SNZR
Scottish Net Zero Roadmap

A NET ZERO ROADMAP FOR SCOTTISH INDUSTRY

NECCUS
UK Research and Innovation

FOREWORD

Ronnie Quinn
Chief Executive
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This project is, itself, a milestone on Scotland's journey towards net zero. How long ago the journey started is difficult to say, but the roadmap sets out quite clearly where we are today and where we are going, using a number of different scenarios. Scenario forecasting can never be precise, but it can identify key actions and these are set out in the report. As a substantial report based on empirical data from a wide cross-section of Scottish industry it clearly sets out costs, benefits, obstacles and importantly the urgency with which we collectively need to act.

One of the cries we all hear in our busy working lives is the need for cooperation, and I'm happy to say that this is an example of how that cooperation when mobilised can deliver a really insightful report. It has brought together the Scottish Net Zero Roadmap (SNZR) partners who have match funded with UKRI to make the outcomes of this project possible.

We have to thank, therefore, UK Research and Innovation (UKRI), Aker Solutions Limited, Altrad Babcock Limited, Costain Limited, Energy System Catapult Limited, Halliburton Manufacturing and Services Limited, the Net Zero Technology Centre, Optimat Limited, Storegga Technologies Limited, the University of Edinburgh, the University of Strathclyde, Wood Limited, Capricorn Energy, Crown Estate Scotland, Harbour Energy plc, Petroineos, Scottish and Southern Energy, SGN and Shell. Not only have these organisations contributed funding for the project, they have also contributed time and resource for which we are grateful.

The next steps on the journey to net zero will be determined on how we use this roadmap to move forward. In this endeavour a continued willingness to collaborate will be essential if we are to address the urgency of the task.

FOREWORD

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The launch of the Scottish Net Zero Roadmap is the culmination of 2 years of collaborative work across industry and academia to understand the current decarbonisation position, and present a range of scenarios for industrial emitters within the cluster to achieve net zero.

SNZR is one of six cluster plan projects receiving funding from UKRI's Industrial Decarbonisation Challenge. The report delivers key actions and recommendations for achieving net zero by 2045, including considerations such as infrastructure availability, technology and policy and also outlines the potential economic impact of decarbonisation.

The SNZR project provides a robust framework for decarbonising industries in Scotland, to support delivery of the net zero targets for Scotland and the UK.

CONTENTS

EXECUTIVE SUMMARY

This document presents a roadmap that sets out how a cluster of the largest industrial emitters in Scotland can move towards net zero by 2045. It is based on:

- Understanding the energy use and emissions of these emitters.
- Exploring how these companies can reduce their emissions to net zero under several different decarbonisation scenarios.
- Identifying the optimum process technologies to use and infrastructure to develop to enable each company and, thus, industry to achieve net zero operations.

The roadmap supports the decarbonisation needs of wider industry as it identifies the key solutions for a range of different types of businesses, reduces the business risk for these companies and defines the common infrastructure required that all companies will be able to access.

The roadmap is based on 28 industrial sites spread across 11 different industrial sectors and 14 local authority areas. It includes most of the top 25 largest emitters in the country, and collectively, they accounted for over 75%, or around 8.6Mt, of Scotland's industrial CO_2 emissions in 2019. This cluster was extended for the analysis of infrastructure needs to support net zero to include planned energy from waste plants and potential blue hydrogen manufacturing capacity to address forecast industrial and domestic needs. The core group of 28 industrial sites represents an important and significant cross section of Scottish industry. Collectively it employs over 6,000 people and generates gross value added (GVA) to the Scottish economy of over £740 million per annum. It is, therefore, a significant part of Scottish industry.

An optimal roadmap for this industrial cluster to achieve net zero by 2045 has been identified based on the analysis of a number of scenarios. This roadmap, however, requires concerted and timely action from a range of stakeholder groups, particularly industrial emitters, infrastructure developers and owners and regulatory bodies. It is critical that each stakeholder group makes and implements decisions on timescales that allow others to do the same.

Key actions identified to deliver net zero for the cluster are:

- Establish ownership and leadership of the roadmap implementation.
- Develop and operate a co-ordination mechanism to ensure that all stakeholder groups are engaged and committed to delivery of the roadmap.
- Support Acorn activities in the North East to establish an initial focal point for the roadmap.
- Investment in CO_2 pipeline infrastructure to support the cluster or, if this does not proceed.
- investment in CO_2 shipping hubs and local transport options.
- Investment in hydrogen manufacturing, transport and supply, linking developing hydrogen manufacturing capacity with industrial users.
- Investment in DACCS capacity of at least 500,000 tonnes per annum capacity.

These actions have been identified, assuming there are appropriate incentives for industry, such as the CCUS and Hydrogen business models being developed by the UK government.

In combination, these actions will deliver net zero and all need to be pursued in an integrated manner. As highlighted above, this requires a cohesive approach where industry, infrastructure owners, government and regulators work together to deliver the roadmap.

Further, these actions will support other companies to pursue net zero, based on the evidence developed in this work and the resultant infrastructure that will be available.

Alternative pathways to net zero that could be pursued have been identified and considered, but each is less optimal in terms of risk, cost, time to net zero, and overall emissions during the period to 2045.

The total cost of these actions is estimated at £6 and £9 billion. This is a significant challenge for the cluster to deliver, but also a massive business opportunity for local supply chains. It is estimated that supporting the cluster of emitters included in this study to achieve net zero could support an average of 5,000 jobs per annum between 2023-2045, comprising 2,800 direct jobs, 1,400 indirect jobs and 1,000 induced jobs, delivering an economic impact of £21 billion.

Based on the work carried out in this study it is recommended that the action plan, as detailed in Figure 22 is implemented without delay. Specific short-term recommendations are:

- Leadership and ownership of the roadmap is developed and established. It is noted that NECCUS is already in discussions with the Scottish Government regarding this recommendation.
- Support is committed to drive forward the Acorn project as the initial focal point for net zero cluster and infrastructure development.
- Development of required infrastructure, as identified in this roadmap, is initiated.
- There is ongoing, regular engagement with key stakeholders (industrial emitters, infrastructure developers and owners, government and regulatory bodies) to ensure that there is a cohesive way forward and that early actions are implemented.
- The organisations responsible for each action commit to pursue actions in a timely manner and update other key stakeholders on key decisions and progress.

ABOUT THE SCOTTISH NET ZERO ROADMAP PROJECT

The Scottish Net Zero Roadmap (SNZR) project has developed a roadmap that sets out how Scottish industry can achieve net zero by 2045, by exploring several decarbonisation scenarios. The project focuses on a cluster of industrial activity on the east coast of Scotland which covers many of the largest industrial sites across a range of sectors and around 80% of Scotland's industrial CO_2 emissions.

The project is jointly funded by Innovate UK, under its "Industrial Decarbonisation Challenge", part of the Industrial Strategy Challenge Fund, and several key Scottish organisations:

SNZR is led by NECCUS and other project partners:

1 INTRODUCTION

This document presents a roadmap that sets out how a cluster of the largest industrial emitters in Scotland can move towards net zero by 2045. It is based on:

- Understanding the energy use and emissions of these emitters
- Exploring how these companies can reduce their emissions to net zero under several different decarbonisation scenarios
- Identifying the optimum process technologies to use and infrastructure to develop to enable each company and, thus, industry to achieve net zero operations.

The roadmap is the key output of Scottish Net Zero Roadmap (SNZR) project.

The roadmap supports the decarbonisation needs of other, smaller, emitters as it identifies the key solutions for a range of different types of businesses, reduces the business risk for these companies and defines the common infrastructure required that all companies will be able to access.

1.1 Context

This roadmap has been developed at a time where there are numerous UK and Scottish net zero policies, initiatives and funding programmes. At the highest level, following the recommendations of the UK Climate Change Committee (CCC) for the 6th Carbon Budget, the UK Government legislated a target to cut greenhouse gas emissions by 78% from 1990 levels by 2035[1] and reach net zero emissions by 2050[2]. In Scotland, a more ambitious target of reducing emissions by 75% by 2030 compared to 1990 levels was ratified in the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019[3], along with a net zero target for 2045.

As outlined in the Climate Change Plan Update[4] ,emissions from the industrial sector, which currently make up 28% of Scotland emissions, need to decrease by 43% on 2018 levels by 2032[1]. This ambitious target is supported by an expectation that over the next two decades the total decarbonisation of the industrial sector will be possible through widespread deployment of carbon capture, utilisation and storage (CCUS), fuel switching (e.g. hydrogen) and negative emission technologies (NETs)[5].

To support the uptake of these technologies, the UK Government, which has powers over industrial policy in the UK, published the Industrial Decarbonisation Strategy (IDS) in March 2021, which sets out how industry can decarbonise in line with net zero while remaining competitive and without pushing emissions abroad[6]. The strategy covers the full range of UK industry sectors and outlines the range of policy actions in place to facilitate and encourage decarbonisation. The IDS set out several long-term policy frameworks which include business models for CCUS and hydrogen, alongside policies to support increased efficiency and fuel switching. The CCUS Business Models[7] include the intention to use an Industrial Carbon Capture Contract (ICC) to incentivise the deployment of carbon capture technology for industry, which covers operational costs, transport and storage fees, and a rate of return for capital investment. They also include a policy framework to support CO_2 Transport and Storage (T&S), a crucial component of industrial decarbonisation. The T&S Regulatory Investment (TRI) Model consists of both the regulatory model and other support arrangements which will facilitate private investment in T&S infrastructure.

The Hydrogen Business Models[8] aim to tackle the higher cost of low carbon hydrogen compared to higher carbon alternatives. The business model is one of a range of government interventions intended to facilitate the deployment of low carbon hydrogen projects necessary to meet net zero targets. The business model is intended to support new production, while existing producers may be eligible to apply for funding through the Industrial Carbon Capture (ICC) Business Model.

Alongside the actions in the IDS, the Prime Minister's Ten Point Plan for a Green Industrial Revolution set out a commitment to deploy two CCUS clusters by the mid-2020s and a further two by 2030[9]. To facilitate this the UK Government launched a Cluster Sequencing Competition to allocate support to CCUS clusters and to enable the Government ambitions to capture 10Mt CO_2 per annum.[10] Phase 1 of the cluster sequencing competition saw the Hynet[11] and East Coast[12] Clusters selected for Track 1 giving them priority for support under the government CCUS programme. From a Scottish perspective, the Scottish Cluster[13] was selected as a reserve cluster, as it met the eligibility criteria and performed to a good standard against the evaluation criteria. As of early 2023, an announcement of the timing of the second phase of the cluster sequencing programme is imminent.

The Scottish Government also has several policy initiatives to support industrial decarbonisation in Scotland. The key initiative is the Scottish Industrial Energy Transformation Fund (SIETF), which is in its third round and provides grant funding to reduce energy costs and emission through increased energy efficiency[14]. In the update to the Climate Change Plan, the Scottish Government also set out targets to improve energy productivity and industrial emission intensity by 30% compared to 2015 by 2032, with the SIETF being used as a key mechanism to achieve this. In 2022, the Scottish Government also published the National Just Transition Planning Framework[15], which sets out how transition plans will be developed for key sectors and geographies – including industrial cluster sites in Scotland and its Hydrogen Action Plan[16], which sets a target of 25GW of hydrogen manufacturing capacity by 2045.

1.2 Definition of the Cluster

The cluster was defined based on the following seven criteria:

1. Size of emissions (largest emitters to maximise reach and impact).
2. Proximity to/availability of gas (CO_2 & hydrogen) transport infrastructure – pipelines.
3. Proximity to/availability of other transport options - shipping, rail, road.
4. Proximity to other large emitters (to maximise potential for sharing of infrastructure).
5. Potential to act as a local CO_2 takeaway 'hub' for smaller, otherwise remote sites.
6. Potential to feed into a local CO_2 takeaway 'hub' (applicable to smaller, otherwise remote sites).
7. Application of any upcoming important sectoral changes (e.g. policy, regulatory).[17]

The cluster covers 28 sites spread across 11 different industrial sectors[18], and 14 local authority areas[19]. It includes most of the top 25 largest emitters in the country, and collectively, they accounted for over 75% of Scotland's industrial CO_2 emissions in 2019[20]. As such it is a complex cluster that covers a wide geographic area. This, however, offers advantages as it identifies the way forward for a range of different types of companies in various locations that wider industry companies can benefit from. The companies and their emissions are shown below (Figure 1).

This cluster was extended for the analysis of infrastructure needs to support net zero to include planned energy from waste plants[21] and potential blue hydrogen manufacturing capacity[22] to address forecast industrial and domestic needs.

The core group of 28 companies represents an important and significant cross section of Scottish industry. Collectively it employs over 6,000 people and generates an estimated gross value added (GVA) to the Scottish economy of over £740 million per annum[23], based on 2020 economic data. It is a significant part of Scottish industry. For example:

- The petrochemical site at Grangemouth (Ineos and Petroineos) accounts for 4% of Scotland's GDP and approximately 8% of its manufacturing base[24]. It has been established for around 100 years, building on an earlier heritage of oil refining in Scotland. It is the main supplier of aviation fuel to Scotland's airports, the major supplier of petrol and diesel in Scotland and a key manufacturer of basic chemicals that underpins the chemical and plastics manufacturing sectors.
- St. Fergus Gas Terminal receives approximately 30% of the UKs natural gas volumes.
- SSE's Peterhead Power Station is the largest power station of its kind in Scotland. The proposed replacement gas-fired power station with integrated carbon capture is expected to generate 290 jobs and £35 million GVA per annum during its first 25 years of operation.[25]
- Diageo's Cameronbridge site is the largest whisky and alcohol distillery in the world.[26]
- Owens-Illinois's Alloa bottle manufacturing site has a 260-year history of glassmaking, producing millions of bottles for whisky and other drinks per annum.
- Dunbar Cement Plant, a limestone quarry and cement works, has been in operation for over 60 years.

It is, therefore, important that this cluster can transition to net zero operations to retain its important and significant contribution to the Scottish economy.

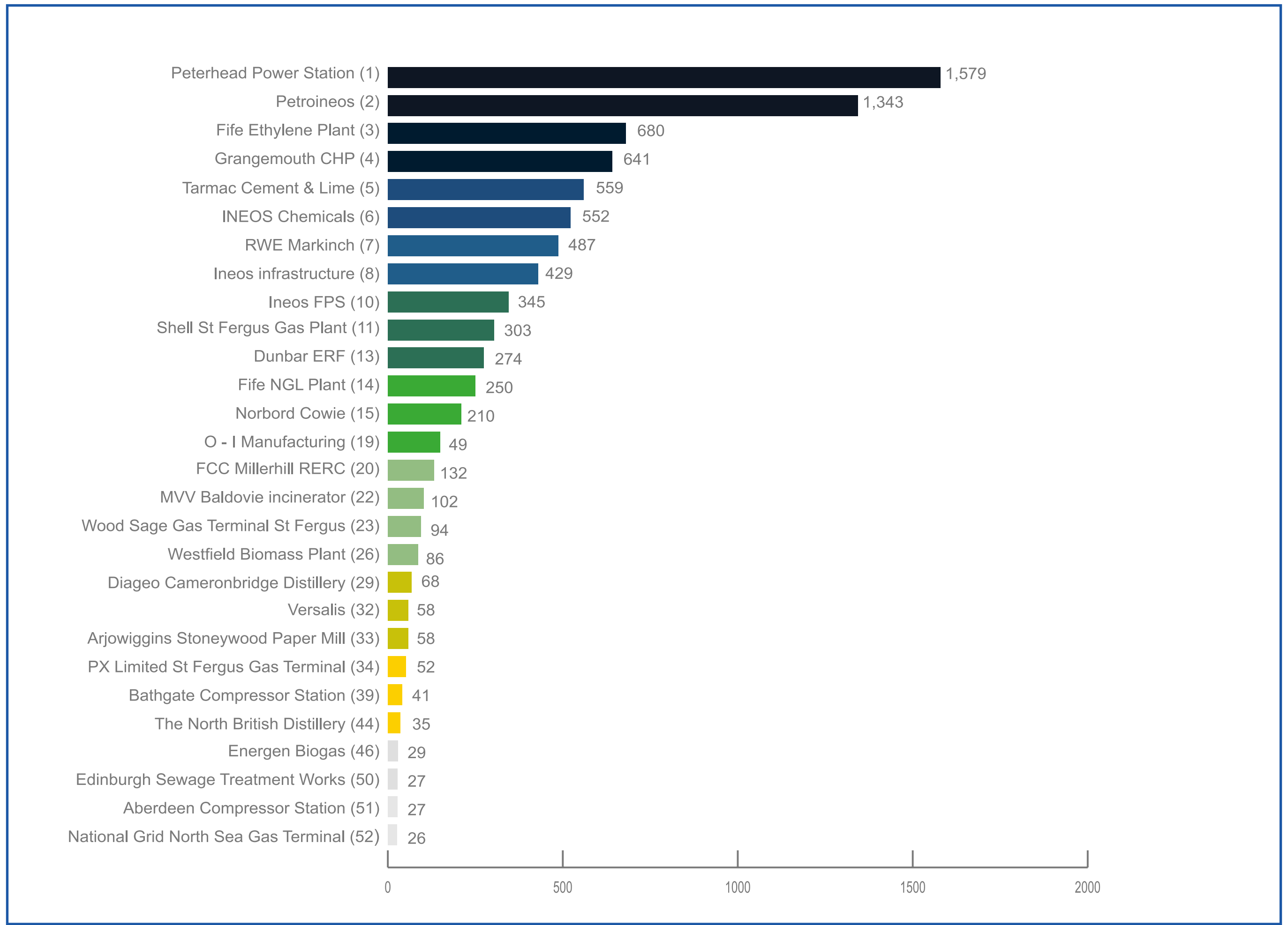


Figure 1: SNZR Company Base and Emissions

1.3 Challenges for Industry

The core group of companies that participated in this study all recognise the need to move to net zero and were actively engaged in work to identify relevant process technologies and external infrastructure requirements as well as site based ("inside the fence") investments that were needed. The key challenges, however, for these companies in pursuing individual net zero strategies are:

- Their dependence on external ("outside the fence") infrastructure that needs to be developed by third parties.
- Identifying site-based investments that are consistent with the development of external infrastructure.
- The need for infrastructure to be developed over a timescale that aligns with individual net zero investment plans.
- Identifying how investments could be made, without available fiscal incentives, while retaining their international competitiveness.

Development of this roadmap addresses the first three of these challenges. It does not address the emerging fiscal and regulatory decarbonisation landscapes.

1.4 Purpose of the Roadmap

This roadmap details company-specific and cluster level investments that are required for the cluster to move to net zero. It shows how the cluster, as a whole, can decarbonise. Further, it identifies the optimum process technologies to use the infrastructure to develop, to enable each company and, thus, industry to achieve net zero operations. As noted above, the core group of companies represents 11 industry sectors, so this roadmap has wide ranging relevance to Scottish industry and the wider Scottish economy.

The roadmap, therefore, provides the basis for a coherent approach, offers some guidance for individual company decarbonisation, highlights the interdependencies of individual company actions and defines a timeline for shorter term actions that offer longer term impact.

In summary, the roadmap provides a decarbonisation blueprint for Scottish industry.

1.5 Methodology

The methodology for this study was developed to accommodate two fundamental observations:

- The core group of companies, as listed in **Figure 1** represents a wide range of businesses of different sizes and operating in different sectors. As a result, they are exposed to numerous different operating and business conditions.
- The technical, commercial, fiscal and regulatory factors that will influence decarbonisation over the period to 2045 are, currently, not well defined.

The methodology, therefore, has two core characteristics. It takes a "bottom-up" approach, based on individual company energy use and emission profiles and uses scenario planning to model several alternative routes to decarbonisation. The full methodology can be shown, schematically, in **Figure 2.**

This figure highlights that the roadmap is built on an initial understanding of the site level emissions and energy use of the core group of companies, obtained through one-to-one discussions, combined with knowledge of existing and planned infrastructure and current and emerging technologies. These technologies were reviewed in detail (**see Section 2.3**) to identify their relevance and suitability.

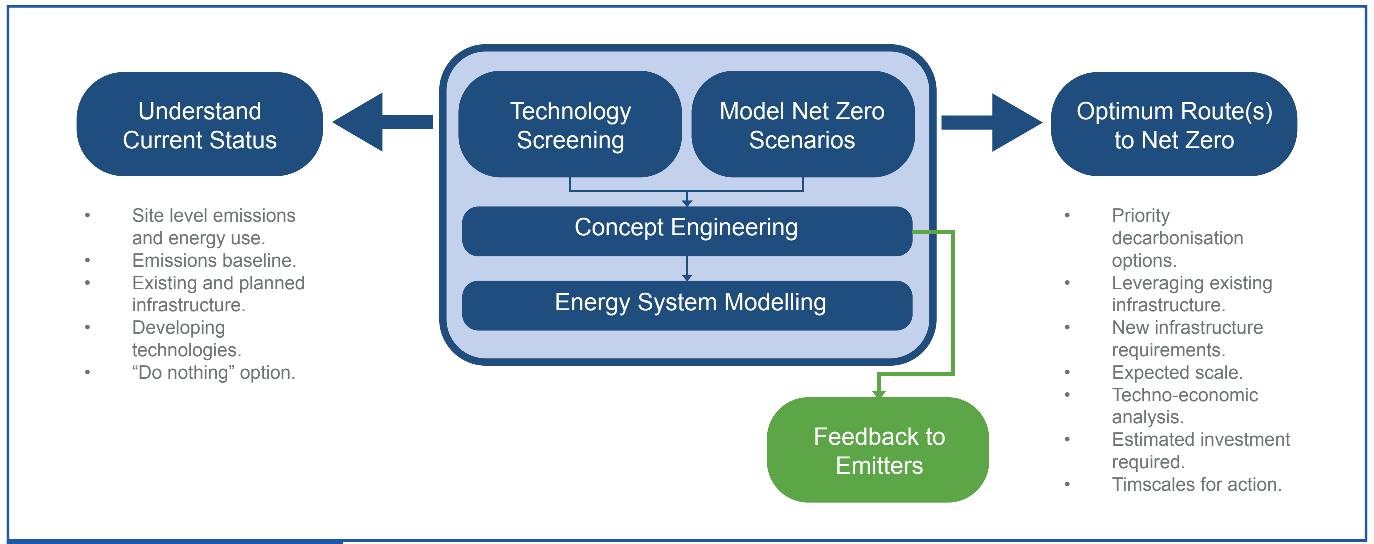


Figure 2: Study Methodology

As indicated above, it is not clear how the different factors that influence individual company decarbonisation plans will develop, so 6 scenarios were developed (see Section 3.1) to model several alternative routes to decarbonisation.

Site level emissions and energy use, potential technologies and the net zero scenarios were then combined in the concept engineering activity. The optimum decarbonisation options for each site were identified for each of the 6 net zero scenarios. This provided 6 potential "bottom-up" routes to net zero for the core group of companies. A site led cluster energy systems model was then developed to synthesise and analyse the data for each scenario to identify:

- Greenhouse gas reduction profile, including progress against targets.
- Year of net zero delivery.
- Residual emissions.
- Pathway cumulative GHG emissions.
- Overall cluster decarbonisation cost (absolute and versus counterfactual).
- Investment & operating cost profiles.
- Energy carrier and emissions usage.
- Volumes of blue / green / bio hydrogen produced & consumed in industry and non-industry.
- Electricity, biomass and fossil fuel consumption.
- CO_2 captured and stored.
- Infrastructure requirements and development.
- Utilisation profiles of common infrastructure.
- Energy centre siting and utilisation.

This energy systems model provided site, local and cluster level results and decarbonisation profiles.

These results and profiles were compared and analysed to define the net zero roadmap presented in **Section 4** of this document.

This methodology, obviously, takes a technical and financial approach to identifying the route to net zero for the industry cluster. This was complemented by a review of societal, economic and policy drivers and challenges for decarbonisation.

2 EMISSION PROFILES AND TECHNOLOGICAL SOLUTIONS

2.1 Current Emission Sources and Profiles

Current emissions for each of the 28 company sites in the cluster are shown in **Figure 1**. Their locations and industry sectors are shown opposite.

Both the absolute and percentage share of emissions for each sector are summarised in **Figure 4**. The cluster is visibly dominated by three sectors, which, combined, account for over two-thirds of emissions in 2019: Power has the largest emissions profile (25% or 2.2MtCO_2), and is closely followed by Chemicals (22% or 1.9MtCO_2) and Refining (21% or 1.7MtCO_2) respectively. The three sectors with the next largest emissions are Oil & Gas (9% or 0.8MtCO_2), Waste (7% or 0.6MtCO_2) and Cement (6% or 0.6MtCO_2).

Note: Figures may not add up exactly due to rounding.

2.2 Projected (2019-2045) business-as-usual geographical, industrial and illustrative future emissions baseline scenarios

This section presents the illustrative future baseline emissions scenarios projected out to 2045 for the sectors within the SNZR cluster. These scenarios incorporate newly operational, announced and/or projected significant[27] developments[28] that have either come online since 2019 or have been assessed as certain to do so during the period 2019-2045, in addition to the original 28 sites. The scenarios assume no deep decarbonisation measures are otherwise implemented within the cluster across those same intervening years, and therefore provide a projected business as usual (BAU) baseline against which potential decarbonisation pathways to 2045 can be assessed. The projections are summarised at both the cluster and sector level. An overview of how geographical emissions profiles across the cluster are projected to change is also given.

2.2.1 Three BAU scenarios assuming no deep decarbonisation

To cover a range of potential futures, a set of three BAU scenarios were developed: 'High emissions', 'Central' and 'Low emissions' - see **Figure 5**. These scenarios are based on the BEIS EEP 'High Growth', 'Reference' and 'Low Growth" scenarios[29] and are representative of hypothetical futures - they are not pathways or forecasts.

2.2.2 Projected future illustrative emissions baseline (2019-2045) - cluster level

By 2045, overall emissions are projected to reduce by 2.0-2.6MtCO_2, compared to 2019 levels. This represents a reduction in relative terms of between 24-30%, depending on the scenario – see **Figure 6**. This reduction is mainly due to a combination of energy efficiency measures and some reduced production activity. Even under the 'Low emissions' scenario, there remains an emissions gap in 2045 of 6.1MtCO_2 to achieve net zero for the cluster.

NB: Intervening years are marked for reference only, and dotted lines have been added to indicate interpolation between these points.

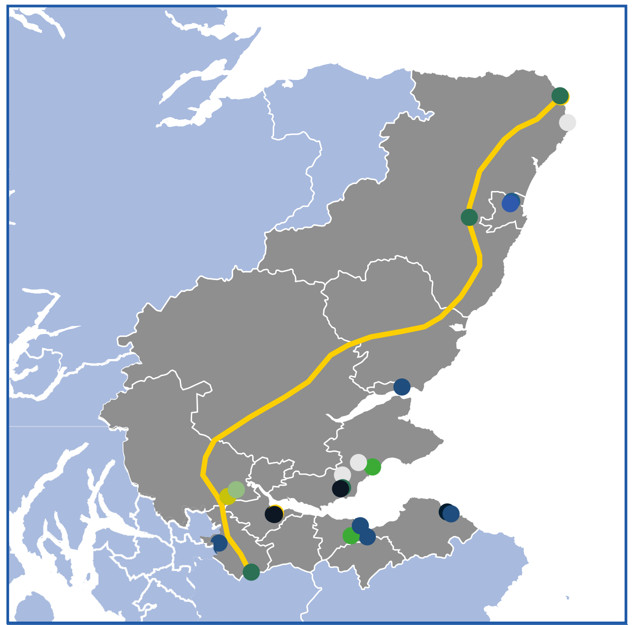


Figure 3: Geographical, industrial and emissions scope of the SNZR cluster overview (cluster level)

Sites in scope: **28**

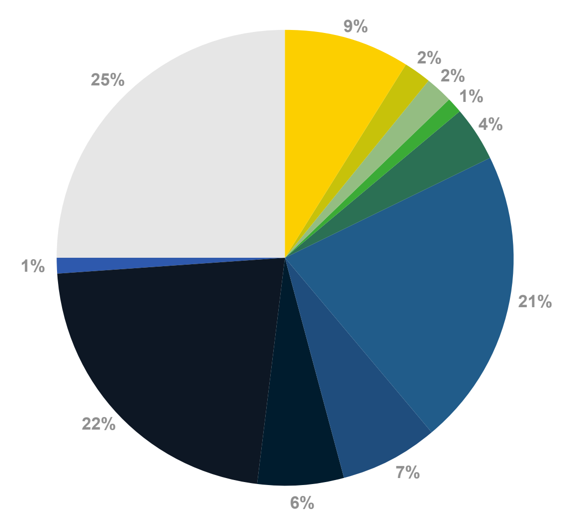
Total CO_2 emissions in scope (%): **76%**

Total CO_2 emissions in scope (Mt): **8.6Mt**

Local authority areas in scope: **14**

- Aberdeen City
- Aberdeenshire
- Angus
- City of Edinburgh
- Clackmannanshire
- Dundee City
- East Lothian
- Falkirk
- Fife
- Midlothian
- North Lanarkshire
- Perth & Kinross
- Stirling
- West Lothian

Industrial sectors in scope: **11**



- Cement
- Chemicals
- Food & Drink
- Gas (processing & distribution)
- Minerals
- Oil & Gas (exploration & production)
- Paper
- Power
- Refining
- Waste & Waste-Water
- Other

Figure 4: Cluster breakdown by sector

SNZR BAU scenario	High Emissions	Central	Low Emissions
Equivalent BEIS scenario	High Growth	Reference	Low Growth

Figure 5: 'High emission', 'Central' and "Low emissions

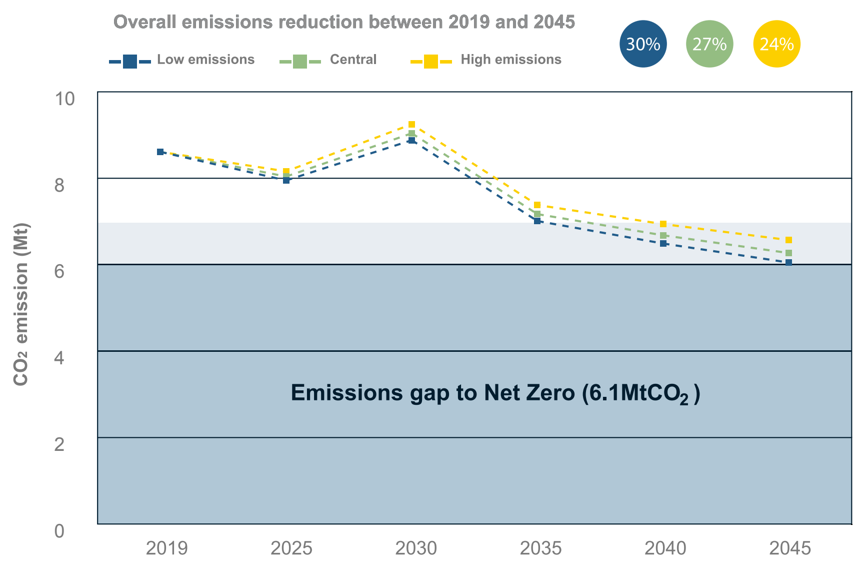


Figure 6: Cluster level projected annual CO_2 emissions 2019-2045 under BAU scenarios, and emission gap to net zero in 2045 scenarios

2.2.3 Projected future illustrative emissions baselines (2019-2045) - sector level

As shown in **Figure 7** opposite, there is considerable variation between sectors in how the projections assume they will evolve. In 2045, most of the sectors indicate a modest contribution to reducing annual emissions, while Minerals is projected to increase slightly, and Waste to increase moderately by around 0.5Mt (from a 565ktCO_2/year 2019 baseline). Chemicals, Power and Refining combined represent the largest absolute emissions reduction potential of between 2.3-2.6MtCO_2 (from a 5.8Mt/year 2019 baseline). This is negated, however, by the projected growth in the Waste sector, which reduces the total reduction potential for the cluster to between 2.0-2.6MtCO_2. This suggests that, at a minimum, the Chemicals, Power, Refining and Waste sectors will have an important role to play in reaching net zero

Note: Figures may not add up exactly due to rounding.

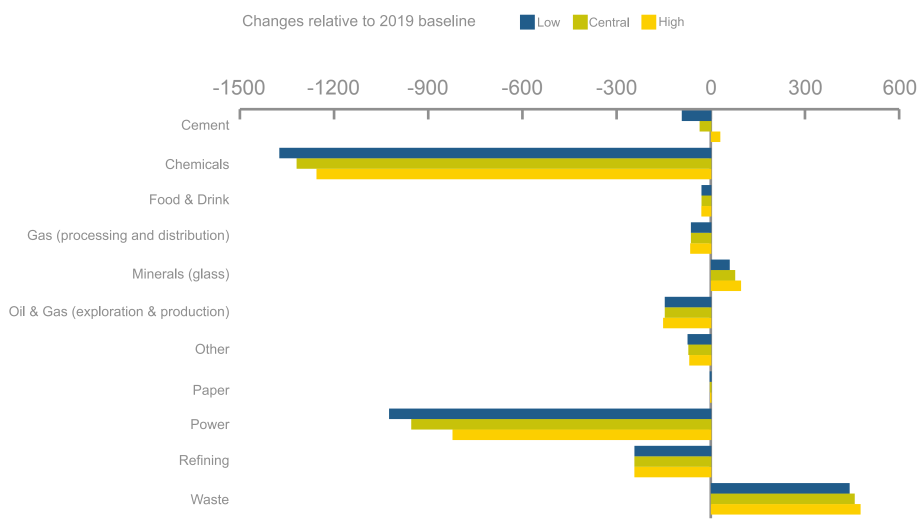


Figure 7: Projected changes in sectoral annual industrial CO_2 emissions in 2045, compared to 2019 baseline

2.3 Negative Emissions Potential

This section outlines the potential for achieving negative emissions within the SNZR cluster boundary in the period 2021-2045, by attempting to quantify the amount of biogenic CO_2 available[30]. The study included a review of a combination of existing Scottish industries that have biogenic CO_2 emissions, covering bioenergy systems for heat and/or electricity generation, which may be combined with CCS – known as bioenergy with carbon capture and storage, or BECCS. Bioenergy systems were segmented into two groups: biomass combustion for heat or combined heat and power (CHP), and anaerobic digestion (AD) to produce biogas and/or biomethane, including AD in landfills, sewage treatment works, wet-waste processing and crop residue treatment. It also covers energy from waste (EfW) systems: the waste treated in these systems is from a mixture of biogenic and fossil origins, so a proportion of captured and stored CO_2 will rate as greenhouse gas removals. The analysis also covers the fermentation industry, included here due to its scale of biogenic CO_2 emissions and the potential for lower-cost capture from concentrated CO_2 streams.

Reporting of biogenic CO_2 emissions in Scotland is not a mandatory requirement. Some data can be found in the SEPA SPRI database, but this is neither comprehensive nor consistent. Biogenic CO_2 emissions were calculated based on publicly reported production or processing capacities: bioenergy sources were calculated based on reported or installed electricity/heat production[31 32]; EfW facilities on waste processing capacity[33]; and fermentation on full alcohol production capacity[34].

2.3.1 Current Biogenic CO_2 Emission Sources and Profiles

In total, 46 individual sources[35] of CO_2 emissions of biogenic[36] origin were identified within the geographical boundary of the SNZR cluster for the period 2021-2045[37]. This covers facilities that were either already operational in 2021 or are new developments that are projected to come online in the intervening years. Almost all facilities (45 out of 46) are within 20km of proposed CO_2 transport infrastructure (pipelines/shipping ports/rail terminals) and/or at least one of the SNZR 28 sites. Of the 46 facilities, 11 are existing SNZR 28 sites and 7 are new/significant developments. The industrial sectors covered by these individual sources are Cement, Commercial/Institutional, Food & drink, Iron & Steel, Other, Power and Waste. **Figure 8** gives an overview of these facilities.

Both the absolute and percentage share of biogenic CO_2 for each source type are summarised in **Figure 9**. Biogenic CO_2 comes predominantly from three sources, which, combined, account for 70% of all biogenic CO_2 within scope in 2021: Biomass (CHP) is the largest source (36% or 590kt); EfW the second largest (19% or 313kt); followed by Biomass combustion for mainly heat provision (15% or 251kt). The three next largest sources are Fermentation (8% or 142kt), Anaerobic digestion with biomethane upgrading (CHP & BtG[38]) (8% or 137kt) and Landfill (CHP) (8% or 129kt).

NB: Figures may not add up exactly due to rounding

2.3.2 Projected future illustrative biogenic CO_2 emissions scenarios (2021-2045)

This section presents a set of illustrative future baseline emissions scenarios projected out to 2045 for the individual sources of biogenic CO_2 within scope. These scenarios incorporate newly operational, announced and/or projected developments meeting the 5kt/yr minimum threshold that have either come online since 2021 or have been assessed as certain[39] to do so during the period 2021-2045, in addition to the 39 facilities that were operational in 2021. The projections are summarised at both the cluster and source level.

2.3.3 Three illustrative scenarios

To cover a range of potential futures, a set of three illustrative scenarios were developed: 'High growth', 'Central' and 'Low growth'. Emissions from bioenergy and waste were plotted using CAGRs based on a

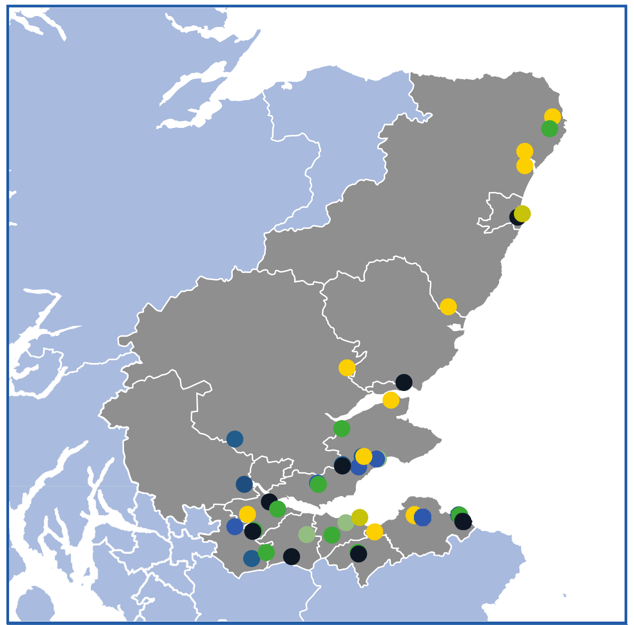


Figure 8: Geographical, industrial and emissions scope of biogenic CO_2 assessment

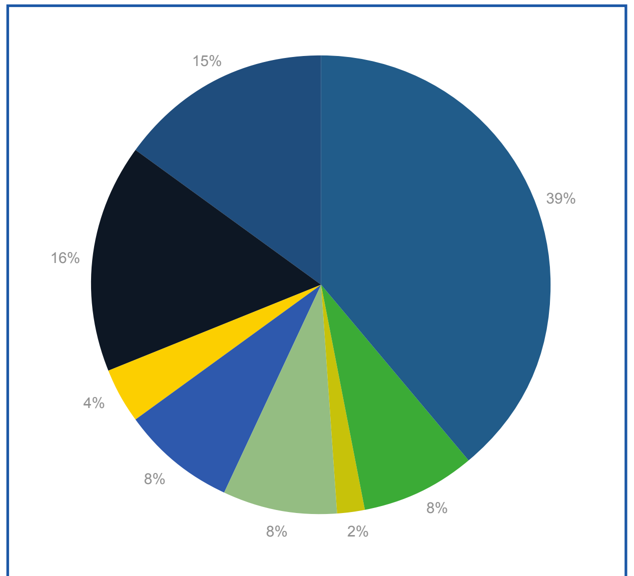


Figure 9: Cluster biogenic CO2 by source (2021)

Facilities in scope: **46**

Existing SNZR sites within scope: **11**

Facilities within 18km and/or at least one SNZR 28 site: **45**

Total biogenic CO_2 emissions within scope (≥5kt/yr) in 2021: **1.7Mt**

Sources of biogenic CO_2 within scope: **8**

- Anaerobic digestion with biomethan upgrading (CHP & BtG) (137kt)
- Anaerobic digestion (CHP) (68kt)
- Energy from Waste (EfW) (280kt)
- Biomass combustion (mainly heat) (251kt)
- Biomass (CHP) (670kt)
- Landfill (CHP) (129kt)
- Sewage treatment (CHP) (28kt)
- Fermentation (142kt)

Industrial sectors covered by biogenic CO_2 sources: **7**

- Cement
- Commercial/Hospitality
- Food & Drink
- Iron & Steel
- Power
- Waste
- Other

combination of reported renewable electricity generation in the BEIS Energy Trends, database[40] and energy and emissions projections in the BEIS EEP 2021 dataset[41]. Emissions from fermentation were projected using historical UK whisky production data[42]. This was because biogenic CO2 arising from the fermentation process - which, within the current scope, came exclusively from grain whisky production - is (by definition) a process emission, rather than from combustion activities for the purpose of energy generation.

NB: These scenarios represent hypothetical futures that are broadly aligned with market growth forecasts and Scottish and UK climate change targets. As such, they offer some insight into how these sectors could develop. They are neither intended to represent pathways nor forecasts of what will happen.

2.3.4 Projected biogenic CO_2 emissions scenarios - cluster level

By 2045, and growing at a CAGR (central estimate) of 6.4%, overall quantities of biogenic CO_2 from across the cluster are projected to increase by between 3.4-8.7MtCO_2/yr, compared to 2021 levels. – see **Figure 10** below.

2.3.5 Projected biogenic CO2 emissions scenarios - source level

As shown in **Figure 11**, there is considerable variation between sources in how the projections assume they will evolve. In 2045, and in line with expected market growth and climate change targets[43,44,45], most bioenergy sources are projected to see increases in biogenic CO_2 emissions, ranging from Anaerobic digestion (CHP) at 230kt/yr (low growth) to Biomass (CHP) at 4.1Mt/yr (high growth), with Sewage treatment (CHP) showing only a very slight increase of around 16kt/yr that is broadly in line with incremental

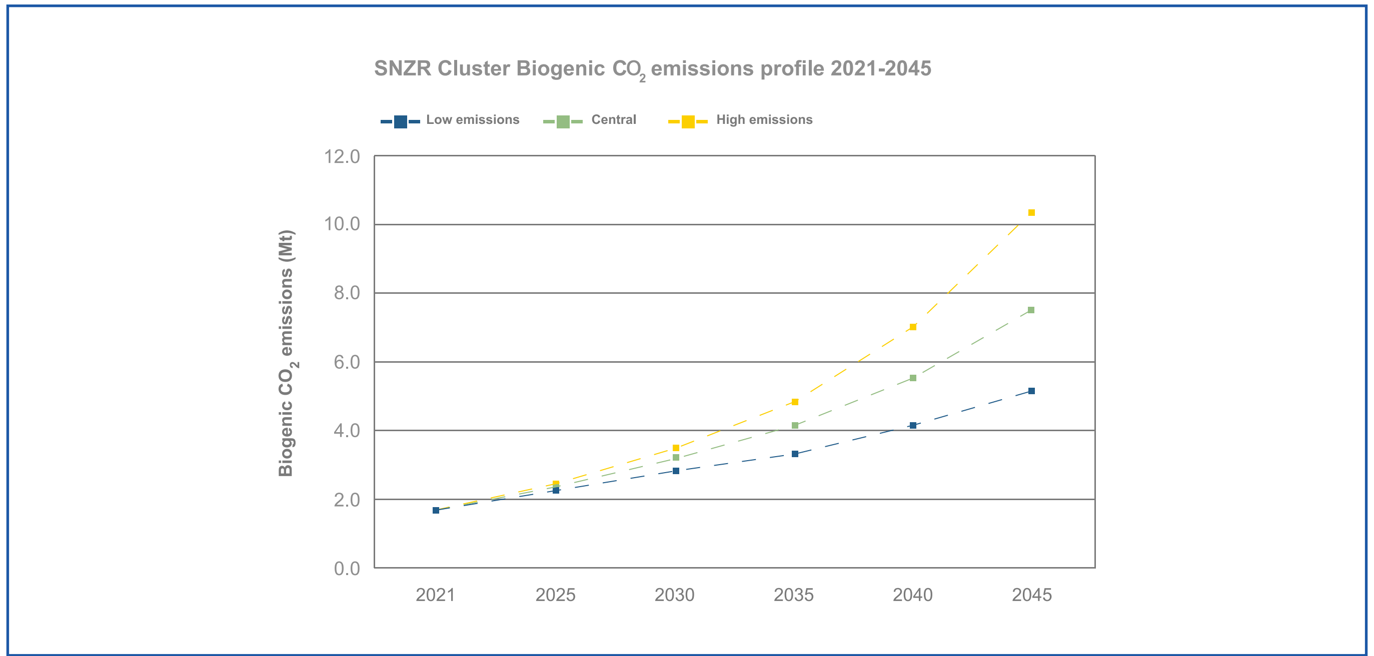


Figure 10: Cluster level project biogenic CO_2 illustrative projections (2021-2045)

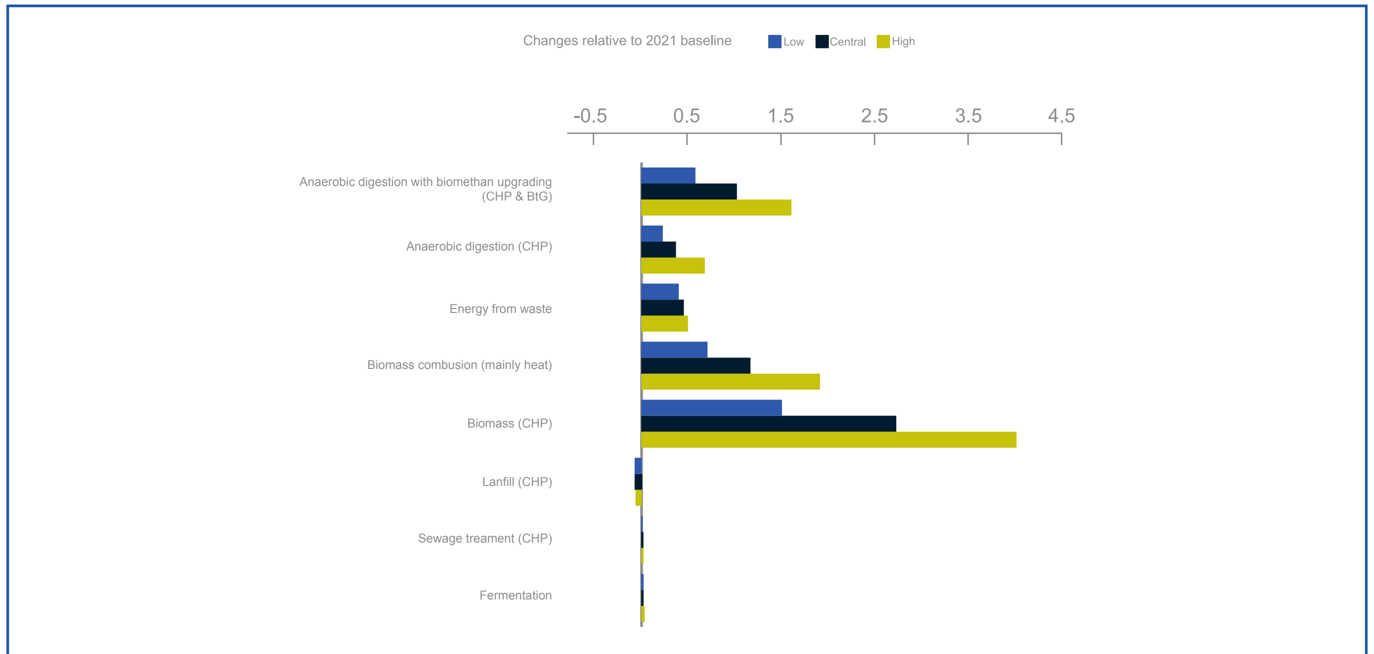


Figure 11: Projected changes in sectoral annual industrial CO_2 emissions in 2045, compared to 2021 baseline

population increase. Landfill (CHP) is the only bioenergy source to see a decrease, attributable to the 'tailing off' of landfill emissions largely as a result of the imminent ban on biodegradable waste to landfill in Scotland, due to take effect in 2025. EfW is projected to account for around an extra 0.5Mt/yr by 2045, attributable also (in part, at least) to the diversion of waste from landfill. Fermentation is projected to see only a very marginal increase of around 25kt/yr, due to expected incremental growth.

2.4 Technological and Infrastructure Solutions

A detailed analysis of the technology and infrastructure solutions to support decarbonisation underpins this roadmap. This analysis is included in Appendix B. It includes information relating to technology readiness level (TRL), advantages and challenges, technology costs, scalability, deployment base, commercial readiness (including time to commercialisation), learning rates and cost reduction opportunities. It includes technologies for:

- Renewable, low carbon and thermochemical hydrogen manufacture.
- Hydrogen storage.
- Fuel switching.
- Electrification of industrial processes.
- Carbon capture.
- CO_2 utilisation.
- CO_2 storage.
- Direct air capture.

The analysis concludes that:

- Many technologies exist today to deliver deep decarbonisation of industry in Scotland. **The biggest barrier to their deployment is the relative costs compared to current fossil fuel alternatives.** Based on carbon taxes and other financial penalties/ incentives, there are very few instances where switching to a new, clean energy vector, or installing carbon capture and storage (CCS) would be cheaper today than current methods. This, therefore, highlights the urgent need to reduce technology costs through research and development, and build local supply chain alongside policy support for commercial deployment activities that enable cost reductions through learning-by-doing and economies of scale.

- **There are numerous technologies under development for producing low-carbon hydrogen, although few have been deployed and proven at large scale.** Steam methane reforming (SMR) with CCS and alkaline electrolysis are the most advanced, but other technologies such as **enhanced autothermal reforming (ATR), partial oxidation (POx) and proton exchange membrane (PEM) electrolysis are gaining traction due to certain advantages.** All are likely to be deployed at large scale by around 2025. Other technology developments are also progressing and are at advanced stages of development – with further anticipated benefits and options for cost reduction through step change advancements in process and process integration.

- **Hydrogen has potential as a clean alternative fuel in many processes**, presenting some opportunities for retrofit rather than complete replacement of existing equipment. The main challenges relate to differing combustion properties of hydrogen compared with natural gas, with impacts on health and safety, performance, nitrous oxide (NOx) emissions, and materials. Most solutions can be classed as reaching technology readiness level (TRL) 7, meaning that further work is required to demonstrate at scale, and assess impacts on product quality. Field trials of blending various compositions of natural gas with hydrogen are currently being undertaken. **Hydrogen fuelled gas turbines will be essential to provide future dispatchable electricity generation, gas compression, and support combined (CHP) decarbonisation while ensuring a second lease of life for existing natural gas-powered turbines.** However, considerable further work is required to develop dry low emission hydrogen fuelled gas turbines and this market is expected to mature by 2030.

- **Biomass presents a key opportunity to decarbonise industrial heating and is already commercially deployed.** Biomass also presents future opportunities to produce clean hydrogen and carbon neutral synthetic fuels through gasification and further processing. However, **the biggest limitation on the use of biomass is likely to be availability of sustainable biomass feedstock locally.**

- **Electrification is feasible and well developed for several industrial processes (TRL 9 for heaters and boilers)** however it has had limited commercial deployment at scale due to high capital and operational expenditure (CAPEX and OPEX), and unsuitability in high temperature applications. Less well developed are plasma torches, electric kilns, infra-red heaters, microwave heaters and high pressure high temperature (HPHT) heat pumps which may be required in certain scenarios. The technology required to integrate clean electricity and new industrial processes is commercially mature and represents a major element of cost. Certain developments are ongoing, aimed at reducing the cost of power conversion.

- **CO_2 capture from low concentration point-source emissions is commercially mature with amine-based solvents** deployed at most post-combustion flue gas capture facilities worldwide. Several pre-combustion technologies are also commercially mature and are currently used in a variety of gas processing applications. Several next generation chemical and environmentally friendly solvents offer exciting potential to reduce solvent degradation and the energy requirements for regeneration. If capturing CO_2 at a cement plant, waste sorbent could be used in the manufacturing process. Calcium looping presents opportunities to capture CO_2 from low concentration sources, using a sorbent derived from cheap and abundant limestone.

- **Direct Air Capture technology** has progressed immensely over the last decade and may be an important technology to reach net zero, potentially providing a CO_2 capture option for emitters who struggle to decarbonise otherwise (e.g. sites where flaring is required). However, the cost must reduce to be an affordable solution. Reducing the cost of electricity, learning-by-doing, and economies of scale are all vital in reducing the cost of CO_2 capture. **Commercial deployment is expected mid-2020s with significant CAPEX reductions by 2030** and continuing to beyond 2050.

- **Carbon capture and utilisation (CCU)** offers the opportunity to create value added products from waste CO_2 that deliver long term sequestration, thus avoiding the requirement for transport and storage. Many products that could be made using CO_2 are already available so incentives will be required to increase the demand for new and alternative products using captured CO_2. Most CCU technologies have not yet been demonstrated at commercial scale and high costs represents a major barrier to widescale deployment. **Research and development into scaling such technologies is imperative to lower the cost of producing products with captured CO_2.** Perhaps most promising is waste CO_2 utilisation in mineral carbonation which can use alkaline wastes to create a variety of saleable products – for example, calcium and magnesium carbonates can be used as aggregates in concrete. "net zero" methanol can be produced using waste CO_2 and renewable hydrogen to significantly reduce the carbon impact. CO_2 can also be used to synthesise polymers to produce products with enhanced physical properties, at potentially lower costs.

- **Depleted oil and gas reservoirs and deep saline reservoirs both offer potentially attractive targets for geological storage of CO_2.** Uncertainty on capacity and injectivity is lower for depleted reservoirs, giving them a potential economic advantage, whereas uncertainty on abandoned well containment favours saline formations in those cases where they have been intersected by fewer wells. Injecting into depleted reservoirs below CO_2 bubble-point pressure presents challenges due to Joule-Thomson effects. If this can be better understood, modelled and components designed appropriately, OPEX can be reduced by eliminating the requirement for CO_2 heating at the wellhead. Net Zero Technology Centre are working on several developments in this space.

2.5 Addressing Cluster rather than Individual Company Needs

The SNZR cluster area covers much of the industrial heart of Scotland, and a requirement for any successful transition to a lower carbon economy is to retain GDP, skillsets and jobs. As well as reducing, capturing and storing greenhouse gas emissions, a meaningful change at cluster level will mean sourcing and using more renewable energy. With regard to their preferred decarbonisation option, individual sites have many factors to consider particularly costs, risks and opportunities.

Considering purely capital investments at industrial sites, post combustion capture plants (PCCP) are likely to be favoured by medium and large emitters as their decarbonisation option, as opposed to fuel-switching and building hydrogen plants as a pre-combustion route. This is also the case for sites where emissions can be aggregated into larger PCCPs, where hydrogen cannot realistically be used for total abatement, or where fossil fuel gases cannot feasibly be reformed. The PCCP option is well represented within the roadmap. It builds critical mass for the cluster CO_2 network but doesn't enable the rest of the cluster to transition on its own.

On the other hand, where nearby or multi-emitter sites cannot feasibly pool emissions into larger PCCPs, and many smaller PCCPs are instead needed, then building a large hydrogen plant with pre-combustion carbon capture and distributing hydrogen for firing becomes more attractive due to economies of scale. Should the core asset throughput shrink, the hydrogen asset is a standalone potential cash generator in the future (especially in future scenarios where hydrogen is exploited in non-industrial sectors) and supports the cluster's low carbon credentials. Conversely, a PCCP asset is more likely to become stranded. The capital cost of a switch from natural gas to hydrogen at the point of use is typically relatively small when compared to the reformer investment and is usually lower than building a PCCP.

Therefore, large sites hosting hydrogen plants, or third-party hydrogen plants (if prepared to sell hydrogen to neighbours or into a regional or national network), will, in addition to building the CO_2 infrastructure, enable new decarbonisation options for other sites, especially smaller sites, and facilitate growth within the cluster. As hydrogen derived from electrolysis develops – whether through specific strategic projects outwith the industrial sector or through targeted and global innovation and capital cost reduction – cost and decarbonisation reduction can be enhanced through a changing the hydrogen source.

At least in terms of capital cost, electrification can be an attractive alternative option, albeit for site applications generally less than 30 MW. Network reinforcement requirements may offer a barrier to deployment, but otherwise such interventions can be exploited without significant regard for the decarbonisation pathways of other sites within the cluster. Unless coupled with appropriately sized low carbon electricity generation, sites adopting such solutions do not offer substantive synergies with a wider strategy for cluster infrastructure. However, inclusion of a significant site like Peterhead (providing a new large dispatchable power station with CCS) and, to an extent, fitting PCCP to energy-from-waste plants, along with access to power from new windfarm sites, will significantly increase the net zero credentials of the cluster, as well as offering support to national targets.

Several non-site initiatives are required to support the cluster development, which the sites would expect to have access to via service contracts. Developing and maintaining the CO_2 network is a clear requirement, but hydrogen transmission and distribution and potentially energy storage to support use of renewables will be required.

Finally, the cluster infrastructure will take several years to deploy, whereas individual sites may be able to commission some solutions within 3-5 years. Sites could opt to delay decisions until future low carbon fuel and infrastructure availability becomes clearer. However, to deliver a substantial emission reduction and to stay broadly consistent with a system-wide trajectory to net zero, the cluster needs a quick, decisive start that can be rapidly scaled. With delays or lagging support to common infrastructure development, the schedule could easily stretch to or past 2045.

In theory CO_2 shipping gives the individual emitter a choice but does not necessarily provide the cluster with a clear low-cost option. Vehicular CO_2 transportation solutions are location-specific, and schedules of ships and road vehicles will depend strongly on volumes of emissions to be removed. Such scenarios do provide an option to import CO_2 from outside Scotland in order to help mitigate offshore storage costs, should infrastructure owners seek to pursue such opportunities.

Therefore, the large Grangemouth emitters are the sites most likely to catalyse a complete net zero solution, and drive change in others, as they will need to develop common infrastructure and can do so at reasonable cost. Progressive technology selection in sites will also drive cost down and attract investment.

3 PATHWAYS TO NET ZERO FOR INDUSTRY IN SCOTLAND

3.1 Scenario Modelling

Our approach to the formation of a robust roadmap for industry in Scotland involves the exploration of several potential development pathways for decarbonisation. Knowledge of existing emissions and recent project developments allows the journey to start assisted by good data and costings, but soon certainty is reduced, and it becomes less clear what the best options will be. Scenarios are developed to test potential decarbonisation pathways and the role of different energy vectors. They are not expected to be equi-probable; indeed, some are explored to better define the difficulties of deployment along certain pathways in order to screen them and to inform decision making.

Fundamentally, our approach to inform scenario development is to select specific well-defined projects to be executed at each of the key emitters in Scotland. These projects represent real, plausible changes that industrial sites could elect to adopt to decarbonise their process or that could be applied to energy infrastructure. The scenarios themselves link together projects associated with a particular holistic philosophy:

Scenario 1. Infrastructure Led

Infrastructure Led represents an approach that focuses on making maximum early impact on today's emissions through a manageable number of projects and stakeholder interfaces. This scenario is centred around three stages:

- The Acorn project as a minimum viable development project to de-risk CCUS, particularly central North Sea storage.
- Then decarbonisation of the Grangemouth sub-cluster, and repurposing of an existing Feeder 10 pipeline.
- Then network extension to other sites in Fife, the Lothians and elsewhere.

Scenario 2. Soft Start

In this option, progress on major projects like Acorn (including elements such as hydrogen production) and existing pipeline repurposing is slower. Thus, a more site-oriented strategy emerges, where early progress focuses on simple fuel-switches and on efficiency improvements, and CCUS, other than Acorn, is built later in the pathway.

This represents a persistent lag of current progress. Investigation of such a scenario allows progress towards net zero to be maintained should key CCUS projects in Scotland be delayed. This may involve lower financial commitment and risk early in the pathways, but less progress towards meeting the target, in particular, regarding interim targets.

Scenario 3. Regional H_2 Networks

The philosophy within this scenario is that hydrogen strategies, going beyond use just in industrial processes (for example in power, transport, homes and commerce) are planned and developed at a regional level in Scotland. Industry-focused local H_2 facilities are developed, with feedstock for blue H_2 being fed by the natural gas transmission system (NTS). The NTS is substantially retained alongside some re-purposing of feeders to carry CO_2. H_2 is fed to a number of assets for fuel-switching options.

This option mitigates against a risk in the base-case that heavy emphasis is placed on investments in a small number of large assets in Grangemouth, in which some sectors such as refining are subject to future uncertainties around product demand.

Scenario 4. National H_2

In this scenario, Scotland contributes substantially to an overall UK hydrogen-focused switching strategy incentivised by government that, again, covers use of H_2 in other sectors such as power, transport, homes and commerce. Scotland's existing fossil fuel infrastructure, alongside onshore and offshore wind development delivers both blue and green hydrogen production and distribution relatively early, with industry and non-industry migrating to hydrogen solutions as appropriate. This scenario is highly interconnected, both to England via hydrogen pipelines (potentially used to balance hydrogen supply and demand by leveraging assets including storage) and potentially to Europe via ships.

Scenario 5. Renewables Push

Investment in renewables and supporting infrastructure continues apace and generation capital costs tumble. Intermittently, power is in considerable surplus and can be very cheap within certain wholesale market structures.

As well as use of green electricity, green H_2 generation grows and becomes available to industry. BECCS is supported by a growth in land use for energy crops alongside continued availability of imported biomass resources and wastes.

Scenario 6. CO_2 Shipping

In this scenario, emerging and persistent challenges to pipeline solutions require alternative strategies to be developed throughout the pathway. An extensive CO_2 shipping solution emerges, with investment in port and harbour infrastructure leading to a potential strategy wherein Scotland maximises the utilisation of its CO_2 storage sites by taking in emissions from other UK clusters and from Europe. The development of onshore CO_2 buffer storage for shipping creates an option for smaller emitters to freight CO_2 to the dockside.

The relatively high cost of CO_2 shipping and relatively high availability of pure CO_2 streams also potentially encourage focused application of CO_2 utilisation to create useful feedstocks.

Each of these scenarios is designed to help address particular uncertainties and to expose risks and opportunities for industrial decarbonisation but also for the wider transition to net zero in Scotland and the UK. They are summarised in **Figure 12**.

Scenario	Decarbonisation	H_2	Dependencies	Wider Synergies	Opportunities / Appeal	Challenges / Threats
Infrastructure	Mixed H_2 / early CCUS	Mainly blue, regional networks, early	CO_2 pipeline availability Readiness of H_2 end-use technologies at scale	No specific synergies	Reliance on existing in-flight projects	Continued use of natural gas
Soft Start	Electricity and later CCUS	Mainly blue, localised networks, early	Near-term energy network reinforcement Strategic plan for later CO_2 transport	No specific synergies	Time to optimise site solutions and align to equipment replacement cycles	Continued use of natural gas Slower initial progress and greater cumulative emissions Local electricity network challenges
Regional H_2 network	H_2 and later CCUS	Blue / Green, national networks, early	CO_2 pipeline availability Readiness of H_2 end-use technologies at scale Local business models / markets for H_2 supply	H2 heat / transport	Link to local areas energy planning and wider H_2 usage Flexibility around H_2 production	Addressing seasonality of H_2 H_2 market maturity CO_2 storage quantity
National H_2	H_2 and early CCUS	Blue / Green, national networks, early	CO_2 pipeline availability Readiness of H_2 end-use technologies at scale National business models / markets for H_2 supply	H_2 heat / transport	Flexibility around H_2 production	Substantial requirements for new infrasturacture with uncertain connection H_2 market maturity CO_2 storage quantity
Renewables Push	Biomass, electricity and early CCUS	Green, national networks, early	CO_2 pipeline availability Electricity network upgrades	Heat / transport electrification	Utilises key resources in Scotland Early action possible	Local electricity network challenges Expense of some site solutions at scale
CO_2 Shipping	Early CCUS	Blue, localised networks, early	Business cases for port / infrastructure owners	No specific synergies	Continued use of natural gas	Port strategies Carbon accounting Operation of vehicular infrastructure

Figure 12: SNZR Scenarios

3.2 Key Considerations for Industrial Decarbonisation in Scotland

Our modelling has explored the emissions, energy use and cost of decarbonisation across our scenarios. Selected outputs are presented in Figure 13 and Figure 14. It demonstrates that there are likely to be multiple plausible pathways that can deliver on a net zero emissions target, although all pathways will require some further CO_2 removal beyond that directly achievable at the existing industrial sites to achieve complete carbon neutrality.

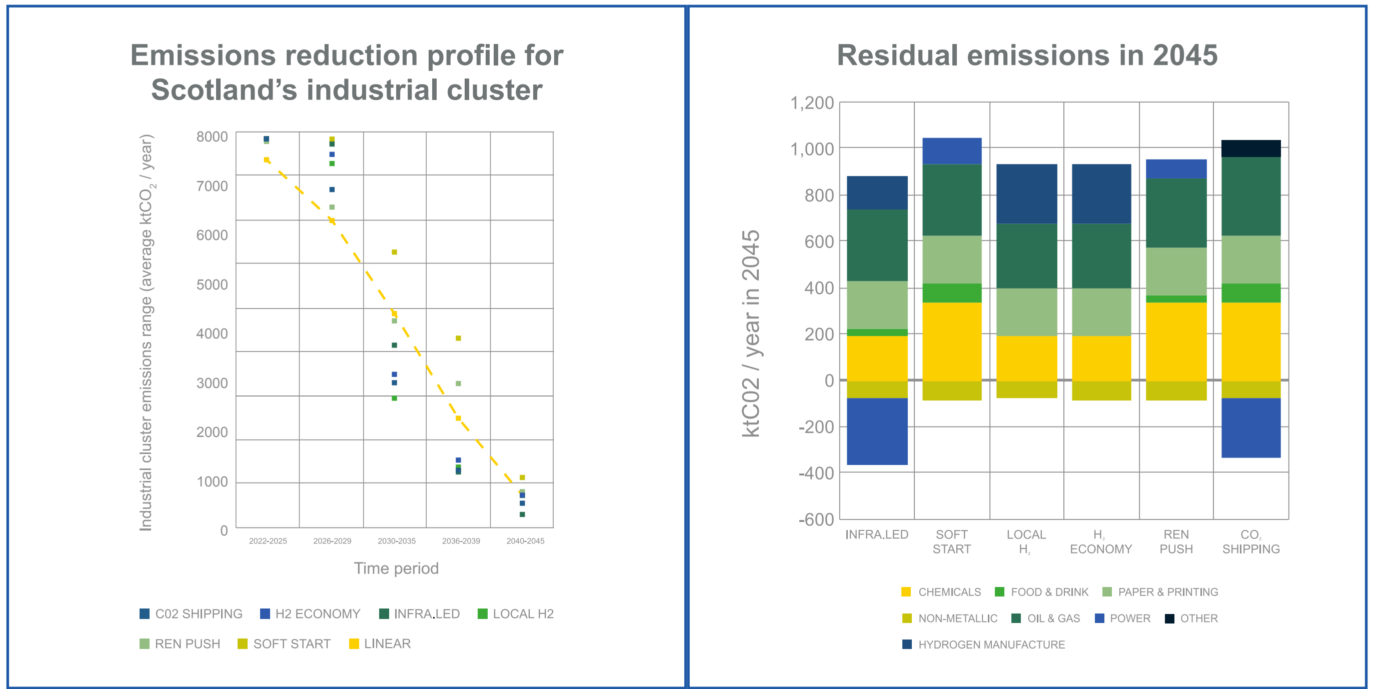


Figure 13: Emissions reduction trends and residual emissions in 2045 across the SNZR scenarios

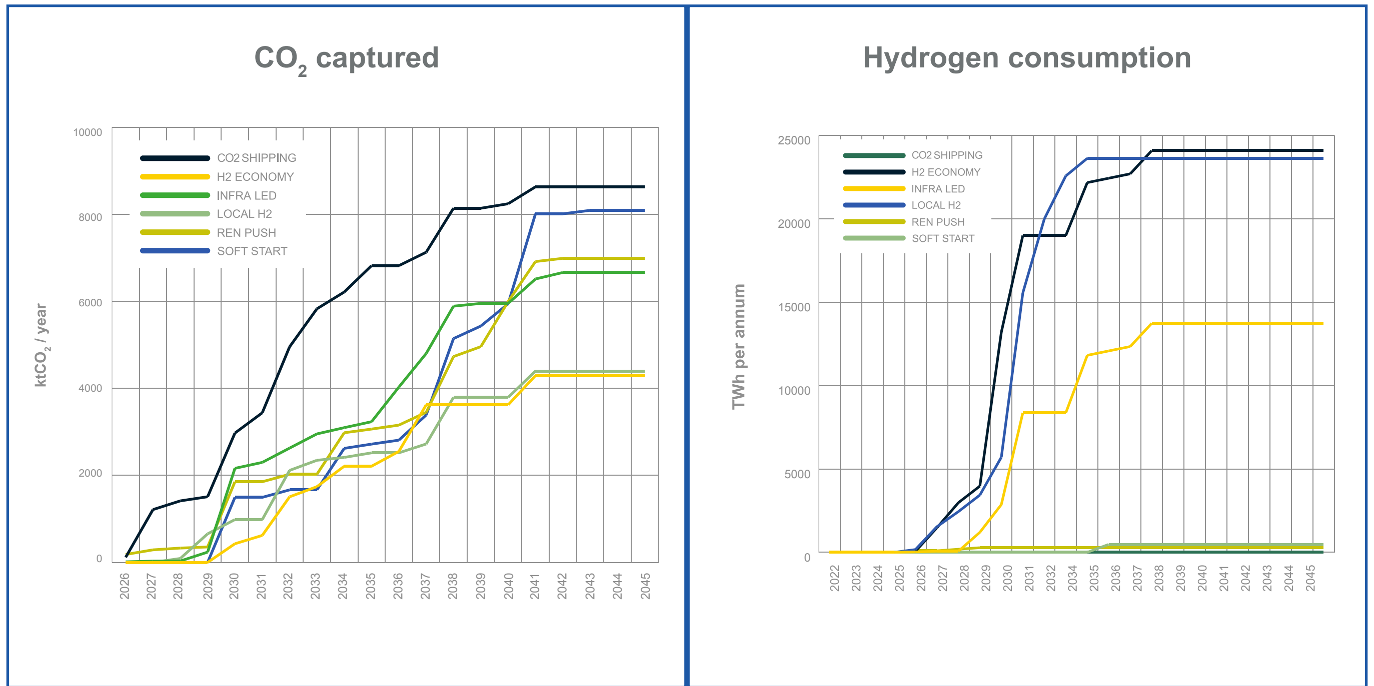


Figure 14: Captured CO_2 and hydrogen consumption at industrial sites across the SNZR scenarios

However, it is critical to acknowledge that a preferred route should depend not only on the cluster's modelled emissions and aggregate costs but on the risks that each chosen pathway exposes industrial business to, and the wider energy system and economic opportunities that emerge within each scenario. Our engineering study and supporting modelling indicate that our Infrastructure led scenario offers a sound starting point for further site and cluster planning:

- It offers the lowest total emissions in 2045, with a small requirement for additional removals to comply fully with a net zero target.
- It retains decarbonisation optionality, with a variety of hydrogen and CCUS options taken up across sites and regions, and is more amenable to adjustments to meet site preferences or to respond to external shocks to the energy system.
- It delivers a competitive cost of decarbonisation and thus offers sound value for business and Government.

Scenario	2045 Scope 1 emissions (ktCO$_2$/years)	Cumulative 2022-2045 Scope 1 emissions (MtCO$_2$)	Approximate cost of decarbonising (NPVE/tCO$_2$ saved)	Key requirements and decisions
Infrastructure Led	100 Kt	90 Mt	£130 / t	CO_2 pipeline availability following on from Acorn project Local H_2 manufacturing hubs and network
Soft Start	500 Kt	117 Mt	£150 / t	CO_2 pipeline availability from 2030s
Local H_2	500 Kt	85 Mt	£130 / t	CO_2 pipeline availability following on from Acorn project Local H_2 manufacturing hubs and network
H_2 Economy	500 Kt	89 Mt	£135 / t	CO_2 pipeline availability following on from Acorn project National H_2 pipeline network
Renewables Push	600 Kt	98 Mt	£170 / t	Sustainable bioenergy availability Electricity network reinforcement

Figure 15: Key features of the SNZR scenarios (inclusive of BECCS but not DACCS interventions)

Considerations, prompted by the modelling and engineering studies carried out for the roadmap project, include:

- To build momentum, the SNZR cluster needs an attractive starting point. The existing Acorn deployment project and related storage asset offers an appropriate route to initiate cluster decarbonisation and to capture impactful quantities of CO_2 from the late 2020s. The Acorn hydrogen plant, which initially feeds the natural gas grid, helps load up the store, and the proposed Peterhead gas-fired CCS project would be an impactful follow-up project.

- Relatively early on, a decision will need to be made on a main North-South pipeline. After some initial CO_2 removal within the North East of Scotland, decarbonisation stalls before accelerating again after 2030. At this point, in most scenarios a CO_2 pipeline solution becomes available and allows large quantities of emissions to be piped north to the store. Getting a repurposed natural gas feeder or an equivalent new pipeline commissioned around 2030 is a key step for the cluster. Achieving high volumes as soon as possible drives cluster costs down. The cluster needs tools and strategy that achieve net zero at cluster level, whereas the individual sites will assess from corporate and site level perspectives.
- Sites and generators will need to align their project timescales with supporting transmission and storage projects, port developments and CO_2 storage capacity. FEED studies and consenting activities will be needed such that investment decisions can be co-ordinated, especially for early and larger projects. The largest projects such as Peterhead CCS may be able to simplify and fund transport systems for their own use.
- Realistic options selected for decarbonisation are relatively limited. Numerous sites have only one technical option for decarbonisation across all scenarios. Of the rest, the lowest emitting ten sites are responsible for only 15% of the CO_2 emitted.
- Provision of clean energy from industry to commercial or domestic users is more of an opportunity than an issue, although policy and business models will inform the viability and extent of any cross-sector energy flows. Although not substantially considered within SNZR, this may lead to a complication in terms of quality of supply (e.g., fuel cell quality hydrogen, reliability criteria).
- The start date substantially shapes the pathway. A later start means less time for scale-up of the Acorn project and offers more risk in terms of parallel dependent projects. Ultimately this could mean smaller emitters cannot find solutions by 2045, in which case DACCS or BECCS grow in importance. The extent of CO_2 pipeline coverage also affects ambition, especially the decision to extend into East Lothian; over a million tonnes of CO_2 emissions are currently eliminated towards the end of the pathway from this region with few alternative options available.
- There are several specific decisions required that relate to the nature of the infrastructure transporting gases. These include the choice of repurposing an existing pipeline versus a new pipeline, date of commissioning of any CO_2 transport branches (e.g., a spur to Fife). In the longer term, should the overall plan for Scotland's transition to net zero require greater quantities of CO_2 removal, there is the need to identify when the repurposed feeder – if chosen – needs to be replaced. These decisions also inform the quantities of offshore storage required, and when commissioning of the second store (East Mey) should take place. This is also informed by a decision around whether to import CO_2 from ships or not.
- All scenarios can reach net zero, however, DACCS is required in all cases to remove some residual emissions – it is critical to reflect on the cost of CO_2 to abate and understand the position of a BECCS alternative.

Overall, we expect that, in overnight cost terms (i.e. excluding interest and financing costs), as much as £9 billion of capital investment may be required to deliver a viable transition pathway for the SNZR cluster, with many interdependencies between investments (e.g. hydrogen fuel-switching cannot be actioned until feedstock becomes available).

Investment	Capital Investment Range	Examples
Industrial equipment fuel-switching	£100m - £1bn	Hydrogen boilers, heaters and furnaces Hydrogen-fired turbines Electric / electrode boilers
Industrial site carbon capture equipment	£1.1bn - £2.4bn	Post-combustion capture equipment for heat production
Low carbon power production	£1bn - £2.6bn	CCGT with CCS Biomass-fired generation Energy from waste
Hydrogen production	Up to £3.8bn	Steam methane reformation Auto-thermal reformation Electrolysis
Infrastructure transporting gases	£1bn - £1.6bn	Repurposing of natural gas pipelines for CO_2 transport New CO_2 / H_2 pipelines Port CO_2 transportation infrastructure
Electricity network infrastructure	Up to £100m	Local distribution network reinforcement
Additional removals	£200m - £900m	Direct Air Capture
Total Capital Investment	**£6bn - 9bn**	

Figure 16: Capital investment requirement across the SNZR scenarios)

This investment of up to £9 billion offers a massive opportunity for Scottish supply chains. The potential economic impact of delivering net zero for this industrial cluster is detailed in section 4.5.

4 NET ZERO ROADMAP FOR THE INDUSTRIAL CLUSTER

4.1 Roadmap Options and Decision Points

Based on the assessment of options to deliver net zero it is clear that there are a number of key decisions that a range of key stakeholders are expected to make that will influence the direction and speed of change to net zero. These include:

4.1.1 Infrastructure

- Pipeline CO_2 transport availability
    - Natural gas feeder repurposing.
    - New trunk pipeline development.
    - Tie-ins, branches and hubs.
- Pipeline hydrogen transport availability.
- Development of ports infrastructure, particularly Forth Ports and Peterhead Port to enable CO_2 shipping, prior to offshore transport and storage. The location of Forth Ports, which was recently selected as a Green Freeport, close to key industrial emitter sites, makes it a potentially important facility for CO_2 transport.
- Capacity of the electricity network.

4.1.2 Supply chain

- Hydrogen production and supply.
- Hydrogen manufacturing supply chain.
- CCS supply chain.

4.1.3 Technology readiness

- Availability of post-combustion carbon capture at suitable capture rates.
- Hydrogen-fired process switch options
    - Turbines.
    - Boilers and heaters.
    - Kilns and furnaces / crackers.

4.1.4 Policy and regulation

- Incentives / policy support for decarbonisation versus fossil fuel use elimination, for example:
    - Incentives / policy support for CCUS, e.g., CCUS Business Models.
    - Incentives / policy support for fuel switching / electrification.
    - Incentives / policy support for hydrogen production, e.g., Hydrogen Business Models.
    - Incentives / policy support for consumption versus production-based emissions reduction.

4.1.5 Wider economic and strategic factors

- Alignment with broader Industrial Strategies (at UK and Scottish Government levels).

- Alignment with Scottish Government National Planning Framework and National Outcomes (through the National Performance Framework).
- Alignment with national infrastructure projects.
- Alignment with strategy around Green / Free Ports.
- Industrial technology preferences at Scotland, UK and global level.

These decisions will all affect the pathway to net zero and would prompt the Scottish Cluster to preferentially adopt features of particular SNZR scenarios. **Figure 17** presents the most critical decision points and outlines how decisions may tip the preferred pathway for industry towards one scenario or another, showing that there are prerequisites and conditions wherein particular scenarios are more likely to arise than others.

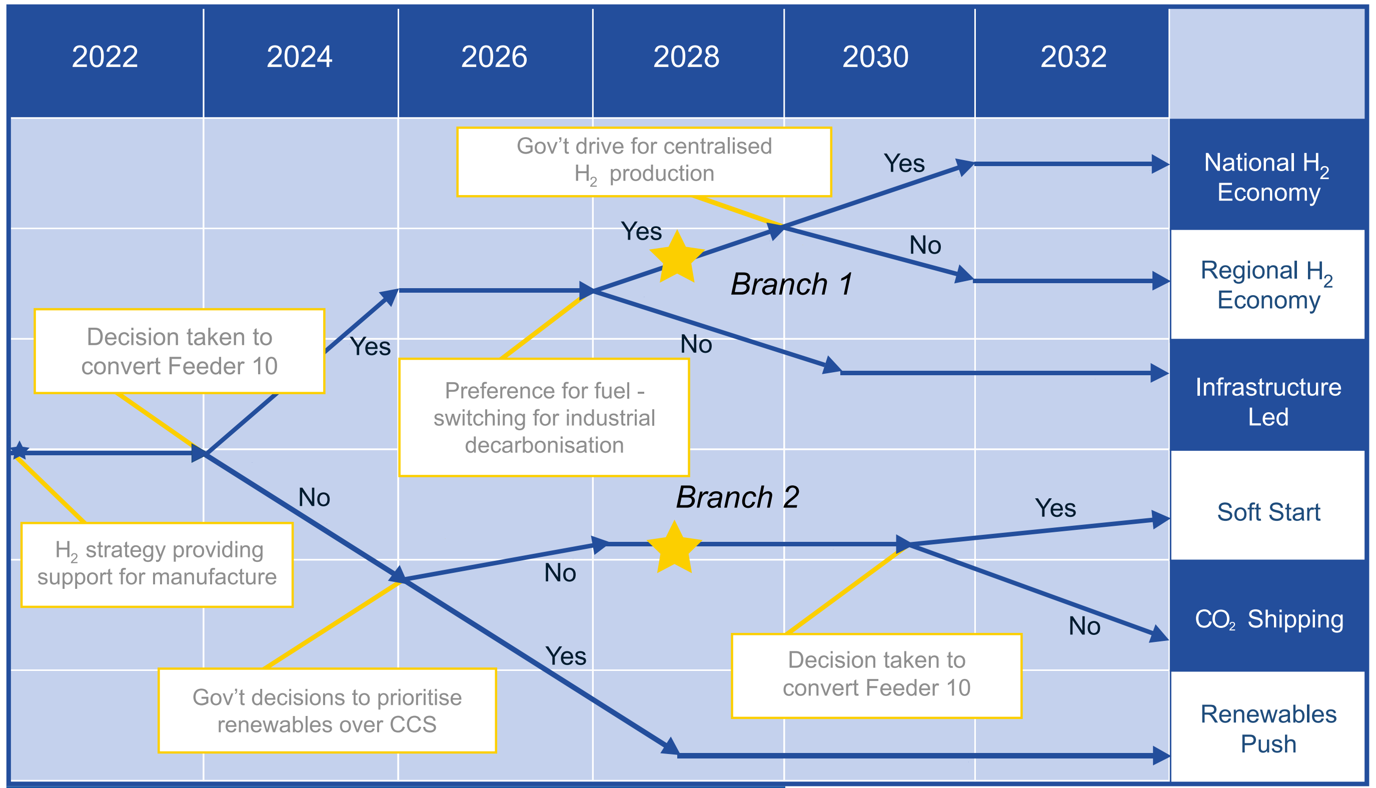


Figure 17: Key decisions and their relationship to the SNZR scenarios

4.2 Roadmap Priorities

At the outset of the project, the following strategic priorities for industry and the wider Scottish economy were identified:

- Economy-wide net zero in Scotland by 2045 and interim greenhouse gas targets [Scottish Government]
- Appropriate contribution to UK-wide greenhouse gas emission targets, including 67% and 78% reductions by 2030 and 2035, respectively
- To be one of the four UK industrial clusters targeted to be deployed by 2030, with a combined total of 20-30Mt per annum of CO_2 captured
- To achieve this transition while retaining skills and GDP and creating growth opportunities

If public funding is required to stimulate the site-based projects, this will involve an assessment of candidate projects for funding, and selection of an initial few which look most likely to be successful i.e., involving companies committed to fund the project, commission it on time and operate it as intended, all at a competitive cost of abatement.

These projects need to be enabled by transmission and storage projects which also need reliable delivery and operation, with coordinated development timescales. Clarity on pipeline pressures, CO_2 quality, layout and tie-in points is needed early to facilitate agreements that enable the early adopters to progress without disadvantaging later additions. While the system modelling in support of the roadmap modelling offers the opportunity to explore the co-ordination of many options, the plans of all key emitters need to be matured to act as waypoints in the wider plan.

From a levelised cost perspective starting the largest projects early is likely to give the best overall results. This will favour projects which have started to develop their decarbonisation plans already.

4.3 Net Zero Roadmap

The key decision points presented in **Figure 17** provide a quandary for Scotland's industrial roadmap. Although there are many actions that must be taken irrespective of the scenario followed, there are several significant decisions which will be made by a range of stakeholders that will affect the direction and nature of the pathway to net zero. The most significant is considered to be the availability of pipelines to transport captured CO_2 north to storage sites as this is identified as critical infrastructure to enable high volume carbon capture, transport and storage. Linked to this will be decisions on wider strategies or incentives addressing the balance of CO_2 capture, hydrogen and electrification at sites where multiple options are present.

From a pure energy system cost perspective, there are several potential solutions that are likely to achieve similar emissions abatement at similar costs, but it should be noted that for these solutions to be realised, action beyond industry is required (e.g. hydrogen supply to domestic / commercial buildings, port developments to facilitate ship movements, etc). These different solutions also expose different risks and opportunities dependent upon factors internal and external to Scotland.

The challenge for SNZR is how we present a logical way forward when there are fundamental decisions to be made by external stakeholders that will influence the available pathways to net zero.

As a result, we have developed two alternative roadmaps; one for each of the two branches of the decision tree identified in *Figure 17*. This is considered a prudent approach to accommodate the number of key infrastructure, technology, supply chain and regulatory decisions that need to be made. These roadmaps are:

- **Branch 1: Pipelines and hydrogen** - this is considered the optimum way forward for the Scottish Cluster. At its core is the availability of pipelines to transport captured CO_2, but, based on the evidence gathered in preparing this roadmap, development of this infrastructure has not yet been confirmed.
- **Branch 2: Shipping and electrification** - this roadmap offers an alternative route to net zero, based on shipping significant volumes of CO_2 if the preferred pipeline-based roadmap cannot be pursued. The roadmap is also instructive as:
    - Sites may still choose to electrify early, especially if markets enable this or if there are delays in CCS / H_2 infrastructure development. Hence, some of the required steps here may apply more widely.
    - Shipping may well take place anyway, although not necessarily being "optimal" for SNZR. Therefore, there is value in exposing elements related to this branch even if we don't think it's "best" for SNZR.
    - Shipping could be used to complement pipeline transport of CO_2 in the future.
    - It exposes common requirements whatever the preferred technical solutions.

In each roadmap there are a series of actions required for the Scottish Cluster to comply with its net zero requirements. These actions are divided into two types:

- common actions (deployment) that must take place irrespective of the overall strategy employed for the cluster and
- conditional actions that must be progressed if following one of the two branches.

In each case we aim to retain as much site optionality as possible – these roadmaps do not prescribe a specific route to net zero but indicate the underlying requirements for the endpoint to be achieved.

4.3.1 Branch 1: Pipelines and Hydrogen

4.3.1.1 Roadmap

This roadmap is the preferred way forward for the Scottish Cluster. It can be presented as follows:

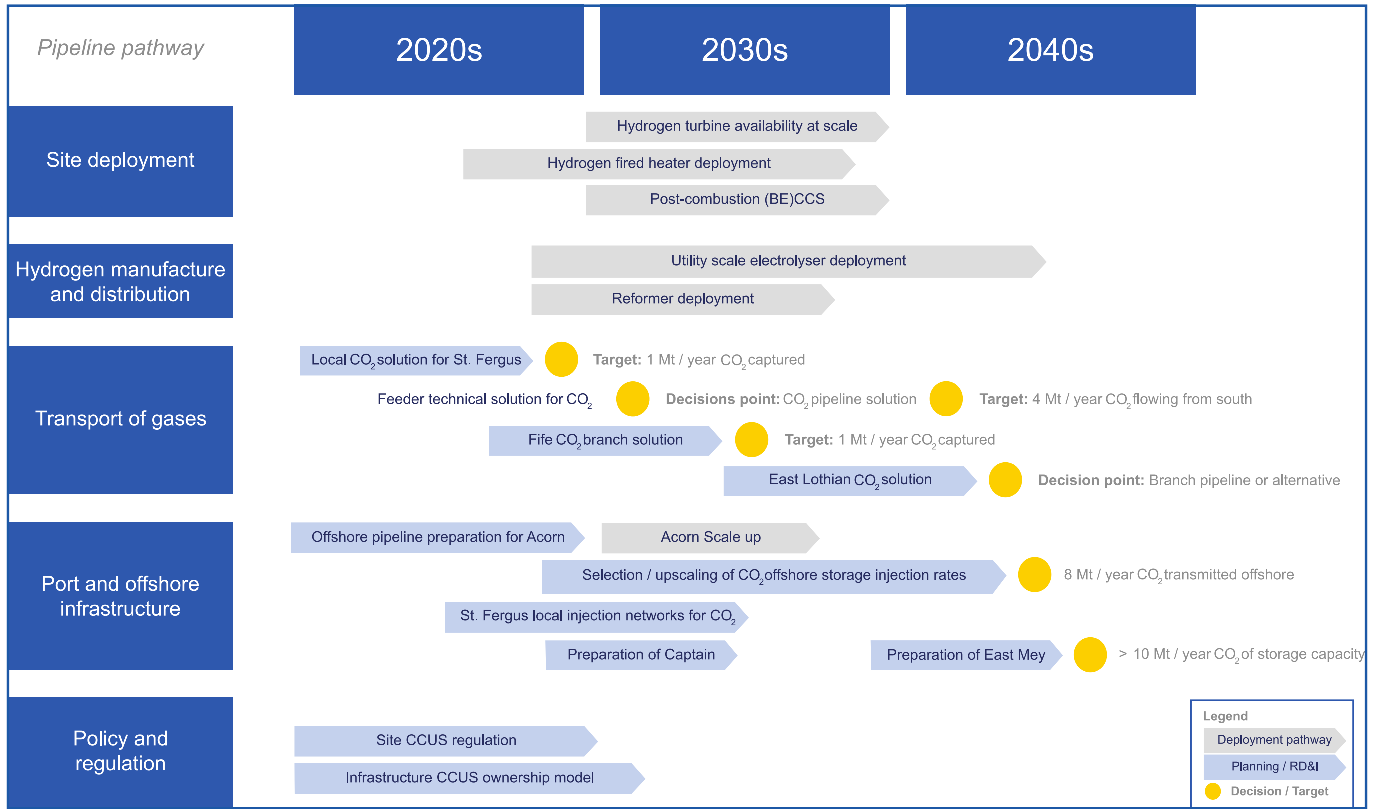


Figure 18: Roadmap for Branch 1 - Pipelines and Hydrogen

4.3.1.2 Influences on Branch 1 Roadmap

Key influences on this branch of the roadmap are:

1. **Slow progress or failure to develop pipeline or offshore storage solutions for captured CO_2.** Without CO_2 transport and storage, many of the options available at industrial sites are eliminated. Furthermore, offsets of industrial emissions via BECCS or DACCS can no longer be progressed within Scotland, with the only options to net-off emissions being nature-based. A more modest slow progression, leading to capture rates of less than 90% or later capture availability will delay emissions abatement and require greater emission removal activity later in the pathway.

2. **Insufficient progress in global development in lowest TRL hydrogen solutions.** Without hydrogen end-use and manufacture options available (e.g. hydrogen-fired turbines at various scales), the options for such processes will be limited to electrification and CCS. The relative lifetime expense of electric solutions fed by imported power, combined with network reinforcement challenges, is likely to delay some decarbonisation interventions and offer business case challenges for affected industrial sites. Interventions with carbon capture may require collection of comparatively small volumes of CO_2 emitted from dispersed sites, leading to network challenges and additional expense.

3. **Inadequate business, policy or regulatory environment for CO_2 removal.** Other than for some initial projects, CO_2 removal infrastructure is required for multiple emitters and decisions that industrial sites take will need to be cognisant of the realistic set of options available at investment time. An appropriate financial model for common infrastructure must be in place such that industry can decide whether CO2 capture is an appropriate solution in each case without causing detriment to business.

4. **Inadequate business cases for hydrogen manufacture and equipment switching** In most of our scenarios manufactured hydrogen is distributed beyond the immediate neighbours of the manufacturing site and into local or national networks. This requires coordination between producers and end-users. A wider strategy for hydrogen beyond the industrial sector will inform any network plans and potentially enhance business cases for hydrogen manufacture.

4.3.1.3 Branch 2: Shipping and Electrification

The roadmap for this branch can be presented as follows:

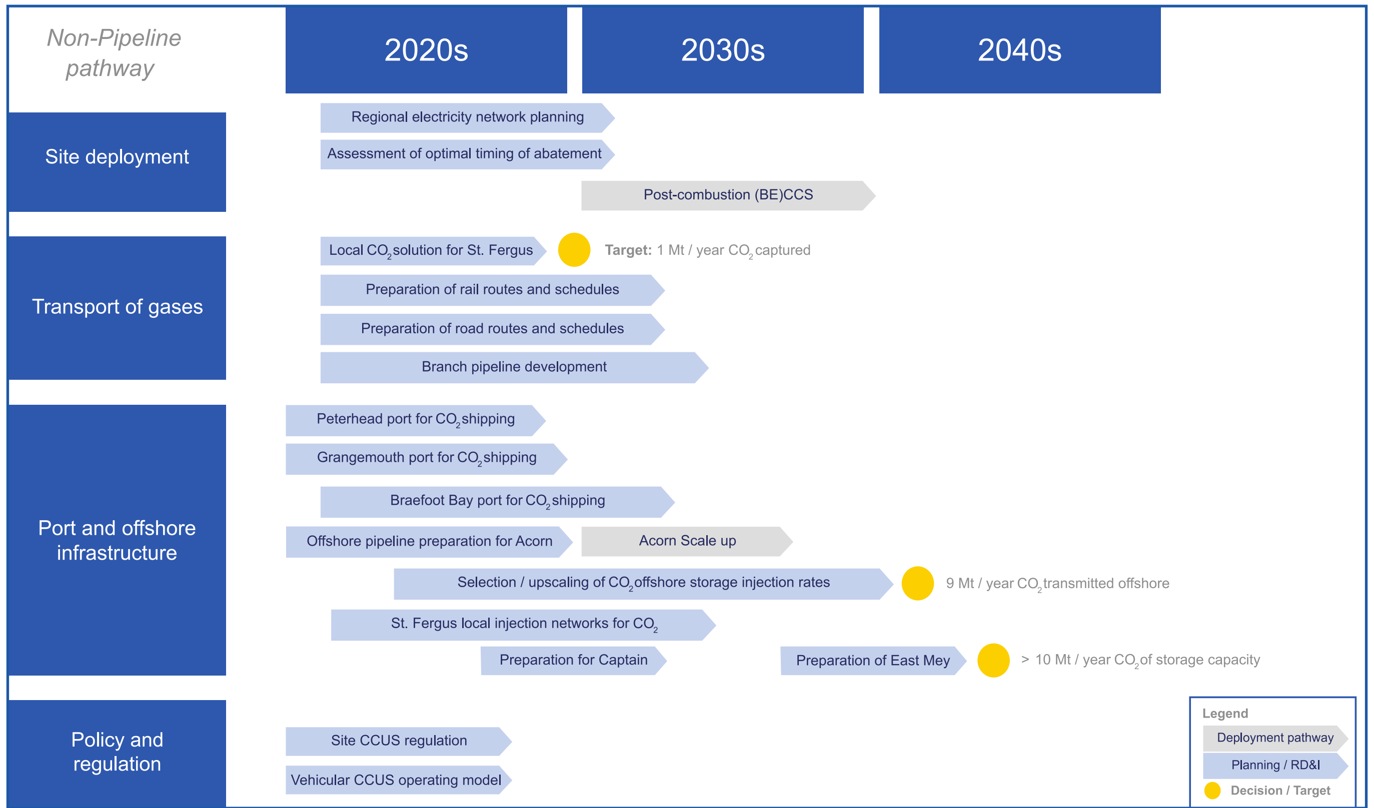


Figure 19: Roadmap for Branch 2 - Shipping and Electrification

4.3.1.4 Influences on Branch 2 Roadmap

Key influences on this branch of the roadmap are:

1. **Port and infrastructure owner emphasis on CO_2 removal.** For this branch to be followed, rapid development of shipping solutions at the three main ports – Peterhead, Grangemouth and (potentially) Braefoot Bay – is required. This requires an investable case for port development to enable removal of CO_2, including dock development, buffer storage and shipping schedules. As other industrial clusters and emitters have a less direct link to suitable offshore storage, opportunities for ports in Scotland may be greatly enhanced by wider potential business outside of the scope of SNZR.

2. **Business models for vehicular movements of CO_2.** For a pathway without extensive pipeline CO_2 networks, vehicular movement of captured emissions is necessary. Providing motivation for development of rail and road routes, and ensuring policy permits appropriate attribution of emissions removals, is necessary before a site would elect to install capture equipment without a pipeline route to storage.

3. **Lead time for electricity network development**. To retain a degree of optionality (albeit less than is present within a roadmap underpinned by gas pipelines), equipment electrification may be appealing, although electricity prices may be initially prohibitive for sites predominantly fuelled by natural gas. Specific challenges for local network reinforcement have not been explored substantively as part of SNZR, although electrification interventions have been modestly delayed to account for expected challenges. Further investigation of the viability of electrification for individual sites, with the possibility of linking into any broader local area energy plans available or underway in regions of Scotland, will help better understand the true business cases for electrification.

4. **Understanding of real-world operating performance of vehicular CO_2 removal**. Based upon the concept engineering study carried out as part of SNZR, fugitive emissions associated with vehicular CO_2 removal are relatively low (albeit substantial in 2045 when most emissions have been eliminated). This is yet to be proved practically and thus innovation activity is required to demonstrate that lifecycle CO_2 emissions from this removal route are as projected and at reasonable cost.

4.4 Action Plan

Based on the evidence presented above, particularly the roadmap, an action plan for development of the necessary collateral to enable industrial decarbonisation has been prepared. This action plan addresses infrastructure requirements, policy and support incentives and overall co-ordination of the roadmap recommendations. Overall co-ordination of activities is critical as decision on investment by both industrial emitters and infrastructure owners are mutually dependent, as well as being influenced by the policy and support landscape.

4.5 Cluster Level Techo-Economic Analysis Study

The nature and extent of potential economic impacts for the cluster under the different scenarios described in Figure 8 have been assessed. It is estimated that supporting the cluster of emitters included in this study to achieve net zero could support an average of 5,000 jobs between 2023-2045, comprising 2,800 direct jobs, 1,400 indirect jobs and 1,000 induced jobs, delivering an economic impact of £21 billion.

4.5.1 Scottish and UK Policies that can Support Scottish Industrial Decarbonisation

Scottish policies driving current and future industrial decarbonisation are primarily the Climate Change Plan update, the Hydrogen Action Plan, and the Draft Energy Strategy and Just Transition Plan. Support is commonly provided through grant capital funding, but can also take the form of developing skills/training opportunities, outlining priorities and/or targets for generation of renewable electricity, and developing and strengthening hydrogen production and use markets. UK-wide industrial decarbonisation is driven through a combination of policies and business models:

- The UK emissions trading scheme is a ‘cap and trade’ system, where certain GHG emissions that eligible sectors can emit are capped. As the allowable GHG emissions to be emitted decrease with time, decarbonisation options become increasingly more attractive.
- UK policy support is primarily provided through the Cluster Sequencing Process, in which UK industrial clusters, formed around shared transport and storage (T&S) infrastructure, compete for funding provided through a variety of business models tailored to each industrial activity.
  - Revenue guarantees for Industrial CCS, dispatchable Power CCUS, low carbon hydrogen and (possibly) GGRs are all provided through contracts for difference (CfD).
  - T&S infrastructure will be likely supported through regulated asset base (RAB) models provided for both CO_2 and hydrogen.

4.5.2 Scottish/UK Potential Policy Interactions with SNZR Investment Scenarios: Conclusions and Recommendations

The suitability of the above policies and business models were examined against the proposed SNZR investment scenarios, to determine opportunities to maximise investment potential, from both a policymaking and private sector perspective. The following key conclusions were made:

- 2025 – 2035 is likely to be a key investment period to maximise UK Gov subsidy opportunities.
- More targeted support from the UK (business models) or Scottish Government (SG) (grant funding) could be considered for dispersed sites and non-piped transport solutions.
- Timing of investment in the SNZR scenarios varies widely, and an accelerated sequencing process (particularly for those scenarios with earliest investment) would enable Scottish industries to maximise the support provided by the maturing business models.
- Scenarios feature (to varying extents) the use of hydrogen in industry. To provide further certainty on hydrogen demand volumes, planned investment in hydrogen production capacity could be complemented with additional demand-side policies and/or support (e.g., such as investment in industrial end-use applications).
- Scenarios also feature (to varying extents) electrification of industry. UK Gov could further support electrification to encourage private sector funding in decarbonisation technologies that can utilise Scotland’s extensive renewable power capacity.
- Government ambitions with respect to CCS in the power sector are “at least one” Power CCUS station by the mid-2020s. Further support to come for subsequent projects, beyond those shortlisted in Track-1, is unclear. Peterhead Power Station will likely act as a key dispatchable generator for the Scottish Cluster, and continued support beyond Track-1 projects will likely encourage the CCS investment needed in the Power Station.
- Bioenergy with CCS (BECCS) is likely to be a key decarbonisation lever and means to achieve Scottish NETs 2032 ambitions, as well as GGR. Energy from waste (EfW) investment could also be targeted prior to 2032 to maximise BEIS funding opportunities.
- Timing of investment in transport and storage (T&S) infrastructure should be aligned with CCUS and hydrogen project investment, to ensure cross-cluster collaboration enables connectivity where it is needed.

4.5.3 Economic Impact Analysis Conclusions

The main goal of the macroeconomic impact assessment exercise was to provide an economic impact analysis of the expenditures invested into the decarbonisation of the major emitters in Scotland under different scenarios. Three main economic indicators were explored in detail, namely gross output (GDP), gross value added (GVA) and employment.

To assess the macroeconomic impacts, an input-output led approach was applied. The analysis relies upon static input-output tables for Scotland. The input-output table shows interlinkages between sectors (i.e., supply chains), and how these combine to meet final demand for industrial output. The approach requires inputs in the form of estimates of additional investment (in technology and infrastructure) and operational expenditure for each year of analysis. These additional investment and expenditure are then mapped to economic sectors where the direct, indirect, and induced effects can be estimated. Their interpretations are as follow:

- Direct impacts are the additional outputs from the sectors which experience the additional expenditure;
- Indirect impacts are those impacts felt upstream through supply chains;
- Induced impacts involve further positive economic impacts resulting from more spending in the economy (coming from wages paid to workers because of the direct and indirect impacts).

The magnitude of impacts is greatest in the CO2 shipping scenario and is smallest in the Soft Start scenario. This outcome is driven by the volume and timing of investment (i.e., in case of Soft Start, CAPEX costs occur later, when technologies can be considered more mature, and therefore, OPEX costs are lower). Conversely, economic impacts occur earlier in scenarios with greater upfront costs, namely the CO2 shipping, H2 economy and local H2 economy scenarios, while impacts are delayed in the Renewable Push and Soft Start scenarios.

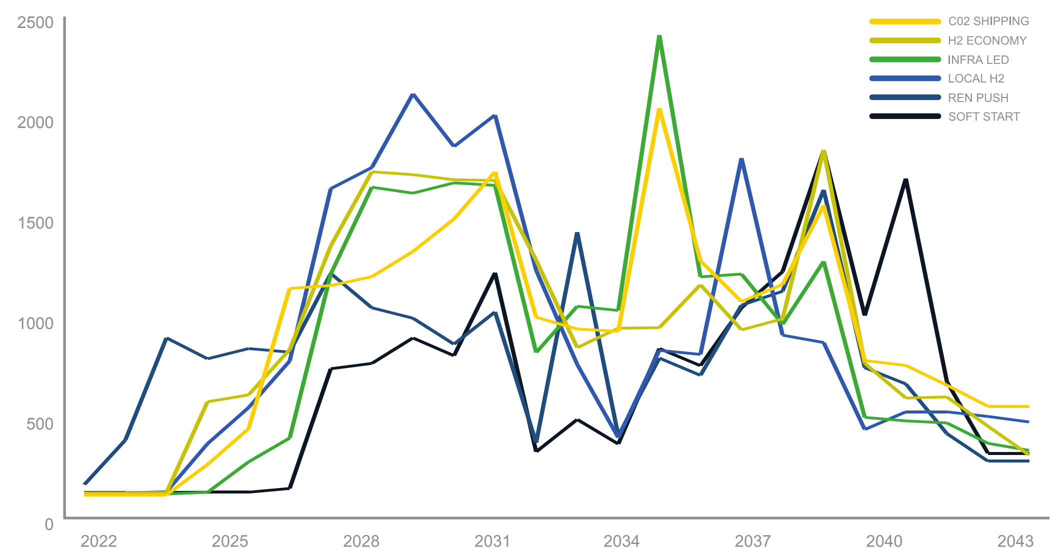


Figure 20: Type II (direct, indirect and induced jointly) GDP impacts in different scenarios between 2022-2045 (in million GDP). Source: Cambridge Econometrics' own calculation

The different scenarios are expected to create an average of 4-6,000 jobs per year, although the profile of employment created over time varies depending upon the profile of capital and operating expenditures. Employment impacts are expected to peak when capital expenditures do likewise, as the investments create jobs across the manufacturing and construction sectors; for example, in the Infrastructure led scenario, total job creation peaks at 12,800 in 2036, and 10,000 of these jobs are linked to capital expenditure in this year, while 2,800 are linked to operations expenditures.

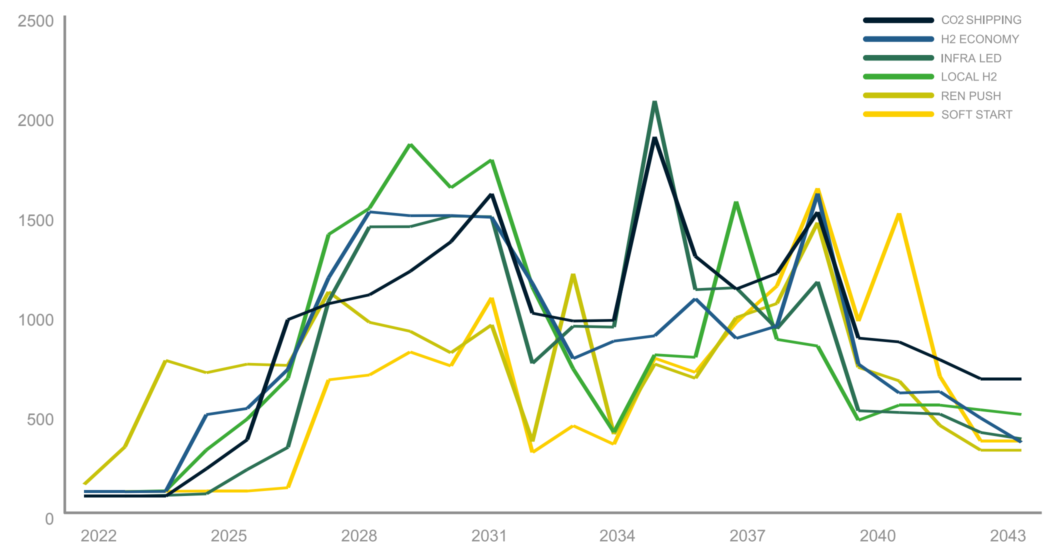


Figure 21: Type II (direct, indirect and induced jointly) employment impacts in different scenarios between 2022-2045 (in full time equivalents). Source: Cambridge Econometrics' own calculation

4.6 Risk Analysis

Several potential risks have been identified that could adversely affect the deployment of the road map. The top five risks are presented along with mitigating actions that can be taken to eliminate or minimise their impact.

1. **Lack of policy support and stability of regulations.**
   Both regulatory and financial policy must be set up to support industrial decarbonisation. This requires that policy supports industries looking to decarbonise in order to prevent offshoring of jobs. It must also encourage them to decarbonise as quickly as possible. Finding the appropriate balance between support and regulation will require further investigation.

2. **Lack of available infrastructure.**
   With many of the scenarios depending on the deployment of an existing pipeline for carbon transport, even though there are contingency scenarios within the roadmap, it is still critically important that infrastructure development is prioritised.

3. **Changes in the market for CCUS.**
   It is difficult to safeguard against swings in the market demand for CCUS as this is largely dependent upon the market conditions of the customers for a CCUS network. The main mitigation that can be undertaken is to ensure that effective financial and policy support is in place as discussed in point 1.

4. **Lack of available workforce to complete required work.**
   Research undertaken within the study has highlighted the potential lack of workforce, skills and expertise to meet demand to deliver infrastructure. Roles affected are in construction, civil engineering and welding. To mitigate this, early engagement with training organisations and Further Education institutions may ensure that a skilled workforce is readily available when projects commence.

5. **Lack of mechanisms to transition into deployment.**
   There is no mechanism in the roadmap to ensure a transition into a deployment phase for the recommendations. It is critical that the roadmap is not left 'on the shelf' but is developed into practical and tangible projects that help to deliver Scotland's net zero targets.

Action	Activities	Target Outcome(s)	Timescale	Lead Organisation(s)	Support Organisation(s)	Dependencies	Priority
Establish leadership and ownership of the roadmap and allocate responsibility for implementation	Continue discussions with key stakeholders to agree consensus way forward	Identified leadership for roadmap implementation Further development of roadmap implementation A regular co-ordination forum for key stakeholders	By the end of 2023 Ongoing action thereafter	NECCUS Scottish Government	Other SNZR partners	Funding	High
Help catalyse the initial focal point	Support Acorn activities in the North East	Local carbon capture and transport in the North East Initial offshore transport and storage implementation	Offshore transport and storage available by 2027	Storegga	Shell Harbour Energy North Sea Midstream Partners	UK Government funding Scottish Government support	High
A decision on investment in CO_2 pipe-line infrastructure	Completion of relevant engineering and financial analysis	Decision to repurpose existing pipeline Strategy for implementing local pipeline connections Proposal for financial model for common infrastructure	Online by late 2026 (assuming repurposed pipeline)	National Gas Transmission	Major Emitters	CCUS business model implementation Viable business cases can be made	High
Investment decisions on hydrogen transport and supply	Plans implemented for H_2 manufacturing Plans for national and regional H_2 pipeline infrastrucutre established	Over 20 TWh of H_2 available Regional and national H_2 pipeline infrastructure set-up linking hydrogen supply to users	Both available by 2030	Exxon National Gas Transmission SGN	Storegga Ineos Exxon/Shell	Hydrogen business model implemented Viable business cases can be made	High
CO_2 shipping proposition developed *Note: Could complement pipeline transport but only required at scale if there is no pipeline infrastructure*	Development of a strategy and business case for shipping hubs and local support options	Viable business case Investment in developing required infrastructure	Business case by the end of 2023 Shipping operations from 2027	Forth Ports Peterhead Port Exxon/Shell National Rail Rail operating companies		Scale of need dependent on decision on CO_2 pipeline development Funding	Medium
Investment decision on DACCS	Development of a business case for 500,000 tonne facility	Viable business case Investment in developing required infrastructure	Business case by the end of 2023 Facility operational from 2027	Storegga Carbon Engineering Carbon Capture Scotland		External Funding	High

Figure 22: Industrial Decarbonisation Action Plan

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

A roadmap for decarbonisation of the Scottish industrial cluster will require concerted and timely action from a range of stakeholder groups, particularly industrial emitters, infrastructure developers and owners and regulatory bodies. It is critical that each stakeholder group makes and implements decisions on timescales that allows other to do the same.

Key actions to deliver net zero for the cluster are:

- Establish ownership and leadership of roadmap implementation.
- Develop and operate a co-ordination mechanism to ensure all stakeholder groups are engaged and committed to delivery of the roadmap.
- Support Acorn activities in the North East to establish an initial focal point for the roadmap.
- Investment in CO_2 pipeline infrastructure to support the cluster.
- Investment in hydrogen manufacturing, transport and supply, linking developing hydrogen manufacturing capacity with industrial users.
- Investment in DACCS capacity of at least 500,000 tonne per annum capacity.

These actions are predicated on the availability of appropriate incentives for industry, such as the CCUS and Hydrogen business models highlighted earlier in this document.

In combination, these actions will deliver net zero and they need to be pursued in an integrated manner. As highlighted above, this requires a cohesive approach where industry, infrastructure owners, government and regulators work together to deliver the roadmap.

Further, these actions will support other companies to pursue net zero, based on the evidence developed in this work and the resultant infrastructure that will be available.

Analysis carried out for this project indicates that the optimal roadmap to industrial decarbonisation should be based on pipeline solutions for removal of CO_2 and, potentially, hydrogen supply. Alternative pathways to net zero that could be pursued have been identified and considered, but each is less optimal in terms of risk, cost, time to net zero, and overall emissions during the period to 2045. We have considered one alternative pathway in detail in this analysis, based on CO_2 shipping and electrification, to demonstrate that there are alternative, but less attractive routes to net zero if required. If this route was to be pursued investment in CO_2 shipping hubs and local transport options would be required.

The total cost of the actions for the preferred pipeline based roadmap is estimated at between £6 and £9 billion. This is a significant challenge for the cluster to deliver, but also a massive business opportunity for local supply chains. It is estimated that supporting the cluster of emitters included in this study to achieve net zero could support an average of 5,000 jobs between 2023-2045, comprising 2,800 direct jobs, 1,400 indirect jobs and 1,000 induced jobs, delivering an economic impact of £21 billion.

5.2 Recommendations

Based on the work carried out in this study it is recommended that the action plan, as detailed in *Figure 22* is implemented without delay. Specific short-term recommendations are:

- Leadership and ownership of the roadmap is developed and established. It is noted that NECCUS is already in discussions with the Scottish Government regarding this recommendation.
- Support is committed to drive forward the Acorn project as an initial focal point for Net Zero cluster and infrastructure development.
- There is ongoing, regular engagement and structured discussion with key stakeholders (industrial emitters, infrastructure developers and owners, government and regulatory bodies) to ensure that there is a cohesive way forward and that early actions are implemented.
- The organisations responsible for each action commit to pursue actions in a timely manner and update other key stakeholders on key decisions and progress.

NECCUS would like to thank all contributors to the SNZR Project for their significant efforts in delivering this outcome and report:

UKRI, SNZR Project Partners, SNZR Project Funders, Steering Committee members, Infrastructure Group, Emitters Forum, Scottish Government, Scottish Enterprise, Launch Event Sponsor: Crown Estate Scotland, The Marketing Department and all other providers of advice and support.

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17 The Scottish Government's near-ban on waste being sent to landfill by 2025 influenced the decision to remove 4 landfill sites that would have qualified for inclusion based on all other criteria. The upcoming landfill ban coincides with an increase in the number of operational Energy-from-Waste (EfW) plants. With more EfW plants either under construction or in planning, these were prioritised for inclusion over soon-to-be-phased-out landfill sites. See: https://www.gov.scot/policies/managing-waste/

18 Applying NAEI sector categories. See: https://naei.beis.gov.uk/data/map-large-source

19 There are 14 local authorities in the cluster: emitters are spread across 12 local authorities; Angus and Perth & Kinross are included as the NTS Feeder 10 pipeline traverses those areas.

20 Site-level direct (Scope 1[5]) emissions data was retrieved from the Scottish Environment Protection Agency (SEPA) Scottish Pollutant Release Inventory (SPRI) dataset [5] for 2019, published in March 2020. See: https://www.sepa.org.uk/environment/environmental-data/spri/

21 Four EfW plants currently under construction and with modelled operational start dates of between 2023-2026 were included.

22 Estimated based on industrial need identified in this project and the potential domestic demand, based on work by SGN (North East Network & Industrial Cluster Development – Summary Report, November 2021)

23 Based on published employment data and sectoral GVA per employee data published in Scottish Annual Business Statistics, 2020 (https://www.gov.scot/publications/scottish-annual-business-statistics-2020/documents/)

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27 Developments with an annual total release of 26ktCO2/yr or above were deemed as 'significant', 26kt/yr being the annual total release for the smallest of the SNZR 28 sites, the National Grid North Sea Gas Terminal at Peterhead. In practice, the smallest development that was incorporated had an annual total release of 90ktCO2.

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36 CO2 emissions produced or brought about by living organisms.

37 Biogenic CO2 emissions were assessed from a baseline year of 2021, to allow incorporation of up-to-date information. 2045 is Scotland's target year for achieving net zero.

38 Biomethane to grid (BtG)

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