Carbon Capture and Storage for Ireland: Initial Assessment

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1. Executive Summary

Large scale climate action is both necessary and urgent

Climate change is one of the greatest challenges facing the world at present. Global warming as a result of deforestation, industrialisation and the release of greenhouse gases is having far reaching and profound impacts on the global community and human health. If the global community wants to avoid the catastrophic impacts of climate change, urgent action is required to reduce carbon dioxide (CO_2) emissions.

At the 2015 United Nations Climate Change Conference of Parties in Paris (COP21), Ireland (as an EU Member State), adopted a legally binding agreement to keep global warming below 2ºC.[1] The European Commission (EC) has also called for a climate-neutral Europe[2] by 2050 and has set progressive targets for reducing its greenhouse gas emissions to meet this goal[3]. To meet these objectives, decarbonisation of our energy systems is essential.

Ireland faces serious challenges in meeting its climate action commitments

Ireland has fallen behind in its international and European commitments; our greenhouse gas emissions per capita are the third highest in the EU[4]. We face particular difficulties in reducing emissions due to the relative scale of our agricultural sector, which accounted for approximately one third (20Mt) of our total CO_2 emissions (60Mt) in 2017. The production of electricity in Ireland is responsible for c.20% of Ireland's CO_2 emissions. Strong economic and population growth is expected to increase annual electricity demand in years to come, which will be further heightened by increasing numbers of electrical vehicles, electric heat pumps, data centres, and new housing units.

The Government has set a target that Ireland will achieve 70% of its future electricity need from renewable sources by 2030, (up from c.32% in 2018[5]). This ambitious increase is expected to be achieved with additional wind and solar power. While this will enhance Ireland's energy sustainability, it will also increase the amount of intermittent (non-firm) generation accessing the national grid. But when the wind doesn't blow and the sun doesn't shine, dispatchable firm power must be available to provide security of energy supply. In order to facilitate future increased renewable penetration on the national grid, Ireland needs to ensure that there are alternate decarbonised firm sources of electricity available.

1 (United Nations, 2015)
2 (European Commission, 2018)
3 (European Commission, 2018)
4 (European Commission, 2019)
5 (DCCAE, 2018)

Decarbonising gas-fired electricity generation is essential to support growth of renewables and provide sustainable, secure energy supply to meet demand

With no nuclear sector and very limited hydro capacity, Ireland does not have the same options as other countries for large-scale, dispatchable electricity generation. Currently over 50% of the country's electricity need is generated from gas-fired power stations and this provides the secure flexibility which is critical to balancing the intermittency of renewables on the Irish energy system. It is clear that Ireland cannot decarbonise its total electricity system without also decarbonising its gas-fired power generation. Decarbonised natural gas generation is the only way to provide the flexibility, security and growth capacity required to meet future electricity demand in a sustainable way.

Carbon Capture and Storage is crucial to electricity decarbonisation at least cost

Carbon Capture and Storage (CCS) is an available, proven technology which can decarbonise natural gas generation and large industry at scale. It works by capturing CO_2 emissions at source and then transporting these to underground sites where they can be safely stored. Where biomass/biomethane is used in the power generation process, CCS results in net negative emissions which makes it a highly attractive option in the pursuit of climate action targets. It is also one of the only technologies capable of delivering the deep emissions reductions needed in key industrial sectors such as steel, cement, and chemicals manufacturing[6].

The significance of CCS as an emissions reduction technology has been recognised internationally by critical stakeholders such as the Intergovernmental Panel on Climate Change (IPCC), the International Energy Agency (IEA), and the European Commission. The IEA has predicted that the cost of decarbonising the power sector will be at least US$3.5 trillion more expensive without CCS[7].

Nationally, Eirgrid's 'Tomorrow's Energy Scenarios'[8] deploys CCS in two of its three scenarios. The report states that "Pursuing both CCUS[9] and renewable gas reduces the risk of reliance on a single option, while helping to mitigate as much as possible a long-term reliance on non-abated fossil fuels." Similarly, the marine and renewable energy research, development and innovation Centre (MaREI) in University College Cork (UCC) is of the view that CCS forms a significant part of a least-cost decarbonisation model for Ireland.[10]

The prospect for CCS has previously been explored in an Irish context. In 2008 Sustainable Energy Ireland (now SEAI) and the Environmental Protection Agency (EPA) published a report into the potential for CCS in Ireland[11]. The study concluded that the Kinsale Head gas field, which is now almost depleted, had attractive potential as a CO_2 store. While preliminary

[6] (IEA, 2019)
[7] (IEA, 2016)
[8] (Eirgrid, 2019)
[9] CCUS – Carbon Capture Utilisation and Storage
[10] (University College Cork, 2018)
[11] (SEI / EPA, 2008)

in nature, the study estimated a high confidence level on the field's suitability for permanently storing CO_2. In 2011, PSE Kinsale Energy Limited (the Kinsale Head gas field operator) commissioned Schlumberger to examine the suitability of the gas field for CO_2 storage[12] and concluded that there were no barriers to continuing the assessment.

Ervia is actively assessing the potential for CCS in Ireland:

As a semi-state company with deep experience of gas infrastructure and transportation, Ervia has established a dedicated team to undertake an initial assessment of the potential for CCS for Ireland. This assessment builds on the work of the 2008 SEI/EPA report. As the project has developed it has assessed the feasibility of a number of alternative CCS options for Ireland. These include:

1. ***Option 1 - Cork CCS Project - Capture CO_2 from power plants and industry in the Cork area and transport the CO_2 for injection in the Kinsale Head gas field.*** This option specifically refers to emissions capture at the Aghada and Whitegate gas-fired power stations and the Irving Oil Refinery. If developed, this option could capture in the range of 1.5 to 2.5 Mt of CO_2 per annum – equating to approximately one quarter of Ireland's annual gas related emissions. Potentially, the CO_2 captured could be transported to the depleted Kinsale Head gas field via the network of existing gas transmission pipes, with only a small element of new pipeline possibly required.

2. ***Option 2 - Ireland Export Project - Capture CO_2 from various industries and power plants around Ireland (in clusters) and ship the CO_2 overseas to other European storage reservoirs.*** This option envisages the capture of CO_2 from large emitters in one or more cluster 'hub' locations close to Irish ports. The CO_2 would be compressed into liquid form and shipped onwards for storage at one of a number of potential stores across Europe. Supporting further work on this option, Ervia has recently signed a Memorandum of Understanding with Norwegian company, Equinor (formerly Statoil), to jointly collaborate in exploring the possibility of CO_2 export from Ireland for storage in Norway's geological reserves in the North Sea. Equinor, along with Total and Shell, is developing the Northern Lights project to accept CO_2 from carbon emitters across Europe.

3. ***Option 3 – Hydrogen Project - Capture CO_2 from a reforming hydrogen production process and use transportation and storage from Option 1 or 2.*** Hydrogen is a gas suitable for long-term storage which, when combusted, produces water vapour alone with no carbon emissions. This means it could be viably used to decarbonise the heat and transport sectors as well as electricity generation. Hydrogen can be produced in a number of ways. The current most commonly used process, known as Steam Methane Reforming (SMR), involves splitting natural gas into its two constituents of CO_2 and hydrogen. Option 3

[12] (Schlumberger / Kinsale Energy, 2011)

envisages using CCS to capture the CO_2 from this hydrogen production process and then deploying transport and storage from Option 1 or 2. Hydrogen produced using methane reforming and CCS is expected to provide a pathway for ‘green hydrogen’ production in the longer term.

Following initial assessment, all identified CCS options for Ireland remain viable

Ervia has conducted an initial assessment of each of these three options based on technical, commercial, public policy and stakeholder factors. The findings are set out in this report and summarised briefly below:

- All three options represent viable technical solutions to support decarbonisation – there are no technical barriers to further progression.
- A number of different commercial models can be considered, based on ownership and management of various elements of the process chain. The emerging ownership structure across European models favours the CO_2 capture process remaining with the emitter, with the remaining process chain elements (compression, conditioning, transport and storage) then owned and managed by a separate entity. Ervia’s initial assessment is that a regulated monopoly is the optimum organisational model for this entity, enabling efficient development and operation and appropriate market oversight.
- For cost assessment purposes, Full System Cost of Abatement (CoA) is used as the comparator metric. This is more robust than the common Levelised Cost of Electricity (LCOE) metric which fails to account for all relevant costs.
- Financial support would be required from Irish and EU sources for a first CCS project in Ireland. Various potential funding sources have been identified. Ervia has applied for European Project of Common Interest (PCI) status for a CCUS[13] project in Ireland and the project was officially awarded PCI status on 31 October 2019. This enables Ervia to apply for funding to the Connecting Europe Facility (CEF) fund.

There are important public policy, legislative and societal considerations for any CCS project in Ireland

Although there are many examples of successful CCS projects worldwide, progress in Europe has been relatively slow. This can be attributed in part to the lack of a clear economic policy framework and the focus to date on supporting renewables rather than setting a carbon target. The renewables bias associated with the commonly used LCOE metric has also mitigated against true cost comparison of alternatives such as CCS which, together with gas generation, can provide the flexible, firm decarbonised power needed for security of supply.

[13] CCUS – Carbon Capture Utilisation and Storage.

There are also legislative barriers which must be overcome if CCS is to be deployed successfully at large scale. At European level, issues associated with enduring ‘State’ liability for any CO_2 leakage have yet to be addressed. At national level, a wide-ranging framework of consents would be required for a Cork CCS project. A much simpler framework would be required for the Ireland Export project.

Societal considerations are also critical to any future CCS deployment. Meaningful stakeholder and community engagement, together with clear, transparent communications, will be vital to satisfactorily address any concerns. Ervia is continuing to engage with stakeholders at local, national, and international level to collate views and inputs to any future progression of CCS for Ireland.

CCS is progressing at pace in Europe and the United Kingdom (UK); Ireland also has clear opportunities which merit further consideration

The EC and the UK have both recognised the critical need to progress CCS and to address the current economic policy framework shortcomings. Given CCS’s fundamental role in addressing decarbonisation and climate change, the UK Committee on Climate Change has identified in its Net Zero report[14], that *“CCS is a necessity, not an option".* In 2019, a Carbon Capture Utilisation & Storage (CCUS) Advisory Group was established which will work with the UK Government to develop the investment framework necessary to deliver the first CCS projects in the UK in the 2020s. Similarly, there has been a resurgence in innovation in CCS projects across Europe (this includes Norway, Belgium, Germany and the Netherlands), with many projects at various stages of development.

From Ervia’s initial assessment, it is clear that Ireland has real opportunities to benefit from the decarbonisation potential of CCS. The three options identified have withstood initial scrutiny from a commercial and technical assessment and merit progression to the next phase of analysis. Building on deep experience of gas transportation, Ervia has established a comprehensive CCS capability which has already delivered a significant European collaboration with Equinor and an approved PCI project status application. This work will continue into 2020 and beyond in close collaboration with all stakeholders.

[14] (Committee on Climate Change, 2019)

2. Introduction

Carbon dioxide (CO_2) is a colourless gas with a density of about 60% greater than that of air. It is present in the Earth's atmosphere as a trace gas. Natural sources of CO_2 include organic decomposition, burning, volcanic activity and the dissolution of carbonate rocks in water and acids.

*The concentration of CO_2 in the atmosphere is on the rise. Increased use of fossil fuels and deforestation have intensified the release of the gas into the atmosphere. The CO_2 that is not absorbed by vegetation and the oceans, remains in the atmosphere absorbing and emitting infrared radiation. Absorption of infrared **radiation by CO_2** traps energy near the surface of the planet, warming the surface and the lower atmosphere (global warming)[15]. While there are other atmospheric gases **(methane, nitrous oxide and ozone)** that also cause this greenhouse type effect; CO_2 with its higher concentration and longer atmospheric lifetime exerts a larger overall warming influence.*

2.1 The Challenge of Climate Change

Climate change is one of the greatest challenges facing the world at present. Global warming as a result of deforestation, industrialisation and the release of greenhouse gases is having far reaching and profound impacts on the global community and human health. Globally average temperatures have now increased by more than 1°C since pre-industrial times. The increase in climatic temperature is melting glaciers and sea ice, increasing sea levels and shifting weather patterns. Projections indicate that global greenhouse gas emissions will continue to grow, resulting in further warming and changes to our climate[16]. This will lead to:

- The occurrence of more extreme weather events with:
  - increased threats to human and animal life; and
  - increased threats to property.

- Higher global sea levels resulting in:
  - loss of habitable land;
  - population displacement; and
  - further pressure on the world's scarce water resources and food production systems.

[15] Global warming is the long-term rise in the average temperature of the Earth's climate system and is a major aspect of current climate change.
[16] (DCCAE, 2018)

If the global community wants to avoid the catastrophic impacts of climate change it needs to act. Decarbonisation of our energy systems is an absolute necessity.

Political commitment in Europe is now moving positively in this direction. At the 2015 United Nations Climate Change Conference of Parties in Paris (COP21), Ireland (as an EU Member State), adopted a legally binding agreement to keep global warming below 2ºC.[17] The European Commission (EC) has also called for a climate-neutral Europe by 2050 and has set progressive targets for reducing its greenhouse gas emissions to meet this goal[18].

2.2 Carbon Emissions

The European Union Emissions Trading System (EU ETS) is the cornerstone of the EU's policy to combat climate change and a key tool for reducing greenhouse gas emissions. There are two separate groupings of carbon emitters in Europe. These emitters are identified into:

- The ETS sector[19] – includes energy, industry, air transport, pharmaceuticals and the power sector.
- The Non-ETS sector – all other carbon emitters including all other transport, agriculture, residential, commercial, waste and small industry.

The EU ETS covers more than 11,000 industrial plants and power stations in 31 countries, as well as all airlines that operate within the EU. The EU ETS is designed to bring about reductions in emissions at least cost. ETS participants are allowed an initial allowance (cap) for the amount of CO_2 that they may emit into the atmosphere. The cap is reduced over time so that total emissions fall. Individual installations must report their CO_2 emissions each year and surrender sufficient allowances to cover their emission reduction targets. If their available allowances are exceeded, an installation must purchase allowances (at the prevalent ETS carbon price). On the other hand, if an installation has succeeded in reducing its emissions, it can sell any surplus allowances remaining. The EU ETS scheme covers about 45% of EU emissions, but only about 28% of total emissions in Ireland.

In the non-ETS sector individual members states are mandated to achieve reductions across a range of sectors (agriculture, heating, and transport). Ireland faces particular challenges in reducing carbon emissions in this area. In Ireland, the non-ETS sector represents a much

[17] (United Nations, 2015)
[18] (European Commission, 2018)
[19] Installations and aircraft operators covered by the EU ETS are those which carry out activities listed in Annex I of the EU ETS Directive.

higher proportion of total CO_2 emissions compared to the rest of the EU. In the EU, the non-ETS sector accounts for c. 55% of annual CO_2 emissions, whereas in Ireland it is 72%. This reflects, among other things, the size and intensity of the agricultural sector here.

Ireland has fallen behind in its international and European commitments to control emissions. Ireland's greenhouse gas emissions per capita are the third highest in the EU[20]. Ireland committed to reducing its non-ETS emissions by 20% from 2005 levels by 2020. However, it is expected that Ireland will only achieve a 1%-2% reduction within this timeframe.

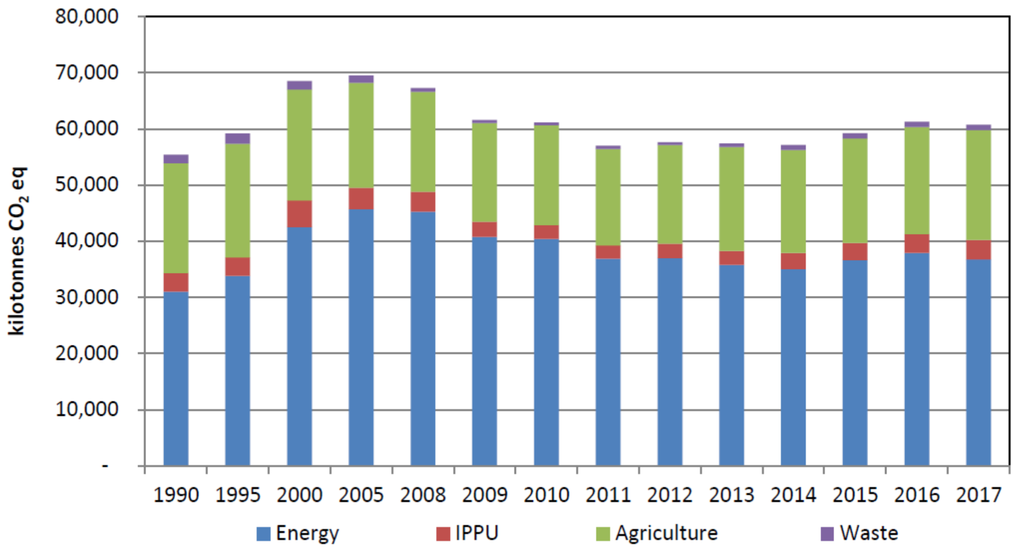

Figure 1. National total greenhouse gas emissions 1990-2017
(Note: IPPU = Industrial processes and product use, Energy = transport, heating and power)

In 2017 Ireland emitted c.60Mt of CO_2. Of this, approximately 20Mt of CO_2 were emitted from the agricultural sector. Achieving the carbon reductions that Ireland committed to under the Paris Agreement will be extremely challenging due to the impact of economic and population growth.

2.3 Power generation and the importance of Natural Gas

Power generation sits within the ETS sector. Overall energy demand (all power, heating, transport etc.) in Ireland in 2018 was c.140,000 GWh[21]. Of this, electricity consumption was approximately 28,000 GWh, or one fifth of total national energy demand. The production of electricity in Ireland is responsible for c.20% of Ireland's CO_2 emissions or 11.2Mt.

With economic and population growth, the annual demand for electricity and its proportion of

[20] (European Commission, 2019)
[21] (SEAI, 2018)

the overall total Irish energy need are expected to increase significantly. Looking at forecasts of possible Total Electricity Requirement (TER) on an 'All Island'[22] basis, significant extra electricity capacity will be needed to meet forecast increasing demand from electric vehicles, electric heat pumps, data centres, population and housing growth.[23]

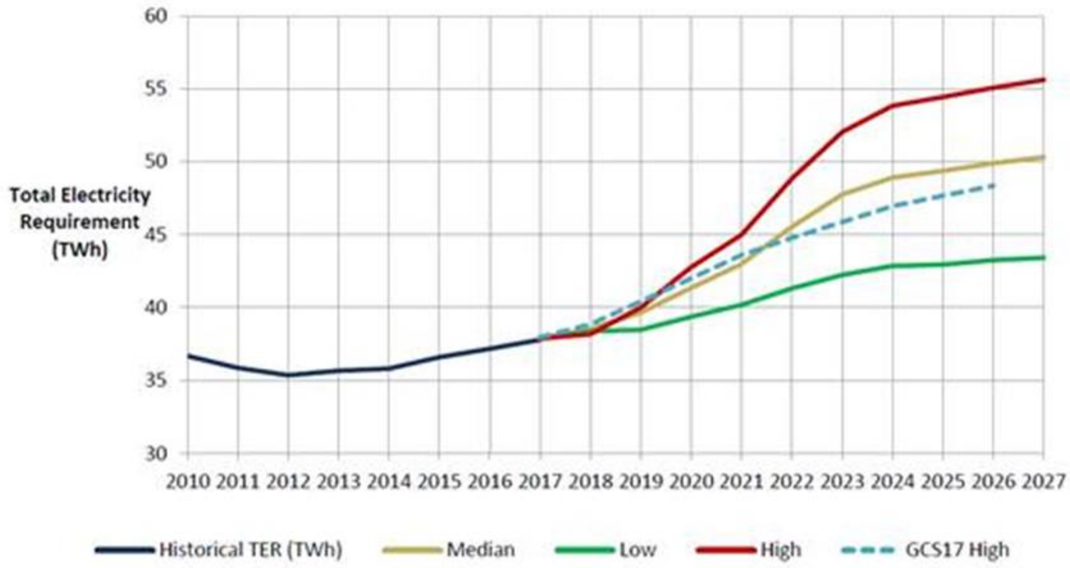

Figure 2. Total Electricity Requirement forecast – All Island

Electricity generation in Ireland is currently provided from a mix of energy sources. These include, natural gas, coal, renewable, peat/biomass, combined heat and power (CHP), distillate oil and pumped hydro-electric storage[24]. In addition to generation capacity there is also the availability of some electricity interconnection from the UK.

Following a recommendation by the Joint Oireachtas Committee on Climate Action[25], the Government has committed that Ireland will achieve 70% of its future electricity need from renewable sources by 2030, (up from c.32% in 2018[26]). This increase is expected to be achieved with additional wind and solar power. While this will enhance Ireland's energy sustainability, it will also increase the amount of intermittent (non-firm) generation accessing the national grid. Non-firm power cannot provide certainty of generation availability and increases grid system security of supply risk. In order to facilitate future increased renewable penetration on the national grid, Ireland needs to ensure that there are alternate decarbonised firm sources of electricity available to deliver enhanced security of supply.

Natural Gas is the cleanest of the fossil fuels. Currently over 50% of the country's electricity need is generated from gas-fired power stations and it provides the critical component of flexibility to balance the intermittency of renewables on the Irish energy system. While coal

[22] I-SEM a wholesale electricity market where electricity is traded in bulk across the island of Ireland.
[23] (Eirgrid, 2018)
[24] (SEAI, 2018)
[25] (Joint Committee on Climate Action, 2019)
[26] (DCCAE, 2018)

and peat are also available, they do not have the same flexibility as the gas-fired plants to ramp up or down and are much heavier carbon emitters.

The critical role of natural gas in offsetting periods of low wind usage over time can be seen below. This graphic shows the wide variation in power generation by source over summer (June to Aug) of 2018 with gas providing most electricity. While there were periods of significant renewable penetration, there were also many periods when very little renewable generation was available. At these times it was the availability and flexibility of natural gas generation which ensured security of supply and stability for the national electricity grid system.

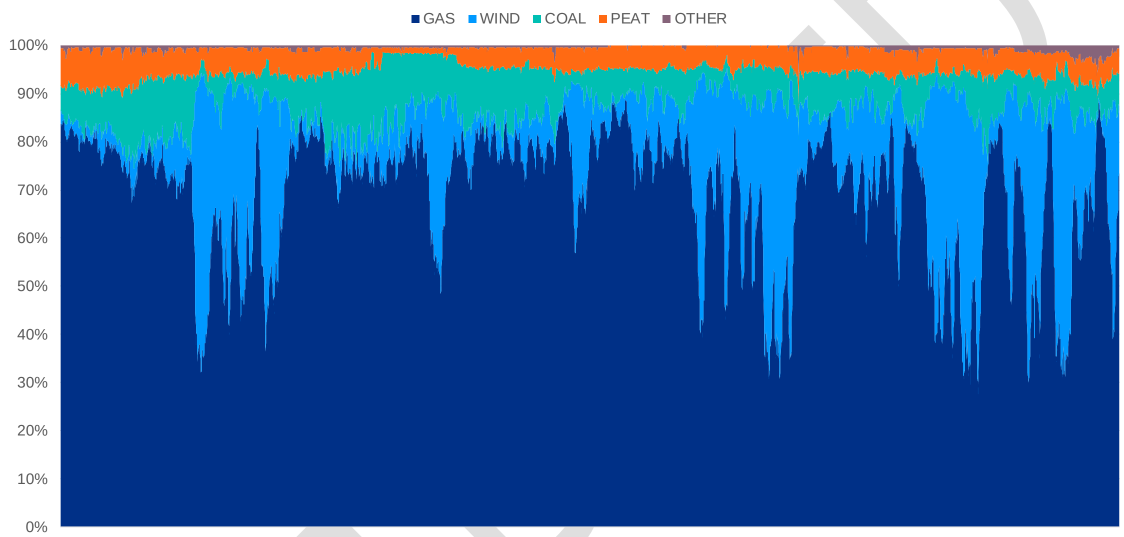

Figure 3. Power Generation as a % of total by Energy Source – 01 June to 31 August 2018

This need for a firm source of power to provide security of supply, whilst most pronounced in the summer, remains across the year. As seen in figure 4, it is the flexibility of natural gas generation which provides the security of supply to balance renewable generation availability across the full year period.

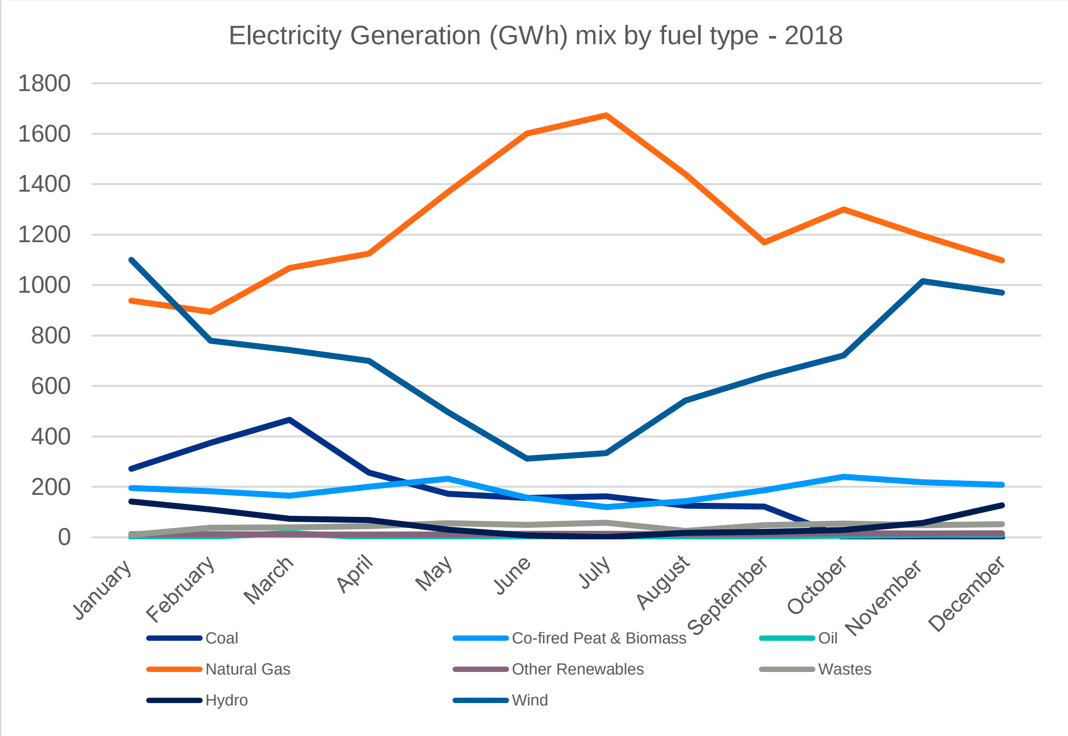

Figure 4. Electricity Generation (GWh) mix by fuel type - 2018

2.4 The Nature of the problem facing Ireland

In order to meet our international climate change commitments, Ireland must decarbonise all sectors of the economy.

The current strategy to attain this objective in the ETS sector is through the proposed increase in renewable generation. Ireland has committed to doubling the proportion of electricity generated from renewable sources from c.35% today to 70% by 2030. This will greatly increase the level of intermittency in the system and the difficulty of maintaining a stable and secure electrical system.

The current strategy to attain this objective in the non-ETS sector is to progress electrification in the (non-ETS) areas of heating and transport emissions. This raises significant issues. According to Eirgrid's 'Tomorrows Energy Scenarios'[27] Ireland's electricity demand could increase from its current level of c.29TWh up to c.50TWh (in the Coordinated Action

[27] (Eirgrid, 2019)

Scenario) by 2040 (driven by new data centres, new housing, installation of heat pumps, switching to electric vehicles (EVs) and increased population). There would be a significant need for additional electricity generation to support these electrification initiatives. These initiatives would in effect move some of these demands from the Non-ETS sector to the ETS sector, further increasing the challenges already faced in decarbonising electricity (i.e. the 2030 target would be 70% of a much greater demand than today).

Gas-fired generation is the primary source of flexible dispatchable (i.e. available on demand) energy to balance renewable intermittency on the Irish national grid. Other flexible dispatchable sources of power are available, however they are very limited in the Irish energy infrastructure mix. There are some sources of hydro power available but they are generally of small-generation scale or limited in running availability. There is no nuclear power sector in Ireland and its development is currently prohibited under Irish law.

Ireland does not have the same available options as other countries for large scale, dispatchable electricity generation. If the current strategies for both ETS and non-ETS targets are to be met (increased penetration of renewables, increased electrification of transport and heat), an even deeper dependency will be placed on natural gas generation to ensure that Ireland can continue to securely meet its growing electricity demand. In a working paper[28], the Economic and Social Research Institute (ESRI) highlighted the importance to the economy of Ireland of a secure and reliable electricity supply. It estimated that a loss of gas-fired generation would result in a loss to the economy of up to €1bn per day (under certain scenarios).

Ireland cannot decarbonise its total electricity system without also decarbonising its gas-fired power generation.

2.5 How can decarbonisation be achieved?

Carbon Capture and Storage (CCS) is a proven technology which can decarbonise the ETS sector (both electricity generation and large industry) at scale. Using Combined Cycle Gas Turbine (CCGT) plants with CCS can provide the technical solution to maximise renewable penetration and meet future growth in electricity demand on a zero-emission basis. Developing CCS in parallel for both power and industry can provide economies of scale in cost and technology. Savings can be enabled through the creation of decarbonised clusters with open access to CCS transportation, shipping and storage.

Ervia has established a dedicated team to undertake an initial assessment of the potential for CCS for Ireland. The purpose of this document is to set out a summary of the findings

[28] (ESRI, 2010)

from this initial assessment. The remainder of this document is structured into the following sections:

Section 3. Carbon Capture and Storage - overview and potential options for Ireland;

Section 4. A Technical Assessment of Initial Options;

Section 5. Commercial Aspects of Initial Options;

Section 6. Public Policy, Legislative and Societal Considerations; and

Section 7. Conclusions.

3. Carbon Capture and Storage – overview and potential options for Ireland

3.1 What is Carbon Capture and Storage?

Carbon Capture and Storage (CCS) is the process of capturing, compressing, transporting and storing CO_2 to ensure that it is not released into the atmosphere. A typical CCS process is illustrated below.

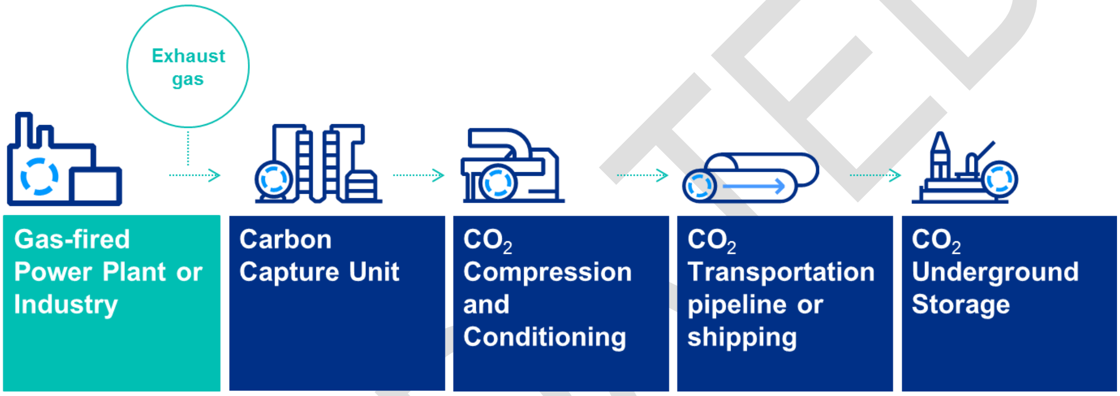

Figure 5. Typical CCS Process Chain

The process starts with the capture of CO_2 emissions from power generation or industry processes. At this point the CO_2 is compressed and conditioned, either as a gas for low-pressure transport, or as a liquid at higher pressure. The CO_2 is then typically transported via steel pipelines or ship to a depleted oil or gas field or a saline aquifer for permanent storage and non-release into the atmosphere.

There are a number of different ways in which CO_2 can currently be captured, these are:

- Post-combustion;
- Pre-combustion;
- Oxyfuel; or
- Direct Air Capture.

Post-combustion capture is currently the most widespread capture process in operation globally and is a cost-effective method for capturing emissions from existing power stations and industrial operations. Following combustion of fuel in a power plant or industrial site the exhaust is diverted into a chemical plant which can capture up to 95% of the CO_2. The captured CO_2 is compressed and conditioned and then transported to a storage site for permanent storage.

Pre-combustion capture is a process where a natural gas fuel source is split into its two chemical constituents, CO_2 and hydrogen (H_2). This is commonly carried out using an industrial process called steam methane reforming[29]. The hydrogen can then be blended with other methane or sent directly as the new fuel source to the power station or to industry for utilisation. Hydrogen combustion produces water vapour alone, with no carbon emissions. CO_2 is captured directly from the methane reforming process. This capture technology is currently under consideration for large projects in the UK to produce hydrogen at scale for power generation, industry and heating.

Oxyfuel capture is a process where 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. While this process is not currently widely proven, a demonstration plant has been built and is currently being trialled in the USA[30].

Direct Air capture is the physical or chemical separation and concentration of CO_2 directly from the air. The cost to capture CO_2 with this technology is currently very high due to the large electrical energy input required. The cost of this technology is expected to drop significantly as it is developed at scale.

As pre and post combustion capture are the two technologies currently deployed at scale worldwide, we consider these further in this initial assessment.

3.2 Why is Carbon Capture and Storage required?

Internationally the need for the increased use of CCS technologies to tackle greenhouse gas emissions and global warming is well recognised.

The special report of the Intergovernmental Panel on Climate Change (IPCC)[31] in 2018, *'Global Warming of 1.5°C'*[32], details the impacts of global warming of 1.5°C above pre-industrial levels. This report identifies that limiting global warming to 1.5°C degrees will require *'the use of negative emissions technology'* (NET) in which bio-based CCS processes will be critical. Bio-based CCS processes can result in a net reduction in carbon in the atmosphere (negative emissions). The vegetation used as the biomass and biogas fuel source extracts CO_2 directly from the atmosphere while it is growing. When burned to produce energy, the biomass/biogas emits the CO_2 extracted during its growth. If CO_2 is captured when the biogas is combusted, then there is a net overall CO_2 reduction from the

[29] 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.
[30] (Netpower, 2019)
[31] The Intergovernmental Panel on Climate Change is the United Nations body for assessing the science related to climate change. The objective of the IPCC is to provide governments with scientific information that they can use to develop climate policies.
[32] (IPCC, 2018)

atmosphere. To achieve a net-zero society, negative emissions at scale will be necessary to offset sectors which are difficult to decarbonise, such as agriculture. CCS with bio-methane provides the largest opportunity to achieve negative emissions in Ireland.

The International Energy Agency (IEA)[33] also assesses[34] CCS as one of the only technologies capable of delivering the deep emissions reductions needed across other CO_2 emitting key industrial sectors such as steel, cement and chemicals manufacturing.

Both the IPCC's and the IEA's assessments look at different scenarios for decarbonisation. Three out of the four scenarios detailed in the IPCC's *'Global Warming of 1.5°C'* report include the need for bio-based CCS to significantly reduce emissions in the energy sector; in addition to being an important compensator for emissions from other sectors (e.g. agriculture). In the IEA's Sustainable Development Scenario (SDS)[35], the use of CCS technology accounts for 7% of the cumulative emissions reductions needed globally to 2040 to meet energy and climate goals.

The European Commission (EC) has recognised in its framework for EU climate and energy policies (2014)[36], the role that CCS will have in reaching the EU's long-term emissions reduction goal. In the power sector, CCS could be a key technology to decarbonise existing fossil fuel-based generation; helping it to balance an electricity system with increasing shares of variable renewable energy.

Eirgrid's 'Tomorrow Energy Scenarios'[37] deploys CCS in two of its three scenarios. The report states that "Pursuing both CCUS and renewable gas reduces the risk of reliance on a single option, while helping to mitigate as much as possible a long-term reliance on non-abated fossil fuels."

In 2018 the EC report, *'A Clean Planet for All'*[38], further identified CCS as a building block to deliver a net-zero greenhouse gas economy by 2050. This report recognised that CCS deployment is necessary especially in energy-intensive industries. It also identifies the role of hydrogen in a zero carbon future.

Following on from this, in 2019 the UK Committee on Climate Change published its report "Net Zero: The UK's contribution to stopping global warming"[39]. This report emphasises the importance of CCS to achieving net-zero emissions and states that ***"CCS is a necessity, not an option"*.**

[33] The International Energy Agency (IEA) is an autonomous intergovernmental organisation established in 1974 under the Organisation for Economic Co-operation and Development.
[34] (IEA, 2019)
[35] (IEA, 2019)
[36] (European Commission, 2019)
[37] (Eirgrid, 2019)
[38] (European Commission, 2019)
[39] (Committee on Climate Change, 2019)

3.3 Is Carbon Capture and Storage a proven technology?

Capturing, transporting and storing CO_2 is a well-established technology. There are 18 large-scale projects in addition to many other smaller facilities operating globally since 1972. The global annual capture capacity of CO_2 is currently circa 40Mt and there are over 6,500km of CO_2 pipelines operating safely in the United States of America (USA) and Canada. CO_2 has been injected and stored in saline aquifers in Norway since 1996 and at pilot scale into depleted gas fields in the Netherlands since 2004.

Post-combustion capture technology is in successful use on two large scale power stations, Boundary Dam[40] in Canada and WA Parish[41] (known as the Petra Nova project) in the USA. The Boundary Dam station entered operation in 2014 as the world's first power plant with CCS. Petra Nova entered operation in 2017 with CCS retrofitted to the existing power plant.

Figure 6. Boundary Dam Carbon Capture plant.

At Sleipner[42] West gas field in Norway, CO_2 has been removed from the natural gas being produced and stored in a deep saline reservoir since 1996. Following this project, a further reservoir at Snøhvit was added. By 2018, the Sleipner and Snøhvit CCS projects had captured and stored 22Mt of CO_2 in saline aquifers offshore of Norway.

CO_2 has been injected into a production gas field in the Netherlands since 2004. The K12-B[43] gas field in the Southern North Sea has been used as a pilot project to improve the

[40] Boundary Dam is a coal fired power station owned by SaskPower, located at Estevan, Saskatchewan.
[41] WA Parish is a coal and natural gas fired power station owned by NRG Energy, located at Smithers Lake, Houston.
[42] Sleipner is a natural gas field in block 15/9 of the North Sea. It is located 250 km west of Stavanger, Norway.
[43] K12-B is a natural gas field which entered production in the Netherlands sector of the North Sea in 1987. It is located 150 km northwest of Amsterdam.

technology of CO_2 injection into depleted gas fields. The result of the pilot project has been positive, demonstrating the technology to permanently store CO_2 in depleted gas fields.

There is a significant body of research, industry standards, directives and guidance setting out the appropriate assessment of a reservoir to meet geological storage. These include:

- Joint research conducted by the University of Aberdeen, University of Edinburgh and University of Barcelona which identifies that in a well-regulated storage site with moderate well densities, 98% of the injected CO_2 would remain in the subsurface over 10,000 years[44].

- UK Government Department for Business, Energy and Industrial Strategy (BEIS) consultation on Business Models for Carbon Capture Usage and Storage, published July 2019, states *"The risk of a CO_2 leak is very low – no reported leakage of any significance has occurred of any of the 250 million tonnes of CO_2 that has been stored underground in the last 47 years*."[45]

- *ISO 27914:2017* '*Carbon dioxide capture, transportation and geological storage – Geological Storage'*. This standard establishes requirements and recommendations for the geological storage of CO_2 streams, the purpose of which is to promote commercial, safe, long-term containment of carbon dioxide in a way that minimises risk to the environment, natural resources, and human health.

- EU Directive 2009/31/EC on the geological storage of CO_2, requires that a geological formation shall only be selected as a storage site, if there is no significant risk of leakage with leakage defined as any release of CO_2 from the storage complex.

The research, standards and directives identify a number of different mechanisms in which CO_2 can safely be retained in a host reservoir, which include:

1) *Structural and stratigraphic*. Injected CO_2 will be retained within the reservoir by impermeable layers of rock above the reservoir. The CO_2 will remain as a free gas and will be contained in the structural trap permanently as long as the structure and caprock have no potential leakage paths within them.
2) *Residual*. As the CO_2 is injected, it will displace any existing fluids as it navigates through the porous rock. During this movement, some CO_2 will become immobilised within the pore space and will stay there permanently.
3) *Solubility*. CO_2 has the ability to dissolve in certain fluids. This phase in the trapping process involves the CO_2 dissolving into the salt water already present in the porous rock. The salt water containing CO_2 is denser than the surrounding fluids and so will sink to the bottom of the rock formation over time, trapping the CO_2 even more securely.
4) *Mineral.* When CO_2 dissolves in water it forms a weak carbonic acid. Over time, this acid

[44] (Juan Alcalde, 2018)
[45] (Dept for Business, Energy & Industrial Strategy, 2019)

may react with the rock, forming solid carbonate minerals which bind the CO_2 to the rock. The process can take many years and the speed of the process is determined by the chemistry of the rock formation and the water.

The IPCC (2005) special report on 'Carbon Dioxide Capture and Storage', has found that for well-selected, designed and managed geological storage sites, the vast majority of the CO_2 will gradually be immobilised by various trapping mechanisms and, in that case, could be retained for up to millions of years.[46]

3.4 What economic factors are needed for CCS?

In addition to the critical environmental need, positive economic drivers also need to be present for CCS development. In North America where CCS has been deployed widely, the captured CO_2 is sold as a commodity. The recovered CO_2 is used extensively in the oil exploration sector in enhanced oil recovery operations. In Norway, the introduction of a carbon tax in 1990 led to the development of the Sleipner and Snøhvit projects. These projects became commercially viable as a result of economic policy and the carbon price set by the Norwegian government.

However across the rest of Europe the lack of a clear economic policy framework is a fundamental barrier which has contributed to a lack of wider CCS deployment. At a European level, support has been focused on providing support for renewable, rather than low-carbon, technologies. Commitment levels from governments on wind and solar supports are over-favourable. There is a positive bias allowed in assessing their financial feasibility. The use of Levelised Cost of Electricity (LCOE) as a cost comparison metric means that the full cost that these renewables impose on the overall energy system is not being calculated correctly.

There has been a low recognition to date of the long-term need for 'zero emission firm power' to balance intermittent renewable energy. The high level of flexibility that current gas-fired power generation provides is taken for granted. Without a focus to support zero emission firm power from CCGT-CCS, legacy generation will not be commercially viable to support the high levels of flexibility needed for intermittent renewables into the future.

In 2012, an EU funding program, New Entrants' Reserve (NER) 300[47], was established, with a c.€2 billion fund for the progression of innovative low-carbon energy demonstration projects. Only one CCS project was selected to receive funding support. The NER 300 funding programme was not a success; the majority of the projects selected found it difficult to raise sufficient equity or to attract external finance and were not able to reach investment decisions stage by 2016. A European Court of Auditors assessment[48] in 2018 concluded that adverse investment conditions, a drop in carbon price, issues with funding competition risk, accountability and coordination, coupled with uncertainty in regulatory frameworks and

[46] (IPCC, 2005)
[47] (European Commission, 2019)
[48] (European Court of Auditors, 2018)

policies were all factors in an unsuccessful CCS deployment through the funding mechanism.

In the UK the picture has been similar. In 2016, the UK Government commissioned the Parliamentary Advisory Group on CCS to prepare the Oxburgh[49] report. This report looked at why public sector competitive approaches to garnering private sector capital investment in CCS technology in the UK, had not been successful in establishing an economic driver for CCS.

The report looked at two prospective UK CCS projects which had been cancelled (Peterhead and White Rose) and concluded that they had both been over risked, over scoped and economically overpriced as a result of the way that the competitions had been structured by the UK government. The UK government wanted the private sector to develop these first-of-a-kind (FOAK) complex projects with minimal state support involvement or liability. The Oxburgh Report identifies that while the CCS technology is proven, the UK government should have sought to support and de-risk the establishment of the fledgling CCS industry in the UK as it had done in the past with support for previous strategic utility sector start-ups.

The Carbon Capture and Storage Association (CCSA) also published its own report[50] setting out the key lessons learned from the Peterhead and White Rose projects for industry and policy. It further identified that given the immaturity of the industry sector model and the lack of appropriate support, a full-chain private sector business model is unlikely to work for a CCS project in the UK. State ownership or state support would be required.

The IEA re-iterated this position in its 2017 report on Energy Technologies[51]. CCS in the power sector is not being realised at scale. This is because the incremental costs of capture, and the development of transport and storage infrastructures are not sufficiently compensated through regulation by market or government incentive.

Without a clear economic policy framework, setting appropriate support and economic signals to change, we will not see a wider CCS deployment.

The EC and the UK have both recognised the critical need to progress CCS and to address the current economic policy framework shortcomings. Given CCS's fundamental role in addressing decarbonisation and climate change; the UK Committee on Climate Change has identified in its Net Zero report, that "*CCS is a necessity, not an option*".

There has been a resurgence in innovation in CCS projects across Europe (this includes the UK, Norway, Belgium, Germany and the Netherlands), with many projects at various stages of development.

[49] (Parliamentary Advisory Group on Carbon Capture & Storage, 2016)
[50] (Carbon Capture and Storage Association, 2016)
[51] (IEA, 2017)

In the UK, the Department for Business Energy and Industrial Strategy (BEIS) is undertaking numerous studies on CCS. In 2019 a Carbon Capture Utilisation & Storage (CCUS) Advisory Group[52] was established which will work with the UK Government to develop the investment framework necessary to deliver the first CCS projects in the UK in the 2020s.

In Europe many CCS projects have either applied for, or have received, Project of Common Interest (PCI) status. PCIs are European infrastructure projects that link the energy systems in different EU countries. They are intended to help the EU achieve its energy policy and climate objectives: affordable, secure and sustainable energy for all citizens, and the long-term decarbonisation of the economy in accordance with the Paris Agreement. PCI status allows a strategic infrastructure project to apply for Connecting Europe Facility (CEF) funding. The Ervia Cork CCUS project was included on the 4th list of PCI Projects which was published in October 2019. This now enables Ervia to apply for CEF funding under the next call for proposals which is anticipated for Q1 2020. The following CCS projects were also included on the 4th list of PCI Projects:

- **CO_2-Sapling Project** is the transportation infrastructure component of the Acorn full chain CCS project (United Kingdom, in further phases Netherlands, Norway);
- **CO_2 TransPorts** aims to establish infrastructure to facilitate large-scale capture, transport and storage of CO_2 from Rotterdam, Antwerp and the North Sea Port;
- **Northern lights** project – a commercial CO_2 cross-border transport connection project between several European capture initiatives (United Kingdom, Ireland, Belgium, the Netherlands, France, Sweden) with transport of the captured CO_2 by ship to a storage site on the Norwegian continental shelf; and
- **Athos** project proposes infrastructure to transport CO_2 from industrial areas in the Netherlands and is open to receiving additional CO_2 from others, such as Ireland and Germany. The concept is to develop an open-access cross-border interoperable high-volume transportation structure.

The international and European consensus is that CCS will be required to decarbonise our electricity systems and industries between now and 2050. The International Energy Agency (IEA) has predicted that "**Without CCS, the transformation of the power sector will be *at least* USD 3.5 trillion more expensive.**"[53]

3.5 What is the potential for CCS to benefit Ireland?

In 2018 the Department of Communications, Climate Action and Environment prepared Ireland's Draft National Energy and Climate Plan 2021 – 2030 (NECP). This plan identifies

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[52] (Carbon Capture and Storage Association, 2019)

[53] (IEA, 2016)

that "*In the absence of nuclear generation and with very limited hydro powered generation, Carbon Capture and Storage seems to be the most promising technology available to decarbonise the electricity generation sector at scale. Subject to economically viable and secure development, the government recognises CCS as a potential bridging technology that could support the transition to a lower carbon energy future*".[54]

Over 50% of all natural gas transported through the gas network in Ireland is used for power generation, mainly in eight CCGT power plants. These CCGT stations are the primary large-scale sources of flexible, dispatchable energy (i.e. available on demand), to balance demand and intermittency on the Irish National Grid. Other flexible dispatchable sources of power are available, however they are very limited in the Irish energy infrastructure mix. Ireland has all but exhausted its hydro power resource at c.2% of national demand, and nuclear power is expensive, complex and not socially acceptable here. Electrical interconnectors, at the scale required, are expensive and have had some reliability issues. For example, the East-West electrical interconnector has had a number of outages, cost twice the amount of the 2nd gas interconnector and transports 1/32 times the energy of the gas interconnector. Biomass is undesirable due to deforestation and the impact on air quality while large scale batteries are expensive and only suitable for short term storage.

CCS is the only technology which can currently decarbonise gas-fired power plants at scale. Ervia started to assess the potential to use CCS technology to decarbonise gas fired power generation in 2017. Decarbonised gas fired generation through CCS could help achieve the targets of a zero carbon source of electricity for Ireland. This would support increased penetration of renewable generation on the Irish National Grid, by providing a flexible, low carbon dispatchable and diversified supply of electricity. CCS could also enable negative emissions from the capture and storage of CO_2 produced from wider biomass or biogas combustion.

The Electricity Supply Board (ESB) in its 2017 document, 'Ireland's low carbon future', envisages a continuing increase in renewables with the development of CCS enabled gas generation to maintain security of supply.[55] ESB's submission to the draft NECP consultation states "*ESB is of the view that Carbon Capture and Storage (CCS) technology will be required in Ireland given the lack of alternatives.*"[56] The Irish Business and Employers' Confederation (Ibec), in their submission[57] to the Draft NECP consultation, further recommended:

- A national working group on CCS;
- The securing of potential storage sites;
- Establishment of a legal and regulatory framework; and
- Demonstration of viability by supporting small scale projects.

[54] (DCCAE, 2018)
[55] (ESB / Poyry, 2017)
[56] (ESB, 2019)
[57] (IBEC, 2019)

The marine and renewable energy research, development and innovation Centre (MaREI), University College Cork (UCC), believes that CCS forms a significant part of a least-cost decarbonisation model for Ireland.[58] MaREI highlights that bio-based CCS is crucial for achieving net zero emissions due to the difficulty in reducing emissions in other sectors (e.g. freight and industry).

The prospect for CCS has previously been explored in an Irish context. In 2008 Sustainable Energy Ireland (SEI) (now SEAI) and the Environmental Protection Agency (EPA) published a report on their study into the potential for CCS in Ireland[59]. The study concluded that the Kinsale Head gas field had attractive potential as a CO_2 store in Ireland. While preliminary in nature, the study estimated a high confidence level on the field's suitability for permanently storing CO_2. However further detailed work would be required to increase technical confidence levels.

In 2011 PSE Kinsale Energy Limited (the operator of the Kinsale Head gas field) commissioned Schlumberger to assess the suitability of the Kinsale Head gas field for CO_2 storage[60]. Schlumberger assessed the potential to inject 6 Mt of CO_2 per annum into the field in a liquid phase. The Schlumberger assessment concluded that there were no barriers to continuing the assessment of the field's suitability for CO_2 storage. The Ervia assessment of the potential for CCS in Ireland, builds on the work of the 2008 SEI/EPA report. As the project has developed it has assessed the feasibility of a number of alternative CCS options for Ireland. These include:

- Option 1 - Cork CCS Project - Capture CO_2 from power plants and industry in the Cork area and transport the CO_2 for injection in the Kinsale Head gas field;

- Option 2 - Ireland Export Project - Capture CO_2 from various industries and power plants around Ireland and ship the CO_2 overseas to other European storage reservoirs; and

- Option 3 – Hydrogen Project - Capture CO_2 from a methane reforming hydrogen production process and use transportation and storage from option 1 or 2.

Over the remainder of this 'Carbon Capture and Storage for Ireland: Initial Assessment', we will look at the options identified to be available to Ireland and assess possible progression under each.

[58] (Marine and Renewable Energy Ireland, 2018)
[59] (SEI / EPA, 2008)
[60] (Schlumberger / Kinsale Energy, 2011)

4. Technical Assessment of Initial Options

The Ervia assessment of the potential for CCS in Ireland, identified a number of alternative possible CCS options. These include:

1. Option 1 – Cork CCS Project - Capture CO_2 from power plants and industry in the Cork area and transport the CO_2 for injection in the Kinsale Head gas field;
2. Option 2 – Ireland Export Project - Capture CO_2 from various industries and power plants around Ireland and ship the CO_2 overseas to other European storage reservoirs; and
3. Option 3 – Hydrogen Project - Capture CO_2 from a methane reforming hydrogen production process and use transportation and storage from option 1 or 2.

In this section, a brief technical overview of each option and what is involved from a capture, compression, transport and storage perspective will be outlined (where relevant).

4.1 Option 1 – Cork CCS Project - Capture from power plants and industry in the Cork area and transport CO_2 for injection in the Kinsale Head gas field.

Following on from the SEI/EPA 2008 report[61], a Cork CCS project is the logical starting point in the development of an initial option for capturing CO_2 from electricity generation in Ireland. PSE Kinsale Energy Ltd. is due to start decommissioning some of its facilities in 2020. The first phase of the decommissioning plan has been approved by the Minister for Communications, Climate Action and Environment.[62] The potential availability of the field presents a unique opportunity to investigate the Kinsale Area facilities in greater detail and to confirm the infrastructure that could be retained for a future CCS project.

There is the potential to add CCS onto two gas-fired power stations in the Cork region (Aghada and Whitegate) in addition to the existing Irving Oil Refinery at Whitegate and transport CO_2 offshore for storage in the depleted Kinsale Head gas field. If developed, 1.5 to 2.5 Mt of CO_2 per annum could be captured with the Cork CCS Project (i.e. up to one quarter of Ireland's annual gas related emissions).

[61] (SEI / EPA, 2008)
[62] (DCCAE, 2019)

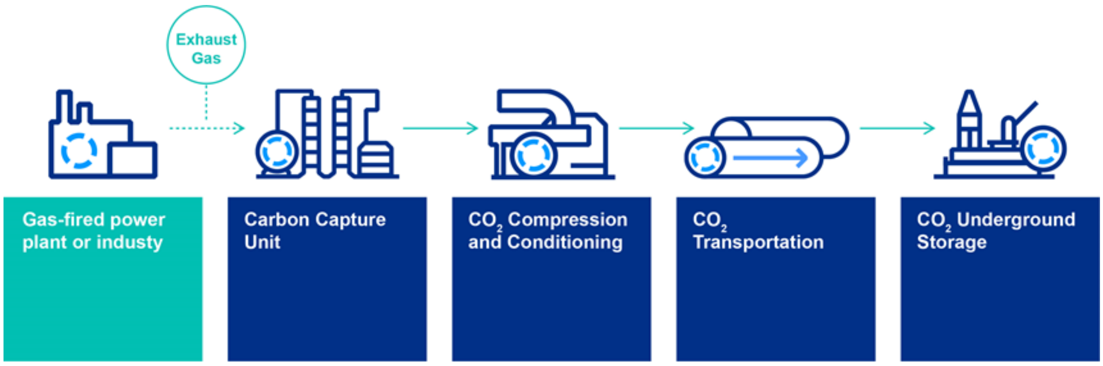

Figure 7. Cork CCS Project process chain

Capture

A post-combustion CO_2 capture process could be retrofitted to the existing Aghada and Whitegate CCGT power stations and the Irving Oil Refinery. These would use an amine-based[63] solvent technology to separate the CO_2 from the power station flue gases. After the fuel is combusted the exhaust gas would be diverted into a chemical plant that utilises a liquid solvent separation method. This method can capture up to 95% of CO_2 emissions.

The flue gas is removed from the power plant exhaust stack. Pre-conditioning of flue gases is utilised to remove contaminants from the flue gas stream, usually with a finely atomised water spray in a feed scrubber. The water spray decreases the flue gas volume, cooling the gas prior to the absorber column. The extent of pre-treatment of flue gases is lower for natural gas than for other fossil fuels. The gas is then blown upward into an absorption tower. CO_2 is absorbed by a downward flowing liquid (an amine based solvent diluted in water), which chemically reacts with the CO_2 by absorption. The remaining treated and cleaned flue gas passes through the absorber to vent to atmosphere via a chimney as normal. The CO_2-laden amine is taken from the bottom of the absorber and heated to over 100°C, which releases the CO_2 in a stripper column. The CO_2 is then ready for compression and conditioning.

The carbon capture plants are anticipated to be located close to the flue gas tie-in location, so as to minimise the length of flue gas ductwork and maximise the system efficiency. It is currently proposed that each capture plant will treat 100% of the power stations' flue gas flow with a CO_2 capture efficiency of up to 95%.

Conditioning and Compression

The separated CO_2 would be subject to further conditioning at the power station and refinery sites, with emphasis on the removal of excess oxygen and water. It would then be compressed for transport. The level of post-conditioning of CO_2 for transportation depends on the downstream CO_2 properties required. The higher the level of conditioning applied to the input CO_2 gas, the drier (less water molecule content) the final CO_2. The dry CO_2 is then

[63] Amine gas treating is a process that use aqueous solutions of various alkylamines (amines) to remove hydrogen sulphide (H_2S) and carbon dioxide (CO_2) from gases. It is a common process used in refineries, natural gas processing plants and other industries.

either compressed at a low pressure for gas transportation or to a high pressure for liquid transport. Gas compression is a proven and common technology internationally.

Transportation

The regulations and design codes around natural gas pipelines in Europe and Ireland are well established[64]. Irish standards for pipelines[65] do not consider CO_2 as a specific named substance; however, the Canadian and Australian standards do address CO_2 transportation as part of CCS systems (CSA Z662 and AS 2885 respectively). An International Standards Organisation (ISO) working group has been established to work on a standard to harmonise the design, construction and operation of CCS infrastructure. This working group has published a number of standards including *ISO 27913:2016 'Carbon dioxide capture, transportation and geological storage -- Pipeline transportation systems'*[66]. This standard provides specific additional requirements and recommendations not covered in existing pipeline standards for the transportation of CO_2 streams from the capture site to storage facility.

Gas Networks Ireland supplies gas to the Aghada and Whitegate CCGT power plants from Lochcarrig Lodge Above Ground Installation (AGI) / Midleton Compressor Station. There is also a pipeline connecting Aghada power plant to Inch Terminal to the south, via Ardrabeg AGI. Inch Terminal connects out to the Kinsale Head gas field via a 24-inch export pipeline.

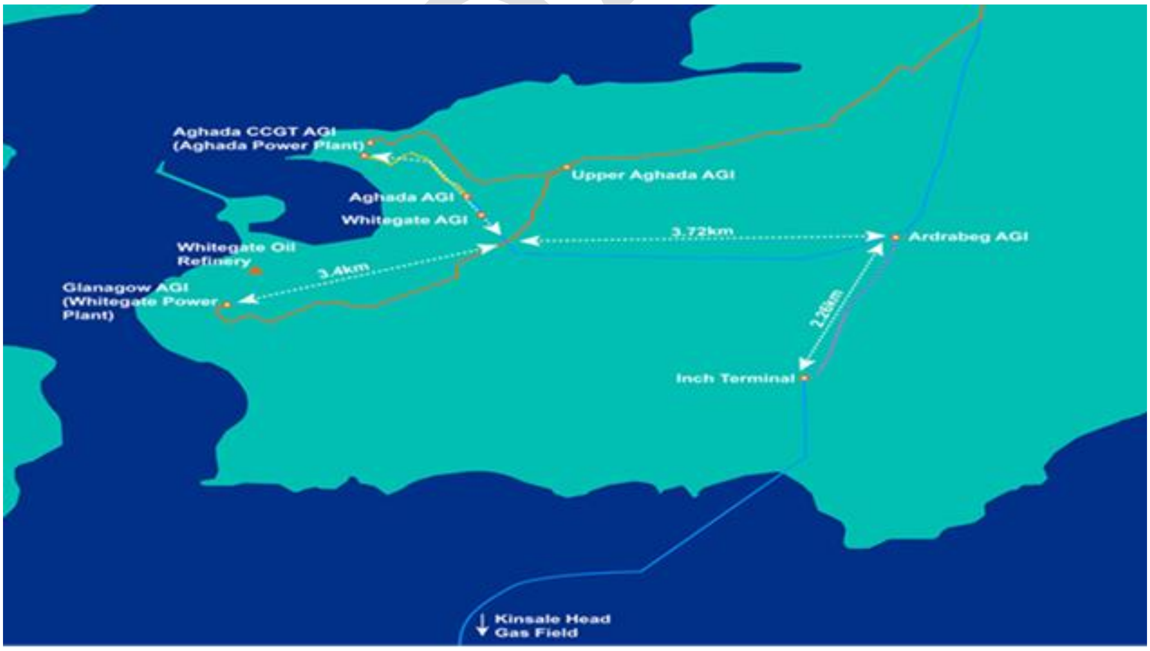

Figure 8. Cork CCS Project Region - Gas Pipe Network

[64] (NSAI, 2015)
[65] (NSAI, 2015)
[66] (ISO, 2016)

The CO_2 captured at the Cork CCS project could be transported to the depleted offshore Kinsale Head gas field via the network of existing gas transmission pipes supplemented with a small element of new pipeline where required. Once the Kinsale Head facilities are decommissioned, the lower pressure pipeline from Aghada power plant to the Inch Terminal would become redundant and available to transport CO_2 from Aghada power plant back into the Kinsale Head gas field. Whitegate CCGT plant and the Irving Oil Refinery are currently not connected to the Aghada - Inch Terminal pipeline; therefore a c.7km pipeline would be required to be installed to transport the CO_2 from the Whitegate power plant and refinery back to the Inch Terminal. The maximum operating pressure of the majority of the pipelines connecting the power plants to Inch Terminal is 37.5 barg. The existing gas transmission network (no longer required as a result of Kinsale Head gas field decommissioning) would be suitable for CO_2 transportation in a “gas” phase to the Kinsale Head gas field. In 2018, Ervia commissioned Xodus Group[67] to undertake an optioneering study, to determine what elements of the existing offshore Kinsale Area infrastructure should be retained to support a potential future CCS project. This study[68] concluded that of the offshore infrastructure to be decommissioned, only the offshore pipeline to the existing fields was required to support a potential future CCS project.

Storage

As outlined in Section 2, CO_2 has been safely stored in saline aquifers in Norway for the past 23 years. The SEI/EPA (2008) and Schlumberger/Kinsale (2011) studies all concluded that the Kinsale Head gas field off the Cork coast is a potential store for CO_2. The Kinsale Head gas field was identified as the most appropriate CO_2 storage option for Ireland at that time.

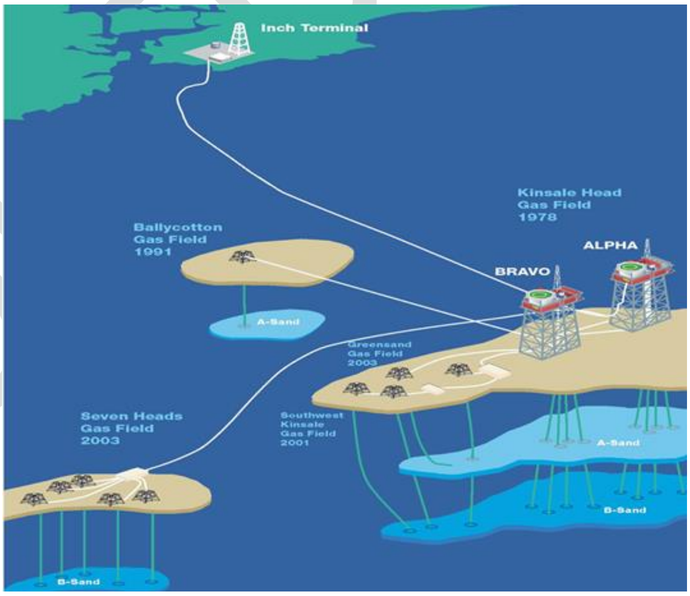

Figure 9. Kinsale Area fields.

[67] Xodus Group – Is an international engineering and advisory services firm headquartered in Aberdeen with experience in the decommissioning of projects in the oil & gas, LNG, renewables and utilities industries worldwide.
[68] (Xodus, 2018)

The Kinsale Head gas field has been in operation extracting indigenous natural gas since 1978 and comprises of 2 fixed platforms - Alpha and Bravo. A number of reservoir fields (A-Sands and B-Sands) are connected to the gas field platforms. While a portion of the B-Sands reservoir has been used by Kinsale Energy for gas storage over the past 15 years, its potential volume for CO_2 storage is too small to be considered. For the Cork CCS option, it would be intended to utilise the A-Sands field (estimated storage potential of c. 250Mt) for the CO_2 storage as part of this project. To confirm this approach, Ervia secured the services of CGG [69] to reprocess seismic data made available by Kinsale Energy. This data reprocessing was positive for the test area examined.

4.2 Option 2 – Ireland Export Project: Capture from various industries and power plants around Ireland and ship the CO_2 overseas to other European storage reservoirs.

A number of potential stores for CO_2 across Europe are either in operation or are being developed. As set out in the table below, the North Sea Basin Task Force Report (2017)[70] has identified significant European storage capacity being available in 2050 in the various national North Sea sectors under a number of development scenarios. These potential storage areas can be seen spread out across the geographical area of the North Sea in figure 10 below.

National North Sea Sectors	Storage Capacity Estimates
British	69,000Mt
Dutch	2,715Mt
German	2,943Mt
Norwegian	66,000Mt

Table 1. Potential European storage capacity in various North Sea sectors - 2050

This creates a significant opportunity for a feasible alternative to Option 1 - the Cork CCS Project.

[69] CGG are a French company who provide detailed geoscience analysis services. They have the capability, services and equipment to acquire extremely precise data and images of the Earth's subsurface. They use-geoscience software to analyse data and develop a deeper understanding of the subsurface for exploration, production and optimization of oil and gas reservoirs.
[70] (NSBTF, 2017)

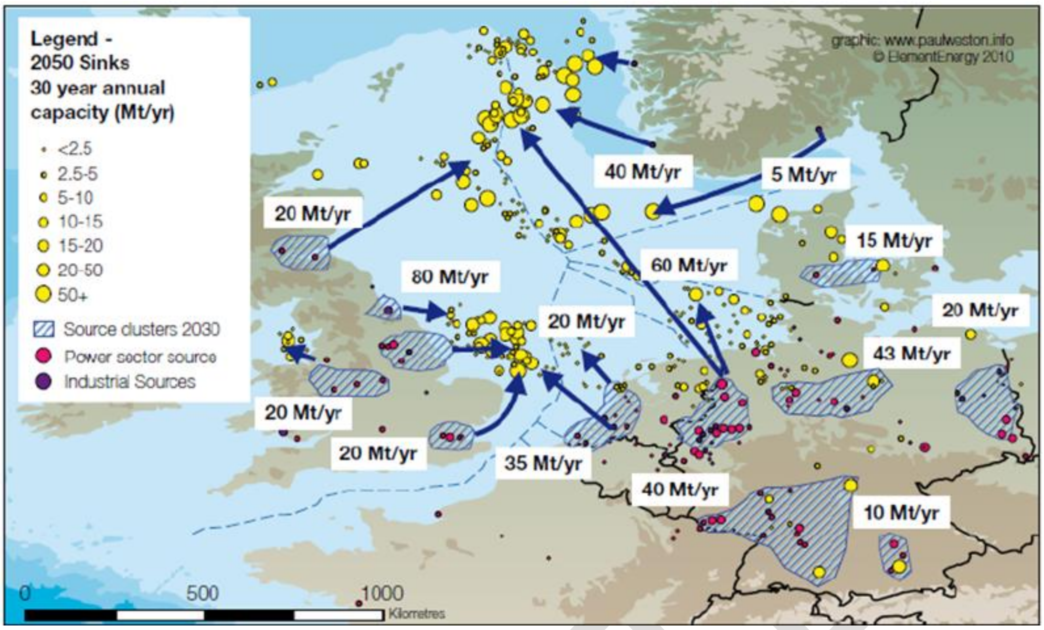

Figure 10. North Sea location of CO_2 Infrastructure development in a "very high" scenario in 2050[71]

CO_2 could be captured from various industries and powers locations across Ireland and shipped to an overseas site for permanent storage. The different industries (e.g. pharmaceutical, cement, waste) and power plants across Ireland which emit CO_2 could be incorporated into an Ireland Export Project by creating a CO_2 hub at one or more ports within Ireland. The CO_2 could then be shipped onwards for storage.

Ervia has recently signed a Memorandum of Understanding (MoU)[72] with Norwegian company Equinor (formerly Statoil) to jointly collaborate in exploring the possibility of CO_2 export from Ireland for storage in Norway's geological reserves in the North Sea. This includes CO_2 capture and liquefaction at a site in Ireland and the transportation of the CO_2 to a storage infrastructure to be constructed by Equinor and its partners in the Northern Lights project in Norway. The Northern Lights[73] project is a full scale CCS project which is being developed by the Norwegian state through the state owned company, Gassnova[74]. Its objective is to capture CO_2 from industry and power plants and to transport it by ship to an offshore geological storage site.

[71] (Element Energy, 2010)
[72] The MOU states that the parties agree to enter into further discussions to explore the possibility of cooperating in CCS development, undertake logistical and technical studies, promote the development of CCS to the European Union and initiate dialogue with our respective national governments.
[73] (CCS Norway, 2019)
[74] Gassnova is a Norwegian state owned company whose mission is to contribute to finding solutions to ensure that technology for capture and storage of CO_2 can be implemented and become an effective climate measure

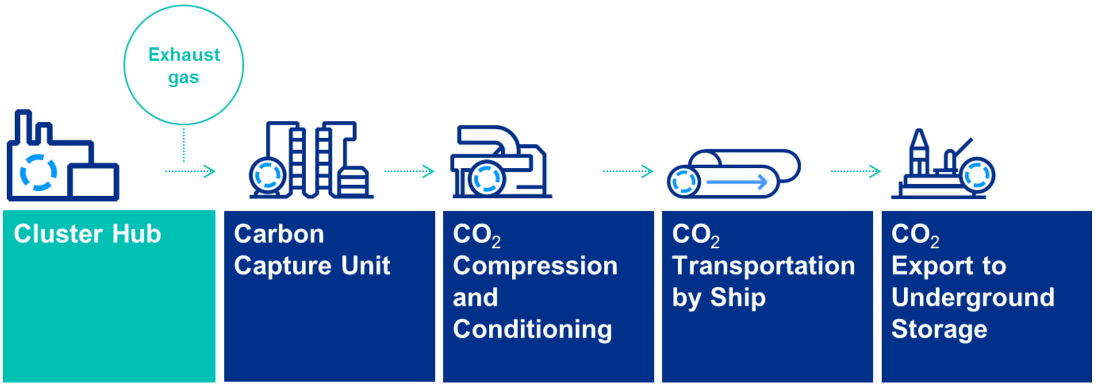

Figure 11. Ireland Export Project CCS process chain

Capture

Data identifying significant CO_2 emitters in Ireland can be assessed from the EU ETS registry[75]. EU ETS emitters in Ireland account for approximately 30% of the State's overall emissions. When the Irish records on the ETS registry are mapped geographically based on industry type and volume of CO_2 emitted; an overlay of the location of potential capture hubs by scale can be seen, as outlined below.

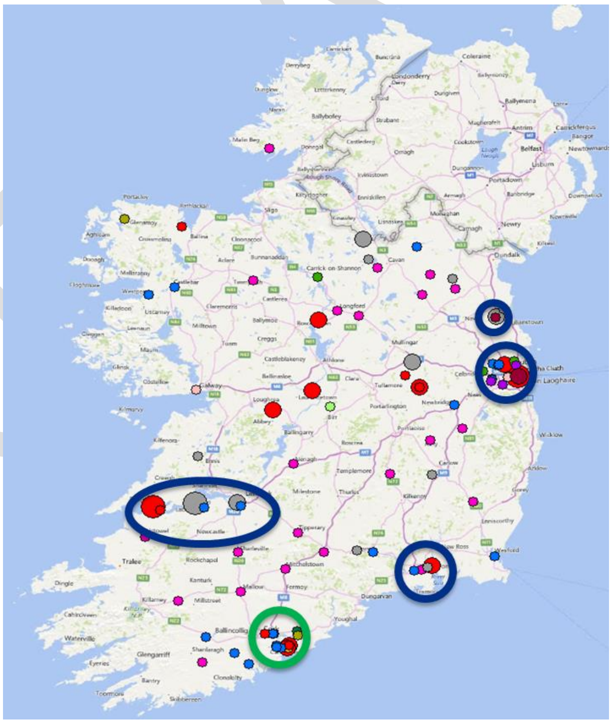

Figure 12. ETS CO_2 emitters in Ireland in 2018.
Emitter industry type identified by circle colour, volume emitted represented by circle size.
Cluster Hubs in blue and Cork CCS Project in green identified.

[75] (European Commission, 2019)

Cluster 'Hub' locations clearly become apparent near the biggest Irish coastal urban areas, i.e. Dublin, Cork, Limerick, Dundalk and Waterford. Irish ETS emitters were mapped down to the following main industrial segments, to identify these cluster hubs:

- Breweries;
- Briquette production;
- Data Centres;
- Food Production;
- Gas Processing;
- Healthcare;
- Heavy Industry (Alumina, mineral and cement production plants);
- Industry (combustion of fuels at manufacturing plants);
- Oil Refineries;
- Pharmaceutical; and
- Power Generation.

As per Option 1, a post-combustion CO_2 capture process could be retrofitted to an existing industry or power station cluster hub. Conditioning of post industry flue gases would be very important in this option, as the industry / power station cluster may produce a significantly contaminated flue gas stream. Again the next step would be the use of an amine-based solvent technology to separate the CO_2 from the cleaned industry / power station flue gases. The gas is then blown upward into an absorption tower. CO_2 is absorbed by a downward flowing liquid (an amine based solvent diluted in water), which chemically reacts with the CO_2 by absorption. The remaining cleaned exhaust gas would pass through the absorber to vent to atmosphere via a chimney as normal. The CO_2 laden amine is taken from the bottom of the absorber and heated to over 100°C, which releases the CO_2 in a stripper column. The CO_2 is then ready for conditioning and compression.

Conditioning and Compression

The separated CO_2 would again require further conditioning and compression. This would be carried out at the cluster hub site prior to any transportation. The level of post-conditioning of CO_2 for transportation depends on the downstream CO_2 properties required. The higher the level of conditioning applied to the input CO_2 gas, the dryer (less water molecule content) the final CO_2.

Transportation

Transport of CO_2 occurs daily in many parts of the world. There are a number of methods of transporting and storing CO_2. At small outputs, transport by either road, rail or inland waterway is possible with temporary storage provided to store the CO_2 between local handling points. At large outputs, transport would be by pipeline or ship.

CO_2 may need to be temporarily stored onshore at a dedicated location (e.g. at the cluster hub location prior to further transportation or at the quayside prior to export via ship). The CO_2 at these onshore storage locations would usually be in liquid form requiring associated compression and conditioning facilities. Specific storage tanks are required to be designed and constructed to meet international safety regulations. Storage of CO_2 would be similar to liquefied petroleum gas (LPG) storage.

In preparing CO_2 for movement to final storage destination, significant investment in transportation infrastructure will be required to enable large-scale deployment. As Option 2 involves export to storage overseas; transportation would be by ship in a LPG-type carrier vessel. Shipment of CO_2 already takes place on a small scale in Europe (3Mtpa), where ships transport food-quality CO_2 from large point sources to coastal distribution terminals (1,000t per ship). Larger-scale shipment of CO_2, with capacities in the range of 8,000 to 10,000m^3, would be carried out using semi-refrigerated LPG-type carriers. There is already a great deal of international experience in transporting LPG, which has developed into a worldwide industry over a period of 70 years. Shipment in this way would require very clean, highly conditioned CO_2 compressed at a high pressure for liquid transport. The cluster hubs identified in Option 2 are all adjacent to the largest Irish ports (Dublin, Cork, Shannon Foynes, Dundalk and Waterford). This means that this option would be capable of facilitating the scale of sea transport required.

Storage

For this option, CO_2 would be stored in a European store, most likely off Norway or off the UK.

4.3 Option 3 – Hydrogen Project Option - Capturing CO_2 from Methane Reforming.

Pre-combustion capture of CO_2 is a process where a natural gas fuel source is split into its two chemical constituents, CO_2 and hydrogen (H_2). This is currently (most widely) carried out using an industrial process called steam methane reforming (SMR)[76]. CO_2 can be captured directly from the methane reforming process. The process is well proven with over 500 large-scale facilities operating worldwide.

Hydrogen can also be produced by the electrolysis of water. This process uses an electric current to break water (H_2O), into its component elements of hydrogen and oxygen. If this electric current is produced by a renewable source (e.g. Solar PV or a wind turbine), the hydrogen produced is known as 'green' hydrogen.

In addition to SMR, methane reforming can also be carried out using other technologies such

[76] Steam methane reforming (SMR) 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.

as Auto Thermal Reforming (ATR)[77]. Hydrogen produced through any methane reforming process is termed ‘grey’ hydrogen. If CCS is integrated with the methane reformer then the carbon is captured and stored permanently and the resulting hydrogen is termed as ‘blue’ hydrogen. Methane reforming with CCS can provide emissions free hydrogen at large scale and at least cost. Blue hydrogen is expected to provide a pathway for ‘green hydrogen’ production in the longer term by initially supplying new uses of hydrogen.

Hydrogen is a gas suitable for long term storage at scale. Hydrogen combustion produces water vapour, with no carbon emissions. This means it could be used viably to decarbonise the heat and transport sectors. It could also complement intermittent renewable electricity generation by providing a clean fuel source to decarbonise dispatchable power generation. Hydrogen can be used directly or blended with other methane as a new fuel source for industry or power generation.

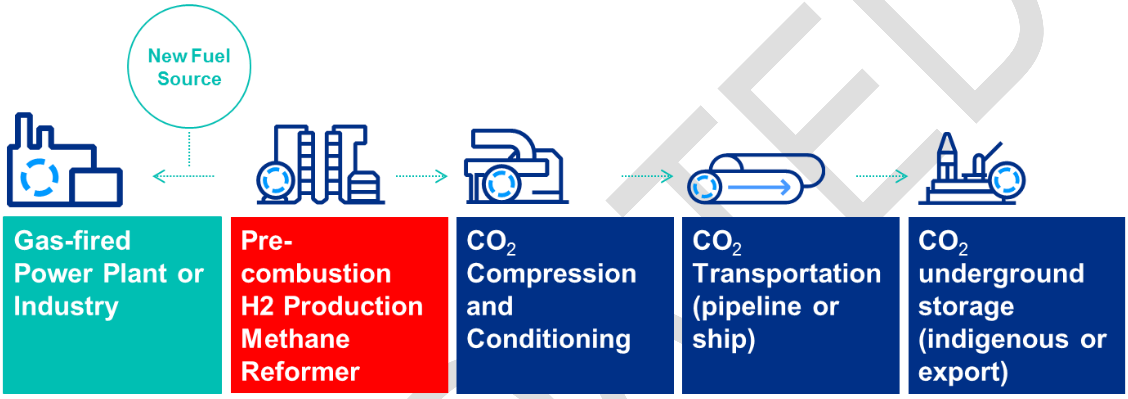

Figure 13. Methane Reforming CCS Process chain

Option 3 ‘Capturing CO_2 from methane reforming’ is in effect only one step of the overall CCS process and would require a conditioning, compression and storage solution to be identified from either the Cork CCS or the Ireland Export Project options.

Capture

Steam methane reforming involves the splitting of natural gas (CH_4) into its two constituents of carbon dioxide (CO_2) and hydrogen (H_2). Steam methane reforming is the dominant production method for the industrial supply of hydrogen globally, due to its lower cost and ability to be deployed at large scale. If the CO_2 released during production is emitted to the atmosphere the hydrogen produced is called “grey hydrogen”. If however, the CO_2 released during production is captured and not released to the atmosphere, the hydrogen produced is blue hydrogen. CCS coupled with reforming technology is the only method available today to produce large quantities of hydrogen.

[77] Autothermal Reforming (ATR) is a process for producing syngas, composed of hydrogen and carbon monoxide, by partially oxidising a hydrocarbon feed with oxygen and steam and subsequent catalytic reforming.

Conditioning and Compression

Post SMR, the separated CO_2 would again require further conditioning. This would be carried out at the methane reforming site prior to any transportation. The level of post-conditioning of CO_2 for transportation depends on the downstream CO_2 properties required. The higher the level of conditioning applied to the input CO_2 gas, the drier (less water molecule content) the final CO_2 will be.

Transportation

For this option, transportation could either be through the use of Option 1 if going to indigenous storage, or Option 2 if going to one of the potential stores for CO_2 across Europe, either currently in operation or in development.

Storage

For this option, storage could either be through the use of indigenous storage (as in Option 1) or through the use of one of the potential stores for CO_2 across Europe, either currently in operation or in development (as in Option 2).

In summary of the initial technical assessment; all three options identified are found to represent viable technical solutions that could be progressed to support decarbonisation.

5 Commercial Aspects of Options

5.1 Introduction

This part of the report provides an initial assessment of the commercial aspects of CCS technology, for the options identified in Section 4 with a particular emphasis on Option 1. The options identified were;

Option 1 – Cork CCS Project - Capture CO_2 from power plants and industry in the Cork area and transport the CO_2 for injection in the Kinsale Head gas field;

Option 2 – Ireland Export Project - Capture CO_2 from various industries and power plants around Ireland and ship the CO_2 overseas to other European storage reservoirs; and

Option 3 – Hydrogen Project - Capture CO_2 from a methane reforming hydrogen production process and use transportation and storage from option 1 or 2.

In looking at the commercial aspects of a CCS project, the following factors are examined:

- Ownership models that may be applied to the CCS process chain;
- Commercial model metrics;
- Options and estimated costs;
- Cost of abatement comparison;
- High level risks;
- Potential grant funding; and
- Cost recovery models.

The section concludes with a high level summary.

5.2 Ownership models that may be applied to the CCS process chain

As set out in Section 2, CCS is the process of capturing, compressing, transporting and storing CO_2 to ensure that it is not released into the atmosphere. The common CCS process chain for Option 1 (Cork CCS Project) and Option 2 (Ireland Export Project) is illustrated below.

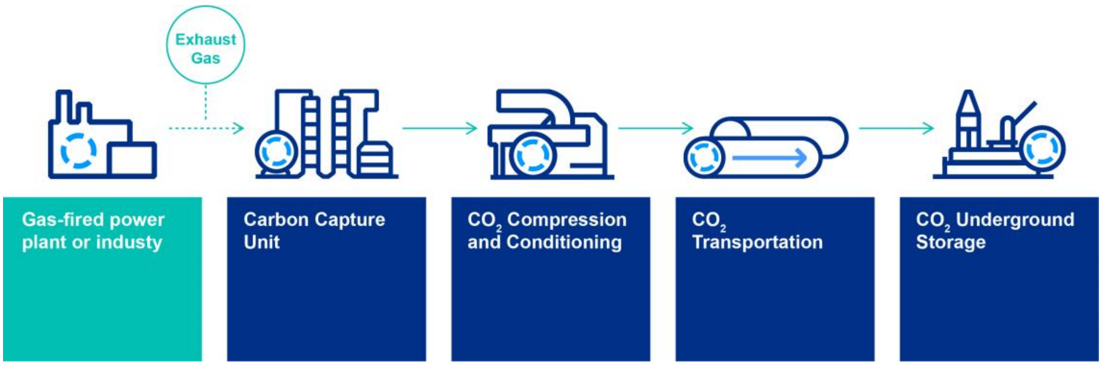

Figure 14. Common CCS Process chain

In identifying an appropriate commercial model for CCS, Ervia considered a number of ownership models across the CCS process chain and these are outlined below.

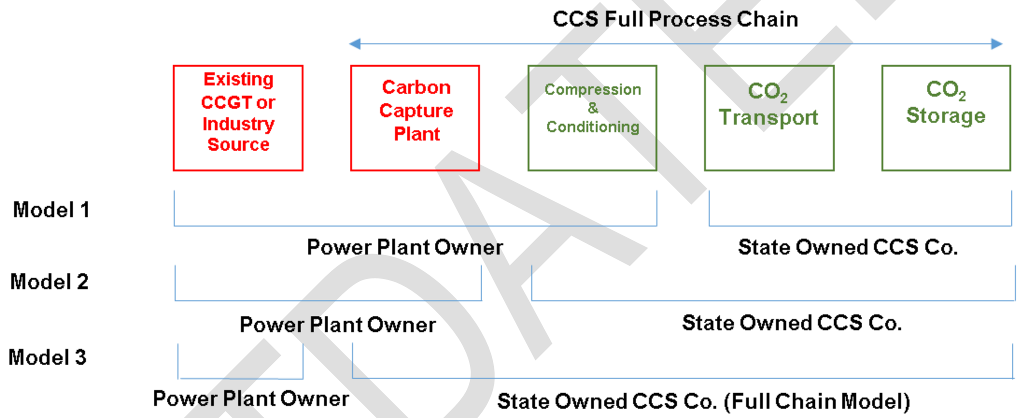

Figure 15. Overview of ownership models for CCS Process Chain

Model 1 envisages CO_2 capture and compression being owned and managed by the emitter, with a state-owned CCS company managing the transportation and storage. This is the recommendation from the Oxburgh Report. This report found that the commercial risks associated with CCS are best managed under a state ownership model for the storage and transport components on a regulated basis. The report identifies that this would significantly reduce the overall CCS project costs.

Model 2 envisages the emitter managing the capture process only. This model simplifies responsibilities for the emitter. They capture the CO_2 from their plant, while all the other CCS process chain elements are managed under a separate single entity which could be either state or privately owned.

Model 3 is the full chain CCS option whereby a single CCS Company manages all the CCS processes including capture. This company could be either state or privately owned.

Current thinking across Europe (BEIS[78], Rotterdam CCS Porthos Project[79] and Pale Blue Dot[80]), is moving towards a structure that sees the CO_2 capture part of the CCS process chain remain with the emitter (i.e. power generator or industry). This is the Model 2 ownership model. A separate monopoly model could then be applied for the remaining process chain elements of compression, transport and storage (either separately or together) on a regulated asset basis (either state or privately owned).

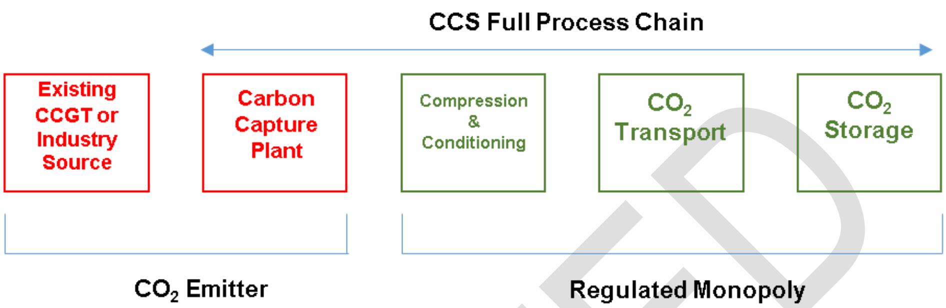

Figure 16. Emerging ownership structure across European models

A regulated monopoly model would be the most appropriate route to deliver the CCS capital expenditure efficiently and ensure robust controls.

5.3 Commercial model metrics

In preparing a cost benefit assessment of the options and possible ownership structure, it is important to identify appropriate and robust cost metrics. In this section the following are reviewed:

- the appropriate choice of metric to compare option costs; and
- options and cost estimates from recent international reports.

Choice of Metric to Compare Option Costs

Levelised cost of electricity (LCOE), expressed as €/MWh, is the average price of electricity that would be needed for a project to achieve a Net Present Value (NPV) of zero across the life of the plant for a given discount rate. It is traditionally used to compare costs for different methods of electricity generation.

This approach has value for cost comparison when you have an equal set of technologies, each providing a similar level and set of services (i.e. where each technology can provide a suite of services e.g. energy, capacity, reserve, response, inertia etc.). It is not an appropriate comparator to use when a technology (such as self-dispatch renewables) can only deliver part of these services. To maintain security of supply, missing services (not provided by

[78] (Business Energy & Industrial Strategy, 2018)
[79] (Rotterdam CCUS, 2019)
[80] (Pale Blue Dot Energy, 2016)

renewables) must still be sourced elsewhere. The addition of renewables to the electricity network incurs significant additional costs such as network upgrades, balancing services cost and curtailment. These are not included in the renewables project costs, but are accounted for separately in transmission service provision costs paid by all consumers. LCOE in this case is not providing a true cost of the average price of electricity from renewables.

Total System Cost of Abatement (CoA), is a much more robust comparator metric. It provides a direct comparison for how much any technology (CCS, renewables, etc.) costs to remove a tonne of CO_2. Total System CoA, expressed as €/tonne CO_2 abated, includes all of the costs imposed by a technology on the system including grid connections, back-up capacity, system integration costs (SIC) etc. Total System CoA provides a more meaningful and true comparison across projects of different scale, and is therefore the primary metric used for comparison purposes in this part of the report.

Options and cost estimates from recent international reports

Option 1 – Cork CCS Project - Capture CO_2 from power plants and industry in the Cork area and transport the CO_2 for injection in the Kinsale Head gas field;

In 2019 Ervia commissioned Wood Group to estimate costs for CCS in Ireland under a number of different scenarios. Wood Group was selected to support Ervia based on extensive CCS financial modelling it had completed on behalf of the UK Government Department for Business, Energy and Industrial Strategy (BEIS) in 2018. As part of the options cost estimate, Ervia included a review of the BEIS 2018 report and the International Energy Agency (IEA) 2019 CCS report in the data assessment. While the results from these reports are subject to key variables (e.g. load factor etc.), they provide a recent indication of costs. Reports included in the cost estimate are set out below:

1. UK Government Department for Business, Energy & Industrial Strategy (BEIS) report 'Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology'[81]. This comprehensive study assessed 10 different cases (scenarios) for CCS and one for hydrogen. For a Natural gas CCGT with post-combustion carbon capture, this report found the cost metrics for the project to be;

[81] (Wood Group, 2018)

Metric	Results
Levelised Cost of Electricity (£/MWh)	69.9
Cost of CO_2 Avoided (zero Carbon Price) (£/tCO_2)	73.1

Table 2. BEIS report – Case 1. Natural gas CCGT with post-combustion carbon capture – GBP.

2. International Energy Agency (IEA) report 'Towards Zero Emissions CCS in Power Plants using Higher Capture Rates or Biomass'[82]. This report assessed the potential to achieve near zero emissions with post-combustion capture. A conclusion of the report is that *"No technological limitation to the increase in CO_2 capture rates was identified, with any limitation likely to emerge from a techno-economic optimisation."* This report looked at a natural gas fired combined cycle with post combustion capture at different CO_2 capture rates with the following results:

Metric	Results		
Capture rate (%)	90	95	99
CO_2 Emission Intensity (g/kWh)	37.2	17.6	0.00
LCOE (€/MWh)	77.6	78.9	82.7
CO_2 Avoided Cost (€/tCO_2)	79.3	78.6	85.5

Table 3. Natural gas fired combined cycle with post combustion capture at different CO_2 capture rates

From the results of the reports above, Cost of Abatement for CCS with gas-fired power generation and offshore CO_2 storage is less than €100/tonne which is very positive compared to many other decarbonisation technologies.

A key advantage of utilising CCS with CCGTs in Ireland is that most of the infrastructure required is already in place when using the existing power station site, gas connection and electricity grid connection etc. Conversely, extensive new infrastructure needs to be put in place to allow renewable electricity to operate on a comparable basis, e.g. grid connection, batteries, electrical interconnection, etc. These costs can be very significant.

Option 2 – Ireland Export Project - Capture CO_2 from various industries and power plants around Ireland and ship the CO_2 overseas to other European storage reservoirs.

[82] (International Energy Agency, 2019)

In this option all of the upstream plant and operation is identical to Option 1 Cork CCS Project, (i.e. the capture plant, compression and conditioning are all the same). In this option, instead of transporting the CO_2 via offshore pipeline to the Kinsale Head gas field, the CO_2 would be transported (by a very short pipeline) to dockside storage tanks (which are similar to LPG storage tanks) for interim storage. The CO_2 would typically be held here for less than a week until a ship arrives. It would then be transferred onto the ship for transport to permanent storage in an underground geological store in the North Sea. The Northern Lights project in Norway is being developed specifically to take CO_2 in this manner from other countries around Europe.

For Option 2 the CCS project would have lower capex than Option 1 (as the project would not need to develop any local offshore storage facilities) and higher opex (as it would pay a premium to the owner of a storage facility to collect the CO_2 by ship and transport it for permanent storage in the North Sea). It could therefore be expected to have a slightly higher Cost of Abatement overall compared to Option 1.

An estimate of the cost to transport and ship CO_2, can be assessed from a UK Government (BEIS) report into the cost of shipping CO_2 compiled by Element Energy[83]. This report assessed the technical and financial aspects of shipping CO_2 at large scale from European ports to UK offshore storage sites.

Metric	Result
T&S Unit Cost from European Port to UK offshore storage (£/t)	< 20

Table 4. BEIS (Element Energy) cost shown above is in GBP/t

From Ervia's interaction with the industry, this data estimate appears low.

Even though the cost of transport and storage of CO_2 to a third party's offshore storage facility is expected to be higher on a €/tonne basis than with indigenous transport and storage the export model holds a number of key advantages. These are:

- Capex for a CCS project in Ireland would be considerably lower;
- All potential future liability in the event of a CO_2 leak would reside with the developer and subsequently the Member State where the CO_2 is stored (expected to be Norway or the UK). This would greatly de-risk the development of CCS in Ireland; and
- Developing facilities to export CO_2 from Ireland would open up the potential to ship the CO_2 to a number of different storage facilities in the North Sea. This would greatly de-risk the commercial contractual arrangements for export by providing options and competition for storage.

Option 3 – Hydrogen Project - Capture CO_2 from a methane reforming hydrogen production process and use transportation and storage from option 1 or 2.

Hydrogen production cost is typically quoted in €/kg. A number of international studies

[83] (Element Energy, 2018)

reference figures in €/kWh, which can be used in order to make a direct comparison with natural gas. Where the hydrogen is used directly in CCGT power stations as a fuel source, LCOE and CoA estimates can also be made. Three reports have been used to prepare initial cost estimates for Option 3. These are:

1. The 'H21 North of England'[84] report. This report assesses the feasibility of converting 3.7 million homes and businesses (equivalent to 14% of all UK heat) to operate on hydrogen. Assuming the price of natural gas to be £23/MWh, this report identifies the following results:

Metric	Result
Wholesale hydrogen price (£/MWh) (2035)	50.69
Annual gas bill increase for 14% hydrogen blend (£)	53
Annual gas bill increase for 14% hydrogen blend (%)	7
Carbon Transport & Storage (£/tonne)	5.54

Table 5. Equinor, Cadent, Northern Gas Networks, costs are in GBP.

2. Hydrogen Mobility Ireland[85] with Element Energy, carried out an analysis of options to produce hydrogen in Ireland for Fuel Cell Electric Vehicles (FCEVs), producing the following result;

Metric	Result
Hydrogen Production Cost (€/kg) – Large gas reformer with CCS	2.5

Table 6. Hydrogen Mobility Ireland (€2.5/kg is equivalent to €83/MWh.)

3. UK Government Department for Business, Energy and Industrial Strategy (BEIS) report 'Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology'[86]. This comprehensive study assessed 10 different cases (scenarios) for CCS and one for hydrogen. The hydrogen case looks at a Steam Methane Reformer with post-combustion carbon capture with the following results:

Metric	Result

[84] (Equinor, Cadent and Northern Gas Networks, 2018)
[85] (Hydrogen Mobility Ireland Steering Group / Element Energy, 2019)
[86] (Wood Group, 2018)

Levelised Cost of Hydrogen (£/kWth)[87]	52.9
Cost of CO_2 Avoided (£/tCO_2)	48.3

Table 7. Case11 - Steam Methane Reformer with post-combustion carbon capture – GBP.

In looking at the reports, the wholesale cost of hydrogen ranges around 2 – 3 times today's wholesale cost of natural gas. However, as the cost to emit carbon increases over time the wholesale cost of hydrogen will become more attractive versus natural gas.

Development of blue hydrogen (from natural gas reforming) has a number of key advantages for Ireland. These are:

1. Existing natural gas pipelines can be repurposed to transport hydrogen into homes and industries thus utilising existing state-owned assets for the energy transition;

2. Development of blue hydrogen provides a pathway to the large-scale development and use of 'green' hydrogen (which is produced from excess renewable electricity which would otherwise be curtailed) as Ireland develops more wind and solar power; and

3. Hydrogen injected directly into the gas network will start to decarbonise all customers downstream including heating and industry in the non-ETS sector – thus helping Ireland achieve its national climate action targets.

5.4 Cost of abatement comparisons

When costed on a Total System CoA basis, the CoA outlined in Options 1 and 2 compare very well with other decarbonisation technologies in Ireland. In particular CCGT/CCS at c.€100/t is substantially lower than:

- biomass for power generation at c.€320-460/t[88]; and
- electric vehicles at €666/t[89] .

It has not been possible to do a direct comparison of CCGT/CCS, on a zero emission firm power basis, with one of the core intermittent renewable technologies such as onshore wind. In order to do this on a Total System CoA basis it would be necessary to have an accurate cost of all the additional infrastructure required to make the renewables firm, such as the electricity grid infrastructure, batteries, system integration costs etc. These costs are currently not available.

5.5 High-level risks

At this stage in the assessment, a detailed risk and mitigation review of all options identified has yet to be completed. However based on the document research carried out (as referenced in the Bibliography); learnings from other CCS projects can be used to prepare a

[87] kWth or Kilowatt thermal, a unit of thermal (heat) power output.
[88] (CEPA, 2018)
[89] (K Rajendran, 2019)

high level risk overview. This overview has identified a number of possible risks specific to the options identified, in addition to a general CCS project, as set out in the table below. Risks associated with a methane reforming process are not separately identified at this stage.

A detailed risk and mitigation exercise will need to be completed, to progress with the development of a CCS project.

Risk Relevance	High Level Risk description
Option 1.	Legacy wells at Kinsale gas field prove to be unsuitable to contain CO_2.
Option 1.	Geological reservoir not suitable to contain CO_2.
Option 1.	Large potential liability for CO_2 leakage.
Option 1.	Difficult to obtain permits and consents for both onshore and offshore CO_2 transport and geological storage as it is a new process for Ireland.
Option 2.	Difficult to obtain permits and consents for onshore CO_2 transport and interim tank storage as it is a new process for Ireland.
Option 2.	EU storage sites such as Northern Lights do not materialise.
General CCS	Significant changes required to existing policies.
General CCS	No grant funding obtained from the EU ETS Innovation Fund as a result of not meeting EU timelines.
General CCS	Value of, or need for, CCGT/CCS not recognised or rewarded via PSO or equivalent support.
General CCS	Unable to gain public support for development.

Table 8. CCS High Level risk definition – non prioritised.

5.6 Potential grant funding

To enable a CCS project in the current energy economic market structure, financial support will be required from Irish and EU sources. A complex CCS project can go through many stages of progression before completion and grant funding will need to be targeted for all project phases. A high-level funding roadmap has been prepared (identifying initial Pre-Feed[90], Feed and Construction phases) and applications have already been made to those funds which could support progression in these different phases.

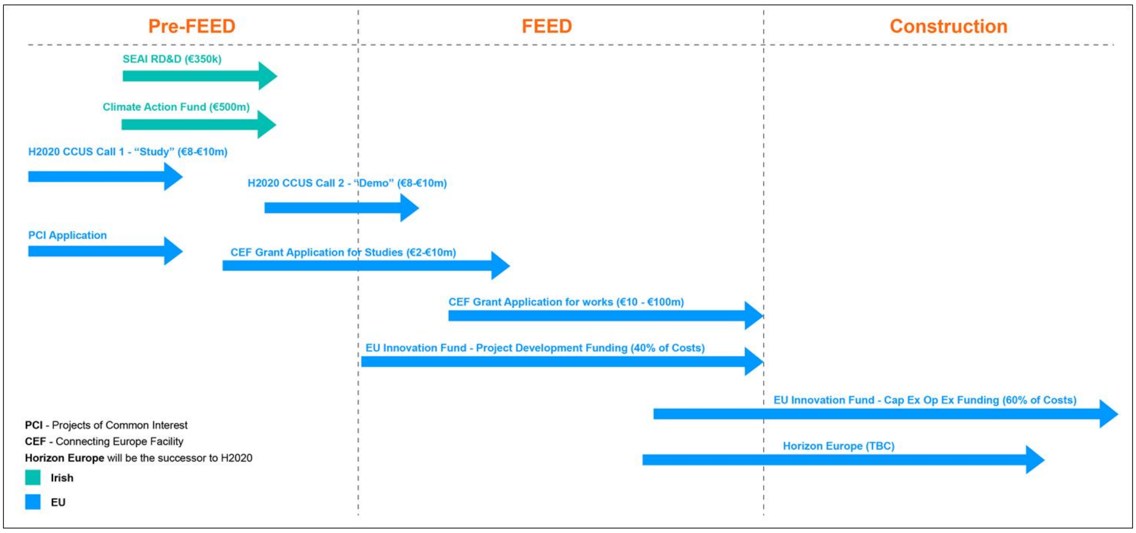

Figure 17. Funding roadmap

Areas of possible grant funding availability for a CCS project include:

- Sustainable Energy Authority of Ireland;
- Department of Communications, Climate Action and Environment;
- Horizon 2020;
- Project of Common Interest (PCI);
- Connecting Europe Facility Fund;
- Innovation Fund; and
- Horizon Europe.

These are described in turn below.

Sustainable Energy Authority of Ireland Research, Development and Demonstration Fund

The Sustainable Energy Authority of Ireland (SEAI) has a funding programme which supports innovative and targeted actions in Research, Development & Demonstration (RD&D) to assist in the delivery of national energy policies. Ervia, in partnership with the Irish Centre for Research in Applied Geosciences (iCRAG), applied to the 2019 call under the topic of "Feasibility of potential for Carbon Capture Utilisation and Storage (CCUS) in Ireland". This

[90] Front End Engineering Design (FEED)

topic has a maximum indicative fund amount of €350,000. This application was submitted in March 2019. The results of the application are expected in 2019.

Department of Communications, Climate Action and Environment, Climate Action Fund

The Department of Communications, Climate Action and the Environment (DCCAE) manages the Climate Action Fund. The Climate Action Fund is one of four funds established under the National Development Plan 2018-2027 as part of Project Ireland 2040. The fund supports initiatives that contribute to the achievement of Ireland's climate and energy targets in a cost effective manner. The fund has an allocation of at least €500 million over the period to 2027. The first call was held in Q3 2018 and targeted decarbonisation in the 2019-2021 period which was too soon a timeframe for CCS impact. Ervia will evaluate future calls for relevance to CCS.

Horizon 2020

Horizon 2020 (H2020) is an EU research and innovation fund that is available between 2014 and 2020. The final work programme of H2020 (and largest funding call to date of c.€30bn) covers the period 2018 to 2020 and was launched by the European Commission in October 2017. CCS is a technology that is identified within the work programme and funding applications will be accepted under the CCS topic for fossil fuel power stations, energy intensive industries, CCUS (conversion and use of captured CO_2), and geological storage sites.

To date, Ervia has applied for H2020 funding as part of a consortium, in response to the call regarding "Low carbon industrial production using CCUS". This project, if successful, would seek to enable the integration and small-scale demonstration of CO_2 capture and utilisation at an oil refinery.

Ervia is also assessing the potential to apply for funding under a Geological Storage Pilots call. The objective of this call is to carry out the identification and geological characterisation of new prospective storage sites for CO_2 (including the 3D architecture of the storage complex) in promising regions of future demonstration and deployment (onshore or offshore) through the implementation of new CO_2 storage pilots. Ervia is engaging with potential consortium partners with a view to potentially applying for this funding in Q3 2020 for a geological storage pilot in the Kinsale Head gas field.

Project of Common Interest (PCI)

PCIs are cross energy infrastructure projects that provide improved energy security of supply, or sustainability benefits across at least two EU member states. The benefit of attaining PCI status is that it enables a project to progress with an application for funding to the Connecting Europe Facility (CEF) fund which can assist with feasibility studies and subsequent capital projects.

In March 2019, Ervia applied for PCI status and developed a transportation plan which demonstrates how the Ervia CCUS project would enhance the prospect of developing an extended CCS transportation network in Europe. The application project submitted by Ervia would involve infrastructure to transport captured CO_2 from a CCS cluster of heavy industry and power stations in Ireland to either a local geological store or another store managed by a CCS project developer in the EU. As part of the project, import infrastructure and geological storage could also be made available as a backup storage facility to other CCS developments.

The application for PCI status was published for consultation, along with four other candidate projects for cross-border carbon dioxide transport infrastructure. The application was assessed by the Joint Research Centre (JRC) and received a positive review. The Ervia CCUS project was subsequently approved by the CO_2 transport thematic group. It has been reviewed by the Member States and Commission and the European Parliament and was officially awarded PCI status on 31 October 2019.

Connecting Europe Facility Fund

The Connecting Europe Facility (CEF) fund is an EU fund to support PCI delivery. A PCI can apply for grant aid for studies, and/or FEED works. To qualify for CEF funding, a project promoter developer must have acquired PCI status. As Ervia's project has secured PCI status, Ervia will target future CEF funding calls.

Innovation Fund

The EU Innovation Fund is the successor to NER 300[91] and will cover the period 2020 to 2030. It will be funded from the sale of EU ETS allowances and is estimated as a c. €10bn fund. Grant aid of up to 40% of development/FEED studies, 60% of Capex, and the first 10 years of Opex costs, may be available to successful applicants. CCS is a technology that will be supported by the Innovation Fund. This is the primary opportunity for large-scale funding for CCS.

Horizon Europe

Horizon Europe will support European Partnerships to deliver on global challenges and industrial modernisation through concerted research and innovation effort with the Member States, private sector, foundations and other stakeholders.

In September 2019 the Commission launched a consultation on the 12 Proposed European Partnerships under the future Horizon Europe Research & Innovation Programme, proposing (specific to H_2/CCS) to:

[91] NER 300 - A 2010 EU funding programme for innovative low-carbon energy demonstration projects

- include an increased scope partnership for clean hydrogen (phrased as ‘nearly-zero carbon hydrogen’).
- assess the role of CCS as a means of achieving the scale required both for volume and cost.

A general comment of Horizon Europe underlines that partnerships offer a clear path for synchronisation and communication of priorities. Industry, national funding agencies and the EC will give feedback through their participation. This can empower industry, encourage research and innovation and create successful circular industries with low-carbon footprints. Further clarity will emerge on the CCS/H_2 funding opportunities from Horizon Europe in 2020.

Ervia will progress funding applications and target all grant funding availability, as part of the progression to the next phase of the project.

5.7 Cost recovery models

Similar to all other low or zero-carbon technologies in the current energy economic market structure, support would be required to enable an initial CCS project. As outlined earlier, the CoA for a potential CCS project is c. €100/t; a carbon price in that range would be required to incentivise the deployment of CCS. Once the carbon price rises above that range, there would be a market commercial driver for CCS.

In terms of other forms of support, in Ireland the Public Service Obligation (PSO) levy is the overall market support mechanism for peat generation, for certain conventional generation constructed for security of supply purposes, and for the development of renewable electricity. If extended to low or zero-carbon electricity, it (or a similar mechanism) could be used to support initial CCS projects.

In 2019, BEIS[92] consulted on potential business models for Carbon Capture, Usage and Storage. In general, separation of capture from transport and storage was proposed, with the transport and storage element regulated and either publically or privately owned. For the UK electricity sector emitter, a Contracts for Difference (CfD) model with capacity payments for the capture element was proposed, with transport and storage pass through cost. CCGT/CCS would be dispatched after wind and nuclear. For the industrial section emitter, direct exchequer funding was proposed for the capture element with an initial grant for capex. Regarding hydrogen, it was proposed that hydrogen should be deployed to home heating where it can make the greatest contribution to decarbonisation.

5.8 Summary of the commercial aspects

[92] (Dept for Business, Energy & Industrial Strategy, 2019)

Current thinking across Europe is moving towards a structure that sees the CO_2 capture element of the CCS process chain remain with the emitter. A separate regulated monopoly model could then be applied for the remaining process chain elements of compression and conditioning, transport, and storage (either separately or together) on a regulated asset basis (either state or privately owned).

Total System Cost of Abatement (CoA) is considered the most appropriate cost comparison metric for assessing low-carbon technologies. It allows comparison between projects of different scale, and unlike Levelised Cost of Electricity (LCOE), it allows a true comparison, with all costs included, across all decarbonisation technologies.

Financial support would be required from Irish and EU sources for a first CCS project in Ireland. Ervia is actively exploring funding opportunities from a number of sources, including the SEAI Research, Design and Development (RD&D) fund, Horizon 2020 (EU), and the DCCAE Climate Action Fund. However grant funding available from the EU ETS Innovation Fund may be at risk as a result of not meeting EU timelines.

In March 2019, Ervia applied for EU Project of Common Interest (PCI) status for a CCUS project. PCI status allows an application to the Connecting Europe Facility (CEF) fund to assist with feasibility studies and subsequent capital projects. Ervia's PCI application was assessed by the Joint Research Centre (JRC) and received a positive review. In July 2019, the project was approved by the CO_2 transport thematic group. It has been reviewed by the Member States and Commission and the European Parliament and was officially awarded PCI status on 31 October 2019.

6 Public policy, legislative and societal considerations

In 2017 the EC published the Eurobarometer report on climate change[93]. It found that 92% of EU citizens see climate change as a serious problem, with 74% considering it to be a very serious problem.

As set out in this initial assessment report, CCS has the long term potential to make a substantial positive impact in reducing the amount of CO_2 emitted into the atmosphere. By providing a flexible, dispatchable and diversified energy supply, decarbonised gas fired generation through CCS could help achieve a zero carbon source of electricity and support increased penetration of renewable generation.

The purpose of CCS technology is to reduce the emission of greenhouse gases to the environment. The environmental assessment of CCS is a critical public policy and societal consideration in determining whether this technology should be a key element of Ireland's decarbonisation strategy. The societal and environmental benefits of CCS need to significantly outweigh any potential concerns. The most important societal concern relates to the safe storage of the captured CO_2. Although highly unlikely, the leakage of CO_2 could negate the initial environmental benefits of capture and storage. These concerns need to be assessed against the potential benefits, but also the possible consequences of inaction.

In this section the following will be assessed in relation to CCS:

- Current Public Policy and Legislative considerations; and
- Current societal considerations.

6.1 Public Policy and Legislative Considerations

There are a considerable number of policy and legislative considerations to be assessed at an International, European and National level in the development and progression of any CCS project in Ireland. A summary is set out below.

International Policy and Legislation

There are a number of international policies, protocols and agreements which have been set out over the last 30 years and which impact the transportation and storage of CO_2 and the potential for CCS. The primary ones explored within this initial assessment report are:

[93] (European Commission, 2017)

- The Basel convention -1992
- The United Nations Convention on the Law of the Sea – 1994
- The London Convention and Protocol – 1996
- The Convention for the Protection of the Marine Environment of the North-East Atlantic – 1998
- The Paris Agreement – 2015

The Basel Convention[94]

The Basel Convention entered into force on 5 May 1992. It aimed to control the transboundary movement of waste. The main issue arising under the Basel Convention was whether CO_2 should be considered a hazardous waste and therefore included in the scope of the Convention. CO_2 is not specifically mentioned in the convention. This supports the argument that transport of CO_2 is not subject to any requirement or obligation.

United Nations Convention on the Law of the Sea[95] *(UNCLOS)*

The UNCLOS entered into force in 1994. UNCLOS was established as an international agreement to define the rights and responsibilities of nations regarding their use of the world's oceans and seas. With regard to the UNCLOS and carbon capture and storage, the global CCS Institute concluded the following[96]: *"UNCLOS does not expressly prohibit CCS activities, but its provisions may well have an impact where the activities are deemed to constitute pollution".*

The London Convention and Protocol[97]

The London Convention and Protocol (a convention on the prevention of marine pollution by dumping of wastes) entered into in force in March 2006. In its original form it could have posed a legal barrier to trans-boundary movement of CO_2 where it is to be stored in geological strata under the seabed. Amendments adopted by contracting parties in 2006 now allow CO_2 from CCS schemes to be stored in subsea/seabed geological formations, provided no wastes or other matter are added. Article 6 of the Convention, which prohibited the export of CO_2 streams from the jurisdiction of one country to another, was amended in October 2019 enabling transboundary export of CO_2 for CCS which permits countries to implement the provisions of the amendment in advance of entry into force. To avail of this provision the parties concerned will need to deposit a declaration of provisional application and provide notification of any bi-lateral agreements or arrangements with the Secretary-General of the International Maritime Organisation (IMO). This will then enable CO_2 to be shipped across borders without contravening international law. The campaign to accept the 2006 amendment will continue to be promoted by the Norwegian, Dutch and UK governments,

[94] (United Nations, 1989)
[95] (United Nations, 1982)
[96] (Global CCS Institute, 2019)
[97] (International Maritime Organisation, 1996)

with the final aim of two thirds of the Contracting Parties accepting the amendment to Article 6 of the Convention.

The Convention for the Protection of the Marine Environment of the North East Atlantic (The OSPAR Convention)[98]

The OSPAR Convention is a legal instrument, part of which relates to European offshore CO_2 storage legislation. It was adopted at a meeting of the Parties to the Oslo and Paris Conventions on the 21 and 22 September 1992. It entered into force on 25 March 1998. The OSPAR Commission took action towards reducing the negative effects of climate change by adopting amendments to the 'Annexes of the Convention' to allow the storage of CO_2 in geological formations under the seabed following OSPAR's 2006 report on ocean acidification. The report indicated that high levels of CO_2 in the atmosphere are changing ocean carbon chemistry faster than at any time in the last 100,000 years. OSPAR has adopted a decision to ensure environmentally safe storage of CO_2 streams in geological formations.

The Paris Agreement

At the Conference of the Parties 21 (COP21) in December 2015, the Paris Agreement[99] was adopted by all parties to the United Nations Framework Convention on Climate Change (UNFCCC). This was the first international, universal, legally-binding global climate agreement**.** The agreement sets out a global action plan to put the world on track to avoid dangerous climate change. The Parties agreed to:

- A long-term goal of keeping the increase in global average temperature to well below 2°C above pre-industrial levels;
- To aim to limit the increase to 1.5°C, since this would significantly reduce the risks and impacts of climate change;
- The need for global emissions to peak as soon as possible, recognising that this will take longer for developing countries;
- To undertake rapid reductions thereafter in accordance with the best available science.

CCS was discussed and proposed as an important option to support climate change mitigation. The EU and 13 other countries included CCS in their nationally determined contributions (NDCs) under the Paris Agreement.

A more recent IPCC (2018)[100] report, further confirmed that CCS is the only technology capable of decarbonising major industry, particularly the high-emitting cement, steel and petrochemical sectors. This IPCC work is a key reference for governments, businesses and Non-Governmental Organisations (NGOs) in setting out climate mitigation strategies. This was evidenced at the most recent Conference of the Parties (COP24) held in Poland, where the role of CCS in meeting climate targets was repeatedly underlined.[101]

[98] (OSPAR, 2017)
[99] (United Nations, 2015)
[100] (IPCC, 2018)
[101] (Global CCS Institute, 2018)

European Policy and Legislation

In 2018, the EC presented its strategic long-term vision for a climate-neutral economy by 2050[102]. This long-term strategy confirms Europe's commitment to be a leader in global climate action while being socially fair and cost-efficient. It presents a vision to achieve net-zero greenhouse gas emissions by 2050.

In order to monitor the progress of the path to accomplish a climate-neutral Europe by 2050, the EU has set targets which are outlined in the:

- 2020 climate and energy package;[103] and,
- 2030 climate and energy framework.[104]

These two documents include targets for greenhouse gas emission reductions, energy efficiency and increased renewable energy. The Commission's proposal for the 2030 climate and energy policy framework acknowledges the potential role of CCS in order to reach the EU's long-term emission reduction goal. The most relevant EU policy instruments that include and/or propose CCS technology for the future are as follows:

- EU Energy Roadmap 2050[105]
- EU Communication – A policy framework for climate and energy in the period from 2020 to 2030[106]
- EU Clean Energy Package
- EU Emissions Trading System (ETS).

The EU frameworks and policy roadmaps set out above outline EU objectives to reduce carbon emissions. They are non-legally binding but are used as a guide to new legislation. EU legislation is implemented through either directives or regulations[107]. Directives require EU countries to transpose the directive into their own national law and allow each country to decide how they will achieve the objective of the directive. There are a number of directives that relate either directly or indirectly to CCS in Europe. These include:

- Directive 2009/31/EC (CCS Directive)[108] on the geological storage of carbon dioxide;
- Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment[109] and the 2014 amendment Directive 2014/52/EU[110];
- Directive 2010/75/EU on Industrial Emissions (integrated pollution prevention and control)[111];
- Directive 2009/75/EC concerning common rules for the internal market in natural

[102] (European Commission, 2018)
[103] (European Commission, 2008)
[104] (European Commission, 2014)
[105] (European Commission, 2012)
[106] (European Commission, 2019)
[107] EU Regulations are legal acts that automatically apply uniformly to all EU countries without change.
[108] (Geological Storage of Carbon Dioxide (CCS Directive), 2009)
[109] (The assessment of the effects of certain public and private projects on the environment, 2011)
[110] (The assessment of the effects of certain public and private projects on the environment, 2014)
[111] (Industrial Emissions integrated pollution prevention and control, 2010)

gas[112];

- Directive 2000/60/EC establishing a framework for Community action in the field of water policy[113];
- Directive 2006/118/EC on the protection of groundwater against pollution and deterioration[114];
- Directive 2004/35/EC on environmental liability with regard to the prevention and remedying of environmental damage[115]; and
- Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.[116]

The most significant of these directives in relation to CCS is the EU Directive 2009/31/EC on the geological storage of carbon dioxide. This Directive was established with specific reference to carbon capture and storage and established a legal framework for the environmentally safe geological storage of CO_2. Subsequently a number of guidance documents were published in 2011 to help Member States implement the Directive.[117]

Irish Policy and Legislation

The extent of the challenge facing Ireland and the need to reduce greenhouse gas emissions, in line with international and EU commitments, is reflected in the following national policy plans and frameworks. A number of these plans and frameworks are relevant to CCS, as set out in the sub-sections below:

- Ireland's Energy White Paper[118]
- National Mitigation Plan[119]
- National Planning Framework[120]
- National Development Plan[121]
- National Marine Planning Framework Baseline Report[122]
- National Energy and Climate Plan (Draft)[123]

Ireland's Energy White Paper (2015)

This includes and sets out the intention to follow the progress of European counterparts in the development of CCS technology before taking action in Ireland.

[112] (Common rules for the international market in natural gas, 2009)
[113] (Establishing a framework for Community action in the field of water policy, 2000)
[114] (The protection of groundwater against pollution and deterioration, 2006)
[115] (Environmental liability with regard to the prevention and remedying of environmental damage, 2004)
[116] (Establishing a scheme for greenhouse gas emission allowance trading, 2003)
[117] (European Commission, 2011)
[118] (DCENR, 2015)
[119] (DCCAE, 2017)
[120] (Government of Ireland, 2018)
[121] (Government of Ireland, 2018)
[122] (Government of Ireland, 2018)
[123] (DCCAE, 2018)

National Mitigation Plan (2017)

This plan recognises the potential for CCS to enable decarbonisation of Ireland's electricity sector while allowing appropriate levels of gas-fired generation to balance intermittent renewable generation. The plan commits to an action to explore the feasibility of storage of CO_2 in Ireland.

National Planning Framework (2018)

In this planning framework, CCS is identified as an enabler of carbon neutral electricity under National Strategic Outcome 8 – Transition to a Low Carbon Climate Resilient Society.

National Development Plan (2018)

This identifies the need to transition to a Low-Carbon and Climate-Resilient Society. It also looks at this transition in the context of National Strategic Outcomes and Public Investment Priorities.

National Marine Planning Framework Baseline Report (2018)

This plan identifies CCS as a technology chain that forms a pillar, along with renewable energy and energy efficiency, to reduce CO_2 emissions to the atmosphere.

National Energy and Climate Plan (Draft) (2018/2019)

This plan identifies a recommendation for the establishment of a Steering Group[124] to examine the feasibility of CCS in Ireland. CCS is also considered in the plan as a method for decarbonising industry, and specifically, alumina production.

In relation to Irish legislation, it is believed that the capture element of a CCS project could largely be regulated under existing planning and environmental law. In relation to storage, the following two Statutory Instruments (S.I.) transpose Directive 2009/31/EC into Irish legislation. These are currently the only two Irish regulations specifically relating to carbon capture and storage:

- European Communities (Geological Storage of Carbon Dioxide) Regulations, S.I. No. 575 of 2011.[125]
- European Communities (Geological Storage of Carbon Dioxide) (Amendment) Regulations, S.I. No. 279 of 2014.[126]

Through these regulations, Ireland is one of several countries that have applied restrictions

[124] (DCCAE, 2018, p. 60)
[125] (e ISB, 2011)
[126] (e ISB, 2014)

on CO_2 storage. Article 4 of the S.I. No. 575 of 2011, Selection of Storage Sites, prohibits storage of CO_2 in amounts greater than 100,000 tonnes. However, the explanatory note accompanying S.I. No. 575 of 2011 recognises the potential value of CCS and states that the restriction will be kept under active review. For a CCS project in Ireland to progress, the regulation would need to be amended or revoked and the full permitting requirements of the CCS Directive would need to be transposed into Irish law. Ultimately this would require a framework of consents for the storage of CO_2 in Ireland to be developed and implemented.

S.I. No. 279 of 2014 clarifies a number of definitions, refers to third party access and states that the Commission for Regulation of Utilities (CRU) is the Competent Authority for S.I. No. 575 of 2011 and S.I. No. 279 of 2014.

There is no specific legislation or consenting regime in place to regulate the construction or operation of a pipeline transporting CO_2 in Ireland. A regime similar to that currently in place for gas pipelines under the Gas Act (1976)[127], as amended, could be introduced for CO_2 pipelines.

As part of this initial assessment, a high-level roadmap[128] has been developed for the key consents required for each element of a potential CCS project.

6.2 Societal considerations in relation to CCS

Research has indicated[129] that collaborative stakeholder engagement and partnerships are necessary for the delivery of complex projects, such as CCS. This ensures that there is a broad awareness of the rationale for the project and the associated benefits. It also provides a clear and transparent approach to the identification of potential issues and concerns in order to mitigate these effectively. The most important societal concern for a CCS project relates to the safe storage of the captured CO_2. Leakage of CO_2 could negate the initial environmental benefits of capturing and storing CO_2 emissions and may also have harmful effects on human health. These concerns need to be assessed against the potential benefits, but also the possible consequences of inactivity.

Consideration of communications is critical at the early stage of a complex project. Clear communication of key messages is central to continued engagement with stakeholders at community, local, and national level. These messages must include:

- The need for a CCS project and an understanding of the benefits it will bring to Ireland;
- Confirmation that CCS technology is proven and is in wide use internationally; and
- A request for national policy to include CCS in the future technology mix to enable Ireland meet its climate obligations.

The following is a summary of the stakeholder engagement that has been carried out, at international, national, local and community levels at this stage of the initial assessment.

[127] (e ISB, 1976)
[128] (Arup, 2018)
[129] (University of Cambridge, 2011)

International stakeholder engagement

In November 2017, a very successful presentation of the CCS project was given in conjunction with the International Energy Agency in the European Parliament to MEP, European Commission, global CCS organisation and British Geological Survey representatives. This led to further presentations to, and engagements with, the Zero Emissions Platform (ZEP), the EU's Strategic Energy Technology (SET) Plan Committee, Total, British Geological Survey, University of Edinburgh, Oil and Gas Climate Initiative (OGCI), Global CCS Institute, UN Gas Forum, EC 2050 Gas Infrastructure Deep Dive, CCS Advocacy Group and Statoil (now Equinor).

As a result of these successful engagements, the Cork CCS project has been listed as a potential demonstration project by the SET-Plan Committee. This development increases the potential of securing future EU funding. The SET-Plan Committee has appointed Ervia as a co-lead of one of its CCS sub-groups.

In September 2019, Ervia signed a MoU with Norwegian company, Equinor (formerly Statoil), to jointly collaborate in exploring the possibility of CO_2 export from Ireland for storage in Norway's geological reserves in the North Sea.

National stakeholder engagements

Ervia has engaged widely with key stakeholders nationally regarding the potential for a CCS project in Ireland.

A Government Steering Group, comprising of representatives from DCCAE, DHPLG, the Department of Public Expenditure and Reform (DPER), Geological Survey of Ireland (GSI) and NewERA, was established in April 2019 to examine and oversee the feasibility of CCS in Ireland. This was set up as a result of Action 33 in the Climate Action Plan 2019. Since April 2019 the group has been expanded to also include SEAI, CRU and EPA.

Local and Community engagement

Ervia has engaged with key stakeholders locally. It is important to gain and maintain the support of the people that live and work in the area of impact and influence of any given project – this is known as social licence. Social licence exists when a project has broad social acceptance as well as ongoing approval within the local community. Community Engagement is the process through which a project team builds and maintains constructive relationships with communities by involving them in a timely and transparent manner over the life of a project.

As the CCS initial assessment is at early stage and a range of options are still being explored, it is considered premature to engage with any community directly on a specific option. However, once options have been further progressed, ongoing stakeholder engagement and communications will be essential.

7 Conclusions

CCS has the long term potential to make a substantial positive impact in reducing the amount of CO_2 emitted into the atmosphere. By providing a flexible, dispatchable and diversified energy supply, decarbonised gas fired generation through CCS could help achieve a zero carbon source of electricity and support increased penetration of renewable generation.

In this initial assessment of Carbon Capture and Storage for Ireland, we have identified that:

- In order to tackle climate change, large-scale climate action is now both necessary and urgent;
- Ireland faces serious challenges in meeting climate action commitments that it has made;
- Ireland must explore all available alternatives and maximise the use of existing state assets to achieve these commitments;
- CCS is a proven technology which has been in operation for decades. There are 72 operational plants, c.18 of which are large-scale plants in operation globally. There are an additional c.25 more in various stages of development;
- It is recognised that CCS is crucial to electricity decarbonisation at least cost. The IEA has stated that without CCS, the transformation of the power sector will be at least $3.5 trillion (USD) more expensive. The European Commission has similarly reported that without CCS, it will cost the EU an additional €1.2 trillion to reach its CO_2 reduction target for the power sector;
- Eirgrid's Tomorrow's Energy Scenarios deploys CCS in its forward planning scenarios. Eirgrid reports that *"Pursuing both CCUS and renewable gas reduces the risk of reliance on a single option, while helping to mitigate as much as possible a long-term reliance on non-abated fossil fuels"*;
- For large-scale industries such as cement and oil refining, CCS is the only technology available. No alternative decarbonisation technology option currently exists for this segment;
- CCS could be utilised to produce 'blue hydrogen' which, in the longer term, is expected to be an enabler for 'green hydrogen' production;
- A potential Cork CCS Project was the starting point for this assessment. However, the potential to export CO_2 to stores off other European countries has also been assessed as a credible option and makes CCS a potential national, as well as a regional, solution;
- An initial assessment of CO_2 capture (from power plants, industry and hydrogen production), transport and CO_2 storage (indigenously and via export) indicates that all of these options are positive and warrant further analysis.

- CCS is progressing at pace in Europe; Ireland has clear opportunities which merit further consideration. The UK Committee on Climate Change has identified in its Net Zero report[130], that *"CCS is a necessity, not an option"*;
- Ervia's application in 2019 to have the Cork CCUS project assigned Project of Common Interest (PCI) status has been approved by the European Commission;
- In September 2019, Ervia signed a MoU with Norwegian company, Equinor (formerly Statoil), to jointly collaborate in exploring the possibility of CO_2 export from Ireland for storage in Norway's geological reserves in the North Sea. Ervia is a co-lead with Equinor of a number of CCS-related SET-Plan activities; and
- There are important public policy, legislative and societal considerations for any CCS project in Ireland. The CO_2 Storage Directive would need to be fully transposed for a Cork CCS Project (i.e. with indigenous storage) but the Ireland Export Project would require fewer regulatory changes due to the CO_2 being stored in other European jurisdictions.

From Ervia's initial assessment, it is clear that Ireland has real opportunities to benefit from the decarbonisation potential of CCS. The three options identified have withstood initial scrutiny from a commercial and technical assessment and merit progression to the next phase of analysis, which would include a detailed risk assessment and mitigation exercise. Building on deep experience of gas transportation, Ervia has established a comprehensive CCS capability which has already delivered a significant European collaboration with Equinor and an approved PCI project status application. This work will continue into 2020 and beyond in close collaboration with all stakeholders.

[130] (Committee on Climate Change, 2019)

8 Glossary

Term	Definition
AGI	Above Ground Installation
AS	Australian Standards
ATR	Auto-Thermal Reforming
Barg	Gauge pressure - zero-referenced against ambient air pressure, so it is equal to absolute pressure minus atmospheric pressure
BEIS	Business, Energy and Industrial Strategy
Bio-based CCS Process	Bio-based processes involve the conversion of biomass (including biogas), which extracts CO_2 from the atmosphere as it grows, to chemical products or other forms of energy with the resulting CO_2 captured and stored
Capex	Capital expenditure
CCS	Carbon capture and storage
CCSA	Carbon Capture and Storage Association
CCUS	Carbon capture utilisation and storage
CCGT	Combined cycle gas turbine (power plant)
CEF	Connecting Europe Facility - a key EU funding instrument
CHP	Combined heat and power
CfD	Contract for difference
CH_4	Methane
CNG	Compressed natural gas
CO_2	Carbon dioxide
CO_2 abatement	Removal of CO_2
CoA	Cost of Abatement
COP21	Conference of the Parties - United Nations 21st Climate Change Conference, Paris, December 2015
COP24	Conference of the Parties - United Nations 24th Climate Change Conference, Katowice, December 2018
CRU	Commission for Regulation of Utilities
CSA	Canadian Standards Association

Term	Definition
DCCAE	Department of Communications, Climate Action and Environment
DCENR	Department of Communications, Energy and Natural Resources (now DCCAE)
DHPLG	Department of Housing, Planning and Local Government
DPER	Department of Public Expenditure and Reform
DG	Directorate-General
EC	European Commission
EEA	European Economic Area
EPA	Environmental Protection Agency
ETI	Energy Technologies Institute
EU ETS	EU Emissions Trading System
ESB	Electricity Supply Board
ESRI	Economic and Social Research Institute
EU	European Union
EV	Electric vehicle
€M pa	Million euro per annum
FCEV	Fuel Cell Electric Vehicle
FEED	Front end engineering design
FOAK	First-of-a-kind
GBP	British Pound – unit of currency of Great Britain
GHG	Greenhouse Gas
GSI	Geological Survey of Ireland
GWh	Gigawatt hour – unit of energy
H_2	Hydrogen
H_2O	Water
H_2S	Hydrogen Sulphide
H2020	Horizon 2020
Ibec	Irish Business and Employers Confederation
I/C	Interconnector
iCRAG	Irish Centre for Research in Applied Geosciences

Term	Definition
IEA	International Energy Agency
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial processes and product use
I-SEM	Integrated single electricity market
ISO	International Standards Organisation
JRC	Joint Research Centre
JV	Joint venture
KEL	PSE Kinsale Energy Limited
LCOA	Levelised cost of abatement
LCOE	Levelised cost of electricity – The average price of electricity that would be needed for a project to achieve a Net Present Value of zero across the life of the plant for a given discount rate.
LPG	Liquefied Petroleum Gas
LNG	Liquefied Natural Gas
MaREI	Marine and Renewable Energy Ireland
MMV	Measurement, Monitoring and Verification
MoU	Memorandum of Understanding
Mt	Million tonnes
Mtpa	Million tonnes per annum
NDCs	Nationally determined contributions
NECP	National Energy and Climate Plan
NER 300	New Entrants' Reserve. An EU funding programme for innovative low-carbon energy demonstration projects.
NET	Negative Emissions Technology
NGO	Non-Governmental Organisation
Non-ETS	Non Emissions Trading System
NPV	Net Present Value
NSAI	National Standards Authority of Ireland
NSBTF	North Sea Basin Task Force
O_2	Oxygen

Term	Definition
OGCI	Oil and Gas Climate Initiative
Opex	Operating expense
OSPAR	The Convention for the Protection of the Marine Environment of the North East Atlantic
PCI	Project of Common Interest
PEES Act	Petroleum (Exploration and Extraction) Safety Act
ppm	parts per million
PSO	Public service obligation - arrangement in which a governing body or other authority offers subsidies
PV	Photovoltaic
RD&D	Research, design and development
REFITS	Renewable Energy Feed in Tariff Scheme
RES	Renewable Energy Scheme
SDS	Sustainable Development Scenario
SEAI	Sustainable Energy Authority of Ireland
SEI	Sustainable Energy Ireland (now SEAI)
SET-Plan	Strategic Energy Technology Plan
S.I.	Statutory Instrument
SIC	System Integration Cost
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 carbon dioxide
T	tonne = metric ton (1,000kg)
TER	Total Electricity Requirement
TWh	Terawatt hour – unit of energy
UCC	University College Cork
UK	United Kingdom
UNCLOS	United Nations Convention on the Law of the Sea
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USD	United States Dollar – unit of currency of the USA

Term	Definition
ZEP	Zero Emissions Platform - European Technology Platform for Zero Emission Fossil Fuel Power Plants

Bibliography

Arup. (2018). *Cork CCS Project Consents Roadmap.* Ervia. Cork: Ove Arup & Partners Ireland Ltd.

Business Energy & Industrial Strategy. (2018, November 28). *UK Carbon Capture and Storage (CCUS) deployment pathway: an action plan*. Retrieved from BEIS: https://www.gov.uk/government/publications/the-uk-carbon-capture-usage-and-storage-ccus-deployment-pathway-an-action-plan

Carbon Capture and Storage Association. (2016). *Lessons Learned and Evidence Derived from the UK CCS Programmes, 2008 - 2015.* London: Carbon Capture and Storage Association. Retrieved from http://www.ccsassociation.org/index.php/download_file/view/1023/76/

Carbon Capture and Storage Association. (2019, October 29). *CCUS Advisory Group*. Retrieved from Carbon Capture & Storage Association: http://www.ccsassociation.org/ccus-advisory-group

CCS Norway. (2019, October 29). *The Full-scale CCS project in Norway*. Retrieved from Northern Lights Project: https://ccsnorway.com/

CEPA. (2018). *Cost-effective decarbonisation and Cork CCS - spreadsheet.* Cork: Ervia.

Committee on Climate Change. (2019). *Net Zero – The UK's contribution to stopping global warming.* London: The Committee on Climate Change. Retrieved from https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

Common rules for the international market in natural gas, EU Directive 2009/73/EC (European Parliament and Council July 13, 2009). Retrieved from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009L0073

DCCAE. (2017). *National Mitigation Plan.* Dublin: Department of Communications, Climate Action and Environment. Retrieved from https://static.rasset.ie/documents/news/national-mitigation-plan-2017.pdf

DCCAE. (2018). *Draft Climate Action Plan.* Government of Ireland. Retrieved from https://www.dccae.gov.ie/en-ie/climate-action/publications/Documents/16/Climate_Action_Plan_2019.pdf

DCCAE. (2018, December 19). *Ireland's Draft National Energy and Climate Plan 2021-2030*. Retrieved from Department of Communications, Climate Action and Environment: https://www.dccae.gov.ie/en-ie/energy/consultations/Pages/Ireland%E2%80%99s-Draft-National-Energy-and-Climate-Plan-2021-2030.aspx

DCCAE. (2019, April 18). *Decision on Kinsale Gas Field Application* . Retrieved from Department of Communications, Climate Action & Environment: https://www.dccae.gov.ie/en-ie/natural-resources/topics/Oil-Gas-Exploration-Production/environment/statutory-consents/ministerial-decisions/decommissioning-kinsale-head-and-seven-heads-facilities/Pages/Decision-on-Kinsale-Gas-Field-Application.aspx

DCENR. (2015). *Irelands Transition to a Low Carbon Energy Future 2015-2030.* Gov Of Ireland, Department of Communications, Energy and Natural Resources, Dublin. Retrieved from https://www.dccae.gov.ie/en-ie/energy/publications/Documents/2/Energy%20White%20Paper%20-%20Dec%202015.pdf

Dept for Business, Energy & Industrial Strategy. (2019, July 22). *Carbon capture, usage and storage (CCUS): business models* . Retrieved from Gov.UK: https://www.gov.uk/government/consultations/carbon-capture-usage-and-storage-ccus-business-models

e ISB. (1976). *Gas Act (1976)*. Retrieved from Electronic Irish Statute Book - Gas Act 1976: http://www.irishstatutebook.ie/eli/1976/act/30/enacted/en/html

e ISB. (2011, November 18). *Statutory Instrument No 575 of 2011*. Retrieved from Geological Storage of Carbon Dioxide Regulations: http://www.irishstatutebook.ie/eli/2011/si/575/made/en/print

e ISB. (2014, June 20). *Statutory Instrument No 279 of 2014*. Retrieved from Geological Storage of Carbon Dioxide Regulations.

Eirgrid. (2018). *All-Island Generation Capacity Statement 2018-2027*. Retrieved from Eirgrid: http://www.eirgridgroup.com/newsroom/gcs-2018/

Eirgrid. (2019). *Planning Ireland's energy future*. Retrieved from Eirgrid TES2019 Scenarios: http://www.eirgridgroup.com/customer-and-industry/energy-future/

Element Energy. (2010). *One North Sea. A study into the North Sea cross-border CO2 transport and storage.* North Sea Basin Task Force. Element Energy. Retrieved from https://www.regjeringen.no/globalassets/upload/oed/onenortsea_fulldoc.pdf

Element Energy. (2018). *Shipping CO2 – UK Cost Estimation Study', compiled by Element Energy.* London: BEIS.

Environmental liability with regard to the prevention and remedying of environmental damage, EU Directive 2004/35/EC (European Parliament and Council April 21, 2004). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004L0035

Equinor, Cadent and Northern Gas Networks. (2018). *H21 North of England.*

ESB / Poyry. (2017). *Ireland's low carbon future - Dimensions of a solution.* Dublin: ESB. Retrieved from https://www.esb.ie/docs/default-source/Publications/dimensions-of-a-solution---full-report-with-contents-links

ESB. (2019). *Ireland's National Energy and Climate Plan (NECP) – ESB consultation response.* Dublin: ESB. Retrieved from https://www.dccae.gov.ie/en-ie/energy/consultations/Documents/42/submissions/ESB.pdf

ESRI. (2010). *An Estimate of the Value of Lost Load for Ireland.* Economic Social Research Institute. Retrieved from https://www.esri.ie/publications/an-estimate-of-the-value-of-lost-load-for-ireland

Establishing a framework for Community action in the field of water policy, EU Directive 2000/60/EC (European Parliament and Council October 23, 2000). Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF

Establishing a scheme for greenhouse gas emission allowance trading, EU Directive 2003/87/EC (European Parliament and Council October 13, 2003). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32003L0087

European Commission. (2008). *2020 climate & energy package*. Retrieved from Climate Action: https://ec.europa.eu/clima/policies/strategies/2020_en#tab-0-0

European Commission. (2011, 6 28). Implementation of directive 2009/31/EC on the geological storage of carbon dioxide. *Guidance Documents*, p. Guidance Documents. Retrieved from https://op.europa.eu/en/publication-detail/-/publication/bdb84106-a565-490a-8a34-cbfeaa53e609

European Commission. (2012). *Energy Roadmap 2050.* Brussles: European Commission. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/2012_energy_roadmap_2050_en_0.pdf

European Commission. (2014). *A policy framework for climate and energy in the period from 2020 to 2030.* Brussles: European Commission. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0015&from=EN

European Commission. (2017). *Special Eurobarometer 459.* Brussles: European Commission. Retrieved from https://ec.europa.eu/clima/sites/clima/files/support/docs/report_2017_en.pdf

European Commission. (2018). *Energy - 2050 Long Term Strategy*. Retrieved from European Commission - A Clean Planet for All: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2050-long-term-strategy

European Commission. (2018, November 28). *The Commission calls for a climate neutral Europe by 2050*.* Retrieved from Press Release Database: https://europa.eu/rapid/press-release_IP-18-6543_en.htm

European Commission. (2019, October 29). *A policy framework for climate and energy in the period from 2020 to 2030*. Retrieved from Eur-Lex Access to European Law: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52014DC0015

European Commission. (2019). *Energy, transport and environment statistics — 2019 edition.* European Commission. Eurostat. Retrieved from https://ec.europa.eu/eurostat/web/products-statistical-books/-/KS-DK-19-001?inheritRedirect=true&redirect=%2Feurostat%2Fpublications%2Fstatistical-books

European Commission. (2019, October 29). *EU Emissions Trading System (EU ETS)*. Retrieved from EC Climate Action: https://ec.europa.eu/clima/policies/ets_en

European Commission. (2019, October 29). *Eur-Lex*. Retrieved from A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773

European Commission. (2019, October 29). *NER 300 programme*. Retrieved from European Comission website: https://ec.europa.eu/clima/policies/innovation-fund/ner300_en

European Court of Auditors. (2018). *Demonstrating carbon capture and storage and innovative renewables at commercial scale in the EU.* European Court of Auditors. Retrieved from https://www.eca.europa.eu/Lists/ECADocuments/SR18_24/SR_CCS_EN.pdf

Geological Storage of Carbon Dioxide (CCS Directive), EU Directive 2009/31/EC (European Parliament and Council April 23, 2009). Retrieved from https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF

Global CCS Institute. (2018, December 18). *COP24 marks constructive progress in global climate action*. Retrieved from Media Releases: https://www.globalccsinstitute.com/news-media/press-room/media-releases/cop24-marks-constructive-progress-in-global-climate-action/

Global CCS Institute. (2019, November 2). *Publications, Reports & Research*. Retrieved from Offshore CO2 storage legal resources: https://hub.globalccsinstitute.com/publications/offshore-co2-storage-legal-resources/united-nations-convention-law-sea-unclos

Government of Ireland. (2018). *National Marine Planning Framework Baseline Report.* Department of Hoysing Planning and Local Government. Retrieved from https://www.housing.gov.ie/sites/default/files/publications/files/national_marine_planning_framework_baseline_report_0.pdf

Government of Ireland. (2018). *Project Ireland 2040 National Development Plan 2018 - 2027.* Retrieved from https://www.gov.ie/pdf/?file=https://assets.gov.ie/831/130718120306-5569359-NDP%20strategy%202018-2027_WEB.pdf#page=1

Government of Ireland. (2018). *Project Ireland 2040 National Planning Framework.* Dublin: Government of Ireland. Retrieved from http://npf.ie/wp-content/uploads/Project-Ireland-2040-NPF.pdf

Hydrogen Mobility Ireland Steering Group / Element Energy. (2019). *April Meeting Minutes.* Hydrogen Mobility Ireland.

IBEC. (2019). Response to Consultation on the draft National Energy and Climate Plan 2021-2030. *Response*. Irish Business and Employers Confederation.

IEA. (2016). *20 Years of Carbon Capture and Storage.* The International Energy Agency. Retrieved from https://webstore.iea.org/20-years-of-carbon-capture-and-storage

IEA. (2017). *Energy Technology Perspectives 2017 - Catalysing Energy Technology Transformations.* Paris: International Energy Agency. Retrieved from https://www.iea.org/etp2017/

IEA. (2019). *Carbon Capture Utilisation and Storage*. Retrieved from The International Energy Agency : https://www.iea.org/topics/carbon-capture-and-storage/

IEA. (2019, October 29). *The Sustainable Development Scenario - 2018*. Retrieved from International Energy Agency: https://www.iea.org/weo2018/scenarios/

Industrial Emissions integrated pollution prevention and control, EU Directive 2010/75/EU (European Parliament and Council November 24, 2010). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32010L0075

International Energy Agency. (2019). *Towards Zero Emissions CCS in Power Plants using Higher Capture Rates or Biomass.* IEA.

International Maritime Organisation. (1996). *The London Convention and Protocol*. Retrieved from IMO: http://www.imo.org/blast/mainframemenu.asp?topic_id=1499

IPCC. (2005). *Carbon Dioxide Capture and Storage.* WMO, UNEP, Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_wholereport-1.pdf

IPCC. (2018, October 29). *Global Warming of 1.5 ºC*. Retrieved from Intergovernmental Panel on Climate Change: https://www.ipcc.ch/sr15/

ISO. (2016). *ISO 27913:2016, Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems.* ISO Central Secretariat. International Organisation for Standardisation. Retrieved from https://www.iso.org/standard/64235.html

Joint Committee on Climate Action. (2019). *Climate Change: A Cross Party Consensus for Action*. Retrieved from Houses of the Oireachtais: https://data.oireachtas.ie/ie/oireachtas/committee/dail/32/joint_committee_on_climate_action/reports/2019/2019-03-28_report-climate-change-a-cross-party-consensus-for-action_en.pdf

Juan Alcalde, S. F. (2018). Estimating geological CO2 storage security to deliver on climate mitigation. *Nature Communications (9)*, Article number: 2201 (2018) .

K Rajendran, B. O. (2019). The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: A case study for biomethane. *Journal of Cleaner Production* , 219 (2019) 278-290.

Marine and Renewable Energy Ireland. (2018). *Zero Carbon Energy System Pathways for Ireland.* UCC. Cork: Taylor & Francis. Retrieved from https://www.tandfonline.com/doi/pdf/10.1080/14693062.2018.1464893?needAccess=true

Netpower. (2019, October 29). *Low-cost, truly clean energy* . Retrieved from Netpower: https://www.netpower.com/

NSAI. (2015). *IS 328:2015 Gas transmission pipelines and pipeline installations. Edition 4 (+AC1:2015).* National Standards Authority of Ireland. Retrieved from https://www.thenbs.com/PublicationIndex/documents/details?Pub=NSAI&DocID=313044

NSAI. (2015). *IS EN 14161:2004 Petroleum and natural gas industries - Pipeline transportation systems.* National Standards Authority of Ireland. Retrieved from https://www.thenbs.com/PublicationIndex/documents/details?Pub=NSAI&DocID=313044

NSBTF. (2017). *NSBTF strategic regional plan on CCS transport infrastructure.* Norwegian Ministry of Petroleum and Energy. London: North Sea Basin Task Force. Retrieved from https://docstore.entsoe.eu/Documents/TYNDP%20documents/TYNDP2018/rgip_NS_Full.pdf

OSPAR. (2017). *The Convention for the Protection of the Marine Environment of the North-East Atlantic*. Retrieved from OSPAR Convention: https://www.ospar.org/convention

Pale Blue Dot Energy. (2016, May 12). *Cost effective CCS storage sites off UK coast*. Retrieved from Pale Blue Dot: https://www.rotterdamccus.nl/en/the-project/

Parliamentary Advisory Group on Carbon Capture & Storage. (2016). *LOWEST COST DECARBONISATION FOR THE UK:.* Report of the Parliamentary Advisory Group on

CCS. Retrieved from http://www.ccsassociation.org/news-and-events/reports-and-publications/parliamentary-advisory-group-on-ccs-report/

Rotterdam CCUS. (2019, November 2). *Rotherdam CCUS Porthos Project*. Retrieved from Porthos Project: https://www.rotterdamccus.nl/en/the-project/

Schlumberger / Kinsale Energy. (2011). *Kinsale Head field CO2 Storage Evaluations.* Kinsale Energy.

SEAI. (2018). *Energy in Ireland Report.* Sustainable Energy Authority of Ireland. Retrieved from https://www.seai.ie/data-and-insights/seai-statistics/key-publications/energy-in-ireland/

SEI / EPA. (2008). *Assessment of the Potential for Geological Storage of CO2 for the Island of Ireland.* Sustainable Energy Ireland / Environmental Protection Agency. Retrieved from https://www.seai.ie/resources/publications/Assessment-of-the-Potential-for-Geological-Storage-of-CO2-for-the-Island-of-Ireland.pdf

The assessment of the effects of certain public and private projects on the environment, EU Directive 2011/92/EU (European Parliament and Council December 13, 2011). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32011L0092

The assessment of the effects of certain public and private projects on the environment, EU Directive 2014/52/EU (European Parliament and Council April 16, 2014). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0052&from=EN

The protection of groundwater against pollution and deterioration, EU Directive 2006/118/EC (European Parliament and Council December 12, 2006). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32006L0118

United Nations. (1982). *United Nations Conventions on the Law of the Sea.* UN. Retrieved from https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf

United Nations. (1989, March 22). *Basel Convention*. Retrieved from UN Environment Programme: http://www.basel.int/TheConvention/Overview/TextoftheConvention/tabid/1275/Default.aspx

United Nations. (2015). *United Nations Climate Change*. Retrieved from Paris Agreement: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

University College Cork. (2018). *Zero carbon energy system pathways for Ireland.* University College Cork, Marine and Renewable Energy Ireland. Taylor & Francis Group. Retrieved from https://www.tandfonline.com/doi/pdf/10.1080/14693062.2018.1464893?needAccess=true

University of Cambridge. (2011, November 3). *Deep issues: communicating CCS*. Retrieved from University of Cambridge - Research: https://www.cam.ac.uk/research/news/deep-issues-communicating-ccs

Wood Group. (2018). *Assessing the Cost Reduction Potential and Competitiveness of Novel UK Carbon Capture Technology.* London: Business, Energy & Industrial Strategy.

Xodus. (2018). *Kinsale Head CCS Optioneering Study.* Ervia.