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Promoting project progression:

Creating a pipeline for industrial decarbonisation in Scotland

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1. Executive summary

In 2019, Scotland committed to achieving net-zero greenhouse gas emissions by 2045, in line with the UK Committee on Climate Change (CCC) recommendations. This commitment will require the decarbonisation of all sectors, including industry. To address decarbonisation in industry, initial targets up to 2032 were established in the 2018 Climate Change Plan (CCP)[1]. In addition to these targets, energy efficiency is a core priority in the Scottish national agenda and is clearly outlined in the Energy Efficient Scotland route map to 2040[2]. The route map makes a clear commitment to work in collaboration with energy-intensive industries (EIIs), to provide incentives for operations to become more energy efficient or to decarbonise, and to address the specific needs of industry.

In line with these commitments, the Scottish Government is working to create the right conditions to support investment in industrial decarbonisation. Such conditions require the reduction of industrial emissions while maintaining a competitive and healthy industrial sector, where decarbonisation is not achieved at the expense of loss of output, jobs or skills. In particular, the ambitious Scottish Government agenda for decarbonisation aims to minimise 'carbon leakage', when production is moved to other countries with laxer emissions controls.

This research aims to establish and develop a greater understanding of industrial decarbonisation projects in Scottish EIIs, to catalogue the pipeline of such projects, and identify overarching decarbonisation themes.

[1] CLIMATE CHANGE PLAN (2018): The Third Report on Proposals and Policies 2018-2032. The report provides proposals for policies up to 2032, including a trajectory to reduce industrial emissions by 21% (or 2.2 $MtCO_2e$) relative to 2015 over the plan's lifetime (2018-2032). The Scottish Government was planning to issue an update to the climate change plan in April 2020 to reflect the 2045 net zero target for Scotland. However, this update is currently delayed due to the unprecedented health and economic implications of the COVID-19 pandemic.
[2] Energy Efficient Scotland : Route map report

It also aims to assess how projects are likely to develop over a 10-year timescale. Barriers, enablers and gaps in industrial decarbonisation in the listed themes are identified through understanding how decarbonisation technologies are adopted in Scotland, based on stakeholder engagement. The final objective is to inform the most likely development pathways and gauge the influence of external factors on optimal project sequencing.

Overarching themes for industrial decarbonisation in Scotland

1. Energy Efficiency (industrial processes and other measures)

Applying various energy efficiency measures can have a significant contribution to reducing energy costs, increasing the resilience and competitiveness of industries against fluctuating energy prices; and making a significant contribution to the decarbonisation agenda in Scotland.

2. Process Change and Resource Efficiency

Utilising products and resources responsibly throughout the wider systems and product value-chains can reduce scope 3 emissions*. This is achieved through the re-use of waste products, waste heat recovery and use of low-grade heat in district heating.

3. Fuel Switching – Hydrogen, Biomass and Electrification

Replacing the use of fossil fuels by clean hydrogen, biomass or electricity in industrial heating processes can lead to reductions in emissions. Fuel switching to either of these fuels will depend on the characteristics of the process.

4. Carbon Capture Utilisation and Storage (CCUS)

CCUS is used to capture and safely store CO_2 emissions from power, hydrogen production or other large-scale energy intensive processes. Alternatively, the captured CO_2 can be used as feedstock for other processes.

5. Regional Projects – indirect impact on industrial decarbonisation

Regional projects are primarily focused on the domestic or commercial sectors but can grow to include other high-demand sectors such as industry. Regional projects are usually whole energy system projects or 'energy islands'. They can help promote certain technology concepts – like hydrogen production from renewable energy – or build infrastructure which will contribute indirectly to EII decarbonisation.

Infrastructure Projects - the underpinning pillar for enabling industrial decarbonisation projects

Developing a full-chain decarbonisation infrastructure and creation of industrial clusters are two key enablers to drive energy and cost savings. Infrastructure projects represent an opportunity to deliver wide-scale decarbonisation with significant impact in sectors like the chemicals sector, where, for instance, fuel switching to hydrogen is tied to the availability of its production, transport and CCS availability. In addition, CCS use in industrial clusters will enable sharing of transport and storage costs amongst different players.

*Scope 3 emissions are not directly emitted by an organisation but result from processes needed to support the organisation's activities, e.g. employers commuting by car to offices.

Industrial decarbonisation in Scotland is differentiated into five major themes

The broad range of industrial subsectors in Scotland means that industrial decarbonisation projects will be widely varied, in terms of scope, level of decarbonisation achieved, and costs. However, projects can be grouped into five major industrial decarbonisation themes: energy efficiency; process change and resource efficiency; fuel switching to hydrogen, biomass or electricity; carbon capture, utilisation and storage (CCUS); and regional, residential and commercial projects (see boxes above). Infrastructure projects are also considered as a theme for industrial decarbonisation, but are considered cross-cutting because they can target multiple major themes at once.

Barriers for a Scotland-wide industrial decarbonisation continue to exist

Engagement with Scottish industry stakeholders, trade associations and sites helped this research to understand the concerns, priorities and thoughts which define, to an extent, the Scottish landscape for industrial decarbonisation.

Economic barriers. The principal barrier to industrial decarbonisation are the long or non-existent paybacks on any commercial investment in projects in the short-to-medium term. Low rates of return often disadvantage energy-efficiency projects in comparison to other investment opportunities, while deeper decarbonisation measures generally increase running costs as a result of more expensive fuels. In the absence of sufficient economic support, investment and project development will simply not arise. In addition, projects which rely on long-term funding mechanisms often experience increased risk premiums due to uncertainties over future availability or due to the requirements to demonstrate continuous project compliance with the agreed-upon funding criteria.

Infrastructure barriers. Infrastructure constraints need a coordinated approach between public and private sectors (infrastructure providers and industry) to drive development, which often requires complex permitting approvals. Commercial sites are usually reluctant to change their traditional equipment and ways of operation with the current level of uncertainty around low-carbon alternatives. For instance, projects investigating hydrogen fuel switching could be delayed due to lack of clarity about hydrogen supply and transport infrastructure.

Political barriers. Strength of political will, decision making and leadership are needed to overcome the challenges of decarbonisation. Many of these projects are a matter of national strategy, which needs to be decided at the highest levels of government before projects can go ahead and funding/business models become available. In addition, changing regulations related to decarbonisation incentives have discouraged many sites from applying to schemes, especially in relation to small-scale decentralised generation from renewable sources. In addition, modifications made to ongoing scheme requirements have caused difficulties for certain energy projects to continue to comply.

Making decarbonisation profitable is the key enabler to successful project development

The low or non-existent payback for industrial decarbonisation can be overcome through making it in industrial sites' interest to decarbonise, however; there is no straightforward solution that can fit all industries. While ongoing economic support for decarbonisation via a number of funding streams is an important lever, other levers could also be deployed to encourage industrial decarbonisation, such as carbon border adjustments, low-cost finance mechanisms,

or encouraging demand for low-carbon products. These other levers can reduce the amount of direct economic support which is necessary. However, different sectors and project types are best supported in different ways, necessitating a flexible approach.

While private sector participation in the development of industrial clusters is critical, government policy and direction remain essential for initial momentum. Government can take the longer-term view, drive the initial development, and create the right regulations to mediate between different interests and set a level playing field for decarbonisation.

Access to the correct information - such as necessary documentation, or any anticipated changes or updates to schemes - around decarbonisation and the available support is key to promoting project development. Supporting those sites without the necessary expertise, and creating a 'one-stop-shop' portal to host the required information, brings greater visibility to industrial decarbonisation options.

Cross-industry collaboration is important to enable the large-scale infrastructure development required to enable industrial decarbonisation. Bringing different industries together to leverage opportunities for shared infrastructure can be done through industrial alliances, ensuring transparent communication and trust between government and the private sector.

Multiple factors determine the likely development of the industrial decarbonisation pipeline

The future development of Scottish industrial decarbonisation projects identified within this study is highly project specific. However, their development is influenced by a number of factors:

Current project stage. Projects further from implementation are more responsive to changes in the environment and policy support available, whereas projects likely to be implemented in the short term are expected to have extensive planning in place.

Project scale. Small projects are more agile and their planning is more responsive. In contrast, large projects can be composed of multiple stages and can thus result in slower progression.

Project type. Energy efficiency projects are not generally contingent on ongoing support, whereas deep decarbonisation projects can be. Without some form of financial support, some deep decarbonisation projects can lack a commercial imperative to progress.

Available economic support. The identified pathway to net zero would inevitably prioritise some technologies and themes over others, and this could have a significant effect on project development and progression.

Different major themes are more prominent at different pipeline stages

Project sequencing and the possible development of the pipeline in the short-to-medium term is highly uncertain. However, there are overarching motifs which run through the projects identified:

Energy efficiency. Energy efficiency measures are continuous and ongoing, with many of the 'low-hanging fruit' already implemented. The economic case for these projects change continuously with fuel costs. An important synergy is that fuel switching, which often results in higher fuel costs, can improve the economic case for efficiency projects.

Process change and resource efficiency. Similar to energy efficiency measures, process change and resource efficiency projects are continuous and ongoing. However, these measures

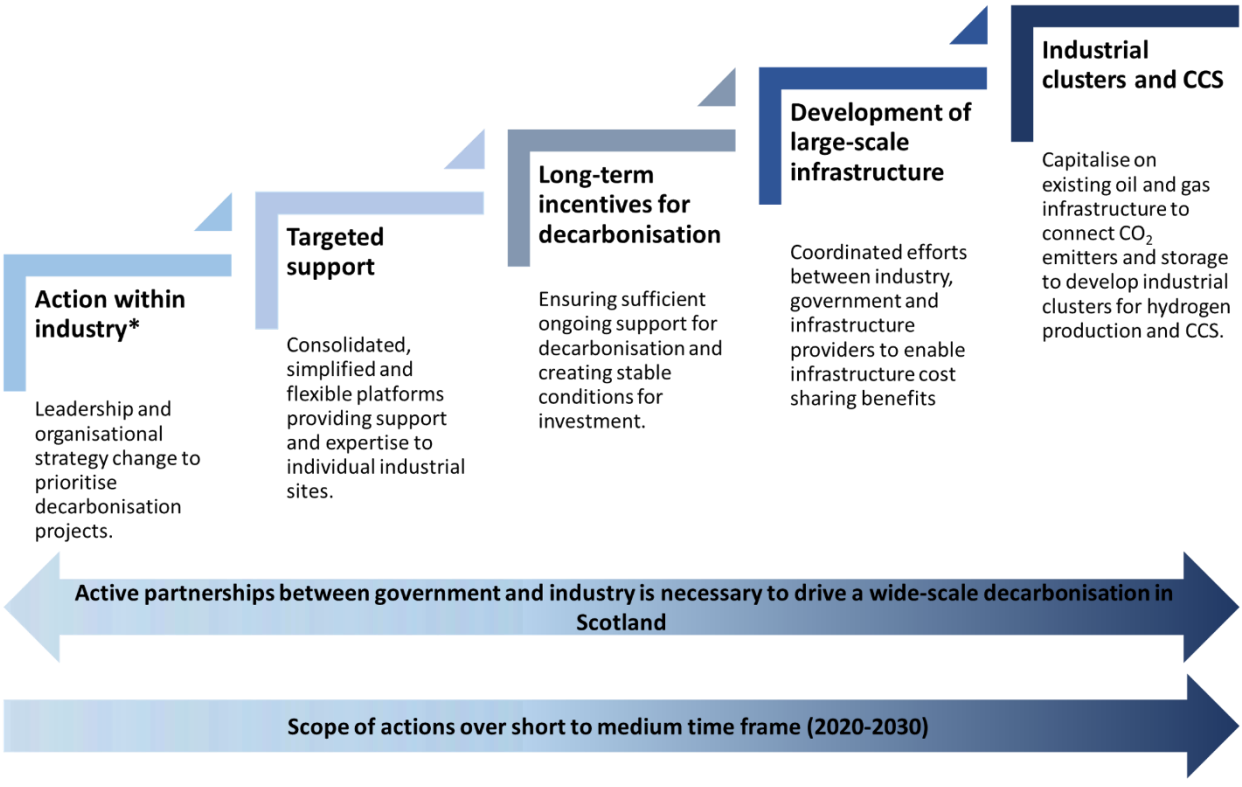
present the opportunity for a wide collaboration among industries to share resources, and so the likely development of new measures depends on collaboration.

Fuel switching. In fuel switching, hydrogen and large electrification projects are generally at a lower stage of development, while biomass and partial electrification are generally implementable sooner. Some fuel-switching projects, especially hydrogen, are wholly dependent on large-scale infrastructure projects, therefore requiring careful cooperation between industrial sites and external stakeholders such as local authorities for a decarbonisation pathway to be realised.

CCUS has been particularly affected by previous withdrawal of incentives, with projects cancelled or delayed. There are significant lead times associated with implementing these projects. However, as the only option to fully decarbonise key sectors, such as refining, without industry closures or radical process change, it is imperative that these projects continue to progress.

Regional and infrastructure projects are important keystones to many of the deeper decarbonisation projects, and delays or cancellations have in the past led to sites being unable to decarbonise.

The way forward: a suggested framework for supporting the pipeline of projects



*Due to COVID-19 outbreak, it might be economically challenging for industry to prioritise decarbonisation projects in the shorter term

Figure 1-1: A suggested framework to address key barriers to industrial decarbonisation

The figure above includes a framework which defines the government and industry actions needed and the scope of actions in the short-to-medium term which could help achieve decarbonisation in the different identified themes.

Key recommendations for the short and medium term to enable project development

Recommendations on specific measures to be considered during the development pathway have been highlighted through the report. These are summarised and collated into six key recommendations for action for the short and medium term below:

Short term: These recommendations should be considered for adoption in the short term, as their function is to shape ongoing work on funding and support programmes, and raise awareness at an enterprise level for industrial decarbonisation.

- **Recommendation 1:** The creation of a single portal through which Scottish industrial sites can access all funding schemes, supporting documents and guidelines. Sites need high-quality advice and support to minimise the lack of capacity which currently exists to work through the complexities of the policy and funding landscape. Such a portal could also reduce any potential gap in competencies or experience which industries seeking to decarbonise may have, especially small and medium enterprises (SMEs).
- **Recommendation 2:** In the private sector, adapting business and corporate strategies to emphasise energy efficiency, decarbonisation, and sustainability programmes is a key goal. Influencing key executives and ensuring these programmes play an integral role in future business competitiveness will encourage business leaders to prioritise them.
- **Recommendation 3:** Funding programmes and any other financial mechanisms which are developed should be flexible enough to ensure they account for the specific contexts and issues of each applicable industrial sector. This might involve providing sector-specific rather than theme-specific funding to ensure synergies between themes are integral to the design.

Medium term: These require considerable preparation and cross-collaboration between industry, the government and other stakeholders as well as additional studies to better understand the socioeconomic implications of these major recommendations.

- **Recommendation 4:** Implementation of a business model within a supportive economic framework to reduce the ongoing costs experienced by industrial decarbonisation projects in Scotland. While this is likely to fall somewhat under the UK government, Scottish Government needs to ensure that this is fit for purpose in the Scottish specific context and that costs are flexibly socialised between private and public sectors where appropriate.
- **Recommendation 5:** A collaborative approach to technology and project development across Scottish (and wider UK) industry. Coordinating the effort between companies in a way that does not impact upon their individual competitiveness can achieve synergies and maximise the ‘learning by doing’ achieved in projects. Collaboration, which can be done in the form of industrial or public-private partnerships, also aids with project sequencing, ensuring a smoother transition to net zero.

- **Recommendation 6:** Specific focus should be paid to deeper decarbonisation projects (and the large-scale infrastructure projects necessary to enable these) as their success is critical to meeting net-zero targets while retaining Scottish industry. To achieve these, ongoing economic support for these projects must reach the critical level and be guaranteed over a long time period.

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- Scotch Whisky Association
- British Glass
- INEOS Grangemouth
- Petroineos
- Liberty Steel UK
- Liberty Steel Dalzell
- Dunbar Cement Plant
- Mineral Products Association
- NECCUS
- EGGER Barony
- Highlands and Islands Enterprise
- Confederation of Paper Industries
- Chemical Industries Association
- Zero Waste Scotland

Note on terminology

Whilst Carbon Capture, Utilisation, and Storage (CCUS) and Carbon Capture and Storage (CCS) are used almost interchangeably in the literature, for consistency purposes, this report only uses CCUS, with an exception when CCS is used directly in the cited sources.

Contents

2. Introduction

This chapter provides an overview of the study context and how it fits within the vision for industrial decarbonisation in Scotland. It discusses the economic opportunity for industrial decarbonisation within the eight main energy-intensive Industries (EIIs) in Scotland and provides a high-level summary of each industrial sector.

2.1 Context and project scope

In 2019, the Scottish Parliament passed legislation committing Scotland to achieving net-zero greenhouse gas emissions by 2045, a target that requires substantial investment in industrial decarbonisation, among other segments of the economy. A supportive policy and funding environment would enable businesses to deploy resources for decarbonisation while still delivering growth and prosperity. To develop an appropriate policy and funding framework, the Scottish Government requires a deeper understanding of the wide range of projects supporting industrial decarbonisation.

This study aims to understand the reality of industrial decarbonisation projects in Scotland, cataloguing ongoing industrial decarbonisation projects in a database for the Scottish Government, organised by sector, location and decarbonisation technology. The improved knowledge base would allow the Scottish Government to promote project progression of current and future industrial decarbonisation projects and to create a closer partnership with industry.

This study was composed of two phases:

- **Phase 1** aims to identify and catalogue the pipeline of industrial decarbonisation projects in Scotland that are currently in development, identifying overarching decarbonisation themes through a detailed literature review and targeted stakeholder engagement. This database is held for Scottish Government use given some of the sensitive information inherent. This was done through initial literature review and horizon scanning, as well as stakeholder engagement. Future work is required to further extend the database and keep it up to date, as an updated database would provide an important resource for project coordination and sequencing going forward.
- **Phase 2** aims to assess how these projects are likely to develop on a 10-year timescale. Barriers, enablers and gaps in industrial decarbonisation throughout the listed industrial decarbonisation themes are identified through in-depth understanding of how decarbonisation technologies fit the specific Scottish context, based on information gathered through stakeholder engagement. The final objective is to inform the most likely development pathways and gauge the influence of external factors on optimal project sequencing. This links into other ongoing Scottish Government work on decarbonisation pathways beyond 2030 to net zero for Scottish industry.

2.2 Current policy outcomes relevant to EIIs

Scotland's Energy Strategy has set a clear target for the decarbonisation of energy-intensive industries through building on existing programmes of support. As a consequence, the Scottish

Government is committed to engaging with industry to promote energy efficiency and decarbonisation initiatives that facilitate investments aimed at achieving two clear targets[3]:

- By 2032, industrial and commercial energy productivity will improve by at least 30% from 2015 levels, through a combination of fuel diversification, energy efficiency improvements and heat recovery.
- By 2032, industrial and commercial emissions intensity will fall by at least 30% from 2015 levels, through a combination of fuel diversification, energy efficiency improvements and heat recovery.

Industrial decarbonisation, to be guided by the two policy outcomes above, can create an economic opportunity for Scotland, by strengthening its existing energy-intensive sectors and attracting new, advanced manufacturing industries. This advantage can be mobilised through the provision of a low-carbon energy supply, new fuels such as hydrogen, and leveraging the location advantages offered by clustering and access to carbon capture utilisation and storage infrastructure.

2.3 An overview of the Scottish energy-intensive industries[4, 5]

Energy-intensive industries (EIIs) are a core part of Scotland's economy and in 2017 contributed to a large portion of the £12bn of GVA and 185,000 jobs generated by the wider Scottish manufacturing sector[6]. This is characterised by eight key sectors: glass; chemicals; cement; oil and gas refining; food and drink; iron, steel and aluminium; paper and pulp; and ceramics[7]. These industries tend to have the highest level of energy consumption and to be the largest point emitters.

In 2017, EIIs' emissions represented around 15% of Scottish GHG emissions (6 of 40.5 $MtCO_2e$[8]). In most cases these industries are located within the Central Belt of Scotland as shown in Figure 2-1, which enables the sharing of utilities and infrastructure and improves efficiency.

[3] Climate Change Plan: The Third Report on Proposals and Policies 2018-2032, Scottish Government, 2018 (p.146)
[4] UK National Atmospheric Emissions Inventory (NAEI)
[5] Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment Study
[6] Scottish Annual Business Statistics 2017, Scottish Government, 2019. The wider Scottish manufacturing sector also includes non EIIs, such as textiles, wearing apparel and leather products or computer, electronic or electrical equipment.
[7] BEIS Industrial Decarbonisation and Energy Efficiency Action Plans Summary Document
[8] Total 2017 CO_2 emissions taken from "Reducing Emissions in Scotland: 2019 Progress Report to Parliament, The Committee on Climate Change, 2019". Total EII CO_2 emissions calculated from EII individual contributions stated in Section 2.3. Excludes ceramics sector, whose emission were only found for 2012 (0.03$MtCO_2$/year).

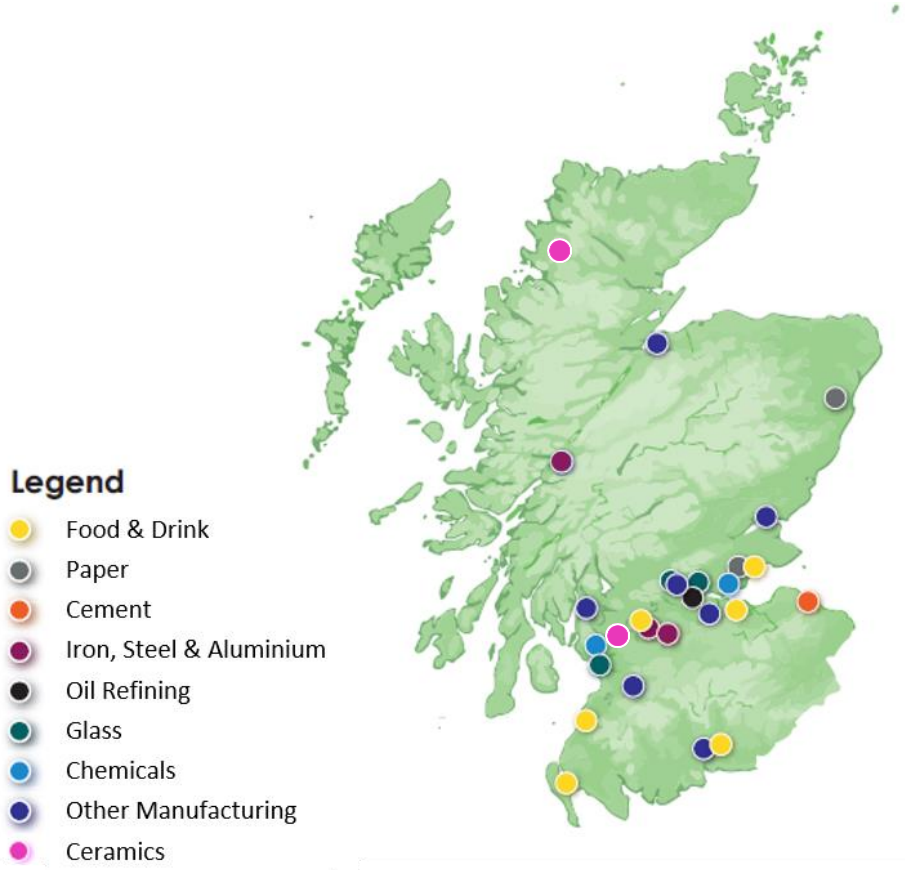
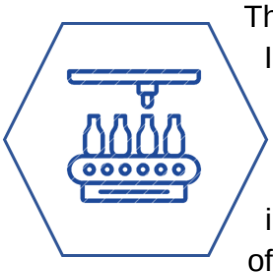


Figure 2-1: EII sites in Scotland. Adapted from[9]

2.3.1 Glass



The Scottish glass sector produces glass containers at two sites, Ardagh in Irvine and O-I Manufacturing in Alloa, while glass fibres are made at Superglass in Stirling. In 2017, the overall sector emissions were around 0.2 $MtCO_2$/year, mostly from the combustion of natural gas, though partly (~10-15%) from the decomposition of raw materials. Decarbonisation and improved efficiency is ongoing (or anticipated) through the implementation of industrial waste heat recovery, electrification or other fuel switching, temperature reduction, and increasing the recycling of glass waste, with the sector active through British Glass and Glass Futures[10].

[9] Adapted from Decarbonising Scotland's Industrial Sectors and Sites: A Paper for Discussion with Scottish Energy-Intensive Industries. Includes Ceramics and Aluminium moved from other manufacturing to Iron, Steel and Aluminium.
[10] In February 2020, BEIS has placed a £7.1million Industrial Fuel Switching Procurement Contract with Glass Futures Ltd to provide in-depth investigations of sustainable alternative fuel sources and innovative scenarios to decarbonise the glass manufacturing process in line with "Net Zero" targets. LINK

2.3.2 Chemicals

The chemicals sector – including both the chemicals and pharmaceuticals industries - represents an important revenue source for the Scottish industry, with exports of over £4.4bn per year[11]. In 2017, emissions from the chemical sector amounted to 2.4 $MtCO_2e$/year, the highest among Scottish EIIs. Main emitters in this sector are the chemical plants in the Grangemouth area and the pharmaceutical sites in Irvine and Dalry. Decarbonisation of the sector is anticipated through energy-efficiency improvements, process changes, fuel switching and the use of waste as chemicals feedstock[12].

2.3.3 Cement

The Scottish cement sector is represented by a single site, the Tarmac plant at Dunbar. It emits around 0.5 $MtCO_2e$/year, of which ~60% are process-related emissions from calcination. The site is currently relying on waste-derived fuels or biofuels to deliver its sustainability and emissions reduction targets. In addition to energy efficiency improvements, fuel-switching, clinker substitution and CCUS are other key technologies that can contribute to the decarbonisation of the cement sector[13].

2.3.4 Oil and gas refining

The oil and gas refining industry has two major sites in Scotland: the Grangemouth refinery complex, and the Shell Fife Natural Gas Liquids plant[14]. The sector is considered the second largest EII emitter with 2.1 $MtCO_2e$/year in 2017. Within the Grangemouth plant, there are several initiatives to implement energy efficiency measures, such as the construction of a new power plant to provide energy for industrial processes. Other measures include fuel switching, CCUS, additional waste heat recovery or energy efficiency.

2.3.5 Food and drink

The food and drink industry is one of the largest sectors in Scotland in terms of employed people, with distilleries a large subsector. Overall, it generates the highest GVA for Scotland, totalling £3.6bn in 2017. The sector was the third largest industrial emitter in 2017 with around 0.5 $MtCO_2$/year. The Food and Drink Federation (FDF) and Scotch Whisky Association have set decarbonisation targets across the sector[15] [16] [17]. Fuel switching to biomass, process change to utilise waste heat and distillation by-products, and improvements to

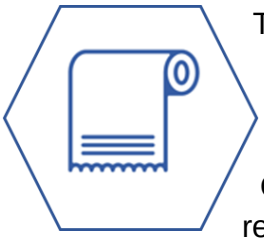
[11] https://www.sdi.co.uk/key-sectors/chemical-sciences
[12] Chemicals Sector: Industrial Decarbonisation and Energy Efficiency Roadmap to 2050 – Action plan document
[13] https://www.parliament.scot/S5_Environment/Inquiries/031_Mineral_Products_Association.pdf
[14] The Shell Fife Natural Gas Liquids (NGL) Plant comprises two sites; the Mossmorran Fractionation Plant and the Braefoot Bay Marine Terminal
[15] Food and Drink Sector: Industrial Decarbonisation and Energy Efficiency Roadmap to 2050 – Action plan document
[16] SWA Scotch whisky Industry environmental strategy report 2018
[17] The SWA is currently commissioning a study for the decarbonisation pathways in the Scotch Whisky industry up to 2045 with the updated targets and decarbonisation technologies for the sector.

energy efficiency and waste heat recovery are amongst key decarbonisation technologies in the sector.

2.3.6 Iron, steel and aluminium

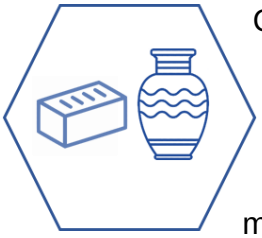
The Scottish iron and steel industry is comprised of three key sites: Clydebridge and Dalzell, operated by Liberty Steel; and Livingston, operated by Wyman-Gordon. There is one aluminium smelter left in Scotland: Lochaber Smelter which produces 50,000 tonnes of aluminium annually. Overall, the sector emitted around 0.1 $MtCO_2e$/year in 2017. Several decarbonisation options are considered for this sector, including fuel switching to biomass, hydrogen or electrification, material and energy efficiency, and waste heat recovery.

2.3.7 Paper and pulp



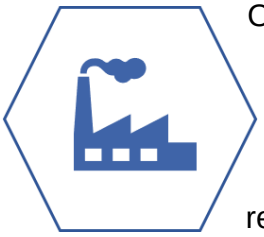
The paper and pulp sector has shrunk substantially over the past years, with a decrease in total employment of 28% between 2008 and 2017[18]. There are only three remaining paper mills in Scotland: Chirnside, Stoneywood and Caledonian. The sector emitted around 0.13 $MtCO_2e$/year in 2017. Over the past 25 years, the industry achieved considerable emissions reductions of around 40%, partially through energy efficiency measures and biomass cogeneration power plants. Other energy efficiency measures for this industry include improving the efficiency of drying processes and recovering waste heat[19].

2.3.8 Ceramics



Ceramics is a relatively small sector with minor emissions and less than 10 operating sites. Production in this sector is limited to heavy clay bricks, technical ceramics and refractories. It is the smallest emitter amongst the eight EII sectors. In 2012, emissions were 0.03 $MtCO_2$/year. The sector relies on grid electricity or natural gas for extremely high temperature firing, meaning its decarbonisation is partly dependent on grid decarbonisation.

2.3.9 Other manufacturing



Other EIIs include manufacturing of wood products, electronics, asphalt and rubber products. The applicable industrial decarbonisation measures vary widely as a result of the wide range of activities. Fuel switching to biomass for combustion is used widely in wood manufacturing sites. Other general decarbonisation measures include optimising heat use and waste heat recovery.

[18] Reducing Emissions in Scotland: 2019 Progress Report to Parliament, The Committee on Climate Change, 2019.
[19] Industrial Energy Transformation Fund: supporting industry on the path to net zero – consultation (BEIS, 2019)

3. Horizon scanning

This chapter includes the outcome of Phase 1 of this study achieved through an extensive literature review and stakeholder engagement. It presents an overview of Scotland's current funding landscape and of the most relevant themes around which current industrial decarbonisation projects are focusing.

3.1 A review of Scotland's funding landscape[20]

An overview of funding initiatives relevant for the EU, UK and Scotland areas, as well as of advisory services in Scotland is below. Many of these are wider in scope and largely fund renewable or low-carbon energy projects which may, or may not, directly impact industrial decarbonisation.

UK programmes[21]

- **Clean Steel Fund** (£250m, not yet started): This new fund supports the steel industry onto a pathway to decarbonisation. A call for evidence has been issued to understand the needs of the steel sector and to help develop the design of the fund.
- **Industrial Energy Efficiency Accelerator (IEEA)** (£9.2m, Phase 2 closed April 2019): Helps to identify new energy-efficient technologies and accelerate deployment in industry. Targets include all industrial and manufacturing sectors in the UK focusing on TRL 5-8.
- **Industrial Energy Transformation Fund (IETF)** (£315m, ongoing): Funds businesses with high energy use to deploy energy efficiency measures and pilot innovative low-carbon technologies at scale. Initial projects can secure funding from 2020 to 2023/24. (see also Scottish programmes)
- **Industrial Fuel Switching Competition** (£20m, Phase 1 closed 2018, Phase 2 closed in February 2019 and Phase 3 closed October 2019): This was an innovation competition aimed at stimulating the early investment in fuel-switching processes and technologies such as biomass, hydrogen and clean electricity.
- **Industrial Strategy Challenge Fund (ISCF) Decarbonisation Research and Innovation Centre** (£20m, closed October 2019): This funding opportunity is the third strand of the ISCF Industrial Decarbonisation Challenge. This call will provide £100,000 of funding for one successful Industrial Decarbonisation Champion as a six-month grant followed by a £19.9 million Research and Innovation Centre, backed until March 2024. Heriot Watt University has been successful in the initial application, and the funding will be used to open the Industrial Decarbonisation Research and Innovation Centre (IDRIC).[22]

[20] The work done in this section was guided Scottish Government Energy efficiency: advice and support for industry page
[21] Funding programmes included in Section 3.1 labelled as "closed" have been included if the projects which they are funding are still ongoing.
[22] UKRI article, Champion appointed to drive forward industrial decarbonisation centre, 2020

- **ISCF Industrial Decarbonisation challenge**[23] (£140m from UKRI, expected to be matched by funding of up to £261m from industry. Phase 1 closed in 2019 and Phase 2 is ongoing): This challenge is part of the UK Industrial Strategy[24]. The challenge aims to accelerate the deployment of low-carbon technologies across the six main industrial clusters in the UK and to enable the deployment of infrastructure at scale by the mid-2020s[25]. It will support delivery of the Industrial Clusters Mission, which aims to establish at least one low-carbon cluster by 2030 and the first net-zero carbon cluster by 2040. Two strands, i) the deployment of technologies such as carbon capture and hydrogen networks in industrial clusters and ii) the elaboration of a roadmap to help these clusters become carbon neutral and achieve net-zero operations. Winners of Phase 1 will compete for additional funding in Phase 2 of the competition.[26]
- **ISCF Transforming Foundation Industries** (£5m initially, ~£60m total, ongoing): Innovate UK is investing in industrial R&D projects for the foundation industries (cement, paper, glass, ceramics, metals and chemicals), funding cross-sectoral research and demonstrations.
- **Low Carbon Hydrogen Production Fund** (£100m, not yet started): This fund supports the deployment of low-carbon hydrogen production capacity and encourages private sector investment. The fund is expected to be launched in 2021.
- **Low Carbon Hydrogen Supply Competition** (£33m, Phase 1 closed July 2019 and Phase 2 is ongoing): This competition aims to accelerate the development of low-carbon bulk-hydrogen supply solutions in industry, power, heat and transport. The project is aimed at technologies at different levels of maturity which have been tested at least in a small-scale prototype project or up to demonstration system and which could result in lower project costs when compared to steam methane reformation plus CCS or improve the carbon capture rates at a comparable cost.
- **Non-Domestic Renewable Heat Incentive (RHI)** (ongoing): Provides financial incentives to renewable heat by businesses, public sector and non-profit organisations. Confirmed until March 2021, the scheme may be subject to further extension.
- **Other funding streams** (£800m): A £800 million pot was confirmed in March 2020 in the budget for carbon capture and storage, to establish at least two carbon capture and storage clusters by 2030.

[23] Grangemouth, one of the six industrial clusters, has the opportunity to tap into the Industrial Decarbonisation Challenge that commits £170 million towards technologies such as CCUS and hydrogen networks.
[24] Industrial Strategy: Building a Britain fit for the future, 2017
[25] These industrial clusters include Grangemouth in Scotland; Teesside, Humber, and Merseyside in the North of England; South Wales; and Southampton in the South of England.
[26] As part of the Industrial Decarbonisation Challenge, two projects for industrial decarbonisation in Scotland have been awarded funding and have progressed to the next competition phase for additional funding. These are the Scotland's Net Zero Infrastructure (SNZI) and Scotland's Net Zero Roadmap (SNZR).

EU programmes[27]

- **Connecting Europe Facility (CEF)** (€30.4bn, ongoing since 2014): This funding is only available for projects of common interest (PCI). This fund aims to promote growth, jobs and competitiveness by investing in energy infrastructure at European level.
- **EU ETS Innovation Fund** (€11bn): Available between 2021-30 to support innovative low-carbon technology projects across energy-intensive industry.
- **NER 300** (€2bn, closed): Set up to support the demonstration of a wide range of CCS technologies and renewable energy technologies. Projects which received funding will enter into operation by 2021 at the latest.
- **Private Finance for Energy Efficiency (PF4EE)** (€80m LIFE + €480m EIB): addressing the limited access to affordable commercial financing for energy efficiency investments.

Scottish programmes

- **Energy Investment Fund (EIF)** (£20m, closed March 2020): Managed by the Scottish Investment Bank (part of Scottish Enterprise) on behalf of the Scottish Government. The scheme provides flexible investment and debt funding for energy projects subjected to a demonstrable funding gap, and which fit with the Scottish Government's Energy Strategy.
- **Green Investment Portfolio** (£3b, ongoing): Operated by the Scottish Government and other partners, the Green Investment Portfolio aims to select and promote market-ready, investor-grade green projects that are seeking private capital.
- **Industrial Energy Transformation Fund (IETF)** (not yet started): Scotland will administer £34m over five years to be targeted towards the needs of Scottish energy-intensive industries. More details to follow during 2020.
- **Low Carbon Infrastructure Transition Programme (LCITP)**: Supported by the European Structural and Investment Funds and led by the Scottish Government, the programme was launched in March 2015 and runs up to Autumn 2021. It is designed to create the conditions to attract commercial investment in innovative, replicable low-carbon infrastructure. It has largely funded renewable energy generation projects, not directly industrial decarbonisation.
    - **LCITP Green Recovery: Low Carbon Energy Project Development Funding** (minimum of £1m, ongoing): This invitation will provide development support for projects with potential to deploy low-carbon heat and/or renewable electricity solutions for buildings or for integrated energy systems.
    - **LCITP Scottish Low Carbon Heat Funding** (£30m, closed October 2019): Support for projects that demonstrate innovative and low-carbon ways of heating buildings. This fund aims to support renewable heat and was announced in September 2019.
    - **LCITP Low Carbon Innovation Funding** (~£13.5m, closed April 2018): Targeted to accelerate the delivery of large-scale, innovative low-carbon infrastructure projects that support the ambitions set out within the Scottish energy strategy.

[27] Some of the EU funding programmes will be applicable Scotland after the Brexit transition period ends in January 2021. Some programmes have been identified as having Scottish stakeholders (details)

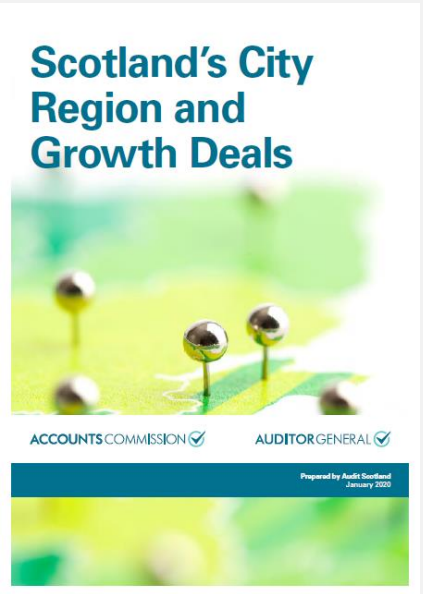
  - **LCITP Innovative Local Energy Systems (ILES)** (£0.1m, closed June 2017): Aims to support and accelerate the development of innovative, low-carbon energy opportunities across Scotland, particularly in rural and remote areas.
  - **LCITP Transformational Low Carbon Demonstrator** (£40m, closed November 2016): Aims to accelerate the delivery of large-scale and transformational low-carbon infrastructure projects in Scotland.
- **Scottish Partnership for Regeneration in Urban Centres (SPRUCE)** (£87m, ongoing): Funded by the Scottish Government but privately managed, this is an innovative source of finance for sustainable urban development launched in 2011, supporting regeneration, property and sustainable energy projects. Energy efficiency projects, which support regeneration, Previous industry-related projects have included low-carbon innovation centres, creation of engineering units and energy centres.
- **Scottish National Investment Bank (SNIB)** (£2bn over 10 years, ongoing): Operated by the Scottish Government, the bank will facilitate patient finance (borrowing money over 10-15 years) for different businesses in Scotland.
- **SME Loan Fund** (ongoing): Operated by the Scottish Government, the funds are aimed at supporting Scottish businesses (SMEs) to reduce energy and resource costs by providing interest-free loans for resource efficiency measures.

3.2 Scottish advisory services and resources

- **Scottish Enterprise (SE)**: A public body of the Scottish Government, SE provides various funding streams (small and large grants) to support businesses, as well as providing advice on available funding from external sources. A portion of SE's work is aimed at delivering sustainability and energy-related projects.
- **Highlands and Islands Enterprise (HIE)**: A public body of the Scottish Government, HIE works with businesses and aims to generate sustainable economic growth by fostering a competitive and low-carbon economy with focus on Highlands and Islands.
- **Scottish Manufacturing Advisory Service (SMAS)**: Delivered by SE, this service aims to improve productivity and investment in the manufacturing sector by delivering expert advice, one-to-one support, training and events to help businesses improve efficiency and adopt digital technologies.
- **Scottish Futures Trust (SFT)**: Established by the Scottish Government, SFT supports public sector organisations and is supporting Scotland's transition to a low-carbon economy and the achievement of its climate change targets. It has a dedicated funding stream for low-carbon infrastructure.
- **Resource Efficient Scotland (RES)**: Funded by the Scottish Government and delivered by Zero Waste Scotland, the programme helps organisations reduce energy costs and improve resource efficiency, by offering free advice, best practice and technical support.
- **Energy Measurement & Quantification (EMQ)**: Delivered through the Scottish Government, via the RES programme mentioned above, it offers consultancy to develop full business cases for a limited number of heat recovery projects. It supports technical feasibility studies that could progress to funded programmes.

- **Scottish Environment Protection Agency's (SEPA) sector plans and Sustainable Growth Agreements (SGA)**: SEPA works with Scottish businesses to ensure they comply with environmental legislation. The sector plans set out how SEPA intends to organise its work with sectors, and the businesses within them, to identify compliance sector-specific issues that need to be tackled. In order to address SEPA's commitments, the SGA initiative has been created. SGAs are formal agreements between SEPA and an organisation where both work collaboratively to improve the organisation's environmental performance beyond existing regulatory obligations.
- **Scotland's National Heat Map**: Managed by the Scottish Government, the map is a visual way to show the supply and demand of heat and, how these can be connected in an efficient way. It also helps identify opportunities for decentralised energy projects across Scotland.

Box 1: Scotland's City Region and Growth Deals [28]



City and Region Growth Deals first started in 2014 in the Glasgow City Region. These deals provide support and funding, aiming to facilitate the collaboration between councils and a set of partners including the business community, voluntary organisations, social enterprises, universities and national agencies. It committed £5.2bn to supporting economic development in all parts of Scotland through different projects, including infrastructure, digital projects, skills development and energy. Funding is provided by both the UK (£1.42bn) and Scottish Governments (£1.5bn), as well as councils and partners (£2.23bn). So far, 12 deals are in various stages of development, bringing additional long-term funding for regional economic development. These deals could have an important role in shaping industrial decarbonisation going forward, as a substantial pot of funding available to promote growth in low-carbon industry.

There are four development stages for various deals:

- Signed and in delivery stage: includes Glasgow, Aberdeen City, Inverness and Highland, Edinburgh and South East Scotland City Region Deals.
- Heads of Terms signed: includes Tay Cities and Stirling and Clackmannanshire City Region Deals as well as Borderlands Inclusive and Ayrshire Growth Deals.
- Funding commitment made: includes Moray, and Argyll and Bute Growth Deals.
- Deal commitment made: includes Islands Growth Deal and Falkirk Growth Deal. However, the funding amount is not yet confirmed.

[28] Scotland's City Region and Growth Deals Report

3.3 Industrial decarbonisation themes

According to the findings of this study, investment for industrial decarbonisation in Scotland currently focuses predominantly around five major themes. These have been listed following a hierarchy towards longer-term decarbonisation:

1. Energy efficiency
2. Process change and resource efficiency
3. Fuel switching to hydrogen, biomass or electricity
4. Carbon capture, utilisation and storage (CCUS)
5. Regionally focused projects

The characteristics of each identified theme are detailed in the following sections, together with examples of relevant decarbonisation projects in development in Scotland. Infrastructure projects, which underpin many of the developments across themes are also discussed.

3.3.1 Theme 1 – Energy efficiency[29]

The application of energy efficiency measures can make a significant contribution to reducing energy costs and increasing the resilience of industries against fluctuating energy prices. On a wider scale, energy efficiency also makes a significant contribution to the decarbonisation agenda in Scotland[30]. However, feedback from industry suggests many of the potential efficiency improvements have already been implemented by sites, and further improvement might be limited in scale. Energy efficiency can be achieved either by:

- **Energy efficiency measures related to industrial processes:** Generally, requires new equipment, upgrades and retrofits or through energy management plans to improve automation, process control, monitoring, planning and maintenance. These initiatives usually require high capital investments and have a relatively long payback period.
- **Other energy efficiency measures**: Not directly targeting the industrial processes but rather energy costs reduction related to buildings efficiency (e.g. change to LED lighting or to buildings insulation/fabric which contribute to improved EPC ratings).

Box 2: Energy efficiency is a common decarbonisation theme across EIIs

Superglass furnace replacement project: Superglass started an initiative to replace its existing two furnaces with one larger single furnace to run on natural gas. Prior to installation, the replacement was expected to result in reduced emissions and increase energy efficiency by 35%[31]. This energy efficiency project, completed in 2019, was executed without disturbing production.

INEOS new energy plant: In collaboration with Fluor, INEOS is investing £350m in building a new power plant, fuelled by mixed gas, to replace its 40-year old one. The project is expected to deliver improvements in efficiency, reliability and environmental performance. The power station will include three boilers and a steam turbine generator[32]. The plant is currently in construction and due on stream in 2022, and will provide a reliable and continuous supply of steam and power to INEOS O&P UK, the Forties Pipeline System and Petroineos.

Dunbar Cement new vertical rollers mill: To be built to replace one of the old mills, the new mill is expected to increase site productivity and to reduce energy consumption of the milling process by 50%. The construction of the mill, which is being completed without stopping cement production, is expected for completion this year.

Caledonian Cheese new power plant in collaboration with BasePower: Operating at full capacity since 2017, the gas-fired 2MW CHP plant provides a containerised energy centre. The plant is projected to generate 77% of the dairy's electricity consumption, whilst also generating 1MW of steam and hot water to supply 24% of the required heat demand. The

[29] In this study, heat recover is categorised under theme 4: Process change and resources efficiency.
[30] Given that the industrial and commercial sector account for ~40% of total energy consumption in Scotland
[31] Superglass Insulation Limited Stirling Operator Initiated Permit Variation, 2019. To date, no reporting of fuel or cost savings has occurred yet.
[32] INEOS NEP PE v0.3, INEOS, 2017

plant tracks temperature and flow requirements in order to improve reliability, increase efficiency and maximise savings.

Norbord's Inverness new electrostatic precipitator and 57 MW heat plant[33]: Two hydroair wet electrostatic precipitators and a heat raising biomass burner were installed between 2016 and 2019. These enhance the oriented strand board production while rendering a more efficient modern plant. A second new heat plant is expected to be installed by 2024. It is estimated that this project will result in 45 new direct jobs, new economic activity, and significant emissions reductions.

3.3.2 Theme 2 – Process change and resource efficiency

This theme involves the utilisation of products and resources in a responsible manner to reduce overall carbon emissions. This can be applicable in EIIs through the re-use of waste products in various processes (ex: glass cullet recycling) and the re-use of low-grade heat in district heating and waste heat recovery for energy efficiency measures. Demand reduction through material efficiency - *enabled by process change* - is seen as a key enabler in decarbonising some EIIs such as glass (ex: glass switching to non-carbonate raw materials), ceramic, food and drink, and iron and steel industries in Scotland.

Box 3: The re-use of waste products in different sectors

Waste Ammonia to Hydrogen Production using Electrochemical and Ecological Processes (WAHEEP): This was a collaborative R&D project funded by Innovate UK which aimed to produce hydrogen via electrolysis of ammonia-rich wastewater both through simulations and real tests. The project developed robust, efficient materials for the electrodes to be used in the electrochemical cells which will yield water suitable for final treatment in the process of electrolysing the ammonia. Information on the findings is not publicly available.

Norbord MDF plant in Cowie biomass facility: The biomass facility is an example of using energy-from-waste by consuming the residue bark and wood residue from the manufacturing process. The biomass facility generates 5MW of heat and 5MW of steam which replace some of the natural gas feedstock, allowing for savings of up to £12,000 per week[34].

3.3.3 Theme 3 – Fuel Switching to hydrogen, biomass or electricity

Hydrogen

There are two forms of clean hydrogen production. Green hydrogen is expected to constitute a long-term solution for industrial decarbonisation once available at scale, while blue hydrogen could be implemented in the nearer term, acting as a clean energy bridge during the transition[35]. Hydrogen produced from the gasification of biomass may additionally have a significant role in a bioenergy-based decarbonisation scenario.

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[33] The Highland Council, South Planning Applications Committee (2014).
[34] Norbord opens biomass plant, TTJ, 2008
[35] SGN Energy Futures, Hydrogen Vision presentation

- **Blue hydrogen:** Hydrogen is commonly produced through the reformation of natural gas, separating natural gas mainly into hydrogen and carbon dioxide, a process already widely used at industrial scale for the synthesis of methanol, fertilisers and petrochemicals. Hydrogen reformed in combination with CCUS, capturing and sequestering the released CO_2, is defined as blue hydrogen and is associated with a reduced carbon footprint as no CO_2 is emitted from hydrogen when combusted. Although reformation of natural gas is a mature technology, the production of blue hydrogen is not yet available at commercial scale.
- **Green hydrogen** is produced through electrolysis of water using renewable electricity**.** While electrolysis is already implemented commercially at small scale, large-scale deployment requires larger scale electrolysers in close proximity to renewable electricity sources and to hydrogen users or grid inject points.

Hydrogen can play a key role in the decarbonisation of EIIs in Scotland through:

- **Fuel switching**: Given the similarities of hydrogen to natural gas, some industrial appliances currently using natural gas (such as boilers, furnaces, ovens and kilns) could be retrofitted and converted to hydrogen rather than fully replaced. This would reduce the extent of the engineering works and the amount of investment required.
- **Decarbonisation of heat networks**: Hydrogen could also be used to decarbonise domestic and commercial heating, with several projects underway investigating a complete gas grid conversion to hydrogen or blending of hydrogen with natural gas[36]. Large-scale hydrogen production facilities that would supply the heating sectors have the potential to be a fundamental part of a wider infrastructure that would facilitate industrial decarbonisation.

Biomass

Replacing fossil fuel sources with biomass in a sustainable manner is a relevant fuel-switching option for several sectors including cement, pulp and paper, chemicals, glass, food and drink, and ceramic industries.

To benefit fully from the advantages of bioenergy, the Scottish Energy Strategy includes a commitment to release a Bioenergy Action Plan during 2020, which will set out a pathway to develop bioenergy in Scotland. To prepare for this, research on competing feedstock issues and long-term availability of supply is being completed to understand in more detail the scope for bioenergy in Scotland.

Electrification

Electrification of industry can be implemented either directly through the electrification of heat using direct heating and heat pumps, or indirectly to generate green hydrogen. In both cases, and unless privately connected to a fully renewable source of electricity, the decarbonisation of industry through electrification is as effective as the level of grid decarbonisation and poses its own challenges associated with the need for grid expansion. Smaller-scale and equally

[36] SGN Hydrogen 100 project

important options for industrial electrification include electric/hybrid boilers in the pulp and paper industry and a variety of electro-thermal technologies for heating and drying[37].

Electrification of heat brings additional benefits to industry other than emissions reductions. The substitution of fossil fuel requirements by electricity allows for material savings, as feedstocks are simplified. In addition, electrification enables the use of demand-side response measures to be implemented, allowing industry to participate more actively in the electricity market and mitigate its energy costs. Finally, industry electrification facilitates deeper integration of renewables, a factor which has been recently cited as sector coupling.[38]

Box 4: Fuel switching initiatives in the food and drink sector

Fuel switching in distillation industry: The Orkney Distillery aims to replace liquefied petroleum gas (LPG) with hydrogen by developing a hydrogen-powered thermal fluid-heater system within the distilling process. The project has the potential for replication at other sites in the distilling industry if the business case proves viable. The project has received £149,000 as part of the Industrial Fuels Switching Competition run by BEIS.

Mackie's new refrigeration system: The project is based on low-carbon, power-efficient units running on ammonia. If successful, this will be Scotland's first large-scale plant combining biomass heat and absorption chilling, enabling the ice cream producer to target ambitious CO_2e reductions of 90% and 70-80% of energy cost savings. The project has received £2m of funds from Scottish Government LCITP, match funded by a loan from the Bank of Scotland.

3.3.4 Theme 4 – Carbon capture, utilisation and storage (CCUS)

CCUS consists of the capture, transport and either storage or utilisation of CO_2 emissions. CO_2 emissions can be captured from power and large-scale energy-intensive processes, such as cement and steel production, chemical processing and hydrogen production. The technology consists of capturing CO_2 from an emissions stream and transporting the captured CO_2 via pipeline at high pressures to a geological storage to be safely sequestered permanently or to a utilisation facility.

CCUS can play a role in developing industrial clusters in North East and Central Scotland. These areas host some of the largest sources of emissions and a well-established pipeline infrastructure to depleted oil and gas fields which could be used for CO_2 storage.

CO_2 utilisation as a feedstock to create various products has been cited[39] as a way to provide an economic advantage for Scotland. By leveraging the value of carbon as a resource, a circular economy opportunity and a sustainable way of carbon management could evolve. Through Living Lab[40], Grangemouth located with the Falkirk area, the Scottish and UK Governments, and

[37] Fahnestock, Jesse & Brolin, Magnus & Rootzén, Johan. (2017). Industry's Electrification and Role in the Future Electricity System: A Strategic Innovation Agenda. 10.13140/RG.2.2.34794.88003.
[38] IPEEC article: Opportunities for electrification of industry in the European Union
[39] SE Report: Actions required to develop a roadmap towards a Carbon Dioxide Utilisation Strategy for Scotland
[40] A Living Lab is a research concept. A living lab is a user-centred, open-innovation ecosystem, operating in a territorial context, integrating concurrent research and innovation processes within a public-private-people partnership.

Falkirk council are looking to enable development of a world-class CCU Innovation and Enterprise hub, demonstrator and value chain. This is being supported through the Falkirk and Grangemouth Investment Zone Growth Deal.

CCUS research and industrial alliances in Scotland

The Scottish Energy Strategy is committed to providing R&D funding and working closely with industry to realise opportunities for small-scale CCUS demonstration across a range of sources and industrial processes:

- **NECCUS –** North East Carbon Capture, Usage and Storage Alliance – is a formal collaboration between industry, academia and government to promote the deployment of both CCUS infrastructure and hydrogen production in Scotland.
- **ALIGN-CCUS –** Multi-partner[41] research project aiming to promote industrial clusters in five countries in Europe, including Teesside and Grangemouth clusters. The project bridges the gap between research and industry by helping to address specific issues faced by industry.
- **Elegancy CCS –** Enabling a low-carbon economy via hydrogen and CCS – An €8.9M Accelerating CCS Technologies (ACT) funded research stream focusing on fast-track energy system decarbonisation through synergies between hydrogen and CCS.
- **Research Centre for Carbon Solutions (RCCS) –** A research centre established at Heriot-Watt University focusing on accelerating the technology innovation needed for the wider deployment of CCUS, low-carbon systems and negative emission technologies.

Synergies with oil & gas industry

Whilst the decarbonisation of the oil and gas sector was not investigated in this study, the synergies between CCUS and this sector cannot be overstated. The existing oil and gas infrastructure and available CO_2 storage capacity make Scotland one of the best-placed countries in Europe to realise CCUS on a commercial scale[42]. As an example, the Acorn CCS project is planning to repurpose some of the North Sea oil and gas infrastructure for CCS use, which is expected to reduce project costs. The project is explained in more detail below.

Box 5: CCUS projects in Scotland – The Acorn Projects

The Acorn Projects are composed of three streams:

Acorn CCS Project: The Acorn CCS project is a large-scale CCS project to be located at St Fergus in North East Scotland. The location has been strategically selected, as the geography enables the re-use of existing oil and gas infrastructure, such as pipelines and depleted reservoirs. This is expected to render a low-cost, low-risk, CCS project. Acorn CCS is divided into two staged phases of growth. Phase 1 is expected to be deployed in the early 2020s and is planning to capture CO_2 emissions resulting from the processing of natural gas at the St Fergus Gas Terminal. Phase 2 is planned for the expansion of Acorn CCS to transport and

[41] Align CCUS project partners
[42] The Global Status of CCS, Global CCS Institute, 2018

store CO_2 emissions from a variety of sources, such as industry, power generation and even CO_2 from imports.

Acorn Hydrogen Project: The second stream plans the reformation of North Sea natural gas into clean hydrogen, with CO_2 emissions safely captured and stored through the Acorn CCS infrastructure. Hydrogen would then be used in transport applications and in the gas grid, through which some industrial sites could benefit.

Acorn CO_2 SAPLING[43] Infrastructure Project: This project represents the infrastructure part of the Acorn CCS project. It aims to develop onshore CO_2 collection though Central Scotland using the existing pipelines, to establish facilities for CO_2 shipping through the port of Peterhead and pipeline extension to serve CO_2-EOR developments in Norway.

Funding: The Acorn projects – across its various streams – has received funding support from the UK and Scottish Governments as well as the EU as follows:

- Acorn CCS was the first project in Europe to receive funding from the European Commission's Connecting Europe Facilities (CEF) fund. Acorn received a second round of CEF funding at the beginning of 2019.
- CO_2-SAPLING is listed as a European Project of Common Interest. It received funding of €0.3m in 2018 and then €2.8m in early 2019 from EU CEF, as well as funding support from the UK and Scottish Governments.
- The Scottish Government has supported the project through the ERA-NET ACT for the development of the ACT Acorn programme and of other CCS projects in Europe. Most recently, in February 2020, the Acorn project was selected as a finalist in the CCUS Innovation Programme, from BEIS, to carry out the detailed engineering towards a final investment decision in 2021.

3.3.5 Theme 5 – Regional, residential and commercial projects

Regional projects are focused on residential or commercial outcomes but have an impact on industry in the form of whole energy system projects or 'energy islands'. These projects can help promote certain technology concepts – like hydrogen production from renewable energy (RE) – or build infrastructure that contributes indirectly to EII decarbonisation. These include regional waste projects which can grow to uptake industrial waste or residential CHP plants which can expand their infrastructure to include nearby industries.

Box 6: Selected regional projects in Orkney

The ReFLEX Orkney[44] (Responsive Flexibility) project's main goal is to maximise the use of locally generated green energy in order to reduce, and eventually eliminate, fossil fuel use in Orkney. The project also aims to address the issue of intermittency of electricity production by creating a 'smart energy island' - developing a 'virtual energy system' which monitors generation, grid constraint and energy demand and then use smart control of energy

[43] CO_2 Shipping And Pipeline Infrastructure and North Sea ReGeneration
[44] Orkney's Responsive Flexibility project: ReFLEX Orkney

technologies to manage and improve the supply-demand balance. The project envisages ReFLEX Orkney to be replicated regionally, nationally and internationally.

BIG-HIT[45] (building Innovative Green Hydrogen System in Isolated Territories) is a five-year demonstration project with 12 EU partners that looks at using excess RE capacity – that otherwise would be curtailed – to produce green hydrogen. This hydrogen is transported across the Orkney Islands and used for transport, heat and power.

3.3.6 Overarching theme: infrastructure projects

Infrastructure projects can fall within a specific industrial decarbonisation theme or encompass various themes simultaneously to enable major decarbonisation projects, depending on the scale. In addition, these projects provide a pathway for decarbonisation which can be shared between sectors other than industry. Infrastructure projects can enable decarbonisation by connecting points of supply and demand, e.g. producers of renewable electricity and industries seeking to electrify. These types of projects can also make decarbonisation projects more cost-effective by enabling multiple industrial sites to adopt decarbonisation technologies in parallel, thus exploiting potential economies of scale. This is especially true for industrial clusters.

Industrial clusters are hubs of large energy-intensive industrial plants that significantly contribute to the local economy and also are a key concept to drive energy savings and carbon emissions. Clustering represents an opportunity for a whole-system impact and offers the potential to deliver significant decarbonisation in those sectors that would benefit from fuel switching to hydrogen, dependent on the availability of a hydrogen supply and delivery infrastructure. Industrial clusters could eventually expand to be CCUS clusters, where multiple sources share CO_2 transport and storage infrastructure, offer cost savings and enable smaller sources to undertake CCUS, which are unlikely to be capable of justifying stand-alone transport and storage systems.

[45] BIG H_2IT Project: https://www.bighit.eu/

Box 7: Opportunities for infrastructure sharing in the East Coast of Scotland

The East Coast of Scotland has an advantageous variety of resources which present an opportunity for collaboration across hydrogen production, CCUS and industrial clusters:

- **The Hydrogen Coast** project is a cluster of projects across the hydrogen value chain along the East Coast of Scotland to support net-zero carbon emissions targets. These include H_2 production from RE, blending H_2 in the local gas network and H_2 storage.
- The **Aberdeen Vision project** is one of these flagship projects and is considered an attempt to link supply and demand, by linking hydrogen production in St Fergus to support the decarbonisation of national and Aberdeenshire gas transmission systems.

The Grangemouth industrial cluster – supported by ALIGN-CCUS and emitting around 4.3MtCO_2/year – is focused around the INEOS refinery complex which annually produces around two million tonnes of chemical products and is Scotland's sole crude oil refinery. The cluster includes the proposed site of **Summit Power's Caledonia Clean Energy Project**, which has completed an interim engineering and design assessment and identified transport and storage options. ALIGN-CCUS identifies opportunities for cost reductions through shared infrastructure and optimised transport and storage plans.

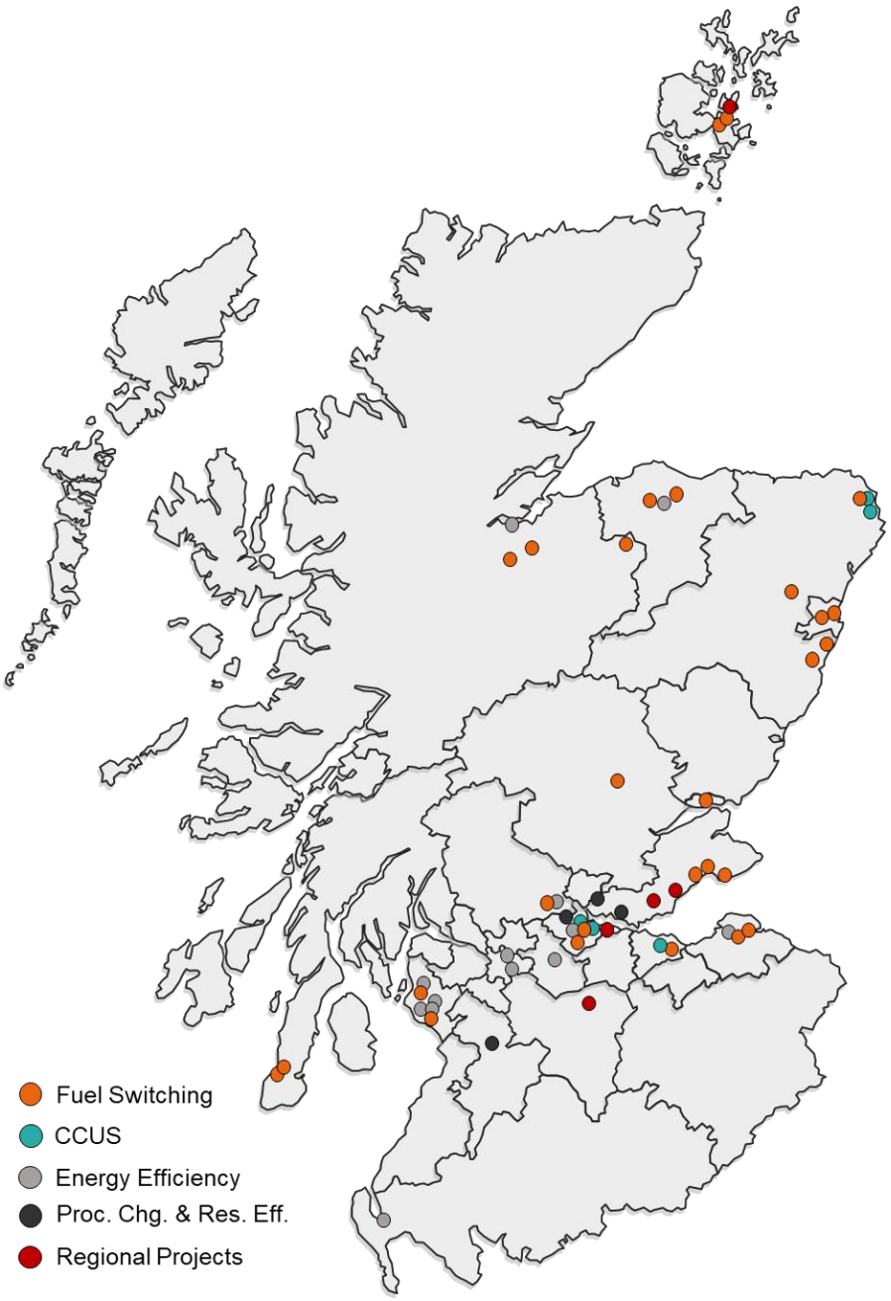

Figure 3-1: Approximate location of industrial decarbonisation projects catalogued. Coloured by main theme.

4. Development pathway for industrial decarbonisation

This section evaluates barriers faced by industrial decarbonisation projects and the potential enablers to overcome these obstacles. These were identified through engagement with stakeholders across different sectors of Scottish industry, as well as an assessment of the decarbonisation technologies and implemented projects.

4.1 Barriers and enablers for industrial decarbonisation

4.1.1 Key barriers

Economic / financial barriers

Economic factors across all industries are a key concern for the viability of decarbonisation with continuing operations. In discussions with industry, this was emphasised in several key points:

- Industrial decarbonisation initiatives relating to energy efficiency lower marginal production costs and provide direct financial payback for companies. However, these often occur over long-time periods with a low rate of return. Since the rate of return required for energy-saving projects on industrial sites typically exceeds 20%, these energy efficiency initiatives are often disadvantaged compared to other investment opportunities. Competition within a limited company investment budget often favours other investment opportunities, typically focused on growth and output, which have shorter payback periods (and small to no decarbonisation benefits).
- There is significant uncertainty and a lack of trust around long-term availability of funding mechanisms for decarbonisation projects. Industry's previous experience with government changing funding/competition rules means decarbonisation projects, which rely on these funding opportunities, are often assigned higher risks. For example, previous experience in cancelled CCUS funding competitions has led to a widespread reticence to allocate resources on propositions with an uncertain future, and has created a weak business case for CCUS investments[46].
- In some specific industries, changing forecasts (and declining demand) has created an uncertain investment climate. This is particularly relevant in industries such as oil and gas, where further investment in decarbonisation of assets, which have a limited lifespan, is not favoured. Refining is another industry where uncertainties over the future direction of the industry can cause reluctance towards financial commitments.

Policy uncertainty on finance/regulation

Some financial barriers are underpinned by policy uncertainty or changing regulations. Several examples were cited by industry:

- Final decision on the cap-and-trade system to be adopted after Brexit. After a period of uncertainty on this front, the UK Government and Devolved Administrations have collectively decided to introduce a UK Emissions Trading Scheme (ETS) as a substitute for the EU ETS, which will come into effect at the end of 2020. Cap-and-trade systems - such as the UK ETS - have a direct impact on investments in industry. The uncertainty

[46] Public Accounts Committee: Carbon Capture and Storage Inquiry, Parliament 2015

on the future of the ETS in the past few years has hindered the creation of decarbonisation strategies, as companies did not have a defined post-Brexit carbon market which could be used to measure the costs of emissions, and the subsequent value of decarbonisation strategies being considered.

- The lack of long-term clarity around the role of bioenergy in the future energy system. In the past, incentives have been available for projects generating heat or electricity from biomass. However, these schemes have been discontinued, with uncertainty over future alternatives.
- Changing regulations related to Feed-In-Tariffs (FIT) and the Renewable Heat Incentive (RHI) have discouraged many sites from applying to these and similar schemes, especially in relation to small-scale decentralised generation from renewable sources. In addition, changes made to the Contracts for Difference (CfD) scheme have caused difficulties for CHP energy-from-waste projects to comply.

These unforeseen changes have led to a perception of various government funding streams as fragmented, complex and rigid. The changes have led to an increased degree of caution when developing decarbonisation projects in industry, which has slowed progression. Additionally, some industry representatives feel that some grants are not suitable for specific sectors or do not actually solve the problems they face.

Other political barriers

The strength of political will, decision making and leadership needed to overcome the challenges of decarbonisation was also raised as another similar, but distinct, barrier. Many of these projects are a matter of national strategy, which needs to be decided at the highest levels of government before projects can go ahead and funding/business models become available. This is particularly acute in the case of large infrastructure projects such as CCUS, where concerted government-industry cooperation is needed to enable project development. This decision making has in the past been slow or uncertain, which can lead to many missed opportunities and a lack of industry buy-in to future opportunities.

In addition, the reserved nature of energy policy means that powers such as renewable energy subsidies and electricity regulation lie with the UK Government[47]. However, some devolved powers that can be used include encouragement of energy efficiency, land-use planning systems other than pipelines and transmission lines, or the provision of grants and loans[48].

Due to the legal nature of some industrial decarbonisation projects, the powers needed to complete a project may also be divided at the two levels e.g. an electrification project which would encourage energy efficiency, but which would require a considerable change in the distribution grid. As a result, the separation of two levers can potentially affect investment decisions for new projects, and there is a distinct need for clarity and cooperation for project development.

[47] The Renewable Energy Sector in Scotland: First Report of Session 2016-17, House of Commons, Scottish Affairs Committee, 2016.
[48] Allan, G., McDonald, J., McGregor, P. G., & Swales, J. K. (2008). A distinctive energy policy for Scotland?. Fraser of Allander Economic Commentary, 32(1), 46-61.

Infrastructure constraints

Infrastructure limitations can range from a small-scale limited grid in a rural area to mega-scale national infrastructure to facilitate the development of a low-carbon industrial cluster. Infrastructure is usually external to the industrial sites - both physically and in terms of ownership and operation - and requires a coordinated approach between public and private sectors (infrastructure providers and industry) to drive its development. In addition, permitting arrangements for infrastructure projects can often be complex.

Shared infrastructure can be one of the approaches to overcome this barrier, but this brings its own challenges in terms of project coordination. Hydrogen fuel switching – a likely decarbonisation technology especially across many industrial sectors currently using natural gas – is often delayed due to lack of clarity about hydrogen supply and transport infrastructure. These projects usually require large investments in furnace replacements, equipment upgrades and retrofits; to put these in place needs a longer-term commitment to guarantee the appropriate infrastructure is available when needed.

Confidentiality and market competitiveness

Confidentiality is a common barrier to progressing several initiatives in individual sites. EIIs usually operate on very low margins, and they are highly reluctant to share details of their operations and their deployment of new concepts, as this is what constitutes their competitive edge. Commercial confidentiality and competition rules usually prevent sharing these initiatives in the public domain, which results in these projects not gathering sufficient support.

Technology-related factors

The optimal combination of heat decarbonisation technologies – hydrogen, biomass, electrification, CCUS – is still not clear and further investigation is needed into the optimal pathway. However, care needs to be taken that this does not become an excuse for inaction: lack of clarity has led to low or non-existent incentives for decarbonisation, locking in natural gas usage instead of promoting a longer-term investment in renewable heat.

There are also some industry-specific challenges. For the chemicals and oil refining industries, well-proven technologies are needed due to the critical and continuous nature of operation in these sectors. Reliability is important, and usually these sectors opt for mature and very well proven technologies (as well as much of industry where possible). The glass and cement sectors can be challenged by the availability of alternatives like cullet or materials suitable for clinker substitution.

Institutional capacity and complex funding schemes

Some industries are also unsure about the right decarbonisation technology mix, lacking the awareness of certain technologies and knowledge of their potential. Improving this and ensuring sufficient engagement can sometimes require inhouse testing for new concepts or the capacity to participate in demonstrations, and these might not be available to SMEs.

EII sites often lack inhouse energy and sustainability-related expertise, and this can become very evident where the number of staff is limited, and core competencies focus on project design and delivery. This has led many industries to refrain from applying for funding schemes, citing the process as overwhelming for a non-specialised team.

The awareness of the need for decarbonisation initiatives, energy efficiency and corporate sustainability goals has been on the rise. However, these topics are not yet always on the top agendas of most companies' board meetings. Management remains driven by commercial and financial imperatives, rather than commitment to emission reduction targets.

4.1.2 Key enablers

Supporting incentives and financial mechanisms

The low or non-existent payback for industrial decarbonisation has a relatively simple solution: make it in industrial sites' interest to decarbonise. While ongoing economic support for industrial decarbonisation is an important lever, others can also be used. For instance, the 2016 decision by the Treasury to increase the levy on industrial use of natural gas through the Climate Change Levy[49] effectively narrows the gap between electricity and gas levies. By increasing the levy on gas, EIIs may show new interest in electrification or other fuel switching in their businesses.[50]

The use of a cap-and-trade system, such as the EU ETS and its UK ETS successor, motivates industry participants to reduce GHG emissions via a financial incentive. In these carbon markets, companies trade GHG emissions allowances according to their emitted GHG amounts. Those participants which emit less GHG emissions can therefore sell their spare allowances in the trading market. This system therefore provides a signal for investment as companies can quantify the costs of emitting and can thus forecast the value of emissions reduction investments. In addition, the two cap-and-trade systems attempt to safeguard competitiveness of the participating industries by providing a proportion of free allowances, with the goal of reducing the risk of carbon leakage[51].

Providing access to low-cost finance mechanisms could also help overcome some economic barriers, creating the right environment for investment. Loan guarantees, for instance, could underwrite some of the risks for industry and help promote a private capital market for decarbonisation projects through engaging third-party investors and unlocking third-party funding, improving confidence in investing[52]. These fiscal mechanisms – backed up by governmental support – help de-risk investments and avoid economic shocks while establishing a steady trajectory to net zero.

Government support through policy alignment, regulation and information

While private sector participation in creating momentum for industrial decarbonisation is critical, government policy and direction remains essential, especially for the initial steps. The government can take the longer-term view and drive the initial development of the required infrastructure and ensure it accounts for long-term growth potential. Government can help reduce some of the tension that results from the involvement of multiple players through regulations and drive the collaboration of different partners. While some of this falls under UK-

[49] Government: Climate Change Levy Rates.
[50] As of June 2020, the UK Government has completed a consultation on extending the Climate Change Agreements scheme, which incentivises a wide range of EIIs to reduce energy use and emissions by receiving a discount on the Climate Change Levy.
[51] Carbon leakage refers to the transferring of businesses outside the country in which the ETS applies, where carbon costs put at risk industry competitiveness.
[52] Industrial Energy Transformation Fund: supporting industry on the path to net zero – consultation (BEIS, 2019)

wide remits, this should be done in a manner that ensures alignment with Scottish energy priorities.

Government support can also be extended to supporting individual sites which lack the required expertise to take advantage of relevant funding schemes. This can be aided through clearer and more accessible information around available funds, for example through the consolidation of funding schemes into a leaner and a more streamlined approach or by creating a 'one-stop-shop' portal which can provide all the necessary support, documentation, contacts, any anticipated changes or updates to schemes. A partnership service which provides a portal is being developed to help Scottish businesses find information, advice and support[53]. However, this service is not currently a dedicated portal for industrial decarbonisation.

Extending decarbonisation benefits beyond local industrial sites

Extending the boundaries of decarbonisation projects beyond individual sites to include local community benefits helps drive these initiatives forward by leveraging the role of the public sector. A whole system approach should be adopted and could be coordinated through the engagement of local councils with industry - developing master energy plans at local authority levels[54]. The EIIs have excess low grade and underutilised heat, generated from CHP systems that can be extended for use within communities and for district heating.

In some industries, such as Scotch whisky, many individual sites are in close proximity to one another, but in relatively remote areas and away from industrial clusters. Developing small hubs around these sites, combined with local community infrastructure can enable cost sharing amongst several parties. This is relevant to the Speyside area where more than 50 distillers are challenged by a lack of infrastructure which can slow down the progress of industrial decarbonisation.

Value chain collaboration

Value chain and cross-industry collaboration is fundamental for large-scale infrastructure development and for major energy efficiency initiatives. Bringing different industries together to leverage infrastructure-sharing opportunities can be facilitated by the Scottish Government and its agencies. This can be mobilised through the presence of industrial alliances and research centres – for example NECCUS and the Industrial Decarbonisation Research and Innovation Centre[55] planned at Edinburgh's Heriot-Watt University – to synchronise the progress across different parts of the value chain, ensuring transparent communication and trust between government and the private sector.

Furthermore, the creation of working groups between government, academia, business partners and industry can influence strategic priorities and drive research and development programmes for innovative technologies, from pilot to commercial scale. This is critical for CCUS and

[53] https://findbusinesssupport.gov.scot/

[54] These plans for industry could take inspiration from the Local Heat and Energy Efficiency Strategies (LHEES), which seeks to deliver energy efficiency of buildings and heat decarbonisation measures and would allow local authorities to prioritise and target work.

[55] Industrial Decarbonisation Research and Innovation Centre – proposed at Heriot-Watt university, the centre focuses at a UK level on the innovation and research needed to make industrial decarbonisation (focusing on clusters) possible.

electrification of heat, where demonstrations can exceed the capacity of individual companies and should be executed on a large-scale partnership level.

At the downstream side of the value chain - the consumer side - it is important to continue to influence public opinion about the importance of low-carbon products and services, and the links to local community benefits. This maintains a steady demand for these products and sustains industry competitiveness.

Box 8: Examples of successful projects

Aberfeldy, Tomatin and Balmenach distilleries: The importance of available funding to promote industrial decarbonisation strategies is exemplified through the £5m in funding that the Green Investment Bank and the private sector made available in 2014 for fuel-switching projects in Scottish distilleries. The Aberfeldy, Tomatin and Balmenach distilleries have successfully replaced their heavy fuel oil boilers with biomass boilers. In doing so, greenhouse gas emissions from these facilities can be reduced by approximately 80%. Several key enablers described above allowed for the success of these projects:

- Value chain collaboration: Exploitation of industry synergies was essential, as part of the funds for the projects were provided by Balcas Limited, a manufacturer of wood pellet biomass which now supplies the distilleries.
- Extending decarbonisation benefits beyond individual sites: The coordination to follow a common fuel-switching approach, in which the available funds and learnings were shared by multiple distilleries, allowed for these projects to be symbolic, making them more likely to be replicated.
- Reducing the financial barrier: The prospect of cutting fuel costs by switching from heavy fuel oil to wood pellets, and not just the prospect of cutting emissions, was used to justify the upfront expenditure. At Balmenach, an expected reduction in energy costs of up to 30% after adopting biomass boilers was reported.[56]

Value chain collaboration is by no means limited to biomass pellet manufacturers and distilleries. However, proximity between the manufacturers and users of biomass may be an important driver for industry synergies. More projects could arise if multiple businesses simultaneously state their intention to follow common decarbonisation goals, which could attract other businesses i.e. providers of new fuels, to exploit the emerging opportunities.

GSK pharmaceuticals Irvine plant: Successful industrial decarbonisation projects may arise for other reasons than purely emission savings. Large facilities, which consume substantial amounts of electricity, may decide to reduce their dependence on the national electricity grid and implement decarbonised solutions in the process of doing so. The GSK pharmaceuticals plant in Irvine is a successful example, where wind turbines, a natural gas CHP plant and a biogas facility have been installed to improve energy and electricity security[57]. All of these measures, while allowing a decreased carbon footprint activity, reduce

[56] Green Investment Group, Another Scottish Distillery Goes Green, 2014
[57] The University of Strathclyde – GSK Case Study on Industrial Energy Autonomy

the risk of being demanded to reduce national electricity grid consumption in case of supply scarcity, a scenario which led to significant financial losses by GSK in 2013.

Pilot plants and demonstration projects

These projects raise awareness of technologies' potentials and pitfalls, gather important performance data, and help remove costing and technical uncertainty and risks. Pilot projects are key in the process of accelerating technology scale-up but require significant upfront capital investment.

Box 9: How can some of these key enablers be addressed?

A series of recommendations have been identified to further strengthen the key enablers for industrial decarbonisation described above.

- Different industrial sectors and project types have differing needs, meaning no single incentive structure suits all project types. The UK and Scottish Governments should develop funding approaches which are flexible on a project-by-project basis. Doing so is likely to achieve the best results, although care must be taken to ensure a fair and just transition to net zero. Flexible incentive approaches which target specific subsectors and their technical commonalities - as opposed to targeting specific themes - would enable decarbonisation in a more cost-effective way. For instance, a cement plant – which can apply for fuel switching, energy efficiency or CCUS incentives separately – could achieve faster and more efficient decarbonisation if it could target multiple themes at once via one industry-specific incentive.
- In order to retain industrial competitiveness while decarbonising, the UK Government should consider adopting a carbon border adjustment policy. This can help industry decarbonise while competing in the international market, though difficulties remain in the accounting and trade agreements required and for industries which export a high proportion of their production.[58,59] Securing demand for low-carbon products can also help to tilt the balance in favour of decarbonisation while limiting the amount of direct support industrial sites need. However, in business-to-business transactions this has limited applicability. A possible carbon border adjustment at a UK level could contribute towards foreign industrial decarbonisation - especially of important trading partners - in addition to bringing additional benefits such as protection against carbon leakage.
- Industrial partnerships which encourage cross collaboration of different stakeholders should be pursued i.e. those in clusters would reduce individual risk and capital

[58] Carbon border adjustments are import fees levied by countries with a carbon tax or carbon price on goods manufactured in countries which do not impose either of these measures. The European Commission has proposed a carbon border adjustment mechanism for selected countries which, if successful, is scheduled for 2021. A UK Lords select committee has been appointed in order to evaluate the trading implications that an EU carbon border adjustment could have for a post-Brexit UK.

[59] Rethinking Decarbonisation Incentives: Future Carbon Policy for Clean Growth, Energy Technologies Institute

involvement in these types of projects and simultaneously allow decarbonisation benefits from demonstrators to be communally unlocked for multiple participants at once.

4.2 A development pathway for industrial decarbonisation in Scotland

4.2.1 Likely development of decarbonisation projects

The future delivery of the industrial decarbonisation projects identified within this study would be highly project specific. Further development and implementation of projects over a short-to-medium time period of ~10 years would depend on a complex mix of factors. These are illustrated below, with reference to the themes identified previously.

Current project stage

Government policy intervention can more easily shape the 'pipeline' environment for projects in the earlier stages of development, purely given the longer timescales involved. The earlier in the process of project development a project sits, the more their development can be managed, and the more reactive the projects can be to changes.

Projects likely to undergo implementation in the short term are expected to have extensive planning in place, and hence their timelines are likely to not be as responsive to policy changes or to support available for project development, having reached this stage of development on the basis of past conditions.

Project scale

The scale of projects also links into their development timescales and pathway. Small-scale projects, such as those on smaller industrial sites, have relatively agile or flexible timescales, if the correct incentives are in place. The limited scope and low number of partners involved in these (potentially just an industrial site and an engineering contractor) makes project management, decision making and planning more responsive.

Large infrastructure projects, or those involving a consortium of partners, or multiple stages can be slower to progress. Further, the time required to plan and make investment decisions is longer. Partners working together in an overarching structure is better than a piecemeal approach, enabling larger, system-wide visions to be implemented.

Energy efficiency vs. deep decarbonisation

Although both result in the reduction of emissions, their capacity to decarbonise can vary considerably. Energy efficiency measures can bring incremental reductions to energy use and be specific to a certain process within an industrial site. On the contrary, deep decarbonisation measures can fully transform an entire industrial process and thus achieve a steep decrease in energy use or emissions, for instance by switching the fuel used to provide energy for an entire industrial site.

Both types of projects involve reductions in carbon emissions and hence a reduction in the carbon costs to industrial sites. However, there is an important distinction which, depending on the policy environment, could result in these broad themes following different pathways.

Energy efficiency projects usually result in a decrease in operational costs due to the reduced fuel consumption but require initial capital expenditure. These could be enabled to proceed with one-off capital support, to reduce the payback period to a sufficient level for industry co-investment. While a strong ongoing incentive for decarbonisation would provide additional encouragement for more projects, they are not contingent on ongoing support.

However, projects which are focused on deeper decarbonisation would, in the vast majority of cases, result in increased operational costs as well as an initial capital outlay. This means that without other incentives or reductions in carbon costs, they lack commercial imperative to progress. While industry has so far developed these projects to a certain level in anticipation of future ongoing support, significant investment is completely reliant on strong ongoing incentive that does not exist in the current policy environment.

Another project interdependency is the synergy between fuel switching and energy efficiency projects. Given that fuel switching is likely to involve switching to a more expensive or less economic fuel, this provides an increased driver for energy efficiency projects.

Given the current environment and lack of business models, it is likely that deeper decarbonisation projects, which rely on a critical level of ongoing economic support, would progress slower than energy efficiency projects that can become economic with incremental changes.

Economic support for decarbonisation

Above all, the key barrier faced by industrial decarbonisation projects is that the economic costs of decarbonisation outweigh the benefits to the industrial site, sometimes many times over.

If the policy environment ensures decarbonisation projects are at the top of the agenda and receive sufficient ongoing support, businesses, industrial sites or project developers are expected to progress projects swiftly through the pipeline to take advantage of the opportunity. This support can come in many different forms, and it is not possible for a ‘one size fits all’ approach to achieve a just and fair decarbonisation pathway.

Box 10: What can be done to ensure the timely delivery of the pipeline of industrial decarbonisation projects?

These recommendations have been identified based on the different project factors which influence the progression of the different decarbonisation themes in the pipeline:

- Resources to support project development should focus on the needs of the next wave of projects, rather than those very close to implementation. To build confidence for future programmes, it is important to ensure currently existing funding mechanisms continue to operate, rewarding and supporting projects close to or at implementation.
- When changes to funding schemes come into place, projects which have reached a certain stage of development should be given the choice to either utilise the new rules or to take advantage of the old rules under which their initial planning occurred, in

order to encourage development over the long timescales typically necessary in industry. This can allow project design to proceed with certainty over future returns.

- Large infrastructure projects need robust, efficient and neutral decision-making which enable a fair and equitable solution to be found quickly when the interests of partners inevitably conflict. This can be achieved if large infrastructure projects receive centralised coordination by public bodies or alternatively by introducing public-private partnerships for this project type.
- Business models which account for ongoing support for deep decarbonisation projects needs to be established in the near future, due to the time involved in the different stages of project development. This is critical for current deep-decarbonisation projects to progress on schedule and for new projects to begin progression through the pipeline.
- Incentives should be designed to reward synergies between fuel switching and energy efficiency, potentially with sector-specific rather than theme-specific funding, so that this is taken into account in initial project design and opportunities are not lost or delayed.
- The Scottish Government needs to proceed with a varied approach to industrial decarbonisation, taking into account sectors' different customer base, fuel use, geographical location, and many other factors. Some incentive mechanisms are more appropriate for some sectors, and the sequencing of these is key in defining the decarbonisation pathways. For example, passing increased costs to consumers is only possible where sites are not competing internationally, whereas direct ongoing support for fuel costs or facilitating demand for low-carbon products is applicable to a greater or lesser extent across the majority of sectors.
- Depending on an industry's contribution to Scotland's ambitious target to reduce GHG emissions by 75% by 2030, it may be more desirable for the Scottish Government and industry to fast track project development on those energy efficiency projects, which can have a broader impact over multiple EIIs.
- Scottish Government should encourage wider cross collaboration of companies in industry clusters, promoting additional process change and resource efficiency projects by unlocking shared resource utilisation. In addition, new projects could also be enabled by business models which promote the circularity of resources and energy sharing, where otherwise wasted products become marketable by-products.

4.2.2 Framework to overcome key barriers

Enabling industrial decarbonisation projects in Scotland requires industry, government, and project developers to work together. As the optimal pathway to industrial decarbonisation is not fully known, compromise is necessary between the flexibility to pursue that path and the certainty desired by industry. This requires a clear definition of what actions are necessary, who is responsible for them, and which actors would bear what costs and risks. A suggested framework to address the barriers to enhance the development of industrial decarbonisation projects is shown in the diagram below.

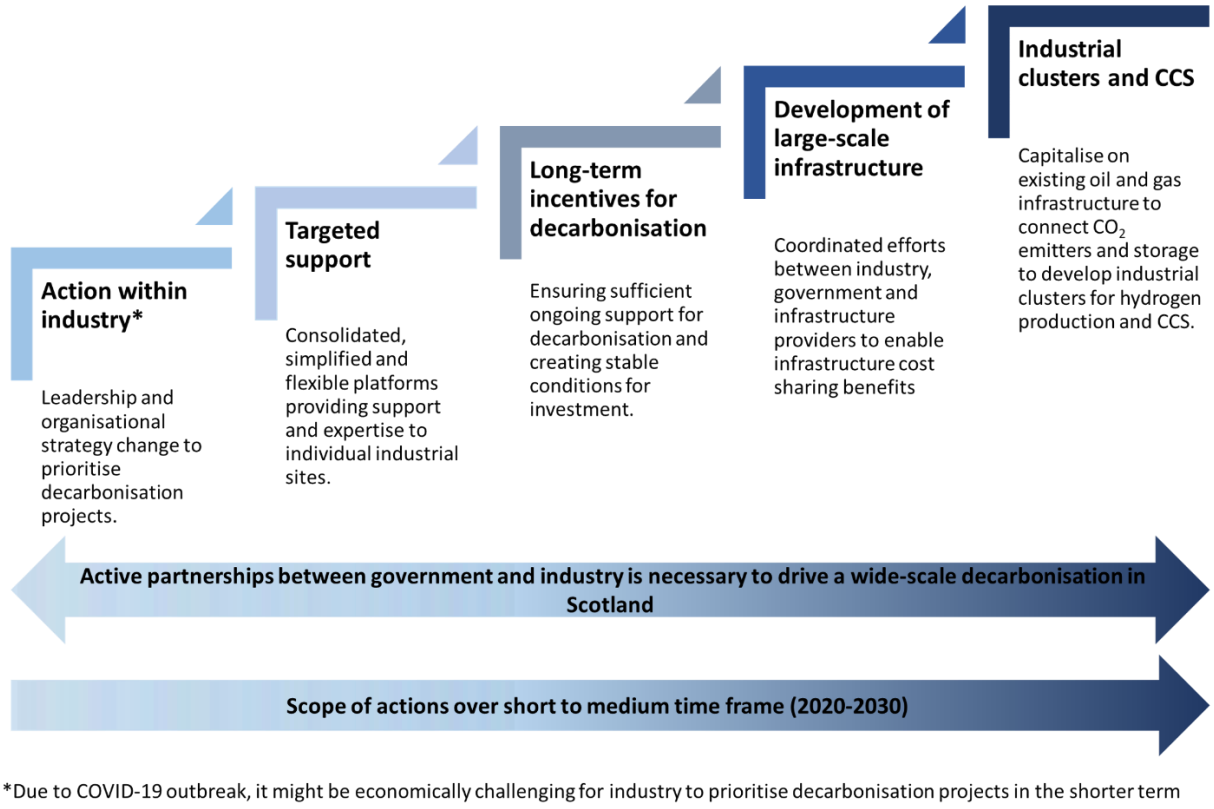

Figure 4-1: A suggested framework to address key barriers to industrial decarbonisation

The suggested framework can be divided into five main actions which highlight the need for an active partnership between the government and industry. These are listed below in terms of chronological action timing:

- **Action within industry:** Conscious of the decarbonisation targets established in the CCP for 2032, industries should increase the number of decarbonisation projects to be included in their organisational strategy. These projects should include a plan and timeline for execution so that the Scottish Government can actively inform itself on the horizon for decarbonisation projects.
- **Targeted support:** By observing the changes in industries' strategies and the resulting intended decarbonisation projects, the Scottish Government can then actively seek a bi-lateral partnership with Scottish industries. Active communication will allow for targeted support, which could be premeditated, contingent on the delivery of the point above. This communication can be active, through support and expertise, and passive, through a platform to inform on funding schemes and on other relevant data.
- **Long-term incentives for decarbonisation:** Long-term incentives would enable industries to follow coordinated and communal strategies to decarbonisation, as opposed to today's scenario where some individual sites are moving earlier and are thus facing higher costs and risks. This stage is considered key to ensure Scottish industry is kept competitive and to create the necessary momentum to enable posterior deep decarbonisation of the actions to follow.

- **Development of large-scale infrastructure:** This action is expected to bridge the different decarbonisation interests of individual industries, which on their own would only have a limited capacity to decarbonise. Action within industry and targeted support will enable a phased approach to decarbonisation but coordinated efforts to rollout infrastructure at scale will truly enable deep decarbonisation.
- **Industrial clusters and CCUS:** The last action will allow industries to achieve deep decarbonisation by creating the necessary CCUS and hydrogen supply chains. The development of large-scale infrastructure will connect different industries, both at a regional and national level, with producers of clean fuels and points of CO_2 storage.

Project sequencing

When assessing the future development of industrial decarbonisation projects, there often are interdependencies between projects, where one project relies to some extent on another. Under these circumstances, careful coordination and sequencing of projects is key to success, for example by ensuring sufficient electricity grid reinforcement takes place before electrifying heat at an industrial site, or by developing CO_2 storage and transportation infrastructure prior to deployment of CO_2 capture.

Where possible, phased implementation of whole system decarbonisation solutions can be a useful way to deploy in stages, enabling both lower cost initial projects, as well as building confidence in the solution. The benefits of oversizing infrastructure (as one large installation or construction phase may, in the end, be more efficient than several phases) vs. a phased development (less risk of redundant infrastructure) need to be balanced.

Careful government allocation of resources and priorities, and a strategic long view on policy, could influence optimal project sequencing to some extent, although industry's own investment views also needs to be regularly considered. Industry alliances such as NECCUS, if sufficiently comprehensive and neutral, can play a key role in coordination, enabling industrial sites to understand where they fit into the pathway to net zero.

Providing a pathway for project sequencing in the short and medium term

The development of the different industrial decarbonisation themes in Scotland in the short and medium term continues to be shaped as supporting policies, available funding and cooperation arise. The earlier deployment of some of the decarbonisation technologies comes with individual benefits to those who implement them. However, as more projects come to operation, general benefits are expected to be attained, as the different industrial decarbonisation themes start exploiting the benefits of project interdependencies.

Energy efficiency

Energy efficiency measures are expected to be implemented continuously across the pipeline of industrial decarbonisation projects. This is because projects within this theme are often site-specific and independent of large-scale infrastructure. Many of the catalogued energy efficiency projects have already been implemented, with those currently under development having a set date of completion over the next five years. The emerging energy efficiency trends in Scotland are varied, from staged investment plans to upgrade facilities, to energy saving measures via energy management plans.

Depending on the energy efficiency measure being implemented, it is expected that new projects which replicate successful past ones would arise in the pipeline. For instance, the battery storage at Ardagh's glass plant in Irvine is a solution which is suitable not only for the glass sector but to any EII which is susceptible to voltage dips or in search of higher energy security. Therefore, it may be more desirable to seek earlier project sequencing on those energy efficiency projects which can have a broader impact within multiple EIIs.

Process change and resource efficiency

Emerging process change and resource efficiency trends in Scotland include recovering energy from a site's own waste, enhanced recycling and material efficiency to provide by-products. Projects in this theme have the potential for short-term delivery, but the lack of a coordinated approach for large-scale projects suggests that additional work needs to be completed if any large industrial projects are to be delivered between now and 2030. Wider cross collaboration of companies in industry clusters would better utilise resources. In addition, the creation of business models which promote the circularity of resources and energy sharing is essential for correct project development and sequencing within this theme.

Fuel switching and CCUS

Earlier examples of fuel switching have come mostly from electrification and switching to biomass. Emerging trends have involved the substitution of heavy fuel oil boilers by biomass in the food and drink and paper and pulp EIIs. It is likely that electrification of low heating processes and biomass fuel switching projects continue to arise in the short term, if sufficient support is available.

To date, projects for hydrogen fuel switching have been pursued mostly for investigative purposes through R&D. This is likely to continue for the next few years as no hydrogen supply chain is available yet at scale. Given the interdependencies between the two themes, large scale sequencing of hydrogen fuel switching would link to large-scale roll out of CCUS. Relevant projects from the two themes[60] are expected to start initial commercial deployment around 2025 in some areas first, such as St Fergus or Aberdeen City. These projects would then continue to grow in a phased manner thereafter and in the 2030s to expand and include more regions.

Essential to the long-term roll out of hydrogen technologies is the success of short- and medium-term feasibility and demonstration studies, as these could potentially accelerate other projects which promote regional supply, storage, transportation and use of hydrogen in power, heat and industry applications. Further, it is important for hydrogen projects to work closely to achieve common goals. For example, successful findings in the H100 and the Methilltoune projects[61] have brought confidence in staged project delivery, something which could lead to the creation of a combined end-to-end hydrogen project[62].

[60] Some of these relevant projects and their earliest deployment dates include Acorn CCS (2024), Acorn CO_2 SAPLING (2024), Aberdeen Vision Project & Hydrogen Hub (2025), Acorn Hydrogen (2025).
[61] The H100 project, which explores the distribution of 100% of hydrogen, and the Methilltoune Project, which explores green hydrogen production and storage, are both in the feasibility stage. These decarbonisation projects should expect commercial scale rollout around 2030.
[62] The Institution of Engineering and Technology: Transitioning to Hydrogen: Assessing the Risks and Uncertainties

Regional projects

Regional projects which have already been implemented in Scotland have targeted themes such as fuel switching to biomass and energy from waste. They have long project completion timelines and may require partnerships between local and national authorities and the private sector. As they are generally not dedicated to industry, involvement in these projects up to 2025 is likely to remain indirect and come in the form of expansion of the existing projects rather than new initiatives. The high decarbonisation potential that these projects can offer may be limited up to 2030.

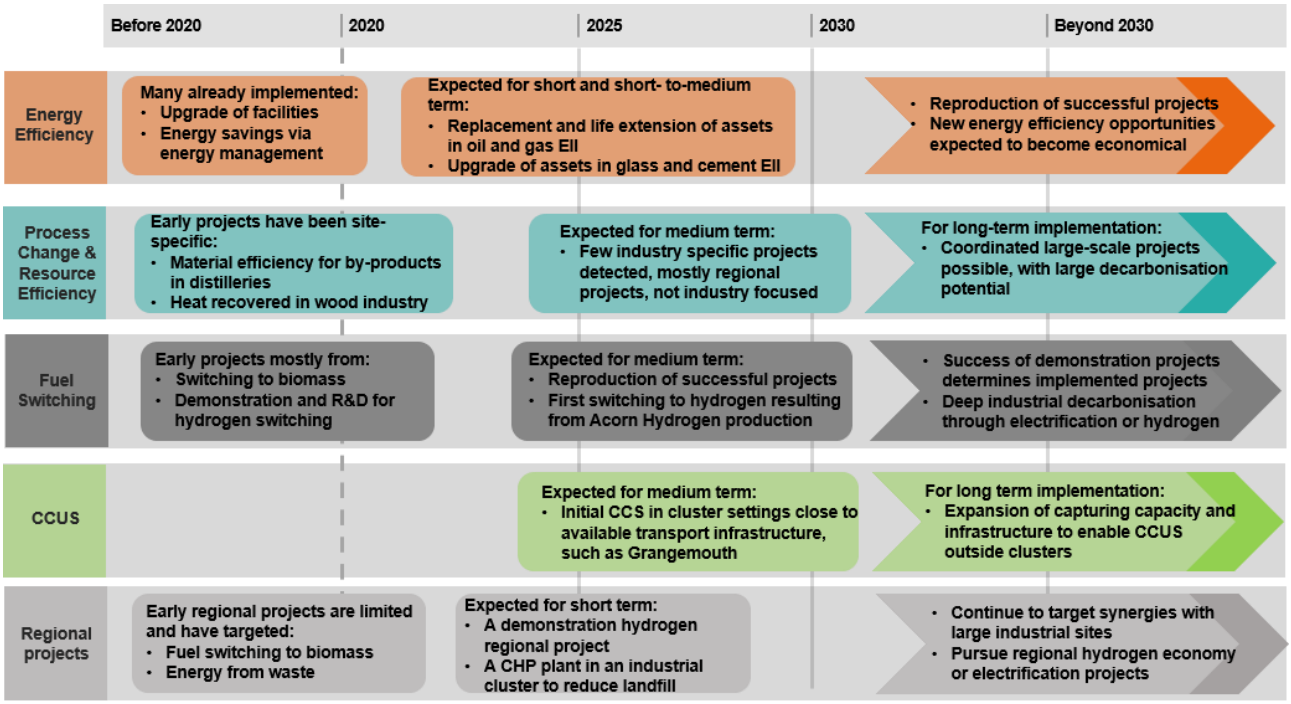

Figure 4-2: Realised or expected date of completion for the projects catalogued, and their potential decarbonisation impact. Short term: 2020-22; short-to-medium term: 2022-mid 2020s; medium mid 2020s-2030; long: 2030s

The figure above shows a possible sequencing of industrial decarbonisation projects within each theme for the medium and short terms. Possible factors to influence new projects in the long term beyond 2030 are also included.

In the short term, the pipeline is expected to focus on projects with low decarbonisation potential, in particular within the energy efficiency theme. A few examples of process change and resource efficiency are also planned for short-term delivery, but these are limited and concern mostly individual sites.

Few examples of regional projects specifically relevant to industrial decarbonisation have been identified in the project pipeline, and so the largest decarbonisation potential before 2030 may arise from expansion of existing regional projects to include industry or the creation of new ones.

Fuel switching is expected to take place throughout the entire timeline, with switching to biomass expected to come earlier than electrification and hydrogen. Projects within this category are

expected to grow in size with time, enabled by planned infrastructure projects expected during the second half of the 2020s.

The commissioning of CCUS projects should also be expected in the medium term but their initial occurrence in the pipeline will very likely be limited to certain regions, such as the North East of Scotland or in the Grangemouth industrial cluster.

Box 11: Possible effects of COVID-19 on the development pathway

The COVID-19 outbreak is having considerable repercussions on the Scottish economy and the wider UK economy. While the full extent of the impact is subject to the evolution of the pandemic and the duration of the restrictions, the Office for Budget Responsibility has forecast a 13% fall in UK GDP for 2020[63]. In Scotland, another study forecast GDP losses in 20Q2 of 20-25%, with highest output losses in the construction and non-manufacturing production sectors.[64]

The 10-year timescale for the implementation of industrial decarbonisation projects implies that - despite the initial economic shock - COVID-19 would not likely have a huge impact on the project sequencing estimated in this study. However, in the nearer term, it is possible that the halt in production and the resulting drop in margins for many industries could result in a partial relocation of funds - whose original use may have been to address decarbonisation projects - to cover more pressing needs or to conserve capital.

A review of the timelines for some of the earlier industrial decarbonisation projects may be undertaken, such as INEOS's six-month delay for the shutdown of the Forties Pipeline System needed to complete upgrades[65]. Other projects at a similar stage of development within the decarbonisation pipeline could become affected in a similar manner - especially those which are developed faster - such as energy efficiency projects. Capital expenditure of projects which have not yet reached financial close may be postponed, but short- and medium-term industrial decarbonisation projects in Scotland are expected to continue to progress forward. Projects further behind in the pipeline such as infrastructure, fuel switching and CCUS projects would have the opportunity to adjust.

As shown in Figure 4-1, the two earliest requirements needed to address the key barriers to industrial decarbonisation are action within industry and targeted support. The development of these early stages of the framework may continue once the estimated three-month restriction period is terminated: government willingness to cooperate and available funding

[63] Figure updated on the 14th of May from the Office for Budget Responsibility's Coronavirus Analysis. The figure assumes a three-month lockdown scenario where economic activity gradually returns to normal over the subsequent three months. Next update to the figure is expected for the 14th of July.
[64] Coronavirus: quantifying the impact on the Scottish economy article. Fraser of Allander Institute, University of Strathclyde. Figure estimated on the 7th of April. The figure assumes restrictions to continue for a three-month lockdown period.
[65] This shutdown was required to perform the upgrades to the Forties pipeline needed to deliver a 20-year lifetime extension aimed at upgrading technology and modernising the environmental systems. Sourced from "Up and running: inside INEOS' decision to keep the Forties pipeline flowing, Offshore Technology, 2020".

streams have not been compromised, with new grants being allocated to the Acorn Project and to the NECCUS collaboration as examples of evolving projects.[66,67]

5. Conclusion and next steps

This study is a step towards understanding the challenge of decarbonising Scottish industry – through assessing what projects exist and what issues in project development they have encountered. Industry engagement emphasised the crucial role the Scottish Government needs to play in supporting decarbonisation while retaining Scottish industry's competitiveness; the lack of economic incentives or business models for decarbonisation continues to drive the discussion. While this is the key driver for how decarbonisation projects generally develop into the future, individual projects will succeed or fail depending on their own unique combination of factors.

Central coordination of project sequencing, whether government or industry led, helps to reduce external causes of project failure and can facilitate a smoother transition to net zero. As part of this, the database of industrial decarbonisation projects catalogued by this study and held by Scottish Government is an important resource. It currently shows a snapshot of the current environment, and needs to be kept up to date and extended to draw further conclusions and ensure continued use.

Key recommendations for the short and medium term to enable project development

Recommendations on specific measures to be considered during the development pathway have been highlighted through the report. These have been summarised and collated into six key recommendations for action for the short and medium term:

Short term: These recommendations should be considered for adoption in the short term, as their function is to shape ongoing work on funding and support programmes and raise awareness at an enterprise level for industrial decarbonisation.

- **Recommendation 1:** The creation of a single portal through which Scottish industrial sites can access all funding schemes, supporting documents and guidelines. Sites need high-quality advice and support to minimise the lack of capacity which currently exists to work through the complexities of the policy and funding landscape. Such a portal could also reduce any potential gap in competencies or experience which industries seeking to decarbonise may have, especially SMEs.
- **Recommendation 2:** In the private sector, adapting business and corporate strategies to emphasise energy efficiency, decarbonisation, and sustainability programmes is a key

[66] Acorn Hydrogen awarded funding from UK Government competition, SCCS, 2020
[67] Scotland's decarbonisation ambitions get cash boost from UK Gov, Gasworld, 2020

goal. Influencing key executives and ensuring these programmes play an integral role in future business competitiveness will encourage business leaders to prioritise them.

- **Recommendation 3:** Funding programmes and any other financial mechanisms which are developed should be flexible enough to ensure that the specific contexts and issues of each applicable industrial sector are accounted for. This might involve providing sector-specific rather than theme-specific funding to ensure synergies between themes are integral to the design.

Medium term: These require considerable preparation and cross-collaboration between industry, government and other stakeholders, as well as additional studies to better understand the socioeconomic implications of these major recommendations.

- **Recommendation 4:** Implementation of a business model within a supportive economic framework to reduce the ongoing costs experienced by industrial decarbonisation projects in Scotland. While this is likely to fall somewhat under the remit of the UK government, the Scottish Government needs to ensure this is fit for purpose in the Scottish context and that costs are flexibly socialised between private and public sectors where appropriate.
- **Recommendation 5:** A collaborative approach to technology and project development across Scottish (and wider UK) industry. Coordinating the effort between companies in a way that does not impact upon their individual competitiveness can achieve synergies and maximise the 'learning by doing' achieved in projects. Collaboration, which can be done in the form of industrial or public-private partnerships, also aids with project sequencing, ensuring a smoother transition to net zero.
- **Recommendation 6:** Specific focus should be paid to deeper decarbonisation projects

  (and the large-scale infrastructure projects necessary to enable these) as their success is critical to meeting net-zero targets while retaining Scottish industry. To achieve these, ongoing economic support for these projects must reach the critical level and be guaranteed over a long time period.

6. Appendix: Project database

This section explains the methodology followed in the process of cataloguing the database of industrial decarbonisation projects in Scotland. In addition, project activity, number of projects per theme, technologies used and other relevant information is also included at a high-level due to the sensitive nature of some of the content of the project database which resulted from stakeholder engagement.

Methodology employed for data collection

Collection of market intelligence data was performed both through engagement with industry stakeholders and through research done by Element Energy.

The project information considered of most value for the completion of the project database includes the project's industrial decarbonisation theme and industrial sector; technology adopted, project stage and location; stakeholders and funding involved, although further information was collected.

A considerable part of the aforementioned project information was found from sources within the public domain, and sources employed include governmental websites, relevant company websites, industrial decarbonisation reports, company presentations, annual reports, specialised digital newspapers and others which have been accordingly referenced where needed. Engagement with industry stakeholders also resulted in further confidential findings on industrial decarbonisation projects. Stakeholders engaged with include industrial sites, trade associations, private companies, industrial alliances and Scottish advisory bodies.

The use of publicly available sources presented an effective method to find project examples, which yielded an efficient methodology given the time available to complete this research. The varied nature of the sources consulted allowed for confirmation of information obtained from public sources at the time of stakeholder engagement by relevant stakeholders.

However, it is likely that gaps exist in the project database between the existing and reported number of projects examples. The number of stakeholders engaged with broadly covers the different EIIs and industrial decarbonisation themes discussed here, but engagement with more stakeholders could have resulted in more project findings, especially regarding those of a more confidential nature.

Further work on project cataloguing should focus on new stakeholder engagement activities in order to find projects which might have been missed or future projects. Continued stakeholder engagement to update the status and project stage of the catalogued projects would allow for a more exhaustive understanding of the most important drivers influencing project development and execution. This information could then be fed into the analysis of project sequencing and the expected timeline and thus a more robust development pathway could be produced.

Summary of contents of project database

The total number of Scottish industrial decarbonisation projects contained in the project database is around 50. These projects have also been catalogued in terms of their geographic location, which is exhibited in Figure 6-1.

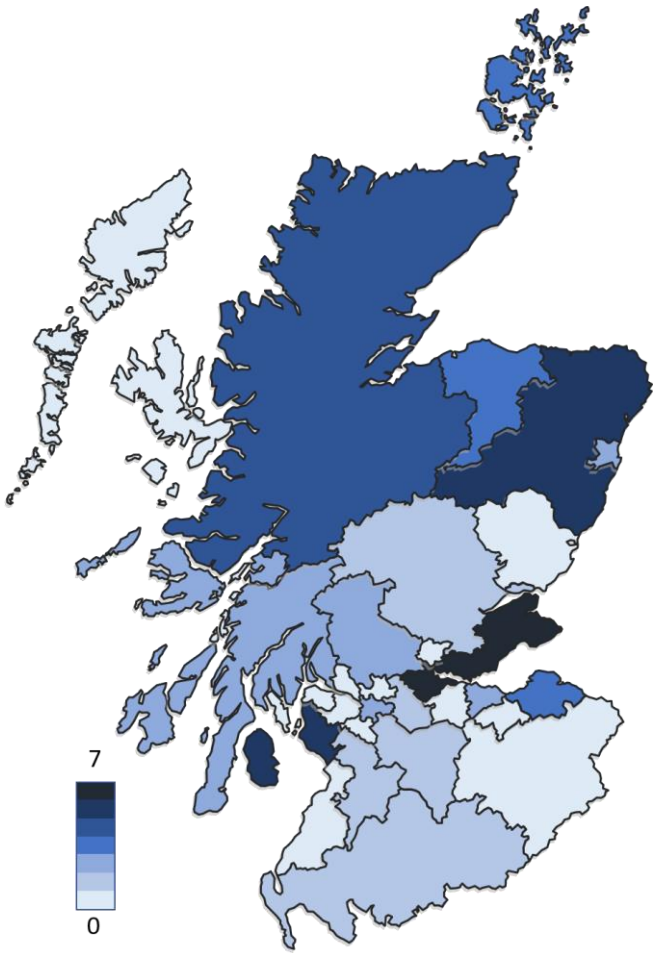

Figure 6-1: Map of industrial decarbonisation projects in Scotland

Industrial decarbonisation projects in Scotland vary widely by location. There is a large number of projects in the Central Belt of Scotland – and in particular in the Grangemouth industrial cluster - where much of the industrial activity in Scotland is found. In addition, the importance of Aberdeenshire as an energy provider for Scotland and the wider UK is reflected in the number of industrial decarbonisation projects found in this region. Lastly, the high number of projects in the Highlands and Moray is mostly linked to the food and drink EII, where many of Scotland's distilleries can be found.

The database projects have also been broken down in terms of their relevant EII and in terms of industrial sector for those projects which are not directly attributable to an EII, as shown in Figure 6-2. Food and drink, as a very important EII in Scotland, leads in terms of projects. Additionally, the number of whole-system and hydrogen projects highlight Scotland's position to pursue projects which can bring about deep decarbonisation.

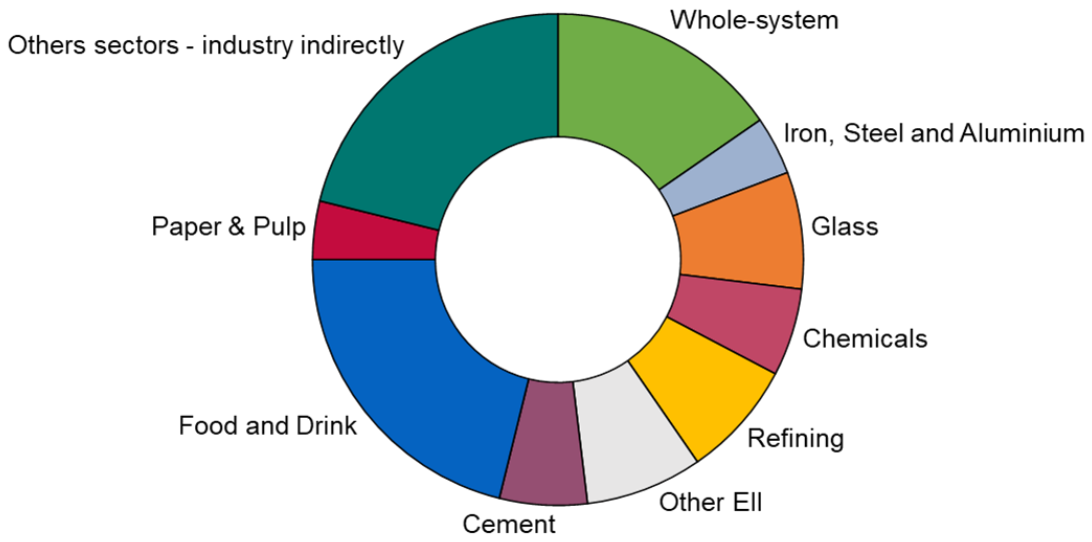

Figure 6-2: Breakdown of number of decarbonisation projects by industrial sector

Some of the catalogued projects are already in operation, while others are at different stages of project development. In addition to private funds, some of these projects have additionally received, or are currently receiving, some form of funding support from public organisations. Figure 6-3 provides a graphic summarising the different projects catalogued in terms of their industrial decarbonisation theme, along with the total public funding received by these and the overall number of projects within each theme which are currently in operation.

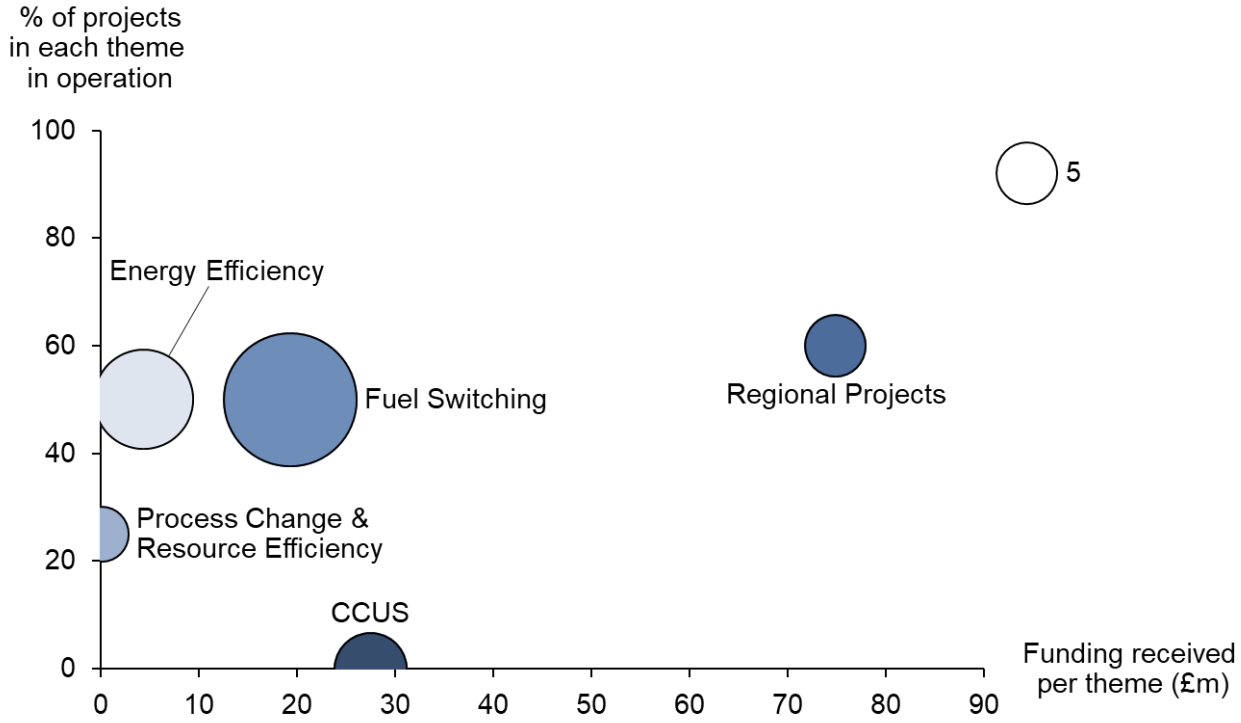

Figure 6-3: Industrial decarbonisation themes plotted based on the total funding received (x-axis) and % of projects in each theme which have been completed (y-axis). Size of the spheres indicates total number of projects per theme

It is noteworthy that many database projects fall within different themes - industrial decarbonisation projects can tackle multiple themes at once. For instance, the replacement of a furnace from heavy fuel oil to biomass can also result in an increase in energy efficiency. In order to present the graph above, projects have been kept to their main theme. This results in few Process Change & Resource Efficiency projects, whereas in reality this is a theme exhibited as a secondary measure of decarbonisation in other projects outside of this theme.

Fuel Switching and Energy Efficiency are the largest themes in terms of number of projects catalogued. The relatively small project scale and availability to use commercially proven technologies has enabled half the projects from these two themes to be already in operation. In terms of public funding received, Regional Projects top the list. The large-scale nature of these projects, which enable decarbonisation in other sectors besides industry, implies that they can sometimes only progress with the aid of public funding. CCUS, although early in terms of theme maturity, has received substantial funds, especially when the number of projects in the theme is considered. The graph above emphasises the importance of initial public funds in order to catalyse the development of decarbonisation themes without sufficient examples of developed projects, such as CCUS.

In terms of current stage of the different projects within the project database, these can be broken down depending on how close these are to completion: concept, feasibility, development, demonstration, and operation. This is shown below in Figure 6-4.

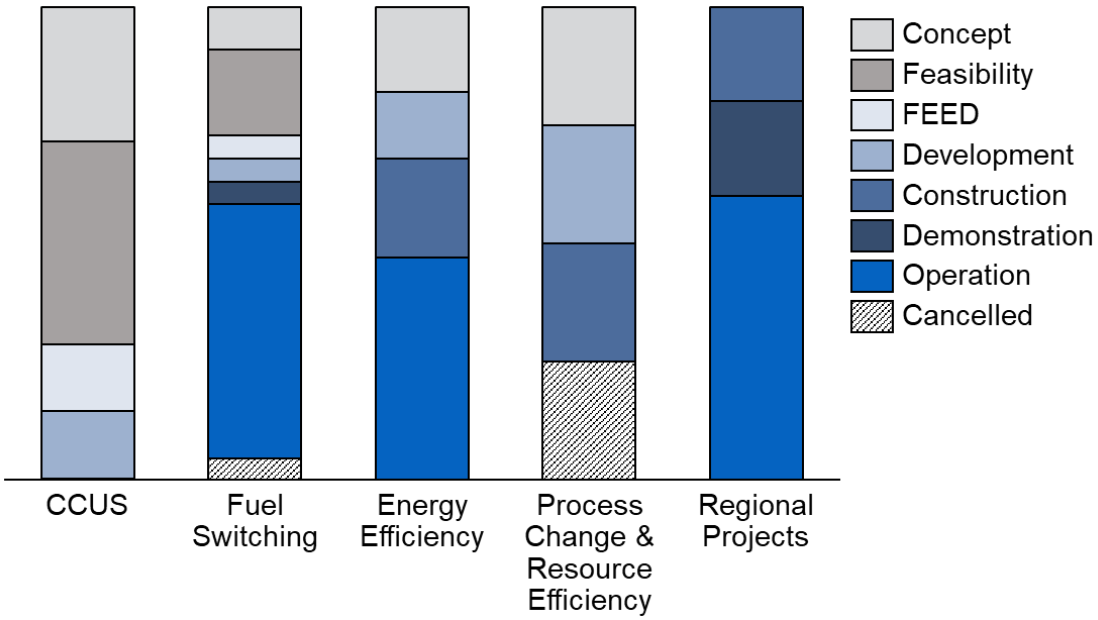

Figure 6-4: Current project stage of the different projects within each major theme. The development section also includes projects currently in construction.

The figure highlights the contrast in terms of development and stage of maturity of the different industrial decarbonisation themes, which is most evident between deep decarbonisation themes such as CCUS and the Energy Efficiency theme. Within the Fuel Switching theme, a considerable number of the projects which are not yet in operation concern switching to hydrogen - which can provide deep decarbonisation opportunities - as opposed to other fuel switching options, such as the more mature biomass technologies.

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