to long-term storage and possible leakage.

Post combustion CCS is proven, is at TRL 9, and with strong policy and national support could potentially be deployed by 2030 on electricity production and within some industrial sectors. Production of low-carbon hydrogen is slightly less well developed but with learnings due from projects currently in development in the UK, the Netherlands and Norway, this technology could potentially be deployed in Ireland by the mid-2030s.

When compared on an Enhanced LCOE basis, CCS has overall lower costs than onshore wind, offshore wind or solar power. This is because Enhanced LCOE also considers the cost of enabling infrastructure required to build out power generation whereas the common metric of LCOE does not consider these costs. Where CCS is coupled to gas fired CCGT power plants on existing sites then no additional grid infrastructure or energy storage technologies are required, and this has a very significant impact on overall cost.

Credible studies from the IPCC, IEA, the EU, the UK and many others all show that CCS will have to play a critical role globally in achieving net zero and offers significantly lower cost than the alternative of not using it.

The level of subsidies that CCS may require is heavily linked to the price of carbon. As carbon prices increase then subsidies required would decrease. A very broad range of forward cost curves for carbon are available from the market including from DPER, EIB, IEA and Baringa. As the price of carbon within the EU ETS has risen significantly during 2021, carbon cost curves on the lower end are less relevant to future economic analysis.

There have been significant CCS developments at Member State level in recent years with the Netherlands, Denmark, Belgium and Sweden progressing projects. In a wider European context, Norway, the UK and Iceland are at the forefront of CCS development and have all stated that they will be available to import CO_2 from European countries.

Ervia’s assessments to date have focused largely on the potential to decarbonise Ireland’s electricity sector with CCS. Information from credible sources has been provided to address, as much as possible, the criteria set out by the Government CCS Committee to also include industry, low-carbon hydrogen and negative emissions (via BECCS). It is recommended that the new Government CCS Research Group (as per the Interim Climate Actions 2021) broaden its research to also include those three other sectors.

Appendix 1 CCS Steering Group Terms of Reference & Criteria of 15/01/21

CCS Steering Group

Terms of Reference & Criteria to Inform the Assessment of the Feasibility of CCS for Deployment in Ireland

January 2020

As required under the Climate Action Plan, a steering group was established in 2019 to examine and oversee the feasibility of the utilisation of CCS in Ireland, and report to the Standing Committee on Climate Action, as appropriate. The key sub actions in this regard included;

- Agreeing appropriate research investment by Ervia/Gas Networks Ireland in CCS feasibility
- Monitoring the progress of Ervia's proposal in Cork, and
- Draft necessary legislation and regulatory regime if CCS research is positive.

Over the last 18 months the steering group has overseen aspects that relate to the first two sub-actions, above. Ervia has now commenced the process of preparing a final report on these actions, which will complete their involvement in terms of reporting under this key action for the purposes of implementing the CAP. It is proposed that this report will be peer reviewed so as to assist the steering group in moving to the next stage in respect of reporting to the Minister (and the Standing Committee on Climate Action, as appropriate). This reporting is in relation to the next steps to be taken in making recommendation on what policy considerations would be appropriate with respect to utilisation of CCS in Ireland having regard to **EU and national regulatory, environmental, technical and financial issues**.

To progress the work of the steering group, it is proposed that the final report by Ervia be assessed across the four criteria outlined below (including sub criteria), including an assessment of where gaps might exist and where additional research might be identified, so as to inform further on any subsequent decisions related to policy considerations . The four main criteria and associated sub-criteria are as follows: *(Consideration should be given to weighting of the criteria. From the State's point of view long term risks and liability would carry a significantly higher weight than some other sub-criteria in the list.)*

1. <u>Environmental Issues: The potential role of CCS in Ireland meeting its climate targets</u>

a. Demonstration (including credible energy modelling) of the need for CCS for Ireland to meet its Climate targets.

- An assessment of the levels of Carbon dioxide Removal (CDR) solutions Ireland will require to meet it climate targets to 2050 and the potential role for CCS in this regard.
- Assessment of the sectors and sub-sectors in which CCS may be appropriately used in Ireland in order to remain consistent with decarbonisation goals.

b. Large emitters/Industry representative bodies recognise potential role of CCS(U) for their decarbonisation and as a feedstock.

- The potential contributions of CSS for the decarbonisation of large emitter/industry including energy, cement, transport and heating.
- The potential utilisation of CCUS, including clustering.
- CCS and synthetic fuels.

c. Material decarbonisation potential of CCS for Ireland.

- CCS should have the potential to decarbonise a material amount of Ireland's non-agriculture-related emissions of c. 40 Million tonnes per annum.

d. Health and Environmental impacts of CCS for Ireland.

Assess the monitoring and assessment that is required in relation to carbon capture and storage to ensure that carbon dioxide streams are retained permanently in geological formations, and evaluate any significant adverse consequences for the marine environment, human health and other legitimate users of the maritime area to inform future developments and to minimise environmental risk. *(Note this focuses on the geological storage; health and environmental impacts of the transport of CO_2 will also need to be outlined).*

2. <u>The technical feasibility of the deployment of the technology in Ireland</u>

a. Technology Readiness Levels for carbon capture, transport and storage technologies for its potential roles.

b. ISO standard (or similar) for the carbon capture, transport and storage elements.

c. Roadmap to export CO2 for storage in Europe.

d. Suitability of a geological reservoir to receive and store the volume of CO2.

The suitability of a geological reservoir for CO2 storage is site-specific to local geological conditions and must be demonstrated in addition to the general technology readiness level of injection and well technologies. Criteria for the characterisation and assessment of a potential storage site are set out in Annex 1 of EU Directive 2009/31/EC.

e. Risk factors, including, but not limited to security of powergen with CCS, potential dependence on overseas storage sites, physical risk to CCS infrastructure and its environment, climate and weather extremes, to include potential for leakage etc.

3. Financial Viability of CCS

The financial viability should demonstrate the need, or not, for CCS based on a bottom up analysis of the cost of deploying CCS in Ireland relative to the counterfactual, no CCS *(over what time line, based on what sort of deployment and the state of development of the technology).*

Where possible, all inputs should be derived from Irish evidence to reflect Ireland's position as an energy importer with limited interconnection, difficulties in planning and higher Levelised cost of energy (LCOEs) relative to European averages.

a. CCS Financial Inputs

- Define all potential roles for CCS in Ireland (i.e. domestic storage and export for industry and powergen etc.)

- Key inputs for the financial evaluation should consider, again not limited to;

  - An indicative timeline for deployment of various technology and sectoral options.
  - Project costs, most likely LCOEs, for CCS and other low/ zero carbon technologies.
  - Learning curves for CCS and other low/ zero carbon technologies.
  - EU ETS forecasts/Carbon tax/Shadow price of carbon.
  - System balancing/ enforcement costs e.g. grid infrastructure, port infrastructure etc.

b. Financial Comparison of CCS and no CCS options

- The comparison should highlight the need, or otherwise, for CCS.

- To establish an unbiased evaluation, the shadow cost of carbon should be used where there is a difference in timing of carbon emissions.

c. Project and Subsidy Evaluation

- Estimates of the likely project costs for each use of CCS technology (i.e. storage and export for industry and powergen).

- Evaluate the range of state financial support mechanisms that may be required to commercialise CCS technology in Ireland.

  - The evaluation should take into account European funding as well as the level and type of support required for debt and equity financing.

d. Evaluation of State Liability (if storing in Ireland)

- Evaluation of the cost of transfer of liability from project sponsor to the State. At a minimum this will require 30 years of monitoring post transfer (according to slides from the previous session).
- Potential funding options for this.

4. EU, National and Other Relevant Regulatory Issues

a. Identification of relevant existing and required regulatory frameworks

- Further transposition of CCS Directive.
- OSPAR Decisions 2007/1, 2007/2 and OSPAR Agreement 2007-12 and ongoing developments
- Environmental planning and permitting.
- Mechanism to provide credit for CO2 exports to emitter.
- Transport of CO2 by Ship (e.g. London Protocol issues).
- Long term leakage liability.
- ETS legislative amendments if any; Environmental Liability legislative amendments; and other legislation (marine side) as listed at the first meeting of the Steering Group; and there may be other legislation e.g. IPPC and EIA

b. Required timeline for regulatory development, based on assessed CCS implementation

c. CCS developments at Member State level

- Outline developments and progress by key players in this field at EU level including Member States (explanatory note from 2011 CCS Regs refers to *awaiting developments and progress by key players in this field, and the more advanced Member States who have committed substantial resources both financial and human to the implementation of the regulatory framework underpinning CCS technology*).

END

Appendix 2 Glossary

	Definition
ºC	Unit of temperature on the Celsius scale
ABP	An Bord Pleanála
ACEI	Alliance for a Competitive European Industry
AD	Anaerobic Digestion
AF	Afforestation
Air Liquide	Industrial Gases Company, founded in France
Air Products	Air Products and Chemicals, Inc. is an American international corporation whose principal business is selling gases and chemicals for industrial uses.
ALARP	As Low As Reasonably Practicable
ASME	American Society of Mechanical Engineers
ATR	Auto Thermal Reforming
Baringa	Baringa Partners is an international management consultancy company.
BC	Biochar
BECCS	When CCS is used in conjunction with bioenergy it actually results in negative emissions. The process is known as bioenergy with CCS or BECCS. In some countries biomass or wood pellets is the feedstock, but in Ireland the more likely available source is biomethane.
BEIS	UK Department of Business, Enterprise and Industrial Strategy.
Bioenergy	A form of renewable energy that is derived from recently living organic materials known as biomass, which can be used to produce transportation fuels, heat, electricity, and products.
Biofuel	Any fuel that is derived from biomass i.e. plant or algae material or animal waste. Since such feedstock material can be replenished readily, biofuel is considered to be a source of renewable energy, unlike fossil fuels such as petroleum, coal, and natural gas.
Bio-methane	A carbon-neutral renewable gas made from farm and food waste through a process known as anaerobic digestion (AD).
Bio-SNG	Synthetic or Substitute Natural Gas produced from biofuels
bn	Billion

	Definition
bnt	Billion tonnes
BSI	British Standards Institute
c.	Circa
CA	Competent Authority
$CaCO_3$	Calcium carbonate
CaO	Calcium oxide
CAP	Climate Action Plan
Capex	Capital Expenditure
Carbfix	Carbfix provides a natural and permanent storage solution by turning CO_2 into stone underground in less than two years. It was founded in 2007 by Reykjavík Energy, the University of Iceland, the French National Centre for Scientific Research (CNRS) in Toulouse and the Earth Institute at Colombia University.
Carbon neutral	Carbon neutral means having a balance between emitting carbon and absorbing carbon from the atmosphere in carbon sinks.
CCAC	The Climate Change Advisory Council is an independent advisory body tasked with assessing and advising on how Ireland is making the transition to a low carbon, climate resilient and environmentally sustainable economy by 2050.
CCGT	Combined Cycle Gas Turbine. A combined-cycle power plant uses both a gas and a steam turbine together to produce up to 50% more electricity from the same fuel than a traditional open-cycle gas turbine.
CCS	Carbon capture and storage - the process of capturing, compressing, transporting and storing CO_2 to ensure that it is not released into the atmosphere.
CCS SG	The government's CCS Steering Group in relation to Action 33 of Climate Action Plan 2019.
CCS(U)	Carbon Capture and Storane (and Utilisation)
CCUS	Carbon capture, utilization and storage, also referred to as carbon capture, utilization and sequestration, is a process that captures CO_2 emissions from sources like industry or power plants and either reuses or stores it so it will not enter the atmosphere.
CDR	Carbon dioxide removal

	Definition
CEF	Connecting Europe Facility
Cembureau	The European Cement Association
CfD	Contract for Difference
CGG	CGG is a French-based geophysical services company founded in 1931.
CH_4	Methane (Natural Gas)
CJEU	Court of Justice of the European Union
CLIMIT	The CLIMIT programme is Norway's national programme for research, development and demonstration of CO_2 capture and storage technology (CCS). It covers the entire chain from long-term, competence-building basic research to projects that demonstrate CO_2 capture and storage technology technologies.
CMI	Cement Manufacturers Ireland
CNG	Compressed Natural Gas
CNRS	The French National Centre for Scientific Research is the French state research organisation and is the largest fundamental science agency in Europe.
CO_2	Carbon dioxide - a colourless gas having a faint sharp odour and a sour taste. It is a greenhouse gas, but it is a minor component of Earth’s atmosphere, formed in combustion of carbon-containing materials, in fermentation, in respiration of animals, and employed by plants in the photosynthesis of carbohydrates.
COP26	26th UN Climate Change Conference of the Parties
CSA	Canadian Standards Association
DAC	Direct air capture
DACCS	Direct Air Capture with CCS
DCU	Dublin City University
DECC	Department of the Environment, Climate and Communications
DG CLIMA	The Directorate-General for Climate Action
Dispatchable power/electricity	A dispatchable source of electricity refers to an electrical power system, such as a power plant, that can be turned on or off; in other words they can adjust their power output supplied to the electrical grid on demand.

	Definition
DMAP	Designated Maritime Area Plan
DNV	DNV (formerly DNV GL) is an international accredited registrar and classification society headquartered in Høvik, Norway.
DNVGL	Now DNV, an international accredited registrar and classification society headquartered in Høvik, Norway.
DOE/NETL	US Department of Energy National Energy Technology Laboratory
DPA	Dispatchable Power Agreement
DPER	Department of Public Expenditure and Reform
EAI	Electricity Association of Ireland
EBN	Energie Beheer Nederland is owned 100% by the Dutch state and is responsible for conducting exploration and extraction, planned management and the best possible sale of hydrocarbons in addition to advising the government on parts of the energy and climate policy.
ECA	Export Credit Agency
EEPR	European Energy Programme for Recovery
EGR	Enhanced Gas Recovery
EI	Energy Institute
EIA	Environmental Impact Assessment
EIB	European Investment Bank
EirGrid	A state-owned company that manages and operates the transmission grid across the island of Ireland.
Enhanced levelised cost (LCOE)	Enhanced levelised cost is similar to levelised cost but also takes account of different wider system impacts between technologies due to differences in the timing of their generation, their location and other characteristics. This results in a fairer comparison between technologies. Importantly, enhanced levelised costs do not show the full system cost of different pathways but provide an indication of the relative marginal impacts of different technologies to the system in different scenarios.
ENTSO-E	European Transmission System Operators - Electricity
ENTSO-G	European Transmission System Operators - Gas

	Definition
EOR	Enhanced oil recovery
EPA	Environmental Protection Agency
eq.	equivalent
Equinor	Norwegian energy company formerly known as Statoil.
ERDF	European Regional Development Fund
ERI	Environmental Research Institute. The Environmental Research Institute (ERI) at UCC brings together over 400 researchers from 20 different academic disciplines and 6 research centres. It uses its core expertise in Marine, Energy, Environment, Materials and Agri-Food research, working in a transdisciplinary approach, to address the global sustainability challenges of Climate Action, Circular Economy and Healthy Environment.
ESB	The Electricity Supply Board is a state owned electricity company operating in Ireland.
ETS	Emissions Trading System
EU	European Union
Eurogas	Eurogas is an association representing the European gas wholesale, retail and distribution sectors towards the EU institutions. Founded in 1990, Eurogas currently comprises 56 companies and associations from 24 countries.
Evergas	Danish gas company
EW	Enhanced weathering
ExxonMobil	American multinational oil and gas corporation headquartered in Texas.
FEED	Front-End Engineering Design
FES	Future Energy Scenarios
F-gases	Fluorinated gases
FGD	Flue Gas Desulphurisation
FID	Final Investment Decision
FOAK	First of a kind
FS	Financial Security
Gaseous phase	One of the three fundamental structural phases of matter in which the thermal mobility of molecules or atoms is strong enough to permit their free motion, significantly exceeding the cohesive force.

	Definition
Gassnova	Gassnova SF is the Norwegian state enterprise for carbon capture and storage.
GDP	Gross Domestic Product
Geological formation	A geological formation is a rock unit that is distinctive enough in appearance that a geologic mapper can tell it apart from the surrounding rock layers. It must also be thick enough and extensive enough to plot on a map.
Geo-Storage	Geological storage – the storage of carbon (fossil fuels, carbonate rock) either naturally or via engineered injection in the earth's subsurface geological formations.
GGR	Greenhouse Gas Removal
GHG	Greenhouse Gas
GHR	Gas Heated Reforming
Gt	Gigatonne
Gw	Gigawatt
H_2	Hydrogen
H&S	Health and Safety
Hellisheiði	The Hellisheiði Power Station is the third-largest geothermal power station in the world. A CCS project has been operating at the plant since June 2014.
HRSG	Heat Recovery Steam Generator
HSA	Health and Safety Authority
HUF	Hungarian Forint - unit of currency
Ibec	Irish Business and Employers Confederation
ICC	Industrial Carbon Capture
IEA	International Energy Agency
IEAGHG	IEA Greenhouse Gas R&D Programme
IEA-SDS	International Energy Agency Sustainable Development Scenario

	Definition
IE-NETs	Investigating the potential for negative emissions technologies (NETs) in Ireland. The IE-NETs project provides the first review of the technical potential for CO_2 removal in Ireland and an assessment of the security of long-term carbon storage. The project was carried out by Dublin City University (DCU) and Trinity College Dublin (TCD) over a two-year period, and published its findings in 2020 in conjunction with the EPA.
IGC	International Gas Carrier
IGCC	Integrated gasification combined cycle
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
IPPC	International Plant Protection Committee
ISO	International Organisation for Standardisation
ISO/AWI	Approved new Work Item
ISO/DTR	ISO Draft Technical Report
ISO/FDIS	Final Draft International Standard
ISO/TR	ISO Technical Report
KEL	PSE Kinsale Energy Limited
KHGF	Kinsale Head Gas Field
Kt	Kilotonnes – unit of measurement
LCCC	Low Carbon Contracts Company
Levelised cost	The levelised cost of electricity (LCOE) in electrical energy production can be defined as the present value of the price of the produced electrical energy (usually expressed in units of cents per kilowatt hour or € per megawatt hour), considering the economic life of the plant and the costs incurred in the construction, operation and maintenance, and the fuel costs.
LF	Load Factor
LNG	Liquefied Natural Gas

	Definition
London Protocol	The London Convention was developed to control pollution of the sea by dumping and to encourage regional agreements supplementary to the Convention. It covers the deliberate disposal at sea of wastes or other matter from vessels, aircraft, and platforms. The 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (the 1996 London Protocol) effectively replaced the 1972 London Convention. In 2006, the Contracting Parties to the 1996 London Protocol adopted amendments to the Protocol. The 2006 amendment provided for the disposal CO_2 streams in sub-seabed geological formations.
Longship	The Longship project is the Norwegian Government's full-scale CCS project, being developed by Gassnova It will capture CO_2 from the cement industry and from a waste-to-energy facility and transport it by ship to an offshore geological storage site.
LPG	Liquefied Petroleum Gas
LRVC	Long Run Variable Cost
MAC	Maritime Area Consent
MACC	Marginal Abatement Cost Curves
MAHP	Major Accident Hazard Pipeline
MARA	Maritime Area Regulatory Authority
MaREI	Marine and Renewable Energy Ireland. MaREI is the SFI Research Centre for Energy, Climate and Marine research and innovation co-ordinated by the Environmental Research Institute (ERI) at University College Cork (UCC).
McKinsey	Global management consulting firm.
MEA	Monoethanolamine - an amine-based solvent commonly used in post combustion CCS.
MPA	UK Mineral Products Association
Mt	Million tonnes - unit of measurement
Mtpa	Million tonnes per annum - unit of measurement
N_2O	Nitrous oxide
N/A	Not applicable
NASA	National Aeronautics and Space Administration

	Definition
National Grid	National Grid plc is a British multinational electricity and gas utility company headquartered in London, England.
NCC	The Irish National Competitiveness Council reports to the Taoiseach and the Government, through the Minister for Business, Enterprise and Innovation, on key competitiveness issues facing the Irish economy and offers recommendations on policy actions required to enhance Ireland's competitive position.
Negative Emissions	The removal of CO_2 from the atmosphere. The three most widely studied approaches are BECCS, which entails the combination of bioenergy with CCS, i.e. capturing and storing the CO_2 emitted from the combustion of bioenergy; planting more forests; and direct air capture, an engineered process for separating CO_2 from the air and storing it permanently underground.
NEMS	National Energy Modelling System
NETs	Negative Emissions Technologies
Net zero	Net zero means any emissions would be balanced by schemes to offset an equivalent amount of greenhouse gases from the atmosphere, such as planting trees or using technology like CCS.
NG	Natural Gas
NOAK	N^{th} of a kind
NOK	Norwegian Krone (Unit of Currency)
Northern Lights	A commercial CO_2 cross-border transport connection project between several European capture initiatives with transport of the captured CO_2 by ship to a storage site on the Norwegian continental shelf. Equinor, Shell and Total are the joint venture partners.
O_2	Oxygen
O&M	Operation and maintenance
OCGT	Open Cycle Gas Turbine
Oireachtas	The National Parliament of Ireland, consisting of the President and two Houses: Dáil Éireann (House of Representatives) and Seanad Éireann (the Senate).
Opex	Operating expenditure
pa	Per annum

	Definition
PCB	Polychlorinated Biphenyls - a group of man-made organic chemicals consisting of carbon, hydrogen and chlorine atoms.
PCI	Project of Common Interest
PEES	Petroleum (Exploration and Extraction) Safety Act 2010
PEM	Proton-Exchange Membrane fuel cells use hydrogen fuel and oxygen from the air to produce electricity
PORTHOS	**P**ort **o**f **R**otterdam CO_2 **T**ransport **H**ub and **O**ffshore **S**torage Project
Pöyry	An international consulting and engineering firm that serves clients globally across the energy and industrial sectors and provides local engineering services in its core markets. Its focus sectors are power generation, transmission, and distribution; forest industries; chemicals and biorefining; mining and metals; transportation and water. It merged in 2019 with Swedish company ÅF into AFRY.
PSO	Public Service Obligation levy
Pyrolysis	The pyrolysis process is the thermal decomposition of organic matter into noncondensable gases, condensable liquids, and a solid residual co-product, biochar or charcoal in an inert environment (i.e., in the absence of oxygen).
REALISE	The REALISE (Demonstrating a **RE**finery-**A**dapted c**L**uster-**I**ntegrated **S**trategy to **E**nable full-chain CCUS implementation) project will involve the deployment of a small pilot carbon capture unit at Irving oil refinery in Cork and a study of how to optimally integrate it into a wider carbon capture cluster.
REFIT 1, 2, 3	Renewable Energy Feed in Tariff schemes 1, 2 and 3
RES-E	Renewable Energy Share - Electricity
RES-H	Renewable Energy Share - Heating
RESS	Renewable Electricity Support Scheme
RES-T	Renewable Energy Share - Transport
RP	Recommended Practice
Sabatier Reaction	The Sabatier reaction is a process that produces water (hydrogen and oxygen) and methane through a reaction of hydrogen with carbon dioxide.
SAC	Special Area of Conservation

	Definition
Schlumberger	Schlumberger Limited is an oilfield services company. Schlumberger has four principal executive offices located in Paris, Houston, London, and The Hague.
SCS	Soil carbon sequestration
SEAI	Sustainable Energy Authority of Ireland
SEI	Sustainable Energy Ireland (now SEAI)
Seveso	Seveso is a borough of Northern Italy, in the Region of Lombardy. It has been especially known since an industrial accident occurred on July 10th, 1976, when a dioxin cloud spread in the area after the explosion of a chemical plant. The catastrophic accident prompted the adoption of legislation – the Seveso Directive - on the prevention and control of such accidents.
SFI	Science Foundation Ireland
Shell	Royal Dutch Shell plc, commonly known as Shell, is a global group of energy and petrochemical companies headquartered in The Hague.
SID	Strategic Infrastructure Development
SMR	Steam methane reforming - methane reacts with steam in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of CO_2.
SNG	Synthetic or Substitute Natural Gas
SOE	Solid Oxide Electrolysis
SPA	Special Protection Area
SRF	Solid Recovered Fuel
SSE	SSE plc is a multinational energy company headquartered in Perth, Scotland. It operates in the UK and Ireland.
Stg	Sterling
T&S	Transport and Storage
TCD	Trinity College Dublin
Total	Total S.A. is a French multinational integrated oil and gas company.
TRA	Technology Readiness Assessment

	Definition
TRL	Technology Readiness Level. TRLs are a method for estimating the maturity of technologies during the acquisition phase of a program, developed at NASA during the 1970s. The use of TRLs enables consistent, uniform discussions of technical maturity across different types of technology. A technology's TRL is determined during a Technology Readiness Assessment (TRA) that examines program concepts, technology requirements, and demonstrated technology capabilities. TRLs are based on a scale from 1 to 9 with 9 being the most mature technology. The US Department of Defense has used the scale for procurement since the early 2000s. By 2008 the scale was also in use at the European Space Agency (ESA), as evidenced by their handbook.
TS	ISO Technical Standard
TSO	Transmission System Operator
UCC	University College Cork
UK	United Kingdom
UK HSE	UK Health and Safety Executive
UK HSL	UK Health and Safety Laboratory
Ultragas	Danish gas company
WAM	With Additional Measures
Wood Group	British multinational engineering and consulting business with headquarters in Aberdeen, Scotland.
WRI	World Resources Institute
ZEP	Zero Emissions Platform
Zero emissions	Zero emission refers to an engine, motor, process, or other energy source, that emits no waste products that pollute the environment or disrupt the climate.

Appendix 3 Bibliography

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