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FOSTERING DISRUPTIVE INNOVATION

INDUSTRY TRANSITION PLATFORM

A report for

CLIMATE GROUP

The Climate Group

Element Energy

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This report has been prepared by Element Energy.

Element Energy is a strategic energy consultancy, specialising in the intelligent analysis of low carbon energy. The team of over 70 specialists provides consultancy services across a wide range of sectors, including the built environment, carbon capture and storage, industrial decarbonisation, smart electricity and gas networks, energy storage, renewable energy systems and low carbon transport. Element Energy provides insights on both technical and strategic issues, believing that the technical and engineering understanding of the real-world challenges support the strategic work.

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Disclaimer

Executive Summary

Governments of highly industrialised regions face the critical challenge of reducing industrial emissions to meet deep decarbonisation or net-zero emissions targets while simultaneously ensuring that the incumbent and future industrial activity maintains its competitive advantage in the long-term. To meet this aim within the Under2 Coalition, the Industry Transition Platform (ITP) works with regional governments to develop strategies to reduce industrial emissions while supporting economic growth, job creation and private sector prosperity.

Building upon this vision, this study explored the potential disruptive innovation (technologies, policies, and finance/business models) available for decarbonising industry which governments should look to incorporate into their future industrial decarbonisation plans. The research in this study has been tailored to the following regions participating within the ITP:


North Rhine-Westphalia (Germany)


Wales (United Kingdom)


Emilia-Romagna (Italy)

California (United States)


Lombardy (Italy)


Minnesota (United States)


Scotland (United Kingdom)


Quebec (Canada)

Regions face unique challenges but can share transferable learnings

Regions vary in their size and scope of industrial emissions, presenting unique challenges to the approaches and strategies governments can take to support decarbonisation efforts. To highlight these differences, this study has characterised the industrial landscape of each of the participating regions through an analysis of:

- **Greenhouse gas (GHG) emissions sources** and distribution across the regional economies and industrial sectors, and where available, fuel use in industry and the required electricity generation.
- **Primary industrial sectors** (e.g. iron and steel, refining, cement, metals, manufacturing, etc.), major sites, key industrial organisations and multinational companies.
- **Current health and outlook for the regional industrial activity** (e.g. future private sector investments or plans, new businesses or plants, etc.).
- **Governments' industrial decarbonisation plans**, policies or programming currently in place or in the pipeline and the extent to which these are aligned with other sectors of the economy to drive deep decarbonisation (i.e. economy-wide climate change plans).

Despite the differences highlighted, there were also a number of shared commonalities amongst the ITP regions (shown in Table 1). These included regional responses to the COVID-19 emergency and government experience engaging with industry, which showcase transferable learnings that governments can use to increase their influence with multinational companies and other private sector actors.

Table 1 Commonalities among the regional governments within the ITP team

Responses to the COVID-19 emergency	Experience engaging with industry
Reports with recommendations that highlight necessary actions to transition towards a net-zero economy (i.e. 'green recovery') **Pro-active management of existing programmes** to respond to the priorities of specific industrial sectors impacted by the current and post-COVID-19 economy **Structured intelligence with industry** to establish how the crisis has impacted investment decision-making for industrial energy efficiency and decarbonisation projects, with a view to tailoring future funding and support to meet industry's changing needs Introduction of **new working groups, funding schemes, and recovery plans** to support businesses in accessing the opportunities of a post-COVID-19 low-carbon economy	**Roundtables and workshops between government and a broad range of industry stakeholders** to build platforms for engagement and collaboration and to gather more robust evidence and inputs on industrial decarbonisation planning and strategies **Focus groups with specific industrial sectors** to engage in more detailed discussion on challenges and opportunities for decarbonising, enabling government to evaluate effective policy and funding designs tailored towards the risks faced by key industrial sectors **Technology and innovation clusters** bringing together academia, private industry and government to share skills, ideas and resources to support the competitiveness of the industrial sector (i.e. bringing research and development projects to pilot-scale)

Future disruptive innovation options identified

In the next 10-20 years, low-carbon markets are expected to continue developing worldwide. In light of this, governments and multinational companies alike will need to be aware of the disruptive innovation that will eventually lead to deep decarbonisation in industry. The future options for disruptive innovation can take several forms and for this study have been assigned the following high-level categories and definitions:

- **Technologies:** Predicted to have large impacts across regional markets and play a key role in industrial decarbonisation as markets are disrupted with more stringent low-carbon procurement or increasing carbon pricing mechanisms.
- **Policies or finance/business models:** Predicted to directly drive disruptive innovation by reducing barriers (i.e. cost, regulatory, carbon leakage) for industrial decarbonisation, providing mechanisms to significantly reapportion the social cost of carbon and changing the value proposition of emerging deep decarbonisation technologies.

A global literature review of disruptive innovation in industry, including options adopted or in planning by governments outside the scope of this study was conducted. A condensed summary of the sub-categories of disruptive technologies, policies and finance/business models is shown in Figure 1 below. Full descriptions and examples of these options can be found in Chapter 3.

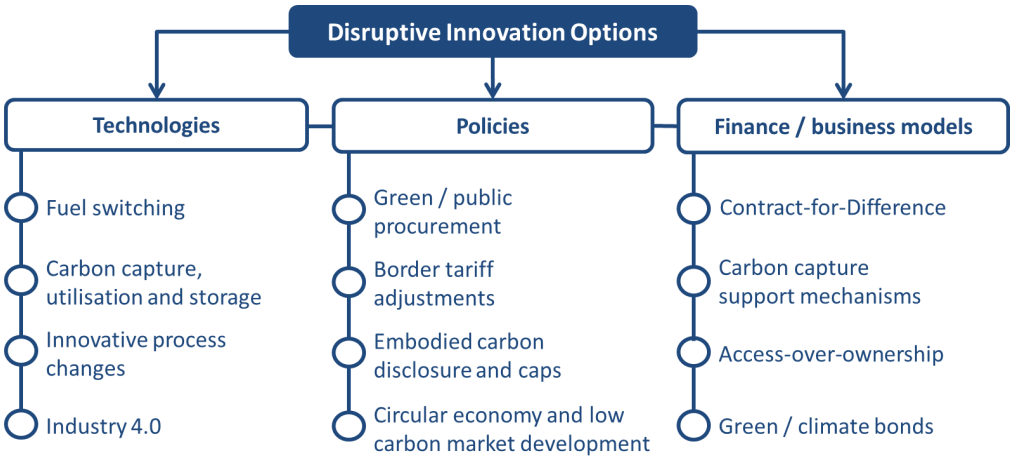

Figure 1 Overview of disruptive innovation options impacting industrial decarbonisation

Opportunities to foster disruptive innovation exist in each region

Based on the characterisation of the current industrial landscape of each region and analysis of opportunities for disruptive technologies, policies, and finance/business models, targeted recommendations were developed for the future industrial decarbonisation planning of each region. A condensed set of recommendations, providing one example for each region, is provided below (full set of recommendations in Chapter 4):

- **North Rhine-Westphalia:** Introduction of a new Contract-for-Difference (or similar) policy for industrial abatement options (fuel switching, process changes, carbon capture, etc.) to drive deep decarbonisation efforts beyond that imposed by the EU-ETS (EU Emissions Trading System) carbon market.

- **Emilia-Romagna:** Support for the uptake of additive manufacturing (e.g. 3D printing in manufacturing or construction sectors) processes alongside Industry 4.0 breakthroughs (e.g. advanced energy management or Internet-of-Things systems) would enable benefits that further support the region's direction towards a wider circular economy.

- **Lombardy:** Investigations into fuel switching to hydrogen or electricity should be evaluated as a potential low-cost, disruptive strategy to drive deep decarbonisation efforts across many existing manufacturing processes in the region (e.g. steam and water boilers, low and high temperature dryers or heaters, etc.) alongside other mixed fuel options for the cement / refining sectors.

- **Scotland:** Scottish industry may soon have access to a Contract-for-Difference (CfD) financing mechanism combined with an upfront grant support for CCUS projects. The UK government aims to have the CfD mechanism implemented in 2022 and is considering its adaptation over time to include other low carbon technology options (fuel switching, process changes, etc.).

- **Wales:** Plan and forecast for the uncertainties regarding new technology deployment (e.g. HIsarna process change with carbon capture technology) at Port Talbot's major iron and steel site, which will be a key driver for economies of scale within the South Wales industrial cluster and heavily influence the regional costs of abatement for fuel switching or CCUS.

- **California:** Plan and forecast for industrial processes that may require adoption of CCUS technologies (e.g. process emissions in cement and chemicals sectors) to achieve deep decarbonisation and how these may be supported by existing federal policies (e.g. 45Q tax credit) or require additional support.

- **Minnesota:** Development of "green product" incentives for industry via minimum product standards in public procurement guidelines (e.g. sustainable metals, plastics and pulp and paper products) to drive regional demand for low-carbon production methods via abatement technology adoption.

- **Quebec:** Strengthen embodied carbon reduction policies such as those in the regional Wood Charter, to include steel and concrete emissions and create a roadmap for introducing a carbon cap for regional building regulations or infrastructure projects.

Acronyms

AI	Artificial Intelligence
BTA	Border Tariff Adjustment
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CCUS	Carbon Capture, Utilisation, and Storage
CfD	Contract-for-Difference
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalents
ETS	Emissions Trading System
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWP	Global Warming Potential
IoT	Internet of Things
ITP	Industry Transition Platform
LEILAC	Low Emissions Intensity Lime & Cement
Mt	Mega tonne
NECCUS	North East Carbon Capture, Utilisation, and Storage
NRW	North Rhine-Westphalia
SWIC	South Wales Industrial Cluster

Note on terminology

Whilst Carbon Capture, Utilisation, and Storage (CCUS), Carbon Capture and Storage (CCS), and Carbon Capture and Utilisation (CCU) are often used interchangeably in the literature, for consistency purposes, this report primarily uses CCUS, with exceptions for when CCS or CCU is used directly in the cited sources or tailored to a specific region.

Contents

1 Introduction

This chapter introduces this report by providing an overview of the context and objectives of the study, followed by the scope of work and analysis undertaken by Element Energy.

1.1 Context

Within the Under2 Coalition, the Industry Transition Platform (ITP) works with governments from highly industrialized regions to develop strategies to reduce industrial emissions while supporting economic growth, job creation and private sector prosperity. The ITP have taken a particular interest in potential options for fostering disruptive innovation in industry, with the aim to promote industrial activity while reducing greenhouse gas (GHG) emissions. Throughout this project, state and regional governments worked together in groups to identify the key challenges they face in transitioning their industry to be low carbon.

The research has been tailored to the participating regional governments, including North Rhine-Westphalia (Germany), Emilia-Romagna (Italy), Lombardy (Italy), Scotland (United Kingdom), Wales (United Kingdom), California (United States), Minnesota (United States), and Quebec (Canada).

1.2 Objectives

To determine the disruptive opportunities for industrial decarbonisation planning that would be best suited for each regional government, this study was tasked with the following objectives (whilst acknowledging the uncertainty of future trajectories given the current international COVID-19 crisis):

- Develop a clearer picture of the industrial base of each participating region, as a foundation for future systems mapping to support smarter policy development and decision-making, and provide a comparison of the types of industries and decarbonisation plans across the ITP membership.
- Identify potential disruptive innovation (technologies, policies, and finance/business models) available for the identified industries and that may be applied/supported by regional governments.
- Identify successful avenues for engagement with industry stakeholders, including opportunities for increasing the credibility and influence of regional governments with multi-national companies.

1.3 Scope of work and analysis

The steps listed below were first taken to complete tasks on regional data collection and analysis:

- **Assessment of the industrial landscape of the regions**: A literature review of information available regarding the industry of each region was performed, assessing current industrial activity and a high-level outlook. Additionally, a brief review of industrial decarbonisation plans currently in place for the regions in the team was performed.
- **Stakeholder engagement:** Interviews with relevant government stakeholders within each region in the team were conducted to support the information and data gathering that was undertaken independently.
- **Region comparison and commonalities**: The collected information was analysed to assess potential commonalities among the regions and offer a comparison between the plans of each in their innovation towards industrial decarbonisation.

Afterwards, an independent assessment of disruptive options for industrial decarbonisation was performed. This began with a broad literature review to gather high-level information on future disruptive innovation options adopted by regions outside the team. Currently implemented technologies and pipeline policies or financing mechanisms of those regions were closely investigated to gather transferrable learnings for the regions in this study. Finally, all information on the characteristics of the regions in the team and on potential disruptive innovation options adopted by other regions were analysed to formulate targeted recommendations for the future industrial decarbonisation plans of each region.

1.4 Report structure

The remainder of this report is structured into 5 chapters as follows:

Chapter 2 presents the analysis of the current industrial landscape for participating regions in the study.

Chapter 3 presents the analysis of future disruptive innovation options adopted by regions outside the team.

Chapter 4 provides the one-page summaries and recommendations for disruptive innovation for the target regions.

Chapter 5 concludes the study.

2 Analysis of current industrial landscape

This section focuses on the industrial landscape characterisation and decarbonisation planning and programming within each region for this study, concluding with an overview of key commonalities between regions (focusing on regional responses to the COVID-19 emergency and government experience engaging with industry). Data was collected through discussions with and requests from relevant government stakeholders from each region. The variability of data aggregation and level of detail (i.e. emissions breakdown by source) was dependent on the availability of information collected at the time of this study. Emissions breakdowns are shown alongside a map highlighting the location of each region in dark blue.

2.1 Characteristics of the local industrial landscape of each region

North Rhine-Westphalia (Germany)

North Rhine-Westphalia (NRW) is the most important industrial region in Germany and one of the most productive in Europe. With many regional cities and industrial companies located along or near the Rhine River, NRW has flourished economically with an industrial base centered around the coal and steel, chemicals, machinery, metals and automobile industries.

The region's industrial activity emits approximately 62.7 $MtCO_2e$[1] annually, making up nearly 23% of the region's economy-wide emissions (247.7 $MtCO_2e$). Figure 2 provides a breakdown of NRW's industrial emissions by key sectors. NRW is also home to Europe's largest iron and steel site in the city of Duisburg, operated by Thyssenkrupp AG, which currently emits an estimated 19.2 $MtCO_2e$[2] annually.

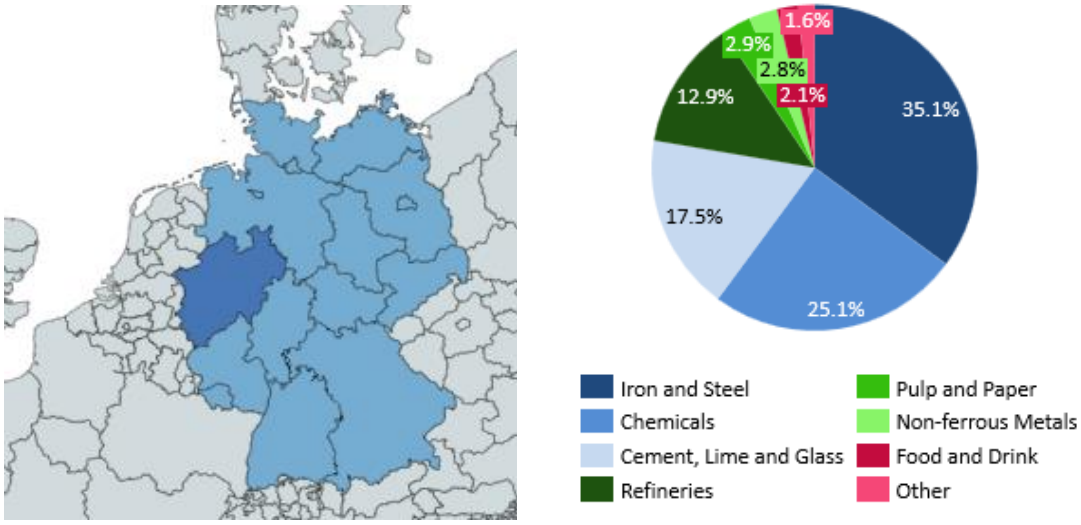

Figure 2 Annual emissions breakdown by industrial sector for North Rhine-Westphalia (2017)[1]

NRW's Climate Protection Plan (2015)[3] supports a resilient pathway to achieving emissions reductions in industry. This is further supported within the region's industrial decarbonisation planning, with the Energy and Climate Policy Framework, Strategies and Instruments (2016)[4] including actions on:

- Increasing energy and resource efficiency with efficiency loans from NRW.Bank and expansion of cogeneration with an impulse program to create financial incentives as well as through the targeted use of EU structural funds.

[1] Greenhouse gas emissions inventory, North Rhine-Westphalia 2017, LANUV technical report 95. Figure includes emissions from refineries under the "Energy Industry" economy sector.
[2] Based on IN4climate.NRW's estimate of Duisburg's steel production of 12 million tonnes of steel every year and the manufacture of 1 tonne of steel generating approximately 1.6 tonnes of CO_2 emissions.
[3] North Rhine-Westphalia's Climate Protection Plan
[4] Energy and climate policy framework conditions, strategies and instruments in NRW: A case study as part of the "Energy Transition Platform 2015-2017"

- Reduction of process-related emissions: the state government promotes open technology research and development in this area (also applies to carbon storage technologies).
- Interdisciplinary instruments to promote economic strategy and market competition alongside innovative solutions for environmental protection in small and medium-sized companies.

The region also hosts the IN4climate.NRW platform which facilitates collaboration between representatives from public, private and academic sectors, fostering a unique space in Germany in which to develop innovative strategies for a climate-neutral industrial sector. IN4climate holds policy working groups with government stakeholders as many as 4 times a year and also has separate focus groups that work with specific companies and sectors themselves.

Emilia-Romagna (Italy)

Emilia-Romagna today is one of the most developed regions in Europe and is a leading region in Southern Europe in terms of competitiveness, gross domestic product (GDP), industrial activity and research and innovation. Emilia-Romagna has strong industrial clusters centered on its manufacturing industries, with specialisation particularly around advanced manufacturing processes in the mechatronics and automotive sectors, two key sectors which are priority areas in the region's Smart Specialization Strategy (2015)[5].

As shown in Figure 3, combustion processes in industry alone make up 23% of the region's economy-wide emissions (total of 32.3 $MtCO_2e$). Emilia-Romagna is currently in the process of formulating a decarbonisation pathway (including for industry) to meet 2050 EU climate neutrality goals. As part of this process, the region is creating a new Regional Energy Plan and Job and Climate Pact, the latter of which includes setting up a working group to incorporate regional stakeholders (industry to be represented through the Confindustria, Association of Small Enterprises, Association of Artisans and the Labour union). The old Regional Energy Plan (2017-2019)[6] outlined a plan for 40% reduction in regional GHG emissions by 2030 compared to 1990 levels and included a target for 27% of the regional energy consumption to come from renewable sources by 2030.

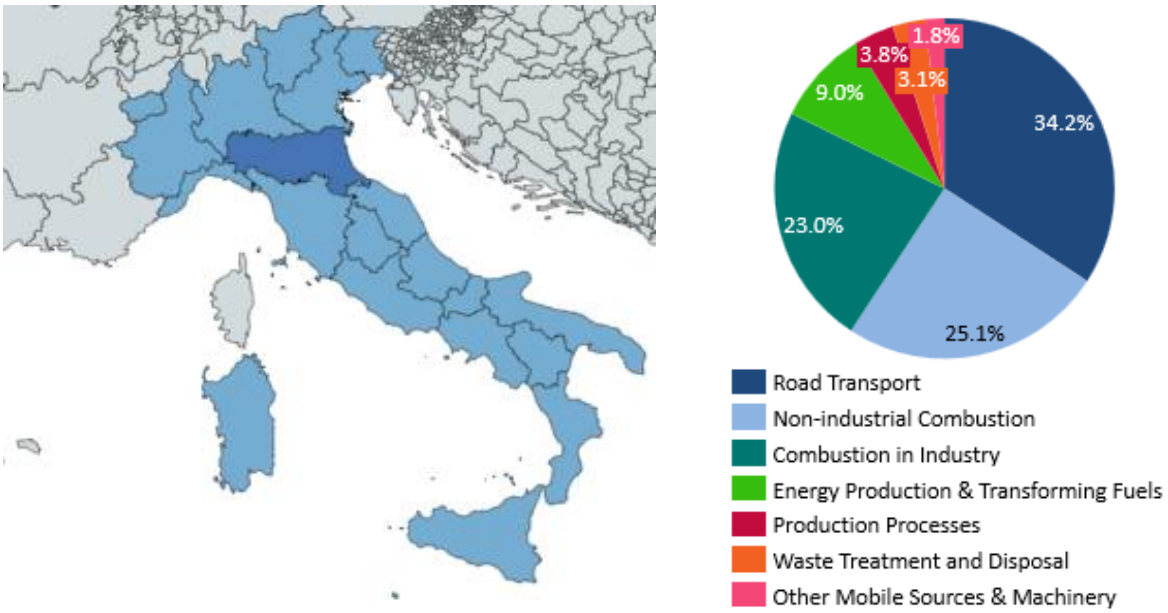

Figure 3 Annual emissions breakdown across the entire economy for Emilia-Romagna (2015)[7]

[5] Emilia-Romagna's Regional Smart Specialisation Strategy
[6] Emilia-Romagna's Regional Energy Plan
[7] Regional Inventory of Emissions into the Atmosphere of Emilia-Romagna Relating to the Year 2015, Final Report

Announced by Italy's Prime Minister in June 2020, Eni (Italian multinational oil and gas company) has proposed a plan for the world's largest CO_2 storage facility in the city of Ravenna[8]. The plan includes capture of CO_2 from industrial and gas power plants, partial utilisation of existing gas pipelines for CO_2 transmission and CO_2 storage in depleted gas fields in the Adriatic Sea off the coast of Ravenna (with a storage capacity of between 300 and 500 million tonnes). While Eni plans to finish preliminary studies and regulation checks by 2025, the project may receive political opposition due to environmental concerns before project execution is officially announced.

Lombardy (Italy)

Lombardy is one of the richest regions in Europe and the wealthiest in Italy based on GDP per capita. With 40% of firms based in Milan[9], the region boasts a strong and diverse industrial presence. Lombardy's main sectors are mechanical, electronics, metallurgy, textiles, chemicals and petrochemicals, pharmaceuticals, and food. Leading the development of advanced manufacturing in the region, the Associazione Fabbrica Intelligente Lombardia is a technological cluster with the main goal to foster research and innovation, promote best practices and enable technologies to support and develop the leadership and competitiveness of manufacturing businesses in the region.

Similar to many other regions, Lombardy's industrial manufacturing base still heavily relies on fossil fuels for energy and heating demands, with nearly 15% of the region's economy-wide emissions directly attributed to combustion processes in industry, as shown in Figure 4. Lombardy is working on a new regional energy programme, the second iteration of the Regional Environmental and Climate Energy Programme which will incorporate carbon neutrality by 2050 (aiming to be approved by regional parliament by the end of this year). The first iteration of the Regional Environmental Energy Programme (2015)[10] initially set out energy saving and renewable energy development targets for the region, with plans to develop biomass and solar to complement Lombardy's large hydroelectric power industry (it is Italy's biggest hydropower producer). The plan required a reduction in GHG emissions of 40% by 2030 compared to 2005 levels in-line with EU targets.

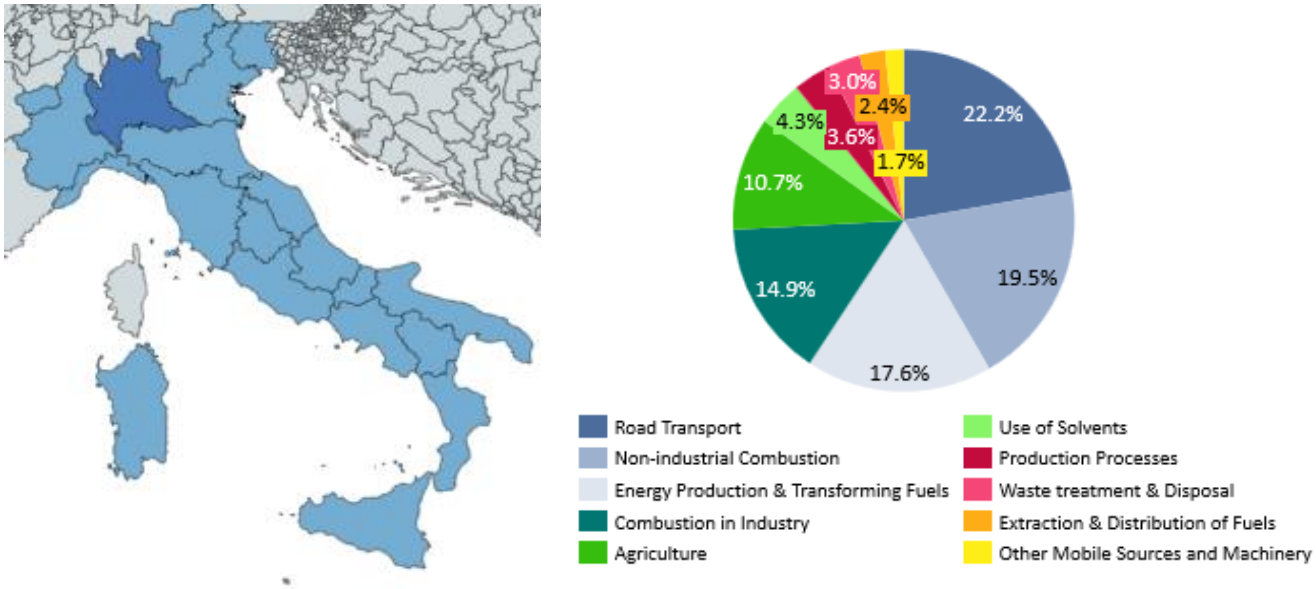

Figure 4 Annual emissions breakdown across the entire economy for Lombardy (2017)[11]

[8] https://www.eni.com/en-IT/low-carbon/catching-co2-off-coast-ravenna.html
[9] https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/lombardy
[10] Lombardy's Regional Environmental Energy Program
[11] Lombardy's Air Emissions Inventory

Lombardy has also set out a Roadmap for Research and Innovation on Circular Economy (2020)[12], which incorporates a framework for the development of a sustainable, low carbon, resource efficient and competitive strategy for the transition to a more circular economy. The plan is complemented by a Memorandum of Understanding between Lombardy and Eni on Sustainability and Circular Economy (2019)[13], which entails the joint study of industrial models for sustainable growth, considering efficient use of resources, extension of product lifetimes, sustainable energy products like biofuels and bio-chemicals, and biomass/waste products.

Scotland (United Kingdom)

Scotland has a core portion of its economy supported by energy intensive industries which in 2017 contributed to a large portion of the £12bn of gross value added and 180,500 jobs supported by the wider Scottish manufacturing sector[14]. In most cases, these industries are located within the Central Belt of Scotland, along with a high concentration of plants and facilities located in the Grangemouth cluster (total emissions approximately 4.3 $MtCO_2e$), providing port access to the North Sea and regional markets beyond.

Scotland's energy intensive industrial emissions, broken down in Figure 5, represent around 15% of total Scottish GHG emissions (6.1 of 40.5 $MtCO_2e$). Scotland's Climate Change Plan (2018)[15] provides proposals and 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 is also planning to issue an update to the Climate Change Plan in order to reflect the renewed 2045 net-zero target for Scotland, which was recently set into law under the Climate Change (Emissions Reduction Target) Act (2019)[16]. The law also embeds the principles of a just transition to reducing emissions in a way which tackles inequality and promotes fair work[17].

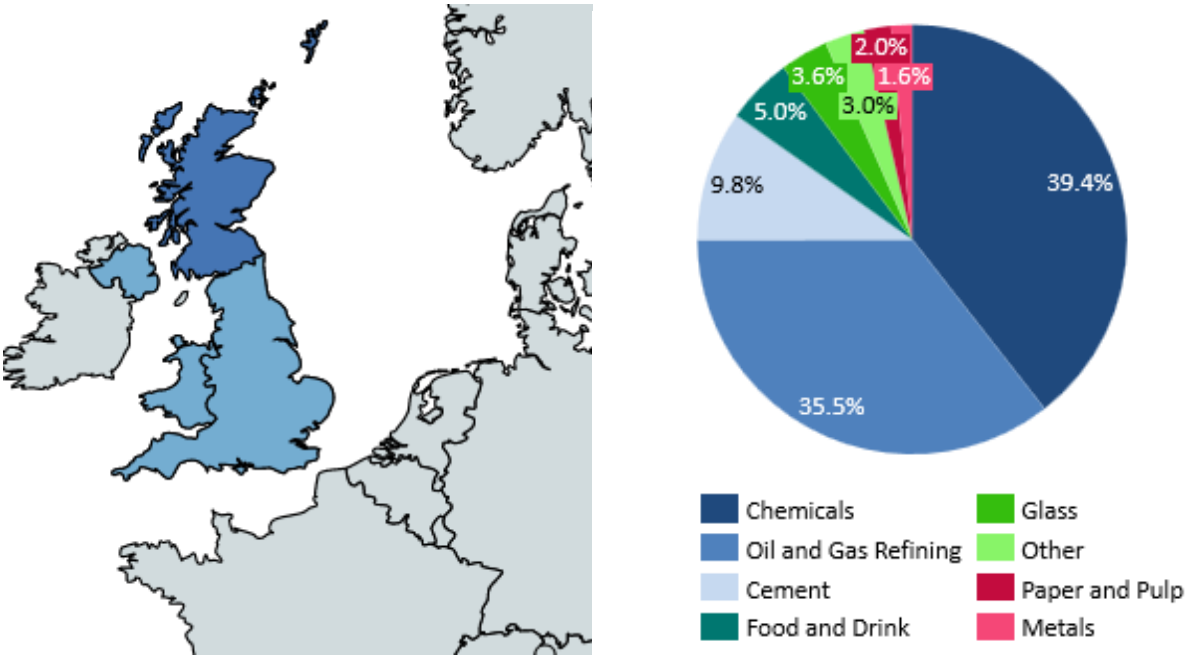

Figure 5 Annual emissions breakdown by industrial sector for Scotland (2017)[18]

Public and private entities are already working together to drive forward opportunities to decarbonise industry via carbon capture, utilisation and storage (CCUS) and hydrogen deployment. Scottish government co-funded

[12] Lombardy's Roadmap for Research and Innovation on Circular Economy
[13] https://www.eni.com/en-IT/media/press-release/2019/07/eni-and-the-lombardy-region-sign-a-sustainability-and-circular-economy-agreement.html
[14] Decarbonising Scotland's industrial sectors and sites: discussion paper; Scottish Annual Business Statistics 2018.
[15] Scotland's Climate Change Plan: third report on proposals and policies 2018-2032
[16] Scotland's Climate Change (Emissions Reduction Target) Act 2019
[17] Scotland's Just Transition Commission, which is preparing advice for Scottish Ministers on how to apply these principles to Scotland, published its interim report in Feb 2020.
[18] UK NAEI - National Atmospheric Emissions Inventory

the development of the emerging industry-led alliance, North-East Carbon Capture, Utilisation and Storage (NECCUS)[19], to identify and join up investment opportunities in the CCUS area. Of additional prominence are proposed projects under the region's Hydrogen Coast consortium[20], which contains the two major projects (amongst others):

- Acorn Hydrogen: plans include 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 industrial sites could benefit.
- Aberdeen Vision: to link hydrogen production in St Fergus (as part of Acorn Hydrogen) to support the decarbonisation of national and Aberdeenshire gas transmission systems.

Wales (United Kingdom)

Welsh industry is often characterised by the significant role of its iron and steel sector. The majority of industrial emissions in Wales arise from a cluster of operations in the South Wales corridor, dominated by the production of iron and steel and oil refining (i.e. Tata Steel's large basic oxygen steelmaking site in Port Talbot and Valero's Pembroke Refinery). The South Wales cluster is the second largest by volume of CO_2 emitted (8.2 $MtCO_2e$) of the six carbon intensive industrial clusters across the UK. In North-East Wales, industrial plants are predominantly concentrated in the manufacture of cement, steel and paper and pulp.

At 14.0 $MtCO_2e$, the industrial sector as a whole accounted for 29% of Welsh economy-wide emissions. Industrial emissions are broken down in Figure 6, showcasing the significance of the iron and steel sector towards decarbonisation planning. Wales is committed to the UK Committee on Climate Change's recommendation of meeting a 95% economy-wide emissions reduction target by 2050, with an ambition to reach net-zero by 2050[21]. The Welsh government recently published Prosperity for All: A Low Carbon Wales (2019)[22] which contained the policies and proposals in place that would deliver the first carbon budget (the period 2016-2020) and the 2020 interim target, which will be further developed in the next plan, due in 2021, for the second carbon budget (the period 2021-2025).

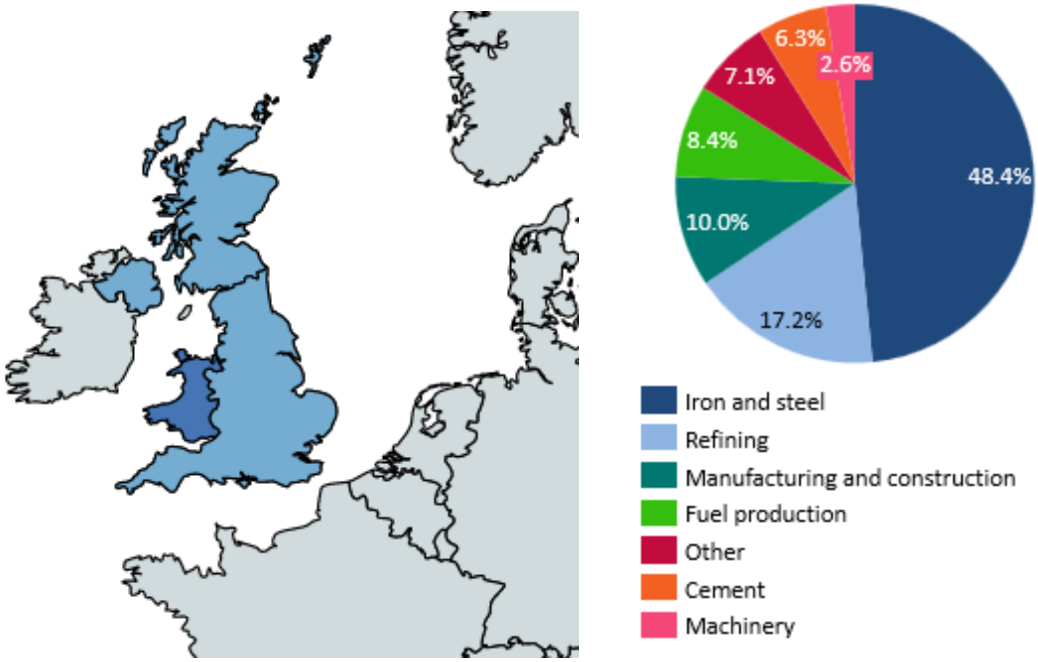

Figure 6 Annual emissions breakdown by industrial sector for Wales (2016)[22]

[19] North-East Carbon Capture, Utilisation and Storage (NECCUS)
[20] The Hydrogen Coast, Digital Summary, Pale Blue Dot
[21] Wales' Response to Committee on Climate Change's Net Zero Report
[22] Welsh Government 2019, Prosperity for All: A Low Carbon Wales

The Welsh government are also heavily engaged with the South Wales Industrial Cluster (SWIC). The SWIC is an emerging industry led consortia working together to consider ways to decarbonise industrial processes, minimise waste, increase energy efficiency and attract government support including through the UK government's Industrial Strategy Challenge Fund[23]. SWIC's roadmap and deployment projects will focus on infrastructure for hydrogen and large-scale CCUS as well as strategies specific to individual industries.

California (United States)

California's economy is the largest in the United States and ranked 5th globally against all other nations in terms of nominal GDP[24]. A large portion of the state's industrial activity is focused on petroleum refining and oil and gas production; however, the state is also home to a number of other high emissions intensity industrial sectors including cement, chemicals, food and drink, glass, and other manufacturing industries. Considering its immense diversity of industrial emissions sources, the study on Pathways for Deep Decarbonisation in California (2019)[25] identified a portfolio of decarbonisation strategies for industry including: fuel-switching (electrification, hydrogen, renewable natural gas, bioenergy), CCUS, reduction of fugitive emissions, etc.

Figure 7 breaks down California's industrial sector emissions (total of 101 $MtCO_2e$), which in total represent 23% of economy-wide emissions, second only to the transport sector. Two key documents driving deep decarbonisation efforts are: (1) Senate Bill 100[26], which states California must obtain all of its electricity from zero-carbon sources by 2045 and (2) Executive Order B-55-18[27], which commits economy-wide carbon neutrality by 2045 then net negative thereafter.

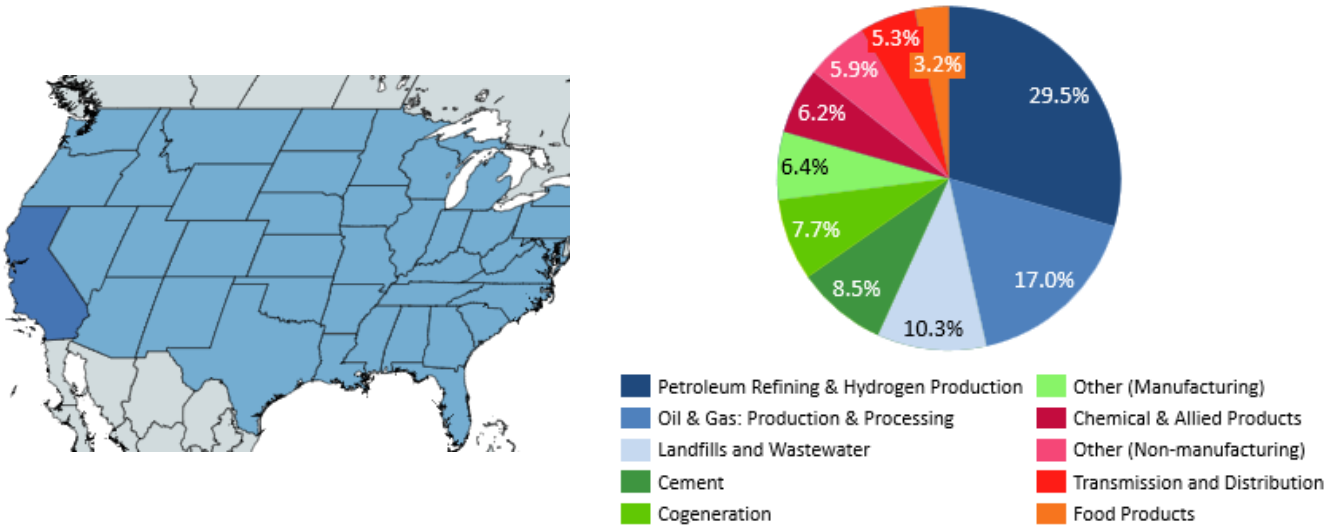

Figure 7 Annual emissions breakdown by industrial sector for California (2017)[28]

California's Cap-and-Trade Program[29], linked with the Canadian province of Quebec's cap-and-trade system through the Western Climate Initiative, is a crucial driver of industrial decarbonisation with approximately 80-85% of California's GHG emissions covered by the program. Proceeds from the auctioning of state-owned allowances are utilised by the California Climate Investments Program. In 2017, $1.2 billion of this was spent on market growth for clean energy technologies and investments in emissions reductions in sectors not

[23] UK Research and Innovation: Industrial Strategy Challenge Fund
[24] https://en.wikipedia.org/wiki/Comparison_between_U.S._states_and_sovereign_states_by_GDP
[25] Energy Futures Initiative, Pathways for Deep Decarbonization in California
[26] California Legislative Information, Senate Bill No. 100
[27] California's Executive Order B-55-18 to Achieve Carbon Neutrality
[28] California Air Resources Board, California Greenhouse Gas Emissions for 2000 to 2017
[29] California Air Resources Board, Cap-and-Trade Program

covered by Cap-and-Trade. The region is also able to tap into the United States' 45Q tax credit for qualifying CCUS projects (greater than 100,000 tons CO_2 per annum) [30].

Minnesota (United States)

Minnesota's backbone of industrial activity is in its agriculture and forest sectors with total agricultural production ($17.1 billion[31]) ranking 5th amongst other states and raw materials providing significant feedstocks for the production of bio-based fuels, chemicals, and plastics. Iron, copper, nickel and other valuable metal ores are located in north central and north-eastern Minnesota in an area known as the "Iron Range". With the depletion of easily accessible high-grade iron ores, the iron mining industry has switched to the mining of taconite and the production of taconite pellets[32].

Combining all industrial sectors, Minnesota's industrial activity emits 20.5 $MtCO_2e$[33] which accounts for approximately 13% of economy-wide emissions (ranked 4th behind transport, electricity and agriculture emissions). The largest emissions contributions are due to the use of coal, oil, and natural gas in industrial processes; however, the production of taconite pellets (taconite induration) is also a GHG-intensive process. Minnesota's Next Generation Energy Act (2007)[34] commits the state by statute to an 80% reduction in GHG emissions (compared to 2005 levels) by 2050 with the next interim target of 30% reduction by 2025.

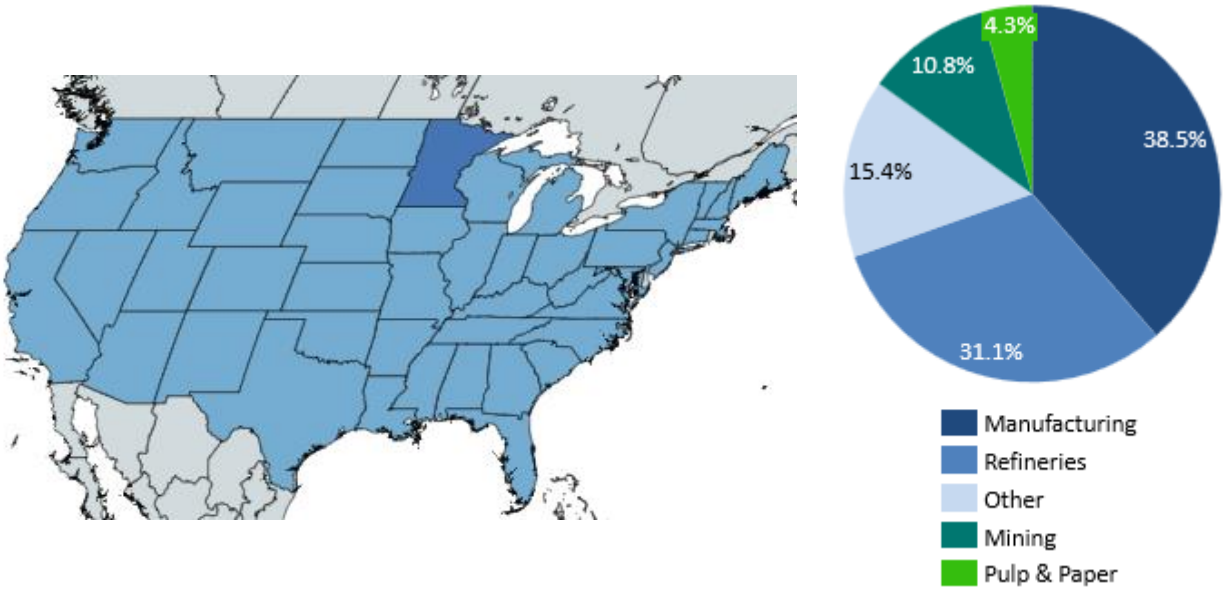

Figure 8 Annual emissions breakdown by industrial subsector for Minnesota (2016)[35]

The Minnesota 2025 Energy Action Plan (2016)[36], which is focused on strategies for decarbonising industry and agriculture, contained 3 focus areas:

- Promoting bioenergy primarily in corn ethanol and biodiesel industries (e.g. in 2016 all gasoline sold had to contain 10% ethanol but will increase to 30% by 2025) and biogas from anaerobic digestion in combined heat and power (CHP) or other industrial process heating applications.
- Reducing waste energy through state and federal programmes (e.g. Minnesota Technical Assistance Program for industry and mandating electric utilities and natural gas utilities to invest in Conservation Improvement Programs which support end users in reducing annual energy usage by 1.5%).

[30] Global CCS Institute, Brief on the US Section 45Q Tax Credit for Carbon Oxide Sequestration
[31] Minnesota Department of Agriculture, Agricultural Profile
[32] Minnesota Department of Natural Resources, Taconite
[33] Minnesota Pollution Control Agency, Greenhouse Gas Emissions Data
[34] Minnesota Pollution Control Agency, State and regional initiatives
[35] Minnesota Pollution Control Agency, Permitted facility air emissions data
[36] Minnesota's 2025 Energy Action Plan

- Promoting clean energy focus in industries by establishing an industry-led organisation coordinating efforts/communication across clean energy sectors (i.e. to utilise existing groups such as Minnesota Sustainable Growth Coalition and Clean Energy Economy Minnesota).

Quebec (Canada)

The Quebec economy is one of the most diversified in Canada, with industrial activity spread across the aluminium, refining, metals and minerals (including cement, lime and glass), iron and steel, pulp and paper, manufacturing, chemicals, and food and drink sectors. Most industries already have overall lower emissions intensity than other regions when considering emissions from electricity consumption, owing to a significant majority of hydroelectric electricity production from government-owned Hydro-Quebec, which is the third largest hydroelectric generation company in the world[37].

In spite of this fact, Quebec's total industrial emissions (24.0 $MtCO_2e$[38]) are still significant when considering the combination of process and fossil-fuel combustion emissions that exist. Of these emissions, 18.0 $MtCO_2e$ are directly captured under the regional Cap-and-Trade program, which is linked with California's cap-and-trade program as part of the Western Climate Initiative and covers industrial establishments with GHG emissions exceeding 25,000 tCO_2e annually (or voluntary opt-in for establishments exceeding 10,000 tCO_2e) as well as fossil fuel distributers (which indirectly captures most of the remaining 6.0 $MtCO_2e$ of industrial emissions). The sectoral breakdown of the Cap-and-Trade emissions are shown in Figure 9, highlighting the diversity of industrial emissions sources.

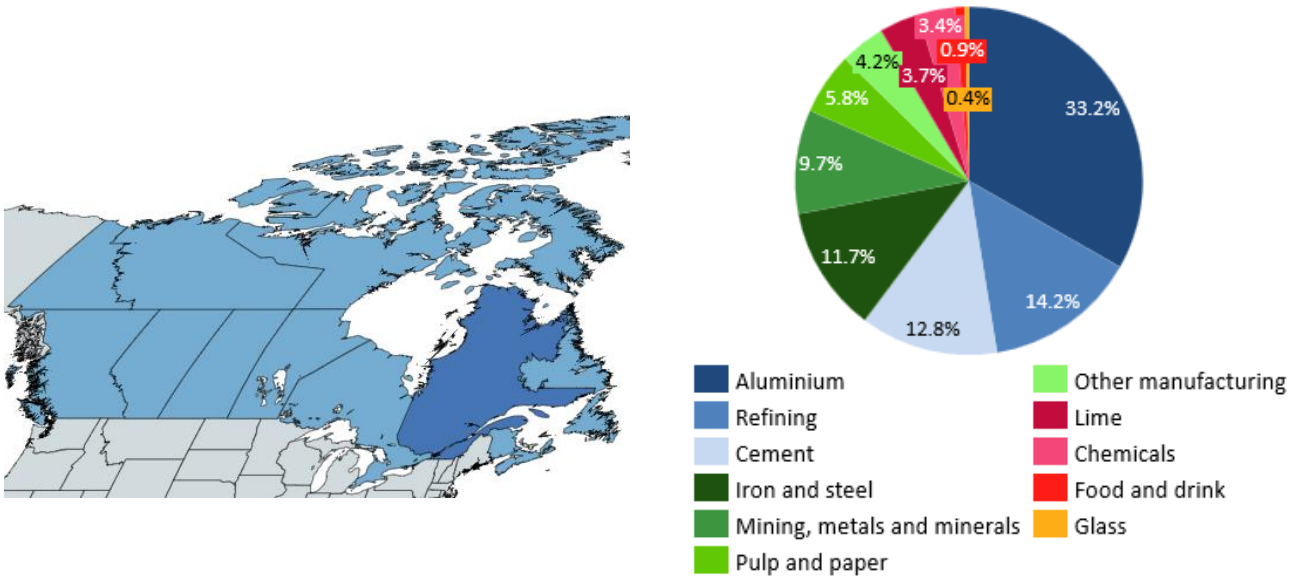

Figure 9 Annual emissions breakdown by industrial subsector in Quebec (2017)[39]

Quebec's 2013-2020 Climate Change Action Plan[40] outlines supportive measures to reduce GHG emissions by 37.5% by 2030 and 80-95% by 2050 (compared to 1990 baseline level), although further action is needed to meet these targets. In addition, the plan's 2020 amendment includes $190 million from the 2019-2020 government budget to encourage large businesses and manufacturers to invest in their energy transition with $48 million of this to support decarbonisation of the industrial sector. Further financial support provided by the plan is managed by the government's Energy Transition Québec team which is responsible for the administration of several energy conversion and efficiency programs (e.g. ÉcoPerformance Program, Residual Forest Biomass Program, Technoclimat Program).

[37] https://www.nsenergybusiness.com/features/largest-hydropower-companies/
[38] Quebec inventory of greenhouse gas emissions in 2017 and their evolution since 1990
[39] Verified and declared Emissions of the Establishments Covered by the Regulation Respecting a Cap-and-Trade System for Greenhouse Gas Emission Allowances. Accessed here.
[40] Quebec's 2013-2020 Climate Change Action Plan (most recent amendment in 2020).

2.2 Commonalities among the regions within the team

The regions involved in this study shared a number of commonalities, including regional responses to the COVID-19 emergency and government experience engaging with industry, which are summarised in Table 2 and Table 3, respectively, alongside regional examples.

Table 2 Regional responses to the COVID-19 emergency

Commonalities	Examples
Reports with recommendations that highlight necessary actions to transition towards a net-zero economy (i.e. 'green recovery')	**North Rhine-Westphalia**: IN4climate's discussion paper (June 2020)[41] on "Pathways to a climate-neutral industrial sector in the aftermath of the coronavirus pandemic": • Highlights key requirements for public-sector stimulus packages to support an industrial recovery programme (e.g. long-term climate neutrality of the industrial sector as a criterion). • Proposes strategies and measures (e.g. promoting market ramp-up of low-carbon technologies, advancing the establishment of a hydrogen economy, investing in infrastructure etc.). **Scotland**: Recent report from the independent Advisory Group on Economic Recovery, "Towards a Robust, Resilient Wellbeing Economy for Scotland" (June 2020)[42]: • Provides a series of recommendations to Scottish Government on how they can transition towards a greener, net-zero economy.
Pro-active management of existing programmes to respond to the priorities of specific industrial sectors impacted by the current and post-COVID-19 economy	**Quebec:** Introduced temporary measures for the Residual Forest Biomass, EcoPerformance and Technoclimat programs[43]: • A 5% increase in financial assistance to be granted for projects underway and for those submitted by December 31, 2020. • Participants will be entitled to a 12-month extension of the deadline for completing their project. **Scotland**: "Making Scotland's Future" Programme, which is supporting the manufacturing sector, is repositioning its plans to respond to the new challenges facing the sector now and in a post-COVID-19 economy. In the medium to longer term, the work will help inform strategic direction to re-focus ambitions back to supporting growth once the sector has secured its foundation for recovery.
Structured intelligence with industry to establish how the crisis has impacted investment decision-making for industrial energy efficiency and decarbonisation projects, with a view to tailoring future funding and support to meet industry's changing needs	**Scotland**: During 2020, Scotland has continued to undertake structured engagement with industry stakeholders, including on the design and timing of an Industrial Energy Transformation Fund[44]. An upcoming short-life focus group will gather market intelligence, including on the additional challenges that businesses are facing in the wake of the COVID-19 crisis.

[41] IN4Climate, Pathways to a climate-neutral industrial sector in the aftermath of the coronavirus pandemic
[42] Scottish Government, Towards a Robust, Resilient Wellbeing Economy for Scotland
[43] Transition Energetique Quebec, Residual forest biomass, EcoPerformance and Technoclimat programs
[44] Scottish Government, support for industrial decarbonisation

Introduction of **new working groups, funding schemes, and recovery plans** to support businesses in accessing the opportunities of a post-COVID-19 low-carbon economy	**Scotland**: Scottish Government has announced the new £62 million Energy Transition Fund[45], which will support businesses in the oil, gas and energy sectors over the next 5 years. **Wales:** The Welsh Economic Resilience Fund[46] offers financial support to help businesses deal with the COVID-19 crisis and help organisations manage cash flow pressures. It is a bespoke additional funding stream designed to address gaps not currently met by schemes already announced by the UK Government, Welsh Government and Development Bank of Wales.

Table 3 Government experience engaging with industry and approaches to increase influence with multinational companies

Commonalities	Examples
Roundtables and workshops between government and a broad range of industry stakeholders to build platforms for engagement and collaboration and to gather more robust evidence and inputs on industrial decarbonisation planning and strategies	**Scotland**: In 2017, Scottish Ministers chaired a roundtable[47] which gathered feedback that directly influenced the industrial part of Scotland's Energy Strategy. Following the roundtable, workshops were held in 2018 to gather evidence on the nature of Scotland's industrial landscape, including the challenges and opportunities for decarbonising (discussion paper[48] released in 2019). **Emilia-Romagna**: In the creation of the region's new Job and Climate Pact, government has set up a working group including regional stakeholders representing industry through the Confindustria, Association of Small Enterprises, Association of Artisans and the Labour Union. **California**: The California Energy Commission holds funding workshops as part of their administration of approximately $150 million per year in research funding, with roughly $30 million going to industrial, agriculture, and water research projects (e.g. biodiesel, industrial scale laundromats, glass, and steel/metal/smelting).
Focus groups with specific industrial sectors to engage in more detailed discussion on challenges and opportunities for decarbonising, enabling government to evaluate effective policy and funding designs tailored towards the risks faced by key industrial sectors	**Minnesota**: The Minnesota Department of Commerce was awarded a U.S. Department of Energy grant to carry out a strategic stakeholder engagement process (2014-2015)[49] and develop an Action Plan for CHP deployment in Minnesota (deliverable being the Final CHP Action Plan[50]). **North Rhine-Westphalia**: The IN4Climate platform holds policy working groups with government and industry stakeholders 4 times a year and has separate working groups that work with specific companies themselves. **Quebec**: In 2019, the Ministry of Environment consulted industrial stakeholders about the adjustments to the Cap-and-Trade free allowance rules for the 2024-2030 period (included two focus groups and bilateral meetings with industries to discuss further details).

[45] Scottish Government, £62 million fund for energy sector
[46] Business Wales, Economic Resilience Fund Phase 2
[47] Scottish Government, Energy intensive industries roundtable
[48] Scottish Government, Decarbonising Scotland's industrial sectors and sites: discussion paper
[49] Minnesota Department of Commerce, Combined Heat & Power Stakeholder Engagement
[50] Minnesota Department of Commerce, Final Combined Heat and Power Action Plan

	California: To develop the California Energy Commission's Food Production Investment Program[51], significant input and engagement from industrial stakeholders occurred in late 2017 / early 2018. Engagement took the form of workshops, meetings, phone calls and surveys.
Technology and innovation clusters bringing together academia, private industry and government to share skills, ideas and resources to support the competitiveness of the industrial sector (i.e. bringing research and development projects to pilot-scale)	**Emilia-Romagna:** Clust-ER Greentech for Energy and Sustainable Development[52] • A cluster focused on research and innovation in the low carbon economy and environmental sustainability, through the development of new products, advanced services and innovative business models. **Lombardy** Energy Cleantech Cluster[53] • One of the most prominent cleantech clusters in Southern Europe with a network of 108 companies, specialising in refuse, hydroelectric, photovoltaic, biogas and solar. **North Rhine-Westphalia**: IN4Climate Platform[54] • Facilitates collaboration between representatives from public, private and academic sectors, fostering a unique space in Germany in which to develop innovative strategies for a climate-neutral industrial sector. **Scotland**: North-East Carbon Capture, Utilisation and Storage (NECCUS) Alliance[19] • Scottish government co-funded the development of this industry-led alliance to identify and join up investment opportunities in the CCUS area. **Wales**: South Wales Industrial Cluster (SWIC)[55] • Partnership to develop roadmap and deployment projects which will look at the infrastructure required for the development of the hydrogen economy, for large scale CCUS as well as onsite strategic opportunities specific to each industry. **Minnesota** Sustainable Growth Coalition[56] • A business-led partnership harnessing industrial expertise to advance the circular economy through various projects in fields such as clean energy and converting organic waste into valuable resources.

[51] https://www.energy.ca.gov/programs-and-topics/programs/food-production-program
[52] https://greentech.clust-er.it/en/
[53] http://www.energycluster.it/en
[54] https://www.in4climate.nrw/index/
[55] https://www.swic.cymru/
[56] https://environmental-initiative.org/work/minnesota-sustainable-growth-coalition/

3 Assessment of future disruptive innovation options

This chapter details the future disruptive innovation options predicted to impact industrial decarbonisation within the coming 10 to 20 years, with examples adopted by regions outside those in this study. An overview of the selected technologies, policies and finance/business models is shown below in Figure 10. Options were selected based on their anticipated measure of disruption, which was qualitatively assessed under each category with the following definitions:

- **Technologies**: Predicted to have large impacts across regional markets and play a key role in industrial decarbonisation as markets are disrupted with more stringent low-carbon procurement or increasing carbon pricing mechanisms.
- **Policies or finance/business models**: Predicted to directly drive disruptive innovation by reducing barriers (i.e. cost, regulatory, carbon leakage) for industrial decarbonisation, providing mechanisms to significantly reapportion the social cost of carbon and changing the value proposition of emerging deep decarbonisation technologies.

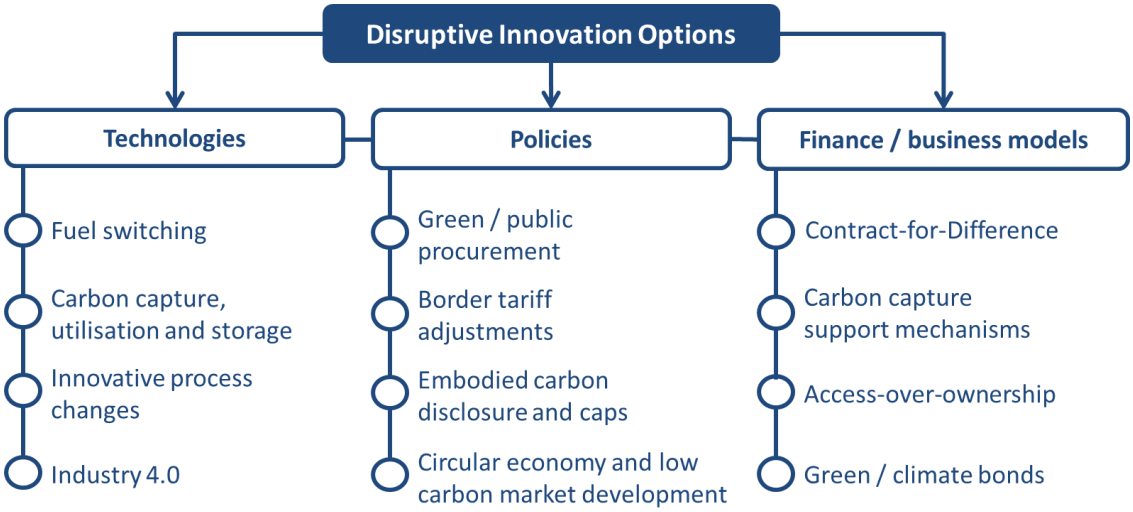

Figure 10 Overview of disruptive innovation options impacting industrial decarbonisation

3.1 Technologies

Fuel switching

Fuel switching encompasses a broad range of technology options that industrial sites may choose to transition towards the utilisation of low or zero carbon fuels (i.e. electricity, hydrogen, biomass, waste-derived fuels[57] or mixed fuel options). With many ongoing pilot projects/trials, fuel switching technologies are predicted to enable deep decarbonisation across a diverse range of industrial sectors. Early adopters of these technologies will be able to meet stringent carbon pricing or emissions trading mechanisms, which is likely to further disrupt low-carbon markets with major demand changes for new or existing fuel types.

Studies undertaken by the UK government have analyzed the suitability of fuel switching options against the vast array of industrial processes (boilers, dryers, reduction processes, kilns, furnaces, etc.)[58], finding that the implementation of many fuel-switching technologies (including hydrogen options, given the absence of experience of hydrogen in most sectors) will only be feasible if further evidence on the suitability and reliability of the technologies in specific sectors is provided. Since that study was completed (2018), a number of developments in industrial fuel switching are now underway.

[57] Waste-derived fuels include: Residues from agriculture or forestry industries, biogenic wastes produced from distribution, service industries or retail industries, and biogenic fractions of municipal solid waste and waste water.
[58] UK Department of Business, Energy & Industrial Strategy, Industrial Fuel Switching Market Engagement Study

For hydrogen alone, several trial projects in **England (UK)** are currently ongoing or soon to be started, including:

- HyNet Project: Merseyside-based industrial cluster hydrogen network.[59]
- Gigastack Project: Phillips 66's Humber Refinery will use renewable hydrogen (produced via electrolysis from offshore wind derived electricity) to produce fuels.[60]
- Tarmac's trial project exploring the viability of hydrogen as an alternative to natural gas for high calcium lime manufacturing.[61]

Other notable fuel switching investigations into high emissions intensity industries include:

- Glass Futures' analysis of fuel switching options in the glass industry (e.g. potential of low-cost biofuels given the similarities of some biofuels to gas oil, the industry's preferred fuel before natural gas).[62]
- Tarmac's and Hanson's trial projects for mixed fuel switching to electricity and hydrogen[61] or biomass and hydrogen[63] in cement kilns, respectively.

Carbon capture, utilisation and storage (CCUS)

CCUS technologies are anticipated to be key disruptors within specific industries that require abatement of process/combustion emissions[64] to be able to produce final products for markets with low carbon content demand. Carbon capture technologies can be applied to industrial applications such as process emissions (e.g. cement, lime, glass, chemicals, refining, iron and steel industries), negative emissions (with existing biomass fuelled processes), combustion (reforming), or kilns (e.g. cement/lime). Early adoption is anticipated to begin at large sites able to drive down economies of scale, with lower capacity industrial emitters eventually taking advantage of low cost regional CCUS infrastructure such as trunk pipeline networks, large-scale storage facilities, or carbon utilisation plants.

Technical, economic, and often political factors play a role in determining whether a particular region will choose to consider the development of carbon utilisation or carbon storage infrastructure. For regions considering investigating routes to CCU adoption, promising carbon utilisation pathways include[65]:

- Conversion to synthetic fuels (methane, gasoline, aviation fuels, etc.), chemicals (methanol, polymers), or building materials (aggregates, cement, concrete)
- Non-conversion / direct use application in yield boosting (e.g. fertiliser), solvent (e.g. enhanced oil recovery), and others (e.g. food and beverage)

Examples of pilot and full-chain CCUS projects include:

- **Belgium**: The Low Emissions Intensity Lime & Cement (LEILAC) project's pilot plant at the HeidelbergCement plant is trialling the Calix capture technology. When integrated into new plants or retrofitted into existing plants, which are fired with biomass or waste, the technology promises to reduce the total CO_2 emissions by more than 85% compared to conventional fossil fuel fired lime and cement plants, without significant operating issues, energy or capital penalty.[66]
- **England (UK)**: Tata Chemicals Europe's plant is the UK's only manufacturer of soda ash and sodium bicarbonate and has been awarded £4.2 million toward the construction of a facility to capture and utilise 40,000 tonnes of carbon dioxide a year. Tata plans to refine the carbon emissions to make a high-grade liquid version of carbon dioxide which will help make sodium bicarbonate, or baking soda.[67]

[59] https://hynet.co.uk/industry/
[60] https://gigastack.co.uk/
[61] https://www.tarmac.com/news-and-media/news/2020/february/tarmac-to-take-part-in-ground-breaking-cement-fuel-switching-trials/
[62] Glass Futures, Alternative Fuel Switching Technologies for the Glass Sector
[63] https://www.hanson.co.uk/en/about-us/news-and-events/fuel-switching-research-project
[64] Several industrial processes emit CO_2 and other greenhouse gases as a result of the chemical or combustion reactions involved in the process themselves (e.g. the cement calcination reaction).
[65] International Energy Agency, Putting CO_2 to Use: Creating value from emissions
[66] https://www.project-leilac.eu/
[67] https://www.tatachemicalseurope.com/about-us/carbon-capture-utilisation

- **Alberta (Canada):** The Quest Project involved retrofitting Shell's Scotford upgrader for CCS, commencing operations in 2015. The project is capturing CO_2 from oil sands upgrading and transporting it 65 kilometres north for permanent storage approximately two kilometres below the earth's surface. Supported financially by the provincial government, Alberta's CCS Fund contributed $745 million in total with 40% of the funding disbursed over a 10-year operational period (until 2025).
- **Norway**: Equinor, Shell and Total's Northern Lights full-scale CCS project includes capture of CO_2 from industrial sources in the Oslo-fjord region (cement and waste-to-energy plants) and shipping of liquid CO_2 from these industrial capture sites to an onshore terminal on the Norwegian west coast. From there, the liquified CO_2 will be transported by pipeline to an offshore storage location subsea in the North Sea, for permanent storage. Norwegian Parliament will make its final investment decision in late 2020. If awarded final approval, the project will undergo a 3-year construction phase with operations commencing in 2023/24.[68]

Innovative process changes

Industrial process changes, coupled with new technologies, will disrupt high-emitting sectors across many regions as multinational companies aim to secure their positions for increasing demand of low-carbon products or increasingly expensive incumbent operations (e.g. due to carbon pricing). This category of disruptive technology includes innovative technology/process designs which are often combined with fuel switching or CCUS options. Given their particular importance for large plants across many regions (e.g. in the iron and steel, cement, glass industries), demonstration and pilot projects are now underway in a number of regions:

- **Sweden**: SSAB's, LKAB's and Vattenfall's jointly created HYBRIT technology is an alternative to steel production via the blast furnace route, instead utilising hydrogen direct reduction of iron and electric arc furnace steel production. A pilot plant is now built at SSAB's plant at Svartön, including production of hydrogen and testing on direct reduction of iron ore with hydrogen.[69]
- **Germany**: Ardagh Group's 'Furnace of the Future' pilot project will be the world's first large-scale hybrid oxy-fuel glass furnace to run on 80% renewable electricity and capable of processing over 300 tonnes of glass per day (aiming to be built by 2022 with production results in 2023).[70]
- **Netherlands**: Tata Steel's HIsarna technology is a new reactor design for steelmaking operations traditionally utilising coal with high concentrations of CO_2 off-gases, promising a reduction in energy use and CO_2 emissions by 20%. To develop and test this technology, a pilot plant has been built at the IJmuiden (port city) site.[71]

Industry 4.0

The term Industry 4.0 is now being widely used to describe a vast array of new transformative technologies applicable across many industrial plants and processes, including:

- artificial intelligence (AI) technologies,
- advanced energy management systems,
- internet of things (IoT) connected applications/processes,
- distributed ledger technologies (e.g. blockchain), and
- additive manufacturing (i.e. 3D printing).

The emerging technologies under Industry 4.0 are expected to cause disruption to existing markets by introducing cross-cutting economic, legal, and regulatory challenges and further anticipated to have a high impact on labour markets (with changes in skillsets) and global value chains across all industrial sectors.

[68] https://northernlightsccs.com/en/about
[69] https://www.hybritdevelopment.com/
[70] https://feve.org/about-glass/furnace-of-the-future/
[71] https://www.tatasteeleurope.com/en/innovation/hisarna/how-it-works

In addition, adoption of Industry 4.0 technologies is anticipated to drive businesses towards significant energy savings and emissions reductions over time. Some of the predicted performance improvements include[72]:

- Energy savings of up to 10% in energy intensive industrial applications with the implementation of AI to predict the future performance of industrial equipment and alert plant operators to potential faults before they disrupt production.
- Possible energy savings of over 10-30% depending on industrial process and technology by utilising a combination of concepts from traditional industrial energy management systems (e.g. ISO 50001) with digital technologies and advanced software applications.
- Construction waste and the quantity of raw material required for construction can be reduced by up to 30% through the use of 3D printing to improve the energy and carbon footprint of the construction industry, given that building materials such as bricks and cement are energy and carbon-intensive.

A couple of prominent examples of Industry 4.0 technology applications are provided below:

- Google recently applied its own artificial intelligence algorithm, known as DeepMind, to identify energy savings opportunities in its network of data centres. The algorithm was able to reduce cooling demand by 40%, a significant increase in efficiency.[72]
- **Lombardy (Italy), Nyborg (Denmark)** and **Antwerpen (Belgium)** have been selected as the three pilot regions for the Horizon 2020 funded R-aces project, over a 30-month period from 2020 to 2022. The goal of the project will be to deploy and test an intelligent energy management platform capable of effective energy cooperation, recovery and heat exchange, in order to support high potential industrial parks in becoming "EcoRegions" that reduce energy consumption by at least 10%.[73]

3.2 Policies

Green / public procurement

Green or public procurement guidelines and codes are those that place value on low-carbon products to be preferred against more carbon intensive ones, even if at a price premium. (e.g. requiring that a certain fraction of the concrete used for public infrastructure must be low carbon). Regional green/public procurement policies have the potential to significantly steer disruption within markets, given the significant scale and scope guidelines can reach (i.e. multi-sectoral, wide range of product categories). Many governments have introduced their own forms of "green" public procurement, the examples below showing just a snapshot of some regional or national policies in this area[74] [75]:

- **Flanders (Belgium):** Implemented in 2014, the Flemish Government introduced a green public procurement program that covers 19 product groups (i.e. materials for building renovation) and a range of sub-groups with a target of 100% sustainable public procurement by end of 2020. Mandatory criteria have been developed for a number of product groups, including paper, textiles, vehicles, electricity, information technology, and cleaning products.
- **New York (United States):** Establishment of the state's Green Procurement and Agency Sustainability Program created specifications for commodities, services, and technology for use by state agencies during procurement. The specifications identify product criteria that minimise volume of packaging, maximise use of recycled content and sustainably managed renewable resources, and reduce other environmental risks.
- **China:** Compared to other countries globally, China has the largest total number of products certified for green public procurement – more than 93,000 products in 44 categories. Key products and categories include water, building materials, office equipment and transport (official vehicles / cars).

[72] International Energy Agency, Energy Efficiency 2019
[73] http://www.energycluster.it/it/progetti/progetti-in-corso/r-aces
[74] Global Efficiency Intelligence, Curbing Carbon from Consumption: The Role of Green Public Procurement
[75] New York State, Green Purchasing Requirements

Border tariff adjustments

Border tariff adjustments (BTAs), also known as border carbon adjustments or border tax assessments, refer to the issuance of import fees on goods manufactured in regions with a lower carbon pricing mechanism. The primary aim of BTAs is to reduce the risk of carbon leakage[76] from occurring in countries/regions with stricter carbon reduction policies. There are currently no regions or countries which have finalised the implementation of a BTA or similar taxation policy (for manufactured products/goods[77]); however, this is predicted to change in the coming decade as government's strive to meet emissions reductions targets while simultaneously mitigating against the risks of carbon leakage.

Introduction of national or multi-regional BTAs are predicted to significantly disrupt markets by enabling sustained demand for low-carbon products and promoting uptake of new disruptive technologies to meet this demand. However, uncertainty remains as to whether state or provincial governments can be directly involved in the implementation of such policies, as these are likely to require coordination at the national level for bilateral trade between countries. Nonetheless, it is critical for regional governments to be involved in consultations at the national level as BTAs will directly disrupt the industries operating in their markets.

Now taking its initial steps towards implementation, the **EU Commission's** proposed creation of a Carbon Border Adjustment Mechanism (CBAM) was identified in the European Green Deal as a policy lever critical to achieving a climate-neutral Europe by 2050. The EU Commission has recently launched consultations (July 2020) on the CBAM, with the aim of adopting an act into EU law by the second quarter of 2021.[78]

Embodied carbon disclosure and caps

Embodied carbon includes emissions associated with materials and construction processes throughout the whole lifecycle of a building or infrastructure. Embodied carbon can be embedded into regional government policies in the form of mandated disclosure requirements for end-use products or buildings regulations which could then lead to the introduction of a carbon cap following a sufficient period of disclosure and data assessment. Most likely to be first introduced on large-scale government procurement (i.e. buildings and infrastructure projects), embodied carbon caps can drive demand for low-carbon material (e.g. steel, concrete, etc.), disrupting the upstream manufacturing and industrial sectors to transition towards innovative, low-carbon production methods.

In 2017, **California (United States)** passed the Buy Clean California Act, a law requiring state-funded building projects to consider the global warming potential (GWP) of certain construction materials during procurement. The bill requires eligible materials (structural steel, carbon steel rebar, flat glass, and mineral wool insulation) to demonstrate GWP below product-specific compliance limits. By January 2021, government will establish and publish the "maximum acceptable" GWP for each product category, which bidders must meet for eligible materials to be used for state-funded projects.[74]

Finland has also set out a roadmap to integrate embodied carbon emissions of building materials into regulations for all building types. The Finnish government has already developed an assessment method which will be incorporated with a generic emission database that will cover all main types of products and materials, sources of energy, modes of transportation as well as other key processes such as site operations and waste management. The prospective methodology is first to be tested on publicly procured building projects on a voluntary basis. Embodied carbon requirements would then be introduced for residential towers before being extended to all building types by 2025.[79]

[76] Carbon leakage refers to the situation that may occur if, due to costs related to climate policies, businesses were to transfer production to other countries with lower emission constraints, thereby leading to an increase in their emissions.
[77] California's cap-and-trade program effectively involves a BTA for importers of electricity who are required to submit emissions permits for their imported electricity into the state.
[78] EU Commission, EU Green Deal (carbon border adjustment mechanism)
[79] Buildings and Cities, Reduced carbon footprints of buildings: new Finnish standards and assessments

Circular economy and low carbon market development

Policies which support the development of circular economies and low carbon markets can take many forms, such as (and including combinations of) market regulations, material/product bans, public-private partnerships and direct technology investment.[80] Such policy interventions can be tailored to specific sectors within regions, enabling low carbon market creation or circular economy support mechanisms with the potential to significantly drive disruption towards deep decarbonisation technologies.

For instance, by setting zero/near-zero emission limits for the production of materials to be sold within a jurisdiction, governments could accelerate the phase out of carbon-intensive production processes. Announcements could alert basic materials producers, financing institutions, and other relevant stakeholders, thus incentivising them to prepare for this shift by dedicating their innovation efforts and investments to low-carbon materials.

Product bans are promising strategies for regional governments to consider for supporting circular economy development by driving industry to develop material alternatives that have lower lifecycle emissions or minimal environmental impact. In the United States, three states (**Hawaii, New York,** and **California**) have bans in effect on single-use plastic bags, with five additional states having now enacted legislation.[81] Another similar example (applied at a national level, but can be replicated at the regional level) is **China's** accelerated ban on the production and sale of single-use plastic products. The ban includes disposable plastic tableware, cotton swabs and straws to be phased out of the end of 2020 and non-degradable plastic bags to be banned in major Chinese cities by the end of 2020 and across the country by 2022.[82]

3.3 Finance/business models

Contract-for-Difference (or similar schemes)

Contract-for-Difference (CfD) financing models have been successful in many regions to support the deployment of low-carbon electricity generation and are now under investigation (or nearing implementation) to similarly support industrial decarbonisation. CfDs offer a targeted mechanism to disrupt markets by ensuring that the carbon price faced by investors in first-of-a-kind commercial scale projects better reflects the true social cost of carbon as it evolves over time in regional economies.[83]

Under a CfD financing mechanism, an industrial emitter who has invested in a new abatement technology (e.g. carbon capture) is paid (or refunded) by the government the difference between a CO_2 strike price contractually agreed, in \$/tCO_2 abated, and the prevailing CO_2 market/certificate price. Such schemes typically quantify the amount of CO_2 abated relative to an industry benchmark to ensure that best available technologies are deployed where possible. The CfD strike price would be fixed for the duration of the contract (e.g. 15 years), but each contract may have a different strike price (i.e. set on a site-by-site basis). A CfD model may provide one single incentive contract to a cluster of industrial emitters, which could reduce complexity for government, allowing negotiation on a cluster basis, rather than a site basis.[84]

CfD financing mechanisms have typically been implemented at the national level of government which often have the administrative capacity to deliver the breadth of programming required. However, while CfDs may not be as efficient to deliver at the regional level (particularly those with a low number of high-intensity industrial sectors), this would depend on a case-by-case basis of governmental authority and capacity. In light of this, regional governments may still be able to support the implementation of CfDs. For example, regional governments could deliver the analysis to set the required strike price for their industrial clusters or coordinate communication and feedback channels between industrial actors and national government.

[80] This can include early-stage research and demonstration funding for CO_2 utilisation technologies to support a circular "carbon" economy by recycling CO_2 and preventing fossil fuels extraction while still creating carbon-based products.
[81] https://www.ncsl.org/research/environment-and-natural-resources/plastic-bag-legislation.aspx
[82] https://www.forbes.com/sites/trevornace/2020/01/20/china-to-ban-all-single-use-plastics/#3802a96b7293
[83] Institute for Sustainable Development and International Relations, Decarbonising basic materials in Europe: How Carbon Contracts-for-Difference could help bring breakthrough technologies to market
[84] UK Department of Business, Energy & Industrial Strategy, Industrial carbon capture business models

As a smaller national example which has successfully implemented the first industrial CfD-like mechanism, the **Netherlands'** Sustainable Energy Transition Scheme (SDE++) applies to a wide range of CO_2 reducing categories (e.g. low carbon heat or production in industry, including CCUS and hydrogen electrolysis) and provides subsidies on the 'operating shortfall' (i.e. difference between fixed 'base amount' and market-fluctuating 'correction amount'). The base amount is set for the entire duration of the subsidy and the correction amount is determined annually such that if the market value rises, the operating shortfall decreases and thus the subsidy decreases as well.[85]

Carbon capture support mechanisms

Finance models that support the deployment of carbon capture technologies include options such as[84]:

- cost plus open book financing (emitter is directly compensated via government grants for operational costs and agreed returns on capital investment),
- tradeable or untradeable tax credits (in $/t$CO_2$ abated, which may taper throughout a contract) potentially alongside government buyback guarantees as well as capital support, or
- tradeable CCUS certificates with obligations for emitters required to surrender a set number of these certificates, which may increase over time.

Financing for bespoke carbon capture projects under a cost plus open book model would disrupt markets by ensuring that the carbon price faced by investors in large-scale CCUS projects better reflects the true social cost of carbon in the economy. Similarly, tax credits or CCUS certificates for industrial carbon capture would be able to significantly reduce costs for new projects and can be tailored as a means to focus disruptive innovation in specific sectors that require CO_2 capture for deep decarbonisation.

In 2008, **Alberta (Canada)** created its provincial CCS Fund, committing $2 billion to fund large-scale CCS projects which would help to lower the costs of the technology through learning by demonstration. The fund allowed for a maximum of up to 40% of funding allocated during the design and construction stage and up to a further 20% on commercial start-up. The remaining 40% of funding is paid as CO_2 is captured and stored over a maximum period of 10 years. Since its inception, the fund has successfully supported two projects: the Quest Project ($745 million for retrofitting Shell's Scotford upgrader with CO_2 capture, transport, and permanent storage) and the Alberta Carbon Trunk Line Project ($495 million awarded to a build a 240-kilometer pipeline to carry CO_2 captured from a refinery and fertilizer plant for enhanced oil recovery projects).[86]

Another prominent example of a carbon capture support mechanism is the **United States'** 45Q carbon sequestration tax credit. The 45Q tax credit provides a set amount of monetary credit for carbon dioxide that is permanently stored via usage, tertiary oil injection, or in geologic formations. Projects will be able to eventually receive $50/t CO_2 for geologic storage and $35/t$CO_2$ for enhanced oil recovery or other CO_2 utilisation methods.[30]

Access-over-ownership

Access-over-ownership (or "X-as-a-Service") business models are those in which industrial customers access services and products as an operational, rather than capital, expenditure. They are anticipated to disrupt markets by driving major energy and material efficiency improvements alongside Industry 4.0 technologies, reducing environmental impacts of total product life cycles and delivering high cost-benefit value for both business owners and consumers. Regional governments can foster the growth of these business models through their industry engagement, showcasing the benefits these services can bring to minimise costs, increase efficiencies, and reduce emissions. Examples of emerging business models include:

- Cooling-as-a-Service: Paying for efficiency services as a means to overcome capital cost barriers. As is already done with other products (e.g. vehicles), organisations can benefit from efficient space cooling technologies by entering into a service agreement rather than being required to purchase these technologies upfront.[72]

[85] https://english.rvo.nl/subsidies-programmes/sde
[86] https://www.alberta.ca/carbon-capture-and-storage.aspx

- Energy-as-a-Service: Broadly describes the growing sub-market of selling not only energy, but also technology, analytics, personalised services and even access to the grid. Driven, in part, by businesses or manufacturers to reduce costs and/or carbon emissions, Energy-as-a-Service can involve the creation of 'energy intelligent' systems for onsite generation which enhance efficiency, reduce costs, and guarantee security of supply. Energy-as-a-Service financing models and solutions can enable manufacturing companies to optimise their energy supply and demand without the need to invest their own capital.[87]
- Product-as-a-Service: As part of the circular economy, Product-as-a-Service models are a paradigm shift from selling physical products to providing functionalities and benefits delivered through tangible products. Product-as-a-Service models keep the ownership with the producer or manufacturer of the goods. This, in turn, makes them responsible for the functioning of the product over time, and with revenue models focused on functionality, makes it easier to design for need-fulfilment with lower environmental impacts.[88]

Examples of companies that have implemented these business models include[89]:

- Kaer: offers air-conditioning as a service by taking responsibility for both the design and installation of the air-conditioning system, thereby avoiding over specification, as well as the operation which ensures the system runs more efficiently.
- SunPower: offers high quality certified solar panels that can be leased for 20 years and, depending on the lease terms, customers may have the option to purchase the solar panel system at the end of the lease. Otherwise when the lease ends, the lease can be renewed for an additional term or have the leasing company remove the panels.
- Cleveland Steel and Tubes: operates under a reuse model whereby the majority of steel piping is sourced as oil field surplus production. Pipes are made fit for alternative applications by refurbishing the materials in-house to remove excess external coatings. Proven to work over the past 40 years, material properties and traceability have been shown to be at least as good as new products.

Green / climate bonds

Over the past decade, green or climate bonds have primarily focused on banks and financial institutions, but are now anticipated to disrupt many other sectors of the economy - utilities, agribusiness, manufacturing - as a means to finance new low-carbon projects. Similar to traditional bonds, green or climate bonds are loans which companies, governments, and banks can use to finance projects with the caveat that they are directly related to emissions reductions or environmental sustainability. Compared to other sectors of the economy, industry has a large gap between GHGs and available green bonds, with recent investor survey respondents highlighting industry as a key area in which they would like to buy more green bonds.[90]

Ontario (Canada) issued its first green bond in 2014, leveraging international investor interest and solidifying Ontario's presence in the Green Bond market as well as bringing visibility to the province by encouraging investments in sustainable projects. Projects that have environmental benefits fall into the following categories are generally considered eligible: clean transportation, energy efficiency and conservation, clean energy and technology, agriculture and land management, and climate adaptation and resilience.[91]

In 2019, **Japan** saw the first certified climate bond linked to Meidensha's manufacture of motors for electric and hybrid vehicles. The proceeds will be used to finance and refinance the expansion of existing and the construction of new facilities at manufacturing sites across Japan. These facilities will be solely and wholly for the purpose of manufacturing motors and related car parts of electric and hybrid electric vehicles.[92]

[87] https://www.raconteur.net/sustainability/future-energy-2019/energy-as-a-service
[88] https://www.firmhouse.com/blog/the-role-of-product-as-a-service-in-circular-economy
[89] https://www.ukgbc.org/wp-content/uploads/2020/03/Circular-Economy-Innovation-Insights.pdf
[90] Climate Bonds Initiative, 2019 Green Bond European Investor Survey
[91] https://www.ofina.on.ca/greenbonds/greenbonds.htm
[92] Climate Bonds Initiative, Meidensha Corporation

4 Regional summaries and recommendations

This chapter covers the regional summaries and transferable learnings that build upon the information characterising each region (Chapter 2) and on the potential disruptive innovation options already adopted or predicted to be adopted in the coming two decades (Chapter 3). An analysis of the current industrial landscape and opportunities for disruptive technologies, policies, and finance/business models were combined to formulate targeted recommendations for the future industrial decarbonisation planning of each region.

Each one-page summary/recommendation is organised into sections as follows:

- **Overview of existing industrial base and expected changes**: Building upon the information in Chapter 2, this section covers important aspects unique to each region's present industrial activity and any major anticipated changes. Depending on data availability, this section also highlights high-level information on regional fuel use and electricity generation, the latter impacting the carbon intensity of electrification in industry.
- **Commonalities and transferable learnings from other regions:** Investigations into disruptive innovations in regions outside the team of this study are featured based on their applicability to be incorporated into industrial decarbonisation planning.
- **Recommendations – technologies**
- **Recommendations – policies and finance/business models**

As an additional note, the regional recommendations provided are non-exhaustive and the disruptive innovation options highlighted in the following pages are deemed to be of the highest priority or of particular relevance to the industrial base of each region. Figure 11 below identifies which of the disruptive innovation options could be directly applied or supported by all participating regions, along with the options that all regions can indirectly support (i.e. border tariff adjustments at the national level of government or uptake of access-over-ownership business models between private businesses) and the options for which implementation will depend on the administrative capabilities of each region.

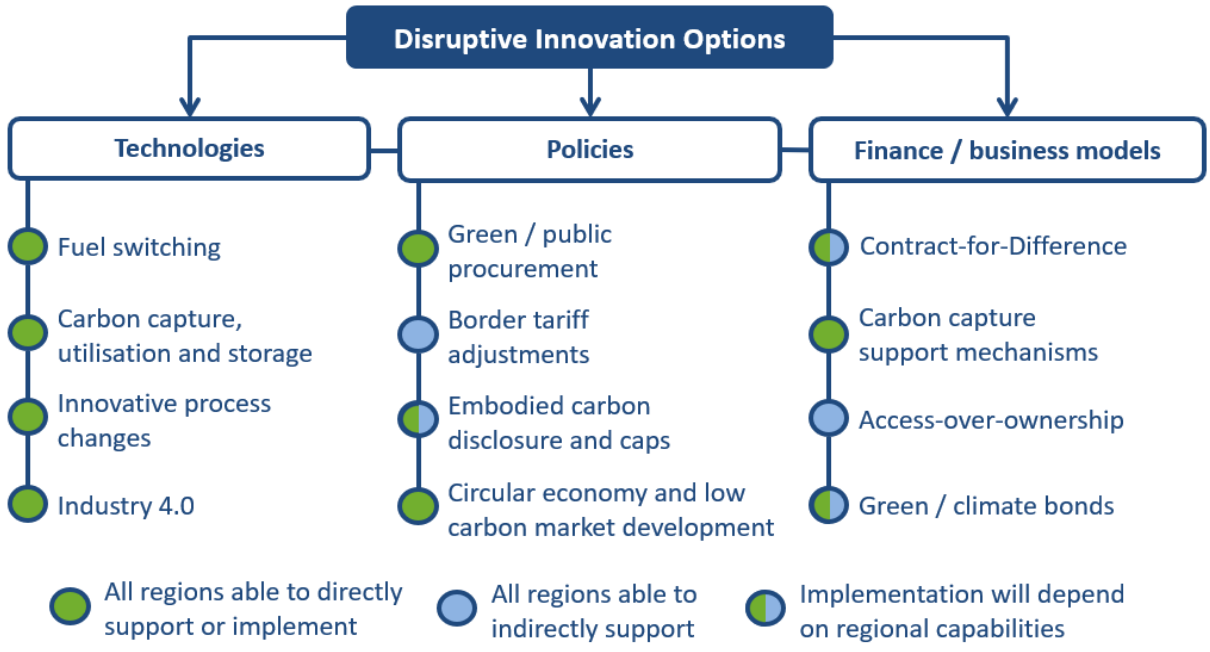

Figure 11 Disruptive innovation options distinguished by regional implementation or supporting role.

4.1 North Rhine-Westphalia

Overview of existing industrial base and expected changes

Accounting for just over 35% of total industrial emissions, the iron and steel sector is anticipated to be a key driver for hydrogen deployment across NRW. Of particular importance is the sector's largest site in Duisburg which is aiming to convert all its blast furnaces to hydrogen in 2022, followed by converting other sites to direct reduction plants and electric arc furnaces in the 2030s and integrating carbon utilisation technology for carbon neutrality by 2050.[93] In addition, hydrogen demand for a climate neutral chemicals sector in Germany could be 2 or 3 times as high as the demand in the steel sector (estimates suggesting as much as 225 TWh annually of green hydrogen[94]), with a large part of this demand centered in NRW.

NRW's fuel consumption across all sectors is dominated by coal/lignite but there is also significant usage of electricity and gas in other key sectors (chemicals, cement, lime, glass, non-ferrous metals, etc.). Electricity generation is currently dominated by fossil fuels (>80%[95]) but is transitioning to be zero carbon by 2050.[96]

Commonalities and transferable learnings from other regions

- Future hydrogen demand will likely need to be met by imports of green hydrogen production in Northern Germany or an EU-wide hydrogen economy (with imports from outside of Europe in the long-term), prospects for which are currently supported via the EU's Green Flamingo/Octopus projects[97]
- HeidelbergCement is operating the Low Emissions Intensity Lime and Cement (LEILAC) project's pilot plant in Belgium and aims to quadruple capacity in a German demonstration plant by the end of 2024[98]
- Shared interest with other EU regions on the impacts and development of the EU Commission's recent consultations on a Carbon Border Adjustment Mechanism to help reduce risk of carbon leakage

Recommendations – technologies

- Supported by regional planning for hydrogen infrastructure deployment (e.g. H2 Startnetz grid proposed by pipeline operators), hydrogen fuel switching will be an important option for sites across various sectors (chemicals, refining, etc.) to drive economies of scale in hydrogen supply
- Demonstration projects for the integration of carbon capture technology, such as that being trialled in the LEILAC project, on difficult-to-abate process emissions (e.g. in cement/lime kilns) could be further supported by investigations into CCU routes to drive value from captured CO_2
- Building upon learnings from the INLUMIA pilot projects[99], government can drive support for large-scale Industry 4.0 innovations (e.g. AI technologies, smart energy management systems) across the region's manufacturing sectors

Recommendations – policies and finance/business models

- Introduction of a new CfD (or similar) financing mechanism for industrial abatement options (fuel switching, process changes, carbon capture, etc.) to drive deep decarbonisation efforts beyond that imposed by the EU-ETS (EU Emissions Trading System) carbon market
- As an alternative financing mechanism for carbon capture technologies, tax credits (in €/tCO_2 captured) may be offered for CO_2 utilisation or transport/shipping to other regions
- Development of "green product" incentives for industry via minimum product standards in public procurement guidelines (e.g. low-carbon steel, aluminium and plastics for car production)

[93] https://www.thyssenkrupp-steel.com/en/company/sustainability/climate-strategy/
[94] https://epub.wupperinst.org/frontdoor/deliver/index/docId/7409/file/7409_Lechtenboehmer.pdf
[95] https://www.theclimategroup.org/sites/default/files/downloads/etp-nrw-casestudy_sep2016.pdf
[96] https://www.cleanenergywire.org/factsheets/germanys-greenhouse-gas-emissions-and-climate-targets
[97] https://www.hydrogen4climateaction.eu/projects
[98] https://www.in4climate.nrw/best-practice/2020/leilac-by-calix/
[99] https://inlumia.de/pilotprojekte/

4.2 Emilia-Romagna

Overview of existing industrial base and expected changes

Emilia-Romagna's manufacturing industries play the leading role for the wider regional economy. The most relevant industries for export markets are linked to mechanical engineering and automotive companies, alongside the food, ceramics and chemicals industries having a strong regional presence.

Gas dominates the industrial fuel consumption mix, accounting for just over 60% of total fuel use in industry, followed by electricity consumption at 27%.[100] Electricity generation is currently dominated by fossil fuels (74%[101]) but will be transitioning to be zero carbon by 2050 in order to meeting the carbon-neutral EU target.[102]

Commonalities and transferable learnings from other regions

- Cluster-based fuel switching projects with dedicated hydrogen supply for energy intensive industrial gas users are currently being undertaken in other regions (e.g. HyNet project in Merseyside, England), offering transferable learnings for Emilia-Romagna's government to engage with industry to consider fuel switching plant suitability and the development of infrastructure
- Eni's proposed CCS Ravenna Hub project[103] in Emilia-Romagna (prefeasibility study ongoing) shares many similarities with other operational or proposed CCUS projects across the wider EU region for carbon capture from industrial emitters and offshore transport/storage to depleted reservoirs (e.g. Scotland's Acorn CCS project or Norway's Northern Lights project)
- Shared interest with other EU regions on the impacts and development of the EU Commission's recent consultations on a Carbon Border Adjustment Mechanism to help reduce risk of carbon leakage

Recommendations – technologies

- Fuel switching to hydrogen or electricity should be evaluated as businesses seek low-cost, disruptive strategies to drive deep decarbonisation efforts across many existing manufacturing processes in the region (e.g. steam and water boilers, low and high temperature dryers or heaters, etc.); such fuel switching interventions would need to be assessed for and coupled with investigations into securing zero-carbon hydrogen or electricity supply
- Support for the uptake of additive manufacturing (e.g. 3D printing in manufacturing or construction sectors) processes alongside Industry 4.0 breakthroughs (e.g. advanced energy management or Internet-of-Things systems) would enable benefits that further support the region's direction towards a wider circular economy

Recommendations – policies and finance/business models

- Emilia-Romagna's circular economy development can be bolstered by government support and engagement with innovative companies offering manufacturers access-over-ownership (e.g. Energy-as-a-Service) business models as a means to simultaneously reduce carbon emissions and costs
- "Green product" incentives for industry via minimum product standards in public procurement guidelines (e.g. recycled material packaging, low carbon steel, and aluminium in automotive industries)
- Introduction of a new CfD (or similar) financing mechanism for industrial abatement options (fuel switching, process changes, carbon capture, etc.) to drive deep decarbonisation efforts beyond that imposed by the EU-ETS carbon market

[100] Emilia-Romagna's Regional Agency for Prevention, Environment and Energy, 2020 Energy Report
[101] Emilia-Romagna's Regional Agency for Prevention, Environment and Energy, Gross production of electricity by source
[102] EU Commission, Energy, Climate Change, and Environment, Long-term strategies
[103] International Association of Oil & Gas Producers, CCUS Projects in Europe

4.3 Lombardy

Overview of existing industrial base and expected changes

Lombardy's manufacturing industries play the leading role for the regional economy, along with refining and cement plants in the region. The manufacturing sectors with greatest value added to the economy, are metal products, machinery and equipment, food products and rubber and plastics.

Electricity and gas dominate the industrial fuel consumption mix, accounting for just over 40% and 36% of total fuel use in industry, respectively, followed by coal and other fossil fuel consumption at 17%.[104] The majority of installed capacity for electricity generation is fossil-fuelled (58%), followed by hydroelectric (24%)[104], but will need to transition to be zero carbon by 2050 to meet the carbon-neutral EU target.

Commonalities and transferable learnings from other regions

- Cluster-based fuel switching projects with dedicated hydrogen supply for energy intensive industrial gas users are currently being undertaken in other regions (e.g. HyNet project in Merseyside, England), offering transferable learnings for Lombardy's government to engage with industry to consider fuel switching plant suitability and the development of infrastructure
- Learnings from trial projects for cement fuel switching (e.g. previously mentioned electricity/hydrogen and hydrogen/biomass trials in England) as well as zero-carbon hydrogen supply to replace grey hydrogen in refineries (e.g. Gigastack project)
- Shared interest with other EU regions on the impacts and development of the EU Commission's recent consultations on a Carbon Border Adjustment Mechanism to help reduce risk of carbon leakage

Recommendations – technologies

- Investigations into fuel switching to hydrogen or electricity should be evaluated as a potential low-cost, disruptive strategy to drive deep decarbonisation efforts across many existing manufacturing processes in the region (e.g. steam and water boilers, low and high temperature dryers or heaters, etc.) alongside other mixed fuel options for the cement / refining sectors
- Evaluation of sites suitable for carbon capture technology adoption, with associated CCUS infrastructure that has the potential to integrate into wider large-scale Italian projects (e.g. proposed CCS Ravenna Hub in Emilia-Romagna)
- Uptake of additive manufacturing (e.g. 3D printing) processes alongside Industry 4.0 breakthroughs (e.g. advanced energy management or Internet-of-Things systems) would enable benefits that further support the region's direction towards a wider circular economy

Recommendations – policies and finance/business models

- Introduction of a new CfD (or similar) financing mechanism for industrial abatement options (fuel switching, process changes, carbon capture, etc.) to drive deep decarbonisation efforts beyond that imposed by the EU-ETS carbon market
- Development of "green product" incentives for industrial manufacturers via minimum product standards in public procurement guidelines (e.g. recycled material packaging, low carbon steel, and bans on single-use plastics) to drive low-carbon content product demand
- Creation of government-backed or promotion of industrial-focused green/climate bonds to support low-carbon investments in new plants or expansions of existing facilities for manufacturers

[104] PEAR (Programma Energetico Ambientale Regionale) Primo Rapporto di Monitoraggio (2017)

4.4 Scotland

Overview of existing industrial base and expected changes

Scotland's chemicals manufacturing and oil and gas processing sectors make up the region's greatest emissions contributions, with anticipated hydrogen and CCUS uptake in these sectors likely to drive wider decarbonisation efforts once full-chain infrastructure becomes available.

Fossil fuels (petroleum products and gas) dominate the industrial and commercial fuel consumption mix accounting for 74% of total fuel use, followed by electricity consumption at 23% (excluding waste / bioenergy).[105] Scotland's low emissions intensity grid makes fuel switching to electricity (where suitable for industrial processes) favourable in the near-term. Electricity generation is dominated by renewable and nuclear power, both making up 43% of the total, with a small fraction of fossil fuel generation (13%).[106] Moreover, the power grid will be transitioning to be zero carbon by 2045 (Scotland's carbon-neutral target).[107]

Commonalities and transferable learnings from other regions

- Norway's Northern Lights full-scale CCS project (currently under final investment decision by the Norwegian government) shares many similarities with Scotland's regional ambitions for the development of CCUS technology adoption and infrastructure (i.e. capture of CO_2 from industrial sites, shipping / offshore transport in the North Sea); key learnings of government investment strategies and decision-making can be incorporated into the regional Acorn CCS project
- Potential learnings from the EU Commission's recently started consultations on a Carbon Border Adjustment Mechanism, which upon successful review and development, will be applied on imports of products to help reduce risk of carbon leakage out of the EU bloc (Scottish government could drive support for a similar UK-wide border tariff adjustment to maintain regional industrial competitiveness)

Recommendations – technologies

- While fuel switching is already prominent on the region's strategy for industrial decarbonisation (e.g. hydrogen infrastructure development, electrification of industrial appliances, etc.) further investigations into more innovative fuel switching options in the cement and glass sectors could be explored for adoption (i.e. mixed fuel electricity, hydrogen, and biomass in cement kilns and glass furnaces)
- Continue engagement with industrial emitters, including North-East Carbon Capture, Utilisation and Storage (NECCUS), to identify and support investment opportunities in CO_2 utilisation or storage
- Government support for Industry 4.0 innovations (automation, artificial intelligence systems, etc.) to enable energy savings and emissions reductions across many sectors

Recommendations – policies and finance/business models

- Scottish industry may soon have access to a Contract-for-Difference (CfD) financing mechanism combined with an upfront grant support for CCUS projects. The UK government aims to have the CfD mechanism implemented in 2022 and is considering its adaptation over time to include other low carbon technology options (fuel switching, process changes, etc.)[108]
- With the UK-wide CfD policy in place, regional financial support for CCUS and fuel switching projects could be directed towards transport and storage infrastructure deployment and grants for early projects
- Strengthen the sustainable procurement duty[109] tools and guidelines with embodied carbon disclosure/caps (e.g. infrastructure projects) to promote regional demand for low-carbon products

[105] UK Government, Total final energy consumption at regional and local authority level
[106] Scottish Government, Electricity Generation High Level Summary of Statistics Trend
[107] Scotland's Climate Change (Emissions Reduction Targets) Act 2019
[108] UK Department of Business, Energy & Industrial Strategy, Response on potential business models for CCUS
[109] Scottish Government, Sustainable Procurement Duty

4.5 Wales

Overview of existing industrial base and expected changes

The iron and steel, refining and cement industries make up the region's greatest emissions contributions, with decarbonisation programming already exploring opportunities for hydrogen (particularly in North Wales for integration with the North West Hydrogen Alliance) as well as CCUS (centered around the cluster of large emitters in South Wales, including Port Talbot Steelworks).

Fossil fuels currently dominate the industrial and commercial fuel consumption mix accounting for nearly 75% of total fuel use, with the remainder met by electricity consumption at 25% (excluding waste / bioenergy).[105] Electricity generation is dominated by fossil fuels (75% of total, of which gas is 72%), with the remainder met by renewables (25%), primarily onshore and offshore wind.[110]

Commonalities and transferable learnings from other regions

- Norway's Northern Lights full-scale CCS project (currently under final investment decision by Norwegian government) shares many similarities with Wales' regional perspective for the development of CCUS technology adoption and infrastructure (i.e. capture of CO_2 from industrial sites, CO_2 shipping in the North Sea or Irish Sea); key learnings of government investment strategies and decision-making can be incorporated, for instance into the decarbonisation planning in the South Wales cluster
- Potential learnings from the EU Commission's recently started consultations on a Carbon Border Adjustment Mechanism, which upon successful review and development, will be applied on imports of products to help reduce risk of carbon leakage out of the EU bloc (Welsh government could drive support for a similar UK-wide border tariff adjustment to maintain regional industrial competitiveness)

Recommendations – technologies

- Welsh government should continue engagement with industrial emitters situated nearby regional planning under the North West Hydrogen Alliance (centered in Merseyside, England) to identify and support CCUS and hydrogen investment opportunities in North Wales
- Plan and forecast for the uncertainties regarding new technology deployment required to decarbonise Port Talbot's major iron and steel site, which will be a key driver for economies of scale within the South Wales industrial cluster and heavily influence the regional costs of abatement for fuel switching or CCUS adoption by other industrial sites
- Investigate fuel switching options in the cement, glass and ceramics sectors (e.g. mixed fuel electric, hydrogen, and biomass kilns / furnaces)

Recommendations – policies and finance/business models

- Welsh industry may soon have access to a Contract-for-Difference (CfD) financing mechanism combined with an upfront grant support for CCUS projects. The UK government aims to have the CfD mechanism implemented in 2022 and is considering its adaptation over time to include other low carbon technology options (fuel switching, process changes, etc.)[108]
- With the UK-wide CfD policy in place, further regional financial support for CCUS and fuel switching projects could be directed towards transport and storage infrastructure deployment, focused on investigations into CO_2 shipping to other UK clusters (e.g. Merseyside, Humberside, etc)
- Development of green public procurement guidelines incorporating embodied carbon disclosure / caps (e.g. promoting regional low-carbon steel and cement) to encourage abatement technology investment

[110] Welsh Government, Energy Generation in Wales 2018 in 5 minutes

4.6 California

Overview of existing industrial base and expected changes

Petroleum refining and oil and gas production industries make up the region's greatest emissions contributions, with the remainder of emissions spread across many sectors/processes (cement, chemicals, cogeneration, manufacturing, etc.). California's top 10 industrial emitters (six refineries, three oil and gas production facilities and one cement plant) alone account for approximately 34% of the region's total industrial emissions.[111]

Fossil fuels dominate the industrial fuel consumption mix accounting for nearly 86% of total fuel use, with the remainder met by electricity consumption at 11% and other renewables at 3%.[25] Electricity generation is dominated by natural gas (47%) and renewables (32%, of which 44% is from solar), with the remainder met by large hydro (11%), nuclear energy (9%), and other fossil fuels (<0.5%).[112]

Commonalities and transferable learnings from other regions

- Learnings for industrial abatement technology suitability from fuel switching trial projects for cement kilns (e.g. electricity/hydrogen and hydrogen/biomass in England) and glass furnaces (e.g. large-scale hybrid oxy-fuel furnace to run on 80% renewable electricity in Germany)
- Regional developments and investment in green hydrogen supply for industry (e.g. replacing grey hydrogen in refineries with green hydrogen from offshore wind in the Gigastack project in England)
- Consideration of a state-wide border tax adjustment can take learnings from the EU's recently started consultations on a Carbon Border Adjustment Mechanism, which upon review and development, will be applied on imports of products to help reduce risk of carbon leakage out of the EU bloc

Recommendations – technologies

- Plan and forecast for industrial processes that may require adoption of CCUS technologies (e.g. process emissions in cement and chemicals sectors) to achieve deep decarbonisation and how these may be supported by existing federal policies (e.g. 45Q tax credit) or require additional support
- Investigate fuel switching and process change technologies that may require initial government support for trial or demonstration projects in the cement, glass and manufacturing sectors (e.g. electric, hydrogen, biomass, or mixed fuel) to drive investor confidence towards wider deployment
- Support the uptake of additive manufacturing processes (e.g. 3D printing in manufacturing or construction industries) alongside Industry 4.0 breakthroughs (e.g. artificial intelligence systems) to drive industry towards high-efficiency, sustainable production processes

Recommendations – policies and finance/business models

- Strengthen the embodied carbon disclosure in the Buy Clean California Act[113] to include additional materials (e.g. cement) and create a roadmap for the integration of a whole lifecycle carbon cap (operational and embodied emissions) of buildings/infrastructure projects
- In addition to the regional cap-and-trade program and federal 45Q tax credit, introduction of a state-wide Contract-for-Difference (or similar) financing mechanism for industrial abatement options (fuel switching, process changes, etc.) can drive deep decarbonisation efforts
- Support and engage with companies offering manufacturers access-over-ownership (e.g. Energy-as-a-Service) business models as a means to simultaneously reduce carbon emissions and costs

[111] California Air Resources Board, GHG Emission Inventory Graphs
[112] California Energy Commission, 2018 Total System Electric Generation
[113] California Government, Buy Clean California Act

4.7 Minnesota

Overview of existing industrial base and expected changes

Accounting for 81% of total industrial emissions, the refining, mining and manufacturing sectors make up the region's greatest emissions sources. Refining and taconite induration (i.e. iron ore pelletizing) process emissions alone account for 87% of total process-based emissions.

Energy consumption emissions derived from fossil fuel usage is dominated by natural gas (62%), however indirect emissions from electricity consumption are currently significant.[33] Electricity generation is met by a significant share of fossil fuels (coal plants accounting for 31%[114]), although many of the state's largest utilities are planning to phase out coal by the end of the decade.[115]

Commonalities and transferable learnings from other regions

- Learnings from regions investing in industrial fuel switching applications (e.g. replacing grey hydrogen in refineries in the Gigastack project in England) or other nearby regional developments towards zero-carbon hydrogen production (e.g. future import/export opportunities as part of Canada's nationwide hydrogen strategy[116])
- Minnesota government can drive further political support to introduce state-wide carbon pricing (such as Alberta's carbon price for large industrial facilities[117] or California's cap-and trade program[29]) which will ensure product exports remain competitive as regions begin to consider border tax adjustments (e.g. EU Commission's recently started consultations on a Carbon Border Adjustment Mechanism[78])

Recommendations – technologies

- Investigations and financial support for demonstration projects into alternative fuel switching options (e.g. electricity, hydrogen, biomass or mixed fuels) for a wide array of sectors currently using natural gas or oil to meet energy and heating demands, with an emphasis on opportunities to utilise renewable natural gas derived from organic waste[118] or biofuels from expanding state-wide production[119]
- Uptake of additive manufacturing (e.g. 3D printing) processes alongside Industry 4.0 breakthroughs (e.g. advanced energy management or Internet-of-Things systems) would enable benefits that further support high energy efficiency savings across many sectors in the region
- Plan and forecast for industries that may require adoption of CCUS technologies (e.g. process emissions in refining and taconite induration) for deep decarbonisation and how these may be supported by existing federal policies (e.g. 45Q tax credit) or require additional support

Recommendations – policies and finance/business models

- Development of "green product" incentives for industry via minimum product standards in public procurement guidelines (e.g. sustainable metals, plastics and pulp and paper products) to drive regional demand for low-carbon production methods via abatement technology adoption
- Creation of government-backed or promotion of industrial-focused green/climate bonds to support low-carbon investments in new plants or expansions of existing facilities for manufacturers
- In addition to the implementation of a state-wide carbon price (which has yet to be legislated[120]), introduction of a Contract-for-Difference (or similar) financing mechanism for industrial abatement options (fuel switching, process changes, carbon capture, etc.) to drive deep decarbonisation efforts

[114] US Energy Information Administration, State Profile: Minnesota
[115] MINNPOST, Phasing out: Utilities, cities prepare for the end of coal-fired energy in Minnesota
[116] S&P Global Platts, Canada confirms it is developing national hydrogen strategy
[117] Alberta's Technology Innovation and Emissions Reduction Regulation currently sets a carbon price of $30/t$CO_2$e.
[118] Minnesota may consider piloting renewable natural gas production from organic waste (e.g. as in Toronto).
[119] Minnesota Department of Agriculture, Biofuels Grants Expand Access and Production
[120] https://priceoncarbon.org/business-society/state-actions/minnesota/

4.8 Quebec

Overview of existing industrial base and expected changes

The aluminium industry alone accounts for 33% of the region's industrial emissions captured by the cap-and-trade program, followed by the refining and cement industries, at 14% and 13%, respectively. However, cement emissions are anticipated to rise in the near-term as a newly constructed cement plant is estimated to emit 1.8 $MtCO_2e$ annually[121].

Energy consumption in industry is primarily from renewable sources – i.e. electricity (50%) and biofuels (15%) – with fossil fuels accounting for the remainder (primarily natural gas at 24%).[122] Electricity generation is met almost entirely by renewable energy sources, primarily hydropower which accounts for 95% of the region's total electricity generation, followed by wind at 4%.[123]

Commonalities and transferable learnings from other regions

- Quebec government can investigate learnings from regions investing in industrial hydrogen fuel switching applications (e.g. hydrogen in refineries, Gigastack project in England) or mixed-fuel switching trial projects for cement kilns (e.g. electricity/hydrogen and hydrogen/biomass in England)
- Opportunities for supply chain and infrastructure synergies from other nearby regional developments towards zero-carbon hydrogen production (e.g. opportunities to align actions with Canada's or Alberta's to-be-proposed nationwide and provincial hydrogen strategies[124])
- Consideration of a provincial border tax adjustment can take learnings from the EU's recently started consultations on a Carbon Border Adjustment Mechanism, which upon review and development, will be applied on imports of products to help reduce risk of carbon leakage out of the EU bloc

Recommendations – technologies

- Supported by regional planning for hydrogen deployment (e.g. Hydro-Québec's Strategic Plan incorporating green hydrogen development[125]), hydrogen fuel switching will be an important option for sites across various sectors (chemicals, refining, etc.) to drive economies of scale in hydrogen supply
- Demonstration projects for the integration of carbon capture technology, such as that being trialled in the LEILAC project, on difficult-to-abate process emissions (e.g. in cement/lime kilns) could be further supported by investigations into CCU routes to drive value from captured CO_2
- Industry 4.0 technologies (i.e. artificial intelligence or Internet-of-Things systems) to enable energy and/or emissions reductions in the aluminium and other manufacturing sectors

Recommendations – policies and finance/business models

- Introduction of a new Contract-for-Difference (or similar) financing mechanism for industrial abatement options (fuel switching, process changes, carbon capture, etc.) to drive deep decarbonisation efforts beyond that imposed by the current cap-and-trade carbon market
- As an alternative financing mechanism for carbon capture technologies, tax credits (in $/t$CO_2$ captured) may be offered for CO_2 utilisation or transport/shipping to other regions
- Strengthen embodied carbon reduction policies such as those in the regional Wood Charter[126], to include steel and concrete emissions and create a roadmap for introducing a carbon cap for regional building regulations or infrastructure projects

[121] https://ici.radio-canada.ca/nouvelle/1530966/reduction-emissions-co2-ciment-mcinnis-port-daniel
[122] Quebec's Energy Sector Management Chair, State of Energy in Quebec 2020
[123] Canada Energy Regulator, Provincial and Territorial Energy Profiles – Quebec
[124] Canadian Hydrogen and Fuel Cell Association, Ottawa, Alberta develop new hydrogen strategies
[125] Hydro-Quebec, Strategic Plan 2020–2024
[126] Quebec Ministry of Forests, Wildlife and Parks, The Wood Charter: The Raw Material for Responsible Development

5 Conclusions

Industrial landscape characterisation and commonalities

This study has demonstrated the unique differences in the characteristics of the industrial landscape of participating regions, including major industrial sites, primary sectors, multinational companies, and GHG emissions. In light of this, regional governments face the challenge of driving decarbonisation strategies across a wide array of industrial plants and processes, with greater uncertainty in planning in the aftermath of the COVID-19 crisis. However, governments now have a critical role to play in supporting an economic recovery while promoting a green transition which enables industrial decarbonisation and avoids offshoring of emissions to regions with less stringent carbon reduction policies.

Despite these challenges, the analysis undertaken in this project has showcased how regional governments share commonalities in their approaches taken to support low-carbon industrial activity. Similar regional responses to the COVID-19 emergency include action plans highlighting necessary steps towards net-zero economies, pro-active management of existing industrial decarbonisation programming, data and intelligence gathering for structuring funding, and new industrial working groups to support low-carbon investment opportunities. Additional commonalities included methods which regional governments have and will continue to utilise in their engagement with industry stakeholders. These approaches aim to increase government influence with multinational companies, such as roundtables and workshops to gather evidence bases for input into industrial decarbonisation planning, focus groups with industrial sectors to evaluate effective policy and funding designs, and technology and innovation clusters that drive collaborative decarbonisation projects between academia, the private sector, and government.

Disruptive innovation options for industrial decarbonisation

Moreover, there exist a multitude of future disruptive innovation options (technologies, policies and finance/business models) anticipated to impact low-carbon markets in the next two decades. These options have been assessed and categorised as follows:

Technologies:

- **Fuel switching**: Includes options to switch existing industrial systems/processes to low or zero carbon fuels (i.e. electricity, hydrogen, biomass, waste fuels or mixed fuel options)
- **CCUS**: Includes technologies applied to industrial applications such as process emissions (e.g. cement, lime, glass, chemicals, refining, iron and steel industries), negative emissions (with existing biomass processes), combustion (reforming), kilns, etc.
- **Innovative process changes**: Includes innovative technology/process designs (which can also be combined with fuel switching or CCUS options) particularly important for high-emitting sectors across many regions (e.g. iron and steel, cement, glass)
- **Industry 4.0**: Includes new transformative technologies applicable across many industrial plants and processes (e.g. artificial intelligence technologies, advanced energy management systems, internet of connected applications, additive manufacturing i.e. 3D printing, etc.)

Policies:

- **Green / public procurement**: Guidelines and codes integrated into government (or private) procurement processes that place value on low-carbon products to be preferred against more carbon intensive ones, even if at a price premium
- **Border tariff adjustments**: Refers to the issuance of import fees on goods manufactured in countries with a lower carbon price, with the aim of reducing the risk of carbon leakage from occurring in countries/regions with stricter carbon reduction policies
- **Embodied carbon disclosure and caps**: Embodied carbon includes emissions associated with materials and construction processes throughout the lifecycle of buildings or infrastructure, with a cap setting a carbon limit, thereby driving demand for low-carbon materials (e.g. steel, concrete, etc.)

- **Circular economy and low carbon market development**: Includes a combination of policy levers (e.g. government standards, material/product bans, technology investment) that incentivise or directly support low carbon or circular economy market development (can be industry specific)

Finance/business models:

- **Contract-for-Difference (or similar schemes)**: An industrial emitter investing in a new abatement technology is paid (or refunded) by the government the difference between a CO_2 strike price contractually agreed, in \$/tCO_2 abated, and the prevailing CO_2 market/certificate price
- **Carbon capture support mechanisms**: Includes cost plus open book financing (government grants for operational costs and agreed returns on capital investment), tradeable or untradeable tax credits (in \$/tCO_2 abated), or tradeable CCUS certificates with obligations
- **Access-over-ownership**: Business models in which industrial customers access services and products as an operational, rather than capital, expenditure and which are anticipated to disrupt markets by driving major energy / material efficiency improvements alongside Industry 4.0 innovations
- **Green / climate bonds**: Loans which companies, governments, and banks can use to finance projects directly related to emissions reductions, which are anticipated to disrupt low-carbon projects in many sectors (e.g. utilities, agribusiness, manufacturing, etc.)

Transferable learnings from these disruptive innovation options were tailored to meet localised requirements for deep decarbonisation in industry for each of the participating regions. In the coming 20 years, the final regional recommendations in this report provide an initial blueprint for fostering disruptive innovation in industry to simultaneously promote industrial activity while effectively reducing GHG emissions.