Energy Innovation Needs Assessment

Sub-theme report: Industry

Commissioned by the Department for Business, Energy & Industrial Strategy

October 2019

Lead:

vivideconomics
putting economics to good use

Partners:

CARBON TRUST

E4tech
Strategy | Energy | Sustainability

Imperial College London

FRAZER-NASH CONSULTANCY

Modelling support by:

CATAPULT Energy Systems

Contents

Acronyms and abbreviations 3
Glossary 5
Introduction 6
Key findings 9
Industrial technologies and the whole energy system 15
Innovation opportunities within industrial technologies 24
Business opportunities within industry 42
Market barriers to innovation within industry 62
Appendix 1: Organisations at expert workshop 68
Appendix 2: Innovation mapping 69
Appendix 3: Business opportunities methodology 83
Appendix 4: GVA from exports 90
Appendix 5: Summary estimates from business opportunities analysis 95
Appendix 6: Technologies included for business opportunities analysis 96
Appendix 7: Assessment of business opportunities uncertainty 100

The views expressed in this report are the authors' and do not necessarily reflect those of the Department for Business, Energy and Industrial Strategy.

Acronyms and abbreviations

Table 1. **Key acronyms and abbreviations**

Acronym/abbreviation	Definition
AHSS	Advanced high strength steel
B2DS	Beyond 2-Degree Scenario
BAT	Best available technologies
BAU	Business as usual
BEIS	Department for Business, Energy and Industrial Strategy
BIS	Department for Business, Innovation & Skills (now BEIS)
BOF	Basic oxygen furnace
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CCUS	Carbon capture, utilisation and storage
CEPI	Confederation of European Paper Industries
CO	Carbon monoxide
CO_2	Carbon dioxide
CSI	Cement Sustainability Initiative
DECC	Department of Energy and Climate Change (now BEIS)
DSRM	Demand-side response and management
DUKES	Digest of UK Energy Statistics
EAF	Electric Arc Furnaces
ECRA	European Cement Research Academy
EINA	Energy Innovation Needs Assessment
EPCm	Engineering, Procurement, and Construction Management
ESC	Energy System Catapult
ESME	Energy System Modelling Environment
ETI	Energy Technologies Institute

EU	European Union
GCCA	Global Cement and Concrete Association
GHG	Greenhouse Gas
GVA	Gross Value Added
IDT	Industrial Digital Technologies
IEA	International Energy Agency
IP	Intellectual Property
LCOE	Levelised cost of energy
MW	Megawatt
NOx	Nitrogen Oxides
O&M	Operations and maintenance
OPEX	Operational Expenditure
PV	Photovoltaics
R&D	Research and Development
RD&D	Research, Development, and Demonstration
SME	Small and Medium-sized Enterprises
TINA	Technology Innovation Needs Assessment
TRL	Technology Readiness Level

Glossary

Table 2. **Key terms used throughout this report**

Term	Definition
Learning by doing	Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards which tend to increase in direct proportion to capacity increases.
Learning by research, development and demonstration	Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D); increases with spend in RD&D and tends to precede growth in capacity.
Sub-theme	Groups of technology families which perform similar services which allow users to, at least partially, substitute between the technologies. For example, a variety of technology families (heat pumps, district heating, hydrogen heating) have overlapping abilities to provide low-carbon thermal regulation services and can provide flexibility to the power system.
System value and Innovation value	Estimates of change in total system cost (measured in £ GBP, and reported in this document as cumulative to 2050, discounted at 3.5%) as a result of cost reduction and performance improvements in selected technologies. This is the key output of the EINAs and the parameter by which improvements in different technologies are compared. System benefits result from increasing deployment of a technology which helps the energy system deliver energy services more efficiently while meeting greenhouse gas targets. Energy system modelling is a vital tool in order to balance the variety of interactions determining the total system costs. Innovation value is the component of system value that results from research and development (rather than from ‘learning by doing’)
Technology family	The level at which technologies have sufficiently similar innovation characteristics. For example, heat pumps are a technology family, as air-source, ground-source and water-source heat pumps all involve similar technological components (compressors and refrigerants). Electric vehicles are also a technology family, given that the battery is a common component across plug-in hybrids and battery electric vehicles.
Gross Value Added	Gross Value Add (GVA) measures the generated value of an activity in an industry. It is equal to the difference between the value of the outputs and the cost of intermediate inputs.

Introduction

Box 1. **Background to the Energy Innovation Needs Assessment**

The Energy Innovation Needs Assessment (EINA) aims to identify the key innovation needs across the UK's energy system, to inform the prioritisation of public sector investment in low-carbon innovation. Using an analytical methodology developed by the Department for Business, Energy & Industrial Strategy (BEIS), the EINA takes a system-level approach, and values innovations in a technology in terms of the system-level benefits a technology innovation provides.[1] This whole system modelling in line with BEIS's EINA methodology was delivered by the Energy Systems Catapult (ESC) using the Energy System Modelling Environment (ESME) as the primary modelling tool.

To support the overall prioritisation of innovation activity, the EINA process analyses key technologies in more detail. These technologies are grouped together into sub-themes, according to the primary role they fulfil in the energy system. For key technologies within a sub-theme, innovations and business opportunities are identified. The main findings, at the technology level, are summarised in sub-theme reports. An overview report will combine the findings from each sub-theme to provide a broad system-level perspective and prioritisation.

This EINA analysis is based on a combination of desk research by a consortium of economic and engineering consultants, and stakeholder engagement. The prioritisation of innovation and business opportunities presented is informed by a workshop organised for each sub-theme, assembling key stakeholders from the academic community, industry, and government.

This report was commissioned prior to advice being received from the CCC on meeting a net zero target and reflects priorities to meet the previous 80% target in 2050. The newly legislated net zero target is not expected to change the set of innovation priorities, rather it will make them all more valuable overall. Further work is required to assess detailed implications.

[1] The system-level value of a technology innovation is defined in the EINA methodology as the reduction in energy system transition cost that arises from the inclusion of an innovation compared to the energy system transition cost without that innovation.

The industry technologies sub-theme report

This industry sub-theme report focusses exclusively on seven industries: chemicals, food & drink, iron & steel, cement, pulp & paper, glass, and ceramics. Together, these industries account for close to two-thirds of all direct manufacturing emissions in the UK. These will need to decarbonise or offset their emissions (with technologies such as carbon capture, utilisation, and storage (CCUS)), in order to meet the UK's 2050 climate change targets.[2]

Overall, the entire industrial sector accounts for 16% of the UK's total energy consumption.[3] This makes industrial energy use a key component of the entire energy system.

The seven industries are also very important sectors in the UK economy. They make up just over a third of the £160 billion that manufacturing adds to the UK economy each year. These industries also account for around 10% of annual R&D expenditure by manufacturing businesses.

Some aspects of industrial technologies are not within the scope of this report as they are covered in other sub-theme EINAs. For example, CCUS is an important technology to decarbonise industry, but is covered in the CCUS EINA. The uses of hydrogen and biomass in industry (for fuel switching) are within the scope of this EINA, but their production is covered in the Hydrogen and Bioenergy EINAs respectively. Heat recovery and reuse is in this report, but heat networks and other heat infrastructure are in the Heating & Cooling EINA.

Significant uncertainty surrounds the future size and composition of industry. This report draws on available information of major industrial decarbonisation technologies but acknowledges the possibility that some industrial segments will undergo radical changes. Changes in the size and composition of industry may affect the value of innovations and associated business opportunities.

The report has four sections:

- **Industrial technologies and the energy system:** Describes the role of industry in the energy system.
- **Innovation opportunities:** Provides lists of the key innovations available within industry, and their approximate impacts on costs.

[2] The Climate Change Act 2008 set a legally binding emission reduction target of at least 80% by 2050 (relative to 1990). The Decarbonisation and Energy Efficiency Roadmaps to 2050 suggest a reduction in overall industry emissions of up to 70% by 2050 (relative to 2009 emissions).
[3] BEIS (2018). Digest of United Kingdom Energy Statistics (DUKES) 2018. Available at: https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2018-main-report

- **Business opportunities:** Summarises the export opportunities of industry, the GVA and jobs supported by these opportunities, and how innovation helps the UK capture the opportunities.
- **Market barriers to innovation:** Highlights areas of innovation where market barriers are high and energy system cost reductions and business opportunities significant.

Key findings

This report focusses on the seven industries, which are chemicals, food & drink, iron & steel, cement, pulp & paper, glass and ceramics.

Innovation areas in industry

The main innovations for industry are identified below. The list is not a substitute for a detailed cost reduction study. Rather, it is a guide for policymakers on key areas to be considered in any future innovation programme design.

The innovation priorities below select individual or groups of the top scoring innovations. Table 3 maps the top scoring innovations to individual technology components, and Table 6 sets out the full list of innovations and their scores.

- Fuel switching to (low-carbon) electricity, biomass, and hydrogen. All industries have the potential for fuel switching to one or various alternatives to displace fossil fuel consumption.
- Efficiency improvements through improved process equipment (such as furnaces and kilns) and increased digitisation of processes (which allow for process optimisation).
- Alternative process technologies at low technology readiness level (TRL) levels that can provide transformative change in industry-specific processes to reduce energy use and emissions.

CCUS is a key technology for industrial decarbonisation (especially for the iron & steel and cement industries) and has a large innovation potential. However, this technology is not within the scope of this EINA. For innovation opportunities in industrial CCUS, please see the dedicated CCUS EINA.

Business opportunities for the UK

Innovation provides an opportunity for the UK to become competitive in industrial decarbonisation technologies. If global industry were to reduce emissions by approximately 70% in 2050 relative to 2012 levels, exports relating to decarbonisation technologies can support roughly £1.4 billion in GVA per annum and 18,000 jobs by

2050.[4] In the business opportunities section below, GVA and jobs results are set out by component (Table 8).

- Engineering, procurement and construction management (EPCm) service exports could support £800 million of GVA per annum in 2050, around 60% of the total opportunity.
- The largest export opportunities in 2050 are primarily in alternative process technologies (44%) and efficiency improvements (33%). The key sector opportunities are in technologies for the cement (42%), food & drink (23%), and chemicals (16%) sectors.
- Overall, trade data suggests the UK is currently not in a particularly competitive position for specialised industrial equipment and engineering, procurement, and construction management (EPCm) services. For example, UK market shares for key equipment markets are around 4% in the European Union (EU) and 3% in the rest of the world (RoW). There are however some niche areas of strength, such as biochemicals and process optimisation.
- The estimated export opportunity assumes a significant increase in UK competitiveness, driven by a suite of innovations in industry. This is possible, but not guaranteed, representing a significant area of uncertainty.
- Export opportunities are likely to be larger than domestic opportunities, which can add £520 million per annum to GVA and support 6,000 jobs by 2050. This is because most specialised equipment and associated services are expected to be highly traded. The UK is unlikely to capture a significantly larger share of its domestic market, and hence growth in domestic opportunity over time is driven by expanding segments of the market for deploying industrial decarbonisation technologies.

Market barriers to innovation in the UK

Opportunities for HMG support exist when market barriers are significant, and they cannot be overcome by the private sector or international partners. In the market barriers section below, the barriers are set out by component, where possible (Table 10). The main market barriers identified by industry relate to:

- Payback periods of decarbonisation technologies are often longer than the private sector is willing to accommodate. Private funding generally requires short life spans

[4] The “Max Tech” scenario of the Industrial Decarbonisation Roadmaps suggests a reduction in overall industrial emissions of up to 70% by 2050 (relative to 2009 emissions).

with payback in the first three years, which cannot be achieved by the innovations considered. Decarbonisation technologies often involve high capital expenditure (capex), and firms cannot recoup investment in the short term.

- Early movers are not compensated for the technical risk of innovation and face the reputational risk of delivering lower quality products as a result of failed innovations or unforeseen impacts. Subsequent innovators can build on earlier iterations and experiences to better target market needs. As a result, firms take a 'wait and see' approach, slowing the progress of innovation. Larger firms can balance innovation risk more easily because they can diversify their investments and recoup potential losses.

- Industry is not sufficiently compensated to commercialise new technologies and bring new innovations to market. New technologies are not commercially tested, making firms reluctant to implement them as they may cause disruptions now or in the future. As a result, innovations are not deployed and the returns to innovation are not achieved. UK government support is currently focussed on early stage innovation. Industry stated that further funding support is needed to commercialise low-carbon alternatives, particularly to pilot and upscale them in the production process.

- There is a lack of access to required infrastructure. This includes hydrogen distribution networks, low-carbon electricity, and CO_2 transport and storage infrastructure. Due to the large upfront cost, shared revenues and long lifetime of infrastructure, investment in it requires a high degree of coordination. Coordination failure of industry actors means there is a role for the UK government to support or take on the provision of shared infrastructure.

Key findings by component

Government support is justified when system benefits and business opportunities are high, but market barriers prevent innovation.

Table 3. **Cost and performance in industry (see key to colouring below)**

Overall statistics for industry: System value = N/A. 2050 export opportunity (GVA) = £1.4 billion, 2050 potential direct jobs supported by exports = 18,000				
Component	**Example innovation**	**Business opportunity**	**Market barriers**	**Strategic assessment**
Efficiency Improvements	Industry 4.0 innovations (industry-wide).	~60% is in cement and chemicals sector	Moderate	Industry 4.0 innovations (such as digitisation and digital twinning) can increase efficiency in industry through process optimisation. Due to the importance of policy alignment, government intervention is needed to speed up the pace of innovation.
Alternative process technologies	Flash condensing with steam (specific to pulp & paper).	~85% is in cement and food & drink sector	Moderate	Alternative process technologies vary across the industries. Flash condensing in the pulp & paper industry could greatly reduce deployment barriers to low-carbon energy. Due to the long lifetime of equipment and plants, government intervention is needed to speed up the development and deployment of such technologies.
Low-carbon substitutes	Fuel switching: hydrogen (industry-wide).	~60% is in chemicals and food & drink sector	Severe	Hydrogen can be used as the primary low-carbon fuel across many industries, but requires an established hydrogen supply chain to reduce its costs. Due to the lack of commercialisation capacity and infrastructure coordination failures, innovation is significantly constrained without government intervention.

Component	Example innovation	Business opportunity	Market barriers	Strategic assessment
Recovery and recycling	Use of recycling in the manufacturing process (industry wide).	~100% in food & drink sector	Moderate	Innovations in the use of recycled products in industrial processes depend on recycling streams. Therefore, due to the importance of regulation, government intervention is needed to speed up innovation in this area and reduce barriers to deployment.
Heat recovery and reuse	Low-grade heat capture (industry wide).	60% is driven by chemicals and food & drink sector	Moderate	Government support would accelerate the development of solutions and innovations to use low-grade waste heat cost-effectively.
Energy systems	On-site renewables (industry wide).	*N/A*	*N/A*	Integrating industrial sites with renewables or storage is not a key priority for industry, although government support would reduce barriers to deployment and costs to encourage it.
Clustering	Industrial symbiosis (industry wide).	*N/A*	*N/A*	Industrial clusters have the potential to reduce costs and barriers to developing low-carbon technologies, and can also reduce costs of raw materials through industrial symbiosis. Without government intervention and coordination, industrial clusters are unlikely to emerge holistically.

Source: *Vivid Economics, Carbon Trust*

Note: *The main innovations per component are the innovations that score highest in the innovation inventory. This table only includes component-specific market barriers. Cross-cutting barriers are included in the market barriers section below. We only include export markets in this assessment because it is more directly linked to additional benefits to the UK economy. However an assessment of the domestic market is included in the report below. Notes on business opportunity for each component indicate the key sectors which explain the demand for industrial decarbonisation technologies. The system value is N/A because ESME does not provide a robust representation of industrial decarbonisation technologies.*

Table 4. **Key to colouring in the key barriers by component**

Business opportunities	**Market barriers**
High: more than £1 billion annual GVA from exports by 2050	**Critical:** Without government intervention, innovation, investment and deployment will not occur in the UK.
Medium-High: £600-£1,000 million annual GVA from exports by 2050	**Severe:** Without government intervention, innovation, investment and deployment are significantly constrained and will only occur in certain market segments / have to be adjusted for the UK market.
Medium-Low: £200-£600 million annual GVA from exports by 2050	**Moderate**: Without government intervention, innovation, investment and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
Low: £0-200 million annual GVA from exports by 2050	**Low:** Without government intervention, innovation, investment and deployment will continue at the same levels, driven by a well-functioning industry and international partners.

Source: Vivid Economics, Carbon Trust

Box 2. **Industry workshop**

A full-day workshop was held on 27th February 2019 with key delegates from UK industry, the academic community, and research agencies. Key aspects of the EINA analysis were subjected to scrutiny, including innovation opportunity assessment, and business and policy opportunities assessment. New views and evidence were suggested; these have been incorporated into an update of the assessments.

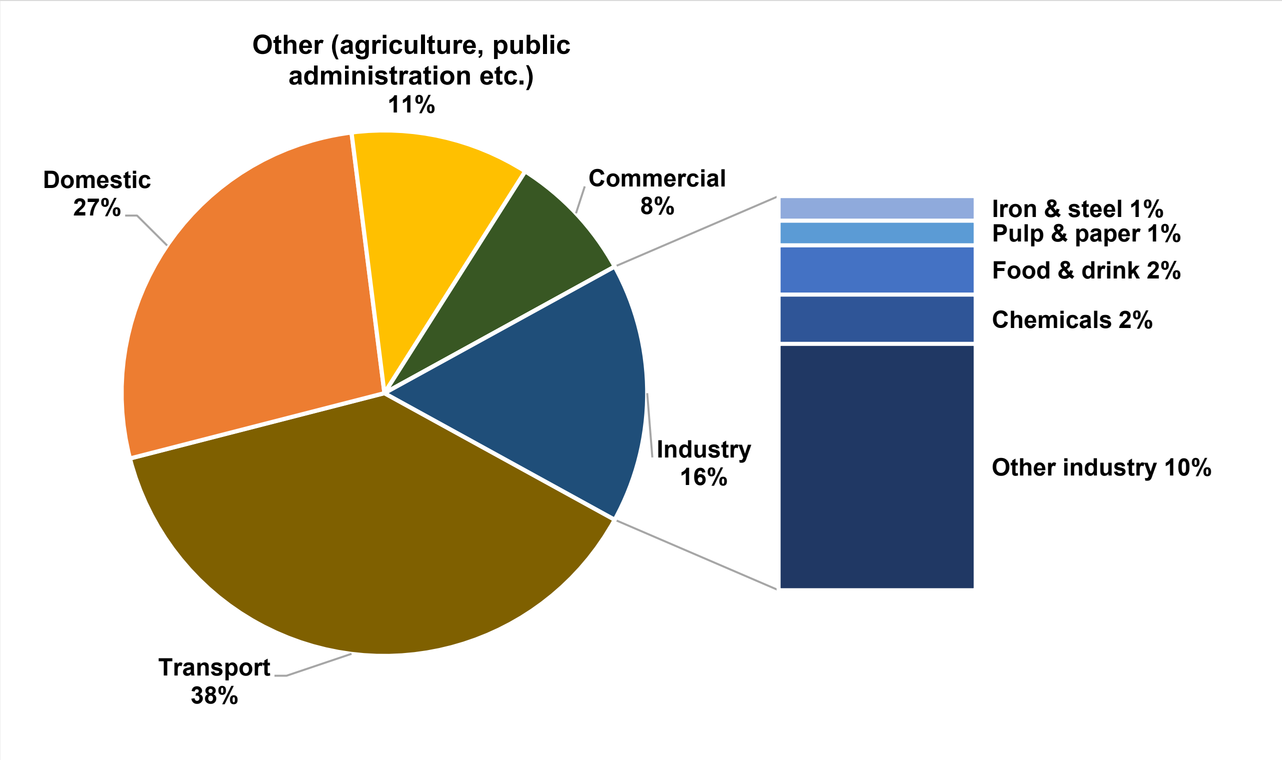
The views of the attendees were included in the innovations assessment, and detailed in the section 'Innovation opportunities within industrial technologies'

Industrial technologies and the whole energy system

Current situation

Sixteen percent of the UK's total final energy consumption was from industry in 2017 (Figure 1).[5] Industry also accounted for 30% of all electricity consumption. Iron & steel, chemicals, pulp & paper, and food & drink combined accounted for 38% of all industrial energy consumption.

Figure 1 **Final energy consumption in the UK by sector (2017)**

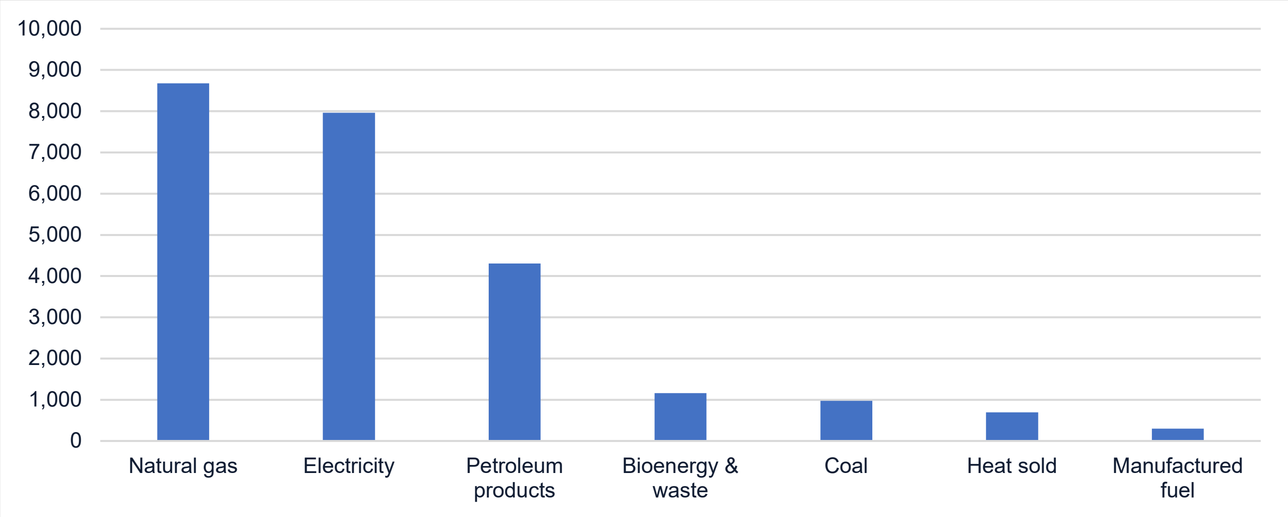


Source: BEIS (2018). Digest of UK Energy Statistics (DUKES)

[5] BEIS (2018). Digest of United Kingdom Energy Statistics (DUKES) 2018. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/736148/DUKES_2018.pdf

Nearly 60% of all primary industrial energy consumption is from fossil fuels and one-third is from electricity (Figure 2).[6] Fuel preferences vary by industrial sector, but natural gas is the most popular fuel for iron & steel (37%), chemicals (50%), food & drink (58%), glass (81%), and ceramics (84%). The pulp & paper sector uses mostly electricity (46%) followed by bioenergy and waste (30%). The cement industry predominantly relies on coal/petcoke (60%), followed by bioenergy and waste (40%).[7]

Figure 2 **Fuels used in final industrial energy consumption (thousand tonnes of oil equivalent)**



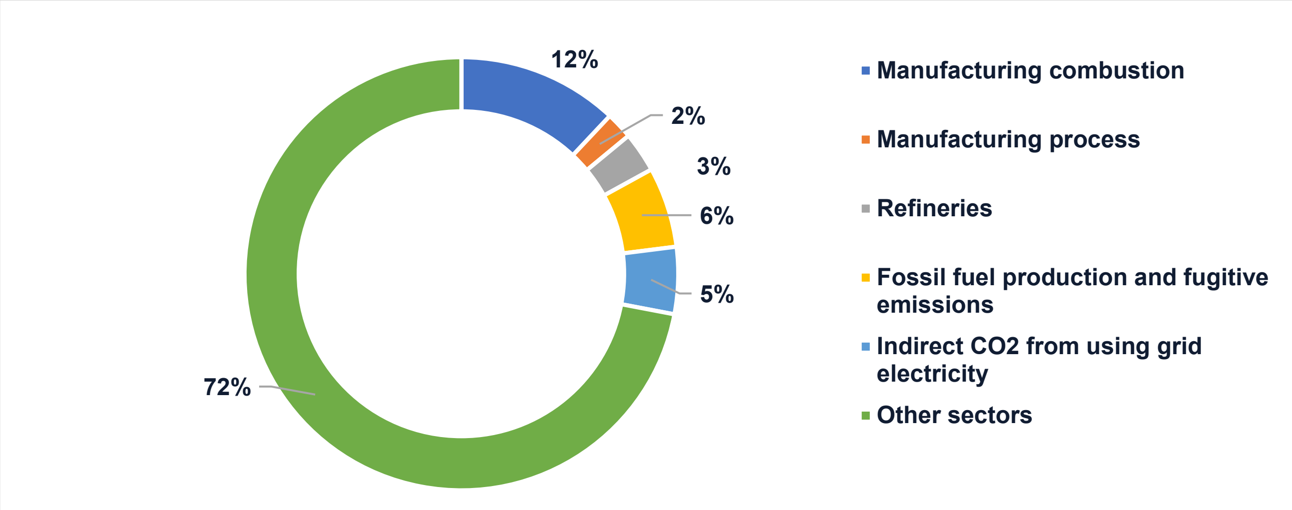
Source: BEIS (2018). Digest of UK Energy Statistics (DUKES)

Note: 'heat sold' It is defined as heat that is produced and sold under the provision of a contract.

Direct emissions from manufacturing industries accounted for 14% of UK greenhouse gas (GHG) emissions in 2017 (Figure 3). [8,9] Most of the manufacturing emissions (85%) are combustion emissions – from burning fuel to produce low- and high-grade heat, drying/separation, space heating, and electricity generation for own use. Process emissions from chemical reactions within industry (e.g. calcination of limestone in the production of cement) accounted for the remaining 15%. Process emissions have halved since 1990, driven mainly by a reduction in emissions from cement production due to lower manufacturing output from this sector.[10]

[6] Ibid.
[7] Steel, chemicals, food & drink, pulp & paper statistics from DUKES (2018). Cement, glass and ceramics from their respective Industrial Decarbonisation Roadmaps (2015), available at: https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050
[8] Direct emissions exclude emissions from generation of electricity supplied through the grid.
[9] Committee on Climate Change (2018). Reducing UK emissions: 2018 progress report. Available at: https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf
[10] BEIS (2018). 2017 UK GHG emissions, provisional figures. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/695930/2017_Provisional_Emissions_statistics_2.pdf

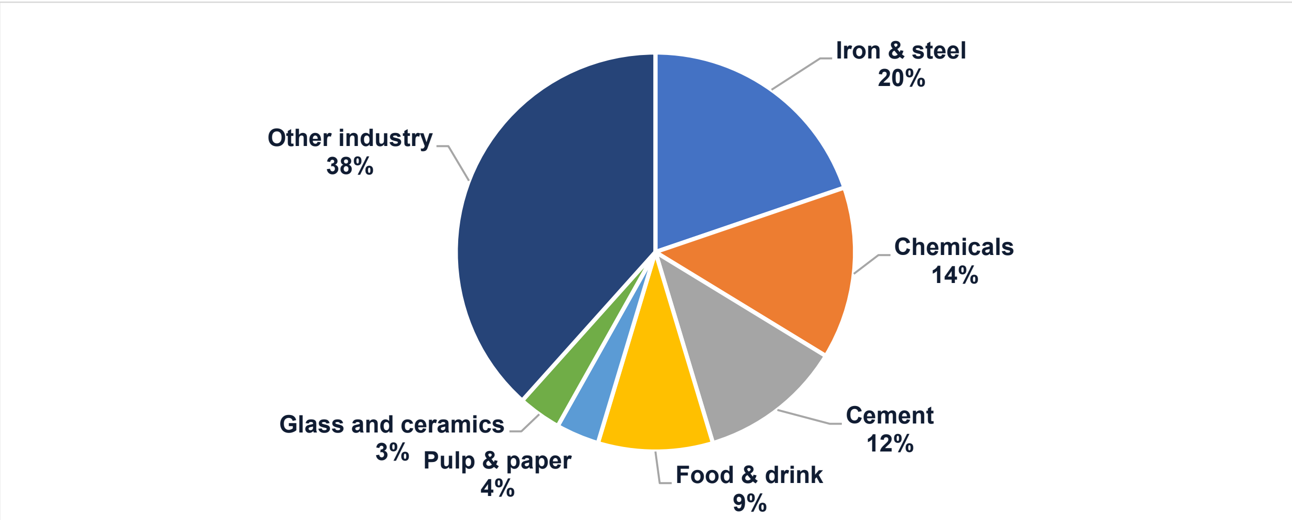
Figure 3 **Direct GHG emissions from industry and indirect emissions from grid electricity use as a share of total UK emissions (2017)**



Source: *Committee on Climate Change (2018). Reducing UK emissions: 2018 progress report.*

In 2015, close to two-thirds of all direct manufacturing GHG emissions from industry came from the 7 industrial sectors covered in this report (Figure 4). Of those, iron & steel, chemicals, and cement were the most polluting.[11]

Figure 4 **Direct manufacturing emissions by industrial sector (2015)**



Source: *Carbon Trust. Adapted from Committee on Climate Change (2018)*

[11] Committee on Climate Change (2018). Reducing UK emissions: 2018 progress report. Available at: https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf

Future deployment scenarios

The 'business-as-usual' (BAU) scenario under BEIS' Industrial Decarbonisation & Energy Efficiency Roadmaps suggests a 29% overall reduction in the UK's industrial emissions by 2050 (relative to 2012).[12] This scenario is based on the continued deployment of existing technologies at the appropriate time for each site, with no additional interventions to accelerate decarbonisation. The emission reductions are expected by a combination of grid decarbonisation (62%), energy efficiency (23%), and the use of biomass as fuel and feedstock (7%). The remaining 8% cut in emissions would come from clustering, electrification of heat, material efficiency, and other fuel switching. Of the seven industries this report focusses on, the cement industry is expected to see the least reductions in emissions (12%), and pulp & paper the most (32%).

The 'Max Tech' scenario under BEIS' Industrial Decarbonisation & Energy Efficiency Roadmaps suggests a 73% overall reduction in the UK's industrial emissions by 2050 (relative to 2012). This is based on the maximum technical potential for industrial decarbonisation, setting aside economic and commercial considerations. These emission reductions are expected by a combination of technologies and innovations: Carbon, Capture and Storage (CCS) (37%), grid decarbonisation (25%), energy efficiency (13%), and biomass (16%). The remaining 9% in emission cuts would come from clustering, electrification of heat, material efficiency, and other fuel switching. Of the seven industries this report focusses on, the cement industry is expected to see the least reductions in emissions (33-62%), and pulp & paper the most (up to 98%). However, the Max Tech scenario does not include some key technologies that have received growing attention more recently, such as the use of hydrogen to decarbonise high grade heat.

The International Energy Agency's (IEA's) 'Beyond 2 Degrees' scenario (B2DS) identifies possible technology innovations that could decarbonise global industries.[13] This scenario is consistent with a 50% chance of limiting average global temperature increases to 1.75°C. Between 2015 and 2050, the scenario expects global industrial emission reductions to come from: efficiency and best available technology (BAT) deployment (41%), CCS and alternative processes (41%), fuel and feedstock switching (11%), and material efficiency (7%). Efficiency gains and low-carbon fuel switching play the most important role up to 2030, whereas alternative processes are crucial in long-term decarbonisation.

[12] BEIS (2015). Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Cross-sector summary. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/419912/Cross_Sector_Summary_Report.pdf

[13] IEA (2017). Energy Technology Perspectives 2017.

Sub-theme system integration: Benefits, challenges and enablers

Decarbonising the electricity grid will facilitate industrial decarbonisation. One-third of industrial energy consumption is met by electricity,[14] so part of industry will decarbonise as the electricity supply decarbonises. The UK grid is expected to be mostly low-carbon by 2035.[15] Therefore, the electrification of low-temperature processes (e.g. for the food and paper industries), as well as some high-temperature processes (e.g. for glass and ceramics) would further accelerate industrial decarbonisation.[16]

Industries with batch processes can benefit from demand-side response and management (DSRM). DSRM can modulate the level of industrial activity in line with the needs of the power system. This could shift loads away from peak demand (for lower prices), as well as to times with high portions of low-carbon generation (to reduce emissions). Industrial processes designed to operate in batches rather than in a continuous mode, such as some food processing activities, are better suited to implementing these strategies.[17] DSRM can also optimise energy use in hybrid systems, such as ovens in food and dryers in paper industries. These can switch between fuels, such as gas and electricity, based on demand, price-signals, and supply of low-carbon energy.[18]

Integrated on-site renewables, such as solar photovoltaics (PV) combined with batteries, can help industrial electricity use decarbonise faster than the grid. The large roof spaces typical of manufacturing facilities make them well suited for solar PV. On-site renewables can provide a predictable and cheap secondary source of electricity, minimising the amount of primary energy used from the grid. Solar PVs offer a relatively fast payback (typically 6-12 years), with 25-year performance guarantees and a life expectancy of over 40 years. Comparison of the levelised cost of energy (LCOE) estimates of PV systems and grid electricity suggest that solar PV can be cheaper over the long-term (after around 9 years).[19] Similarly, as the cost of battery storage keeps falling, PV systems integrated with storage will be able to meet an even larger portion of industrial

[14] BEIS (2018). Digest of United Kingdom Energy Statistics (DUKES) 2018. Available at: https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2018-main-report
[15] BEIS (2018). Updated energy and emissions projections 2017. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/671187/Updated_energy_and_emissions_projections_2017.pdf
[16] BEIS (2015). Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Cross-sector summary. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/419912/Cross_Sector_Summary_Report.pdf
[17] IEA (2017). Energy Technology Perspectives 2017.
[18] U.S. Department of Energy (2015). Improving Process Heating System Performance. Available at: https://www.energy.gov/sites/prod/files/2016/04/f30/Improving%20Process%20Heating%20System%20Performance%20A%20Sourcebook%20for%20Industry%20Third%20Edition_0.pdf
[19] BRE (2016). Solar PV on commercial buildings: a guide for owners and developers. Available at: https://www.solar-trade.org.uk/wp-content/uploads/2016/10/123160_nsc_solar_roofs_good_practice_guide_web.pdf

electricity demand.[20] Storage technologies would also facilitate the greater use of the DSRM services mentioned above.

Waste heat recovered from industry can be fed into district heating networks to provide heating services to users.[21] Some industrial heat loss from flue and exhaust gases, solid and liquid industrial streams, and dissipated from hot equipment surfaces are unavoidable. This waste heat is often low-grade and therefore difficult to reuse on-site for high-temperature processes. It can still be used to provide space heating to domestic and commercial users by connecting to a heat network. However, as industries optimise their processes and increase their efficiency, the availability of industrial waste heat to supply heat networks will be limited in the long-term.[22] Feeding waste heat into heat networks will also be constrained by the relatively limited extent of heat networks in the UK (which currently provide around 2% of overall heat demand), although this is expected to increase in the coming decades (see Heating and Cooling EINA).

Industrial use of alternative fuels and innovations in industrial CCUS could support their deployment across sectors. Switching to lower-carbon industrial fuels will support the broader use of these fuels across the economy, such as for heating and/or transport. This will be achieved by supporting the development of biomass supply chains (see Bioenergy EINA) as well as infrastructure requirements for hydrogen (see Hydrogen EINA) to meet industrial demand. However, for these fuels to become widely used in industry, they will have to overcome the market barriers explored in the section below. Similarly, the development of CCUS as a key industrial decarbonisation technology (particularly for steel and cement production),[23] can facilitate the application of CCS to decarbonise hydrogen and power generation (see CCUS EINA).

[20] KPMG (2016). Development of decentralised energy and storage systems in the UK. Available at: http://www.r-e-a.net/upload/rea_storage_report-web_accessible.pdf
[21] BEIS (2018). Heat networks: Ensuring sustained investment and protecting consumers. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/774586/heat-networks-ensuring-sustained-investment-protecting-consumers.pdf
[22] IEA (2017). Energy Technology Perspectives 2017.
[23] McKinsey & Company (2018). How industry can move toward a low-carbon future. Available at: https://www.mckinsey.com/business-functions/sustainability/our-insights/how-industry-can-move-toward-a-low-carbon-future

Box 3. **System modelling: Industrial fuel-switching technologies in the UK energy system**

Following the BEIS EINA methodology, whole energy system modelling was conducted using the ESME^{TM} Version 4.4 to estimate where innovation investments could provide most value to support UK energy system development.

ESME is a peer-reviewed whole energy system model (covering the electricity, heat and transport sectors, and energy infrastructure) that derives cost-optimal energy system pathways to 2050 meeting user-defined constraints, e.g. 80% greenhouse gas (GHG) emissions reduction.[24] The model can choose from a database of over 400 technologies which are each characterised in cost, performance and other terms (e.g. maximum build rates) out to 2050. The ESME assumption set has been developed over a period of over 10 years and is published.[25] ESME is intended for use as a strategic planning tool and has enough spatial and temporal resolution for system engineering design.

Like any whole system model, ESME is not a complete characterisation of the real world, but it is able to provide guidance on the overall value of different technologies, and the relative value of innovation in those technologies.

The EINA Methodology prescribes the approach to be taken to assess the system-level value of technology innovation. This involves creating a baseline energy system transition without innovation (from which a baseline energy system transition cost is derived), and on a technology-by-technology basis assessing the energy system transition cost impact of “innovating” that technology. Innovation in a technology is modelled as an agreed improvement in cost and performance out to 2050.

Industry sector decarbonisation is not characterised well in the ESME model. The exceptions to this are fuel-switching technologies (described below) and CCUS (as set out in the CCUS EINA). Fuel-switching further subdivides into electricity, biomass, gas and hydrogen. Energy efficiency and decarbonisation technologies at an industry sector level are not included, and further work is required to include them in the modelling.

For the EINA analysis, the technology cost and performance assumptions were derived from the standard ESME dataset as follows:[24]

- In the baseline energy system transition, the cost and performance of all technologies is assumed to be frozen at their 2020 levels from 2020 out to 2050.

- The "innovated" technology cost and performance for all technologies are assumed to follow the standard ESME dataset improvement trajectories out to 2050 (these are considered techno-optimistic).
- In the case of industrial fuel-switching technologies, the assumed "innovated" installed cost reduction is of 25% by 2050. This compares to a reduction of over 50% for other direct decarbonisation operations such as CCUS.

The BEIS EINA "High Innovation" scenario expects around 15% of industrial energy demand to switch fuels by 2050. Around 5.5% of industrial energy demand is expected to have switched to hydrogen, and another 3% to hydrogen with CCS (the uptake of which accelerates after 2045). Close to 3% of industrial energy demand switches to biomass with CCS by 2050. The EINA modelling suggests that biomass is the most popular fuel-switching option up to 2035. However, after the commercialisation of CCS in the 2030s, unabated biomass is phased out in favour of biomass with CCS or other fuels. Gas with CCS accounts for another 4% of the industrial fuel switching by 2050, and even though some industrial demand switches to unabated gas until 2030, this is also phased out by 2050. Overall, the BEIS EINA modelling assumes a 10% fall in industrial energy demand by 2050.

The fuel switching where innovation has the largest impact is switching to hydrogen with CCS in later years. Innovation in this area could increase deployment to account for over 3% of industrial energy demand by 2050, rather than around 1% as expected by the baseline scenario. The deployment rates of other fuel-switching options remain the same in the high innovation scenario as in the baseline.

The system value of industry fuel-switching, the largest component of which is hydrogen, is around £0.14 billion cumulatively to 2050, discounted at 3.5%. Whole system analysis using the BEIS EINA Methodology described above would imply that there is limited value to the UK in continued (and accelerated) innovation in industrial fuel-switching technologies. This suggests that at the system level there are lower-cost decarbonisation options than industrial fuel switching, even with the cost reduction implied by the EINA "High Innovation" cases described above. However, as mentioned earlier, this comes down to the lack of granularity used to model industry and as a result this conclusion should be viewed with caution.

[24] More details of the capabilities and structure of the ESME model can be found at eti.co.uk/programmes/strategy/esme. This includes a file containing the standard input data assumptions used within the model.
[25] The ESME assumption set has been developed is published with data sources at https://www.eti.co.uk/programmes/strategy/esme

The modelling will be enhanced in future iterations. Further work is required to estimate the value of innovations in industrial technologies, or how these estimates may change in the case of different energy system scenarios.

Box 4. **Learning by doing and learning by research**

The total system value follows from two types of technology learning:

- **Learning by doing:** Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards, which tend to increase in direct proportion to capacity increases.
- **Learning by research:** Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D). It increases with spend in RD&D and tends to precede growth in capacity.

The EINAs are primarily interested in learning by RD&D, as this is the value that the government can unlock as a result of innovation policy. Emerging technologies will require a greater degree of learning by RD&D than mature technologies. Academic work suggests that for emerging technologies around two-thirds of the learning is due to RD&D, and for mature technologies it contributes around one-third.[26]

Therefore, to reach a quantitative estimate of the innovation value attributable to RD&D, the two-thirds ratio is applied to the system values of the fuel switching options. This would suggest that £0.1 billion is attributable to RD&D. Note, this is an illustrative estimate, with the following caveats:

- The learning-type splits are intended to apply to cost reductions. However, in this study, they are applied to the system value. As system value is not linearly related to cost reduction, this method is imperfect.
- In practice, learning by research and learning by doing are not completely separable. It is important to deploy in order to crowd-in investment to more RD&D, and RD&D is important to unlock deployment.

These estimates are used in the EINA Overview Report to develop a total system value that results from innovation programmes across the energy system.

[26] Jamasb, Tooraj (2007) Technical Change Theory and Learning Curves, The Energy Journal 28(3).

Innovation opportunities within industrial technologies

Introduction

Box 5. **Objective of the innovation opportunity analysis**

The primary objective is to identify the most promising innovation opportunities within industrial technologies and highlight how these innovations may be realised and contribute to achieving the system benefit potential described above. This section provides:

- A breakdown of the costs within industrial technologies across key components and activities.
- A list of identified innovation opportunities, and an assessment of their importance to reducing costs and deployment barriers.
- Deep dives into the most significant technology innovations.

Innovation opportunities within industrial technologies are those that enable the industrial sector to meet its decarbonisation targets cost-effectively. The "Max Tech" scenario of the Industrial Decarbonisation Roadmaps suggests a reduction in overall industrial emissions of up to 70% by 2050 (relative to 2009 emissions).[27] However, this scenario had not included hydrogen as an option. Therefore, taking innovations in hydrogen into account, there is further room to decarbonise industry in that timeframe, assuming the deployment of the maximum technical potential for decarbonisation. The innovation opportunities explored in this EINA are for the following 7 industries: chemicals, food & drink, iron & steel, cement, pulp & paper, glass, and ceramics.

This report has identified seven sub-categories across these industries where the main innovation opportunities to reduce emissions lie. These are:

- **Efficiency improvements**
  - Increased digitisation and automation of processes (known as Industry 4.0).
  - Other efficiency improvements (such as improved process equipment and new process materials).

[27] BEIS (2015). Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Cross-sector summary. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/419912/Cross_Sector_Summary_Report.pdf

- **Alternative process technologies:** transformative change to industry-specific processes (e.g. contact-free grinding in cement production and field-assisted sintering for ceramics).
- **Low-carbon substitutes**
    - Fuel switching: changing the primary fuel of industrial processes from fossil fuels to low-carbon alternatives such as electricity, hydrogen, or biomass.
    - New raw materials (such as alternative binding materials for cement).
- **Recovery and recycling:** recovery and reuse of materials, equipment, and other resources.
- **Heat recovery and reuse:** capturing waste heat from industrial processes. This heat could be integrated back into industrial processes or disseminated through a heat network.
- **Energy systems:** integrating the industrial process with the broader energy system, such as through demand-side response and management (DSRM), thermal or electricity storage, and use of on-site renewables.
- **Clustering:** industrial symbiosis (using by-products of one industry as raw materials in another), shared use of waste heat, and shared development of technologies (such as CCUS and hydrogen).

Cost breakdown

Industrial innovations, such as alternative processes and energy efficiency, can reduce energy costs across industries by reducing energy demand. Alternative processes have the transformative potential to reduce energy costs in more energy-intensive industries (such as cement and iron & steel). For example, alternative grinding processes in cement (e.g. contact-free grinding systems, ultrasonic comminution) could save energy costs and reduce emissions, as grinding accounts for up to 70% of the electricity demand for clinker and cement production.[28] Energy efficiency measures can also have a large impact on energy savings. For example, around half of the food & drink sector's electricity consumption comes from industrial refrigeration. Therefore, improved refrigeration technologies, combined with smart control systems that optimise energy use, can cut energy costs by up to 10%.[29]

Swapping raw materials can have a large impact on reducing emissions but may not yield cost reductions as low-carbon alternatives can often be more expensive than readily available raw materials. For example, using alternative binding materials instead

[28] European Cement Research Academy (2017). Development of state-of-the-art techniques in cement manufacturing. Available at: https://ecra-online.org/fileadmin/redaktion/files/pdf/CSI_ECRA_Technology_Papers_2017.pdf
[29] Carbon Trust (2012). Food and drink processing. Available at: https://www.carbontrust.com/media/39212/ctv004_food_and_drink_processing.pdf

of ordinary Portland cement clinker have the potential to reduce process emissions by 44%, but are expected to increase raw material costs.[30]

Most fuel-switching technologies are expected to have a higher lifetime cost than their fossil fuel equivalent, mainly due to the higher cost of fuel.[31] Fuel-switching technologies are expected to have a capital cost premium over the incumbent technology, but the larger the annual demand for a specific process, the more fuel costs will dominate its lifetime costs. For example, capital costs represent around 10-15% of the lifetime cost of a boiler (with a demand of 45GWh per year), or a kiln (with a demand of 113GWh per year).[32] Therefore, running these technologies on electricity, hydrogen, or biomass will likely be more expensive than on natural gas (though this depends on different fuel-cost estimates and future carbon prices). Heat pumps can be cheaper than gas boilers over their lifetime, but they are assumed to be suitable to displace only around a quarter of the gas boiler demand due to their heating capabilities.[33]

Due to the uncertainty around future costs of hydrogen, biomass, and electricity, it is not possible to definitively predict which options will be most attractive. However, electricity is expected to have the highest fuel costs. The Element Energy and Jacobs study[34] expects biomass to be the cheapest fuel-switching option by 2030, whereas the Committee on Climate Change expects hydrogen to be more cost-effective (for innovation opportunities in the production of hydrogen and biomass, please see the Hydrogen EINA and Bioenergy EINA respectively).[35]

[30] IEA (2018). Tracking clean energy innovation progress. Available at: https://www.iea.org/tcep/innovation/
[31] Element Energy and Jacobs (2018). Industrial Fuel Switching Market Engagement Study. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764058/industrial-fuel-switching.pdf
[32] Ibid.
[33] Ibid.
[34] Ibid.
[35] Committee on Climate Change (2018). Hydrogen in a low-carbon economy. Available at: https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf

The following are the key cost components in industry:

Table 5. **Indicative shares of production costs by industry**

Cost Element	Share of cost of product per unit produced (%)						
	Chemicals	Food & drink	Iron & steel	Cement	Pulp & paper	Glass	Ceramics
Energy	17	Varies by subsector.	43	31	5	27	8
Raw materials	59		41	28	67	16	44
Labour and O&M	13		7	30	18	41	36
Capital costs	6		9	11	10	10	12
Other	5					6	

Notes: *These costs are indicative only and based on a variety of sources from comparable countries (across Europe and the United States).*
Given that the food & drink industry has many sub-sectors, the share of the costs will vary depending on the product and process used. However, energy typically accounts for 2-3%, and raw materials 50-80% of the costs, according to conversations with industry.

Source: ***Chemicals:*** *Deloitte (2014) Pricing in the chemical industry.*
Iron & steel: *Data for 2018 UK steel production (basic oxygen furnace) provided by economic adviser at www.steelonthenet.com.*
Cement: *Lafarge (2011). Annual Report.*
Pulp & paper*: Technopolis (2016). An assessment of the cumulative cost impact of specified EU legislation and policies on the EU forest-based industries.*
Glass: *Wrap (2008). Realising the value of recovered glass: An update.*
Ceramics: *U.S. Environmental Protection Agency (2003). Economic Impact Analysis of the Clay Ceramics Manufacturing NESHAP: Final Rule.*

Inventory of innovation opportunities

The key technological innovations across all industries that have the highest potential for reductions in costs and barrier deployments were identified as being:

- **Fuel switching to (low-carbon) electricity, biomass, and hydrogen.** All industries have the potential for fuel switching to one or various alternatives to displace fossil fuel consumption.
- **Efficiency improvements** through improved process equipment (such as furnaces and kilns) and increased digitisation of processes (which allow for process optimisation).
- **Alternative process technologies** at low TRL levels that can provide transformative change in industry-specific processes to reduce energy use and emissions.

CCUS is a key technology for industrial decarbonisation (especially for the steel and cement industries) and has a large innovation potential. However, this technology is not within the scope of this EINA. For innovation opportunities in industrial CCUS, please see the dedicated CCUS EINA.

Below is an overview of the key innovations by subcategory, based on research and conversations with industry leaders during the workshop.

Fuel switching is the key innovation priority across most industries. According to a recent study on fuel switching in UK industries, close to a third of current industrial demand has the technical potential for fuel switching by 2040.[36] This could be met by a variety of options, including electricity, hydrogen, and biomass. However, not all low-carbon fuels are suitable for decarbonising all industrial processes. Thus, the choice of fuel will be based on process-sensitive factors, such as temperature requirements and the need for direct or indirect heating. However, implementation will only be feasible following further evidence on the suitability, reliability, and impact on product quality of the technologies (especially hydrogen options, due to a lack of experience of hydrogen in most sectors). In addition to feasibility testing, the deployment of these fuels will be determined by the cost, supply, and availability of the fuels (such as considerations on the best use of the limited national supply of sustainable biomass and the development of a hydrogen infrastructure).[37]

[36] Element Energy and Jacobs (2018). Industrial fuel switching market engagement study. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764058/industrial-fuel-switching.pdf

[37] BEIS (2018). Clean Growth: Transforming Heating – Overview of Current Evidence. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766109/decarbonising-heating.pdf

Efficiency improvements, such as upgrading equipment, vary by sector, but Industry 4.0 Innovations can optimise processes across all industries. They include improved dryers and kilns (such as low-mass kiln furniture for ceramics). These innovations are mostly incremental but can have a large compound impact on cost and emission reduction. Moreover, some efficiency improvements can be retrofitted, rather than requiring entirely new machines. This report has grouped together various efficiency improvements to highlight their importance across the value chain. Materials which increase thermal conductivity and wear resistance in processes (such as graphene in chemical production) are also included under efficiency improvements. Furthermore, Industry 4.0 innovations (through increased digitisation) can act as an enabler for other innovations. Advanced sensors and algorithms can optimise processes, detect faults, and illustrate the process in more detail (allowing for savings in energy usage, costs, and emissions).

Alternative process technologies provide the opportunity for long-term transformational change across the industries. New processes have the potential to save costs and reduce emissions, but require further research, development, and demonstration (RD&D) to be commercialised. Some examples of industry-specific alternative processes include contact-free grinding in cement production, field-assisted sintering in ceramics, and flash-condensing in the pulp & paper industry. These innovations will likely be implemented in the long-term as they will have to wait for the remaining lifetime of current equipment and technologies to expire (which can range from 15 to 40 years).

Recovery and recycling of materials can be facilitated by new equipment that speeds up the sorting and disassembly process but requires policy support. For example, improved equipment would allow for better sorting through recyclate for the paper industry and allow the glass industry to extract flat glass from double-glazed windows more rapidly. A key barrier to using more recycled material is the lack of availability of reliable quality recycled material. For example, there is not enough end-of-life steel available to produce all new steel from recycled sources.[38] Similarly, the availability of competitively priced, uncontaminated recycled glass is the key limiting factor to using more recycled glass in manufacturing (which requires 25% less energy than using raw materials).[39,40] Innovations at the design level are

[38] World Steel Association (2015). Steel in the circular economy. Available at: https://www.worldsteel.org/en/dam/jcr:00892d89-551e-42d9-ae68-abdbd3b507a1/Steel+in+the+circular+economy+-+A+life+cycle+perspective.pdf

[39] BEIS (2015). Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Glass. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416675/Glass_Report.pdf

[40] WRAP (2008). Realising the value of recovered glass: An update. Available at: http://www.wrap.org.uk/sites/files/wrap/Glass%20Update%20Market%20Situation%20Report%20Autumn%202008.pdf

important to overcome this, as products designed for deconstruction will be easier to recycle at the end of their life cycle. Further regulatory support to improve recycling streams is also being considered as part of the decarbonisation action plans for the glass and pulp & paper industries.[41]

The innovation need for heat recovery and reuse is in technologies that can increase the temperature of low-grade heat. The recovery and re-use of industrial waste heat has multiple benefits, such as reducing fuel demand, energy costs, and CO_2 emissions. However, as most of the waste heat is low-grade, the largest technical barrier is finding an appropriate heat sink or appropriate use for it.[42] This waste heat could be fed into heat networks to provide domestic heating or be shared with industries that have higher demand for low-grade heat (through clustering). However, these solutions will depend on the local availability of heat networks and the location of industries. A key innovation would be in finding an economically viable way to upgrade the low-grade heat to higher-grade heat (or electricity) to be reused in the industrial process.[43]

Energy system integration may provide benefits to industry but is not seen as a key innovation priority. Industries with batch processes (such as ceramics) can benefit more from DSRM as their processes are more flexible, allowing them to shift loads based on electricity price signals. However, continuous processes require an undisrupted steady supply of energy. Integrated on-site renewables (such as solar PV and storage) can also provide cheaper electricity than grid electricity in the long-term on an LCOE basis.[44] On-site renewables and DSRM could also allow energy-intensive industries to save costs from Triad charges during the yearly peak demand for grid electricity through load-shifting and auto-generation.[45] However, most industrial energy consumption is non-electric, and the portion which is electric often requires high demands that can't be fully met by on-site renewables (and/or storage). Therefore, meeting partial electricity demand with on-site renewables is not regarded

[41] BEIS (2017). Industrial decarbonisation and energy efficiency action plans. Available at: https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-action-plans
[42] BEIS (2016). Barriers and enablers to recovering surplus heat in industry. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/565230/Understanding_Barriers_to_Heat_Recovery_-_Final_Report.pdf
[43] BEIS (2015). Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Cross-sector summary. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/419912/Cross_Sector_Summary_Report.pdf
[44] BRE (2016). Solar PV on commercial buildings: a guide for owners and developers. Available at: https://www.solar-trade.org.uk/wp-content/uploads/2016/10/123160_nsc_solar_roofs_good_practice_guide_web.pdf
[45] National Grid (2015). Introduction to Triads. Available at: https://www.nationalgrid.com/sites/default/files/documents/44940-Triads%20Information.pdf

as a key priority. However, this provides an innovation opportunity for integrated renewable systems with larger capacities.

Industrial clusters can enable mutually beneficial innovations for various industries. Clustering facilitates industrial symbiosis, which is when the waste or by-products of one industry are used as raw materials or inputs in another. Industries that use lower-grade heat in their processes (such as food & drink) could benefit from being located close to industries with available low-grade heat (such as iron & steel).[46] Clusters also allow for the shared development of technology. Industries are reluctant to bear the costs of investing in innovative technologies by themselves, hence industrial clusters would allow for joint development of mutually beneficial technologies and infrastructure. This includes the use of hydrogen (see Hydrogen EINA) or carbon capture, utilisation, and storage (see CCUS EINA). However, clustering is difficult for industries that tend to be remotely located (such as cement being located close to quarries). Another key barrier is the perceived risk of becoming dependent on partners that may not be present in the long-term.[47]

Overall, the key innovation areas by industrial sector, as identified by the workshops, roadmaps, and other research are:

- **Chemicals:** fuel switching, alternative process technologies, and efficiency improvements.
- **Food & drink:** fuel switching, improved industrial refrigeration, Industry 4.0 innovations.
- **Iron & steel:** fuel switching to hydrogen (for details on hydrogen production, see the hydrogen EINA) and CCUS (see CCUS EINA).
- **Cement:** fuel switching, raw material substitutes, and CCUS (see CCUS EINA).
- **Glass:** Industry 4.0 innovations, alternative process technologies, and improved furnaces.
- **Ceramics:** alternative process technologies and improved kilns.
- **Pulp & paper:** fuel switching and alternative process technologies.

The experts who attended the workshop discussed the contents of the table of innovations for their sector and offered feedback. The updated table was afterwards circulated amongst workshop delegates with the opportunity to provide further comments, which were incorporated. The list organisations that were present

[46] BEIS (2015). Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Cross-sector summary. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/419912/Cross_Sector_Summary_Report.pdf
[47] Workshop conversations with industry experts.

is provided in Appendix 1: Organisations at expert workshop. The tables of innovations by industry can be found in Appendix 2: Innovation mapping.

Prioritisation of cost reduction and the reduction of deployment barriers was elaborated by the Carbon Trust to reflect the importance of some innovations in the workshop interaction. The magnitudes of the contribution to cost reduction and reduction of deployment barriers are described in qualitative terms relative to other innovation opportunities:

- Significantly above average = 5
- Above average = 4
- Average = 3
- Below average = 2
- Significantly below average = 1

Table 6 summarises the discussed opportunities across industries. It is colour coded based on high, medium, and low potential to reduce costs and deployment barriers.

Box 6. **Industry workshop feedback**

The workshop was divided by industrial sectors (some of which were grouped together) and relevant industry associations and industry leaders shared their opinions about the innovations required. The key points raised at the workshop and afterwards are as follows:

- CCUS was identified as a key decarbonisation technology across industries. However, CCUS is not within the scope of this EINA. For more information on CCUS innovation opportunities in industry, please see the CCUS EINA.
- The alternative fuel that industry will switch to (electricity, biomass, or hydrogen) will largely be based on market signals, regulation, and policy objectives.
- Recovery and recycling of materials is mostly dependent on local and regional policies to increase recycling rates, rather than technical limitations to using recycled materials.
- The Energy Systems Catapult projections of industrial demand up to 2050 do not reflect industry expectations, as most industries expect their energy demand to be considerably higher.
- The Digest of UK Energy Statistics (DUKES) grouping of industries combined industries that should be assessed separately. For example, glass and ceramics are based on gas, whereas cement is not, therefore their grouping for energy demand does not provide an accurate overview.

Table 6. **Innovation mapping for industrial technologies based on workshop feedback**

	Description	Industries						
		Chemicals	Food & Drink	Iron & Steel	Cement	Pulp & Paper	Glass	Ceramics
Efficiency improvements	Industry 4.0 (digitisation, automation, digital twinning etc.)			Monitoring defects in coil.				
	Equipment and other efficiency improvements and upgrades	Process material innovations (for resistance and thermal conductivity).	Improved industrial refrigeration technologies and process material innovations.		Improved kiln technologies.	Improvements to paper machines, dryers.	Improved furnace design and construction.	Kiln improvements and upgrades (e.g. low-mass kiln furniture).
Alternative process technologies	*Varies by sector – see individual boxes on the right*		Technical study to identify the greatest innovation opportunities.	Use of alternative reductants.	Completely new process technologies (e.g. contact-free grinding).	New processes (e.g. flash condensing, deep eutectic solvents), and fibre supply technologies.	Batch pelletisation and new coatings (for light-weighting and strengthening).	Alternative drying processes, and field-assisted sintering.
Low-carbon substitutes	Fuel switching: electrification, hydrogen, biomass, and other (see boxes)							Decarbonised methane or syngas.
	Raw material substitutes: *Varies by sector – see individual boxes*	Bio-based feedstock.			Alternative cement constituents and binders.		Alternative batch materials to make glass with lower melting temperatures.	Changing raw material composition for lower firing temperatures.

	Description	Industries						
		Chemicals	Food & Drink	Iron & Steel	Cement	Pulp & Paper	Glass	Ceramics
Recovery and recycling	*Varies by sector – see individual boxes*		Food packaging reduction.	Better design for durability and deconstruction, higher quality scrap in electric arc furnaces (EAF), and more scrap steel in basic oxygen furnaces (BOF).	Productive use of kiln dust.	More efficient recycling, handling, storage, and processing.	Improvements in glass separation process (e.g. recovery of flat glass from double-glazed windows).	Use of waste within ceramic products.
Heat recovery and reuse	Waste heat, use of CHP			Potential to make use of low-grade waste heat (e.g. by raising temperatures).			Batch and cullet pre-heating facilitating heat recovery.	
Energy systems	On-site renewables, flexibility and DSRM, storage (electricity and thermal)						Thermal storage and hybrid systems	Thermal storage and hybrid systems
Clustering	Industrial symbiosis and shared development of technologies (e.g. hydrogen and CCUS)		Would also benefit from clustering around supermarkets/ retailers to share biomass waste and waste heat.		Often located remotely (e.g. close to quarries). Would benefit from joint CCUS development.			

Key:

(dark blue)	Large impact on reducing costs/deployment barriers
(medium blue)	Medium impact on reducing costs/deployment barriers
(light blue)	Low impact on reducing costs/deployment barriers

Notes: *For detailed tables of individual innovation categories by industry, please see Appendix 2: Innovation mapping*

Source: *Carbon Trust research and workshops*

Innovation opportunity deep dive: Fuel switching (electrification)

There is potential for electrification of industrial processes across industries. The advantages of electrification include reducing on-site emissions, using existing efficient technologies, and the potential access to low-cost surplus renewable energy (for highly flexible industries).

Due to their high efficiency, heat pumps could cost-effectively meet low-temperature, indirect heating demands. Heat pumps with capacities in the region of 100s of kW could provide lifetime cost savings over gas boilers, even with the current differential between gas and electricity prices.[48] The food & drink and the pulp & paper industries have a large part of their heat demand at low temperatures, and therefore could benefit from greater electrification.

Electrification of higher-temperature processes is also possible, but most equipment has not been developed at the necessary scale, which may result in lower efficiencies compared to other fuels.[49] Electrification of very-high-temperature heat (>1,600°C) used in cement production would require research, as these temperatures are not yet reached in electric furnaces.[50] However, some high-temperature processes are already widely electrified, such as steel production through EAFs. This production process is profitable, and the quality of steel produced in modern EAFs is almost indistinguishable from that produced in BOFs.[51]

Access to a low-cost and stable electricity supply is essential to allow electrification to compete with lower-cost fossil fuels (such as liquid fuels and natural gas). Future price signals and the cost of electricity will inform the broader electrification of processes. Grid reinforcements may also be required for the electrification of specific industrial sites to ensure enough grid capacity for energy-intensive processes. Ultimately, even if industrial processes are electrified, the

[48] Element Energy and Jacobs (2018). Industrial Fuel Switching Market Engagement Study. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764058/industrial-fuel-switching.pdf
[49] BEIS (2015). Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Cross-sector summary. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/419912/Cross_Sector_Summary_Report.pdf
[50] McKinsey & Company (2018). Decarbonization of industrial sectors: the next frontier. Available at: https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability/Our%20Insights/How%20industry%20can%20move%20toward%20a%20low%20carbon%20future/Decarbonization-of-industrial-sectors-The-next-frontier.ashx
[51] Pistorius, C (2017). Higher-Quality Electric-Arc Furnace Steel. Available at: https://www.cmu.edu/engineering/materials/images/news-images/pistorius-Industrial%20Heating_apr17.pdf

overall emission reductions will depend on the broader decarbonisation of the grid (which is expected to be mostly low-carbon by 2035).[52]

Innovation opportunity deep dive: Fuel switching (hydrogen)

Fuel switching to hydrogen has a high overall potential as it could be used in most sectors and across most processes. The variety of processes includes low-temperature steam production, as well as high-temperature direct heating (e.g. in furnaces and kilns). This is significant to decarbonise industries requiring very high temperatures and loads (such as cement), as using other low-carbon fuels may not be economically feasible or technically suitable.[53]

It is important to note that fuel switching may not be a like-for-like changing of fuels in existing processes but may require an alternative process in the first place. For example, the use of hydrogen in steel production will be enabled by alternative processes. This includes the HYBRIT process, which uses hydrogen as a reduction agent to produce direct reduced iron, which is then fed into an EAF.[54] UK manufacturers are more likely to shift to a blast furnace/basic oxygen furnace (BOF) derivative of this.[55]

Further demonstration and deployment of hydrogen technologies is essential to enable market acceptance. Demonstration is required to show that hydrogen can be deployed at the necessary scale without compromising product quality (e.g. in the food and glass industries). Demonstration will also address concerns regarding the safety of using a new fuel, as well as other uncertainties surrounding the technology (such as nitrogen oxides (NOx) emission management requirements).[56]

Ultimately, the use of hydrogen will depend on a low-cost, low-carbon national hydrogen supply, which now is not developed in the UK. Industries are unwilling to switch to hydrogen by themselves, so market signals, regulatory support, and

---

[52] BEIS (2018). Updated energy and emissions projections 2017. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/671187/Updated_energy_and_emissions_projections_2017.pdf
[53] Committee on Climate Change (2018). Hydrogen in a low-carbon economy. Available at: https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf
[54] Stockholm Environment Institute (2018). Hydrogen steel making for a low-carbon economy. Available at: https://www.sei.org/wp-content/uploads/2018/09/hydrogen-steelmaking-for-a-low-carbon-economy.pdf
[55] Element Energy & Jacobs (2018). Industrial Fuel Switching Market Engagement Study. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764058/industrial-fuel-switching.pdf
[56] Ibid.

industry cooperation is essential to developing a national supply chain. It is also likely that the most cost-effective hydrogen supply will be via the grid (provided the gas-grid switches to hydrogen in the first place), therefore using hydrogen may not be as suitable for industries located off the grid.[57]

Innovation opportunity deep dive: Industry 4.0

Industry 4.0 is a name given to the current trend of automation and digitisation in manufacturing technologies. Industry 4.0 includes cyber-physical systems, intelligent sensors (the Internet of Things), cloud computing, and algorithms to process vast amounts of data. All of these technologies come under the realm of ‘industrial digital technologies’ (IDTs). These technologies can foster a “smart factory” through which the entire production process and value chain can be optimised for higher efficiency. The positive impact of faster innovation and adoption of IDTs could be as much as £455 billion for the UK manufacturing sector over the next decade.[58]

A key Industry 4.0 innovation which can help achieve higher efficiencies in the seven industries identified by this report is “digital twinning”. This is the creation of a real-time digital image of the physical objects and processes of manufacturing.[59] Digital twinning allows for the creation of a sensor-enabled digital model of their products from design and development through to the end of the product’s life cycle. This model would increase understanding not only of the product but also of the system that built it. It would solve physical issues faster by detecting them sooner (preventing defects and waste), predicting outcomes to a much higher degree of accuracy, and ultimately enabling the design of better products.

In addition to increasing process efficiency, digital twinning would also allow for whole-system energy models and simulations. These would assess how changing the energy infrastructure and specific equipment could impact the manufacturing site. This would be a key enabler of other technologies. For example, a digital twin could illustrate precisely how electrification of processes would impact costs, emissions, and energy use, as well as provide solutions for how to optimise these.

[57] Ibid.
[58] Maier et al. (2017). Made Smarter Review. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/655570/20171027_MadeSmarter_FINAL_DIGITAL.pdf
[59] Deloitte Insights (2017). Industry 4.0 and the digital twin. Available at: https://www2.deloitte.com/insights/us/en/focus/industry-4-0/digital-twin-technology-smart-factory.html

Industry 4.0 innovations are underpinned by existing Industry 3.0 infrastructure. Industry 3.0 entails greater automation of processes and the use of robotics, which can then be connected to smart sensors through IDTs. A key challenge in this area is that many industries (such as the food and steel industries) lack these capabilities at a wide scale due to the variety of operations requiring automation and the complexity of their plants. Digitisation also faces the issue that the cost of installing sensors and trackers across the entire production process is both daunting and costly. Therefore, access to finance and expertise on digital ecosystems will enable IDT deployment.

The scale of impact that will be brought by Industry 4.0 innovations is particularly uncertain. Beyond improving the efficiency of particular industrial processes, automation and digitisation are general purpose technologies that can transform the size and composition of industry. The spillover effects of Industry 4.0 innovation will be widespread.

Innovation opportunity deep dive: Alternative processes

Alternative process technologies have the potential to save costs and reduce emissions but require further RD&D to be commercialised. Alternative process technologies vary by industry but have the potential to enable transformative change. Some examples of industry-specific alternative processes are set out below.

Alternative grinding processes in cement can save energy costs and reduce emissions, as grinding accounts for up to 70% of the electricity demand for clinker and cement production.[60] Several higher efficiency grinding technologies are currently at TRL 6, while others are in earlier stages of development. They include contact-free grinding systems, ultrasonic comminution, high voltage power pulse fragmentation, and low-temperature comminution.[61] The European Cement Research Academy (ECRA) has established a pre-competitive research project on efficient grinding technologies to support the demonstration of such technologies.

[60] European Cement Research Academy (2017). Development of state-of-the-art techniques in cement manufacturing. Available at: https://ecra-online.org/fileadmin/redaktion/files/pdf/CSI_ECRA_Technology_Papers_2017.pdf
[61] IEA (2018). Tracking clean energy innovation progress. Available at: https://www.iea.org/tcep/innovation/

Flash condensing with steam in the pulp & paper industry could half CO_2 emissions and save 20% of primary energy use in the paper making process.[62] Steam forming of paper would require only one-thousandth of the volume of water used currently, which could be easily absorbed and dried out of the paper sheet by condensing. For commercialisation of this entirely new production process, more research is needed into both the fluidising of fibres in water vapour and the process to achieve inter-fibre bond formation during drying. Along with flash condensing, the Confederation of European Paper Industries (CEPI) has identified another 9 breakthrough innovations for decarbonising the pulp & paper sector.[63]

Batch pelletisation of glass could reduce process temperature demands while also resulting in higher glass quality. This would entail introducing an additional step in the glass production process to produce pre-mixed pellets with the correct proportions of ingredients, which would be quicker and easier to melt than loose powder. However, this technology requires full-scale trials before it can be deployed.[64]

Innovation opportunity deep dive: Industrial clustering

Industrial clusters are interconnected networks of industrial sites through which energy, materials, and knowledge is shared in a mutually beneficial way.[65] Industrial symbiosis is when side streams of one company or sector is used as a raw material or energy supply by another. For example, low-grade waste heat from steel manufacturing could be used in low-temperature processes in the pulp & paper industry.

Clustering also allows for the development of expertise in upcoming innovations and technologies, such as by testing the use of hydrogen and the deployment of CCUS. Clustering is a key pathway for integrating hydrogen into industrial processes through shared development and testing in suitable regions (such as those with large industrial fuel demand and existing hydrogen plants with

[62] CEPI (2013). Two Team Project. Available at: http://www.cepi.org/system/files/public/documents/publications/innovation/2013/finaltwoteamprojectreport_website_updated.pdf
[63] Ibid.
[64] BEIS (2015). Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Glass. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416675/Glass_Report.pdf
[65] European Commission (2018). Cooperation fostering industrial symbiosis: market potential, good practice and policy actions. Available at: http://www.technopolis-group.com/wp-content/uploads/2018/08/1_IS-Cooperation-Study_Final-Report.pdf

spare production capacity).[66] The HyNet North-West project is a proposed regional cluster around Liverpool Bay which will modify boilers, kilns, and furnaces, as well as develop a pipeline network for hydrogen to connect to industrial sites.[67] Similarly, some existing clusters (such as Teesside) are well positioned to collaborate in the deployment of CCUS technologies.[68]

However, developing geographical clusters can be difficult when industries have specific location requirements. For example, the cement industry is often located in proximity to quarries to facilitate the transport of raw materials. Furthermore, industries have expressed worry about becoming dependent on other industries for access to raw materials, as it poses a business risk.

[66] Committee on Climate Change (2018). Hydrogen in a low-carbon economy. Available at: https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf
[67] HyNet (2019). About: Industry. Available at: https://hynet.co.uk/industry/
[68] Ecofys (2017). ICCUS Readiness of UK industrial clusters. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/759424/iccus-readiness-of-uk-industrial-clusters.pdf

Business opportunities within industry

Introduction

Box 7. **Objective of the business opportunities analysis**

The primary objective is to provide a sense of the relative business opportunities against other energy technologies. To do so, the analysis uses a consistent methodology across technologies to quantify the ‘opportunity’; in other words, what *could* be achieved by the UK. The analysis assumes high levels of innovation but remains agnostic about whether this is private or public. This distinction is made in the final section of the report. The two key outputs provided are:

- A quantitative estimate of the gross value added, and jobs supported associated with industrial decarbonisation technology, based on a consistent methodology across technologies analysed in the EINA. Note, the GVA and jobs supported are *not* necessarily additional, and may displace economic activity in other sectors depending on wider macroeconomic conditions.

- A qualitative assessment of the importance of innovation in ensuring UK competitiveness and realising the identified business opportunities. Note, the quantitative estimates for GVA and jobs supported cannot be fully attributed to innovation.

The following discussion details business opportunities arising both from exports and the domestic market. An overview of the business opportunities, and a comparison of the relative size of export and domestic opportunities, across all EINA sub-themes is provided in the overview report.

More detail on the business opportunities methodology is provided in Appendix 3.

Globally, industrial decarbonisation creates market demand for a diverse set of technologies. Reductions in industrial emissions between 2015 and 2050 are expected to arise from efficiency and BAT deployment (41%), CCS and innovative processes (41%), fuel and feedstock switching (11%), and material efficiency (7%).[69] Each of these broad categories contain a wide range of technologies that are often highly specialised and sector-specific, such as the use of hot charging in steel-making and oxygen enrichment in some cement kilns. These technologies are further characterised by distinct markets for related equipment and EPCm services.

[69] As specified in the B2DS scenario in IEA ETP 2017, which is the scenario consistent with a 50% chance of limiting average future global temperature increases to 1.75°C.

The business opportunities analysis covers 74 technologies deployed across seven industrial sectors. This is a subset selected from the 216 technologies identified by the "*2050 Industrial Decarbonisation and Energy Efficiency Roadmaps*" published by the Department of Energy and Climate Change (DECC) and the Department for Business, Innovation and Skills (BIS) in 2015. This selection is based on ruling out insignificant markets (technologies for which global deployment represents a negligible capex) and the exclusion of technologies covered in other EINA subthemes (CCUS and biomass). Given the large number of technologies within its scope, this analysis aims to highlight key observations rather than provide an exhaustive assessment.

Overall, the market for these technologies is only partially tradeable. While the R&D, engineering, and design services related to these technologies are highly traded due to the high transferability of specialised knowledge, the manufacturing of related equipment is often performed regionally or locally due to trade costs over long distances.[70]

Our focus is on UK business opportunities from supplying equipment and EPCm services related to the set of 74 technologies. The specialised nature of the market for industrial equipment means that domestic expertise concentrates in several niche areas of strength rather than across the full spectrum of technologies. This analysis estimates the current UK competitiveness in equipment markets based on available trade data and uses it as a proxy for competitiveness in markets for EPCm services. Therefore, variations in the competitive landscape for individual technologies are partially captured in this approach, and outlying data points are likely overlooked. This is, nonetheless, adequate for estimating the overall size of opportunities because aggregate estimates are not so sensitive to individual errors at the technology level.

Market shares and GVA multipliers are estimated for each *category* of the technologies. Due to the lack of disaggregated trade and GVA data that can be matched with each individual technology, the 74 technologies are placed into nine categories based on proximate types of machineries involved. Corresponding trade data and GVA data for each category thus provide the parameters that are mapped to the corresponding technologies. The categorisation of technologies, along with mapping to sectors and innovation types, are displayed in *Appendix 6: Technologies included for business opportunities analysis*.

Intellectual property (IP) licensing revenues could be significant for the technologies considered but are not quantified. Expert feedback suggests the

[70] In line with the previous TINA approach in Industry.

UK has strong research capabilities in biochemicals and data analytics. However, IP generated in the UK and subsequently licensed abroad for production would not lead to substantial additional jobs or GVA in the UK. Given the focus of the analysis on business opportunities which ultimately generate jobs in the UK, IP-related opportunities are not quantified.

The business opportunities analysis is set out as follows

- An overview of the global market, with a focus on markets for exports
- A discussion of the UK's competitive position, with a focus on exports
- A discussion of the business opportunities from exports
- A discussion of the UK business opportunities in the UK's domestic market, including a comparison of the relative importance of export and domestic opportunities

Box 8. **The UK's current industry**

- Manufacturing sectors combine to add £160 billion to the UK economy each year. The seven industries considered in this EINA make up to 34% of this, of which 18% is in food & drink, 6% in chemicals, 5% in pulp & paper, 3% in iron & steel, 1% in glass, and 1% in cement and ceramics.[71]

- Together, however, the seven industries represent close to two-thirds of all direct manufacturing emissions from industry, and hence represent the main market for industrial decarbonisation equipment in the UK (and hence export opportunities globally).[72]

- Annual R&D expenditure by manufacturing businesses is £14 billion. The seven industries in this EINA make up 10% of it, of which 3% is in food & drink, 6% in chemicals, 0.4% in pulp & paper, and 0.3% in iron & steel, and 0.5% in glass, cement, and ceramics.[73]

- Annual turnover from the manufacture of machinery and equipment is £36 billion, of which £7 billion is special purpose machinery. Installation of industrial machinery and equipment has a turnover of £3 billion.[74]

[71] Based on 5-year averages from Office for National Statistics (ONS) data in the Annual Business Survey.
[72] CCC (2018). Reducing UK emissions 2018 Progress Report to Parliament https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf
[73] Based on 5-year averages from ONS data in Business Enterprise Research and Development.
[74] Based on 5-year averages from ONS data in the Annual Business Survey.

Market overview

The market within the scope of this analysis consists of a wide range of specialised buyers and sellers with fragmented market shares. The demand for technologies is driven by industrial companies seeking to reduce costs, in part as a response to increasing carbon prices and/or sector-specific regulations. As a subset of the wider market for industrial machinery and related EPCm services, there are some similarities in the deployment trends across these technologies despite differences in their competitive landscapes. This section provides a high-level discussion of the market containing this diverse set of technologies.

Currently, global deployment of the industrial decarbonisation technologies within scope has an estimated market turnover of £26 billion per annum.[75] Based on available trade data of proximate equipment, an estimated 30% of the turnover is driven by demand in the EU. As alternative process and fuel technologies face relatively large deployment barriers and costs, the current market consists mainly of efficiency improvement technologies and heat recovery methods that are mature and easy to deploy. In 2015, most of the market value came from the food & drink sector, which outpaces other sectors in terms of deploying the set of technologies considered in this analysis.

Market turnover is expected to grow by an average of 5% per annum between 2020 and 2050, driven by the increasing commercial viability of a wide range of technologies. Global deployment is expected to accelerate for most technologies that have already demonstrated cost savings for early adopters. However, technologies with lower compatibility with existing production methods are deployed more slowly because companies are unlikely to overhaul current operations to adopt such technologies. The deployment profile of each technology further depends on the availability of necessary infrastructure and supply chains, as well as policy incentives to encourage deployment. These factors are not explicitly modelled but are embedded within the deployment scenario used for this analysis.

Global market turnover could reach £120 billion per annum by 2050. Nearly half of this market value would consist of demand from the cement sector, which spends over £30 billion on deploying BAT kilns and £11 billion on oxygen enrichment technology. It is followed by the food & drink sector, which deploys a wide range of technologies with a combined expenditure of £27 billion. While there is a similarly accelerated deployment of technologies across other sectors, their individual market sizes are not as significant.

[75] Only capex associated with the technologies, along with related EPCm services, are considered.

The market for EPCm services is highly accessible for the UK exporters, whereas only a fraction of the equipment market is likely to be traded. Given the substantial heterogeneity of technologies within the scope of this analysis, their individual tradability is difficult to establish. However, in line with previous Technology Innovation Needs Assessment (TINA) analysis, the following is assumed across all technologies:

- **Equipment**, which accounts for roughly 60% of the capex, has limited tradability due to geographical distance. Overall, tradability of the equipment market is 50% in the EU and 10% in the rest of the world.

- **EPCm services** related to the R&D, engineering, and design of those technologies, which make up 16% of the capex, are assumed to be 100% tradeable given the high transferability of specialised expertise. EPCm services related to installation are not tradeable.

Figure 5 **The current and future market for industrial decarbonisation technologies**

Current market for related technologies

- *Production:* Global deployment of the full range of technologies currently represents ~£26 bn in turnover
- *Trade:* Roughly half of the market is traded globally
- *Markets:* The EU is currently the largest market for the set of industrial technologies considered, at roughly 30% of global deployment

Tradability of market

- *Goods:* Equipment is traded regionally due to geographical limits
- *Services:* EPCm services which span from R&D, engineering to installation, are specialised and therefore highly traded
- *Trends:* International trade is expected to grow proportionately to global deployment

Trends in deployment

- *Global:* deployment of the full set of technologies is expected to grow at 5% CAGR between 2020 and 2050
- *Growth pattern:* substantial variations exist across sectors and technologies. Some technologies that represent minor retrofits to existing plants can be readily deployed in the near term. Alternative process technologies are adopted more rapidly post-2030.

Global and regional market size to 2050

- *Growth trend*: tradeable market reaches £60 bn in 2050, a majority of which are EPC services
- *Key markets:* as industrial activities shift towards emerging economies, the EU share of the global market for such industrial technologies is expected to decline from the current level of 28% down to 19% in 2050.

Source: Vivid Economics

UK competitive position

UK competitiveness varies across different industrial decarbonisation technologies. Disaggregated by their core components, current UK markets shares in the EU span from 2% for heat exchange units (for waste heat recovery) to 10% for enzymes (for food preparation). Many of the technologies under consideration do not have strict definitions, for example 'kiln process technology' or 'improved process control', making it difficult to establish individual market shares. Therefore, as the next best alternative, the technologies are categorised based on the most proximate type of industrial machinery for which trade data can be accurately identified, such as furnaces and kilns (see *Appendix 6: Technologies included for business opportunities analysis*). This set of trade data, summarised in Table 7, along with expert evidence, is then applied to determine the UK's key international competitors.

Overall, the UK does not enjoy a comparative advantage in specialised industrial equipment. The extent of this weakness is driven by both a lack of domestic engineering expertise as well as manufacturing capabilities, which in turn dampen incentives to undertake R&D. For example, ceramics manufacturers in the UK are reliant on importing kilns and associated technologies from European companies due to a lack of kiln technology innovations locally. Most industry experts agree that they are dependent on foreign suppliers for specialised equipment for their factories.

Table 7. **Current UK market shares in relevant equipment markets**

Equipment	Share in EU market	Share in RoW market
Bioprocessing and catalysts	10%	3%
Machinery for processing stones, ceramics, cement	8%	6%
Furnaces and kilns	4%	2%
Industrial control equipment	4%	5%
Pumps, compressors, motors	4%	3%
Steam production and distribution	3%	1%
Food processing machinery	2%	2%
Paper-making machinery	2%	2%
Waste heat recovery and/or reuse	2%	3%

Note: *UN COMTRADE data for HS codes 3507, 3815, 8438, 8416, 8417, 8514, 831110, 831120, 8481, 9026, 9028, 8464, 8474, 8439, 8441, 8413, 8414, 8402, 8404, and 841950. Five-year averages are used to calculate market shares.*

Source: *Vivid Economics.*

For EPCm services, the UK's comparative advantages are concentrated in domains involving process optimisation and digitalisation. The UK has a relatively strong expertise in data analytics, in both academia and industry, which could play a large role in developing and implementing advanced process control methods in industry. Given the importance of Industry 4.0 in the future of manufacturing, this is potentially a significant business opportunity. Due to the lack of disaggregated trade data in services, this analysis proxies current UK market shares in tradeable services (R&D, engineering, and design) for each technology by trade data in corresponding equipment markets (see Appendix 3: Business opportunities for detailed methodology).

The key international competitors for the UK are Germany, the US, and China, with Italy also providing strong competition in the EU. Germany is the leading exporter to the EU market across the full range of industrial machineries considered and is particularly strong in bioprocessing and furnace equipment. In the rest of the world, China and the US are the two dominant exporters of the equipment considered, with China being particularly strong in steam systems and the US in bioprocessing. The variation in sector-specific equipment market shares across countries is relatively limited due to the wide range of equipment used in a sector. For example, although the UK is relatively competitive in bioprocessing, the chemicals sector has a much larger capital expenditure in deploying improved furnaces and steam systems. From this perspective, UK industrial suppliers for the chemicals sector are not particularly competitive. However, it should be noted that these industrial sectors tend to be operated by large multinational corporations with supply chains spreading across entire regions. Expertise and technical knowledge can be dispersed from foreign direct investments, such as setting up new manufacturing facilities in different countries. It is therefore possible for the UK to gain or lose comparative advantage from the activities of such multinational corporations.

Figure 6 **The UK's competitive position in trade**

Current UK competitiveness

- *Market shares:*
  EU *(excl. UK) ~ 4%*
  RoW *~ 3%*
- *Strengths:* research in biochemicals; data analytics and process optimisation
- *Weaknesses:* weak R&D in the industrial technologies within scope; difficulty to attract specialised engineers and technicians

Competitor – Germany

- *Market shares:*
  EU *~ 22%*
  RoW *~ 14%*
- *Strengths*: Strong domestic industry to support manufacturing of industrial machinery; leader in R&D for a wide range of industrial processes

Competitor – China

- *Market shares:*
  EU *~ 5%*
  RoW *~ 16%*
- *Strengths*: competitive manufacturing base particularly for steam systems and cement processing equipment; access to growing industrial hubs across Asia
- *Weaknesses*: Limited presence in the EU market

Competitor – USA

- *Market shares:*
  EU *~ 5%*
  RoW *~ 12%*
- *Strengths:* predominant in bioprocessing technologies and early-stage research; leader in robotics and digitalisation for industrial purposes
- *Weaknesses:* Limited presence in the EU market

Note: *Market shares based on analysis of HS Codes: 3507, 3815, 8438, 8416, 8417, 8514, 831110, 831120, 8481, 9026, 9028, 8464, 8474, 8439, 8441, 8413, 8414, 8402, 8404, and 841950*

Source: *Vivid Economics*

Box 9. **Industry workshop feedback regarding business opportunities**

- UK competitiveness in industrial machinery has been weakening in recent years. Examples include the relocation of R&D centres from the UK to Europe and the reliance on imported equipment for UK industrial plants.
- A common concern was that the manufacture of industrial machinery would be outsourced to more competitive foreign firms even if the UK pursues stronger R&D. The lack of engineers and technicians with niche knowledge is seen as a barrier to the UK becoming competitive.
- The market for EPCm services in the design of industrial processes, and subsequent installation and maintenance of equipment, consists of many highly specialised providers. The UK is strong in some niche areas but is not seen as a strong exporter overall.
- Customer-facing industries see growing demand for 'green' sustainable products. Product innovation would be important in capitalising on this opportunity.

Table 8. **Export market shares and innovation impact – Industry**

Technologies deployed in	Tradeable market 2050 (£bn)	Current market share	2050 outlook *with* strong learning by research: Market share (weighted average of equipment and services)	Captured GVA (£m)	Rationale for the impact of innovation
Cement	**EU: 4** RoW: 9	Not commercial	**EU: 12%** RoW:11%	**World: 580**	Strong innovation has the potential to bring the UK into a leading position across the markets considered. This analysis considers a catch-up scenario where, • Equipment: UK market shares in 2050 reach half of the current share enjoyed by the market leader (Germany) • EPCm services: UK market shares in 2050 comparable to current UK market share in oilfield services Refer to *Appendix 3: Methodology for the business opportunities analysis* for detailed methodology.
Ceramics	**EU: 0.6** RoW: 1	Not commercial	**EU: 12%** RoW: 10%	**World: 90**	
Chemicals	**EU: 2** RoW: 3	**EU: 4.2%** RoW: 3.9%	**EU: 11%** RoW: 10%	**World: 220**	
Food & drink	**EU: 3** RoW: 5	**EU: 3.1%** RoW: 3.1%	**EU: 11%** RoW: 11%	**World: 320**	
Glass	**EU: 0.7** RoW: 1	Not commercial	**EU: 12%** RoW: 11%	**World: 90**	
Iron & steel	**EU: 0.4** RoW: 0.9	**EU: 3.6%** RoW: 2.1%	**EU: 11%** RoW: 10%	**World: 50**	
Pulp & Paper	**EU: 0.2** RoW: 0.3	**EU: 2.3%** RoW: 1.8%	**EU: 11%** RoW: 11%	**World: 20**	

Note: *The possible market share of the UK, and rationale for the impact of innovation, are based on stakeholder input gathered in the workshop. Key technologies cannot be perfectly matched against trade data because it is not available at the required level of disaggregation. Therefore, current market shares are estimated with proximate machineries for which COMTRADE data is available. The following HS codes were used: 3507, 3815, 8438, 8416, 8417, 8514, 831110, 831120, 8481, 9026, 9028, 8464, 8474, 8439, 8441, 8413, 8414, 8402, 8404, and 841950. Sectoral market shares displayed in the table are weighted averages from corresponding equipment and services.*

Source: *Vivid Economics.*

UK business opportunities from export markets

Box 10. **Interpretation of business opportunity estimates**
The GVA and jobs estimates presented below are *not* forecasts, but instead represent estimates of the potential benefits of the UK capturing available business opportunities. The presented estimates represent an unbiased attempt to quantify opportunities and are based on credible deployment forecasts, data on current trade flows, and expert opinion, but are necessarily partly assumption-driven. The quantified estimates are intended as plausible, but optimistic. They assume global climate action towards a 2 degree world and reflect a UK market share in a scenario with significant UK innovation activity.[76] More information on the methodology, including a worked example, is provided in Appendix 3, and a high level uncertainty assessment across the EINA subthemes is provided in Appendix 7.

UK exports related to industrial decarbonisation technologies could add £1.4 billion to GVA per annum and support 18,000 jobs by 2050. Given that the UK may capture a share of this growing market – 8% of the £30 billion global tradeable turnover in 2050 – this represents a significant business opportunity for UK exporters of relevant industrial equipment and EPCm services. Within the estimated UK GVA from these exports in 2050, 44% relate to alternative process technologies, 33% for efficiency improvements, 18% for low-carbon substitutes (mainly fuel switching), 4% for heat recovery, and 1% for other forms recovery and recycling (Figure 7).[77] Of the £1.4 billion total, £800 million per annum will be generated by EPCm services exports and rest generated by equipment exports.

Exports for the cement sector can create £580 million in GVA per annum and 8,000 jobs by 2050, which is the highest of all seven industrial sectors (Figure 7). This is primarily driven by the rapid adoption of improved kiln process technologies in cement production sites from 2030 onwards, with corresponding GVA from exports reaching £380 million per annum by 2050. Also significant in the cement sector is the deployment of oxygen enrichment technology, which will only be deployed after 2040, but export opportunities can reach £130 million per annum in 2050.

Exports for the food & drink sector can contribute £320 million in annual GVA and 3,900 jobs by 2050 (Figure 8 and Figure 9). Opportunities in the food & drink sector

[76] Note, other IEA climate scenarios were also used as a sensitivity. Where the level of global climate action has a meaningful impact on market size, this is highlighted in the market overview section. Full results are available in the supplied Excel calculator.
[77] See Appendix 4 and Appendix 6 for disaggregated estimates.

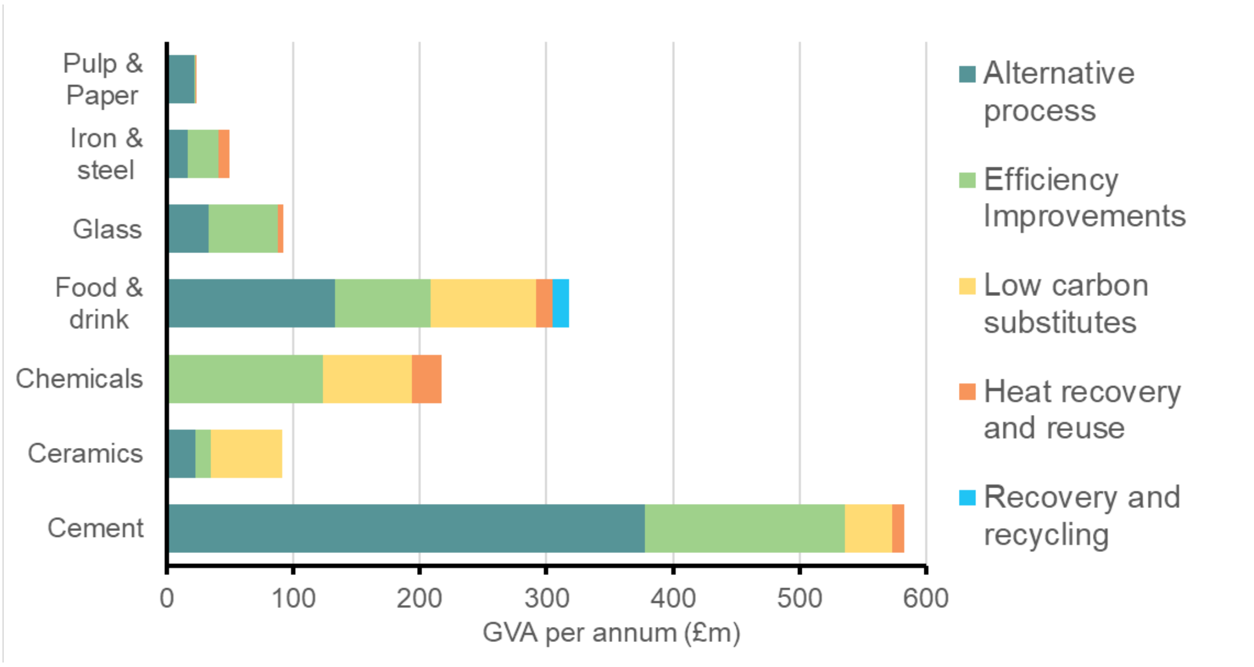
span across the deployment of over 20 technologies in the sector. Initially, business opportunities concentrate in heat recovery and efficiency improvements, accounting for over 80% of potential exports in 2020. Subsequently, alternative process technologies and low-carbon substitutes (particularly through electrification of heat) become more important and combine to explain 70% of potential exports in 2050.

Exports for the chemicals sector contribute £220 million in GVA annually and 2,600 jobs by 2050 (Figure 8 and Figure 9). Opportunities in the sector would be concentrated in improving the general equipment efficiency of chemicals plans and, from 2035 onwards, to facilitate fuel switching towards decarbonised methane. Efficiency improvements and fuel switching combined explain up to 90% of the export opportunities in 2050.

The four remaining sectors (iron & steel, ceramics, glass, and pulp & paper) combine to create export opportunities worth £260 million in GVA per annum and 3,400 jobs by 2050. A diverse range of technologies is responsible for the demand from these sectors. These mainly consist of improved furnace and kiln designs worth up to £130 million in GVA per annum across the glass and ceramics sector. There is also a variety of alternative process technologies, such as electric melting for glass and near net shape casting for iron & steel.

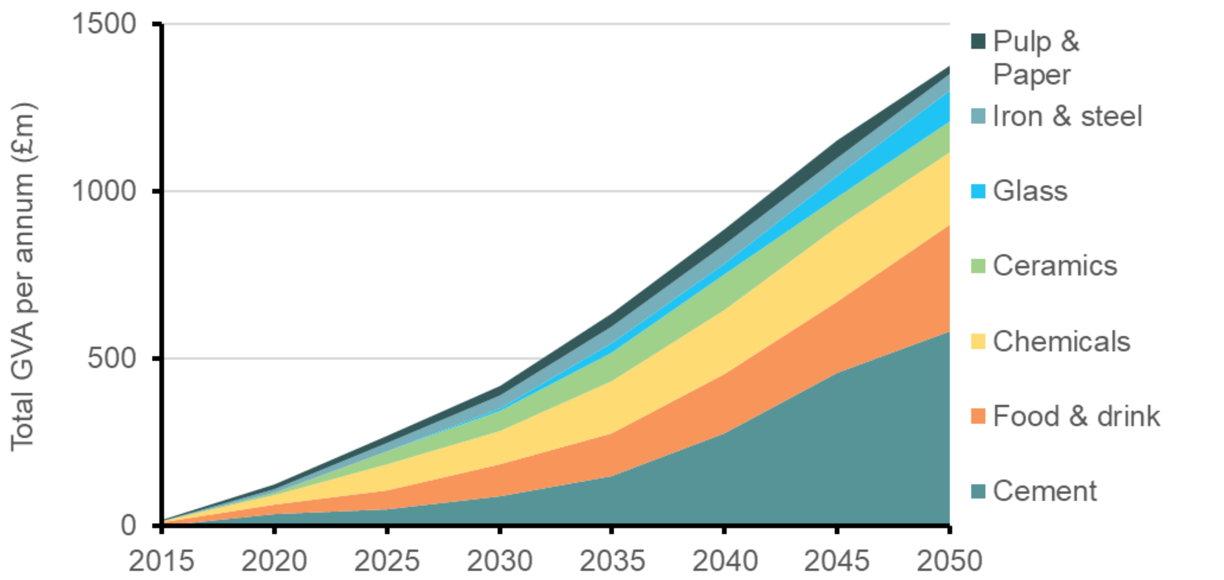
Overall export opportunities for the UK depend significantly on the deployment profile of technologies and the UK's ability to expand its market share. The technology deployment scenario considered for this assessment represents the high scenario. In the alternative, Business-as-Usual scenario, the estimated size of business opportunities in 2050 would be 47% smaller. This assessment also assumes strong innovation in the UK, resulting in large gains in market shares across the full range of technologies (Table 8). It should, however, be noted that market shares reported at the sectoral level conceal heterogeneities across the various categories of equipment involved. If the UK's market shares remain constant at current levels, the estimated size of business opportunities in 2050 would instead be 67% smaller.

Figure 7 **GVA per annum from export markets by industry sector and innovation type in 2050**



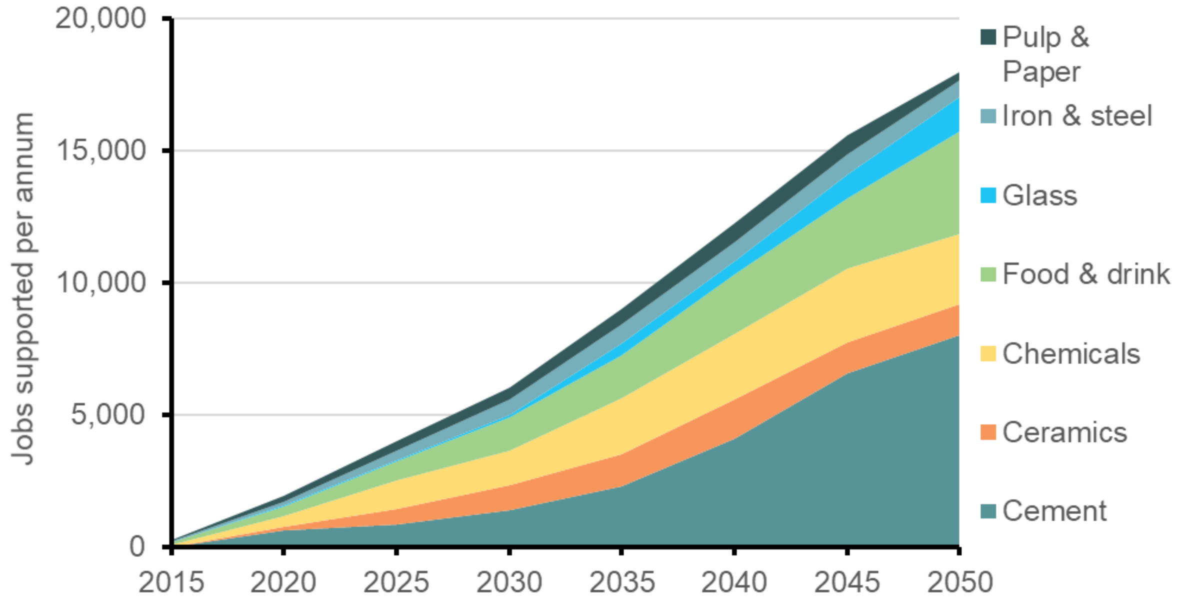
Source: *Vivid Economics*

Figure 8 **GVA per annum from export markets by sector – Industry**



Source: *Vivid Economics*

Figure 9 **Jobs supported per annum from export markets by sector – Industry**



Source: *Vivid Economics*

UK business opportunities from the domestic market

Industrial decarbonisation creates domestic business opportunities across a wide range of technologies. In 2017, UK industrial emissions amounted to 105 $MtCO_{2e}$.[78] According to the UK Committee on Climate Change (CCC), meeting the existing 80% emissions reduction target would require a set of "core" technology options that reduce industrial emissions down to 56 $MtCO_{2e}$ per year in 2050.[79] This consists of a variety of sector-specific technologies that span energy efficiency improvements, fuel-switching, alternative processes, recovery and recycling, and CCS. Meeting a net zero target will additionally require "further ambition" and "speculative" options that lower emissions down to 6 $MtCO_{2e}$ in 2050. Industry will need to deliver much more abatement than in the 80% scenario.[80,81] The government's Clean Growth Strategy has set out an ambition to support emissions reductions while maintaining industrial competitiveness. To understand the business opportunities that are likely to emerge from these technologies, this analysis uses the "Max Tech" scenario from the *2050 Industrial Decarbonisation and*

[78] CCC (2019) Net Zero The UK's contribution to stopping global warming: https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-The-UKs-contribution-to-stopping-global-warming.pdf
[79] Ibid.
[80] Ibid.
[81] These further ambition and speculative options involve the extensive use CCS, hydrogen, biomass and electrification. This assessment includes electrification, but excludes CCS, hydrogen and biomass as they are covered in other EINA subthemes.

Energy Efficiency Roadmaps ("2050 Roadmaps"),[82] which is broadly in line with the CCC's core options and the existing 80% target. [83]

The analysis of domestic opportunities covers the same 74 technologies considered and 7 sectors as in the export analysis, but additionally considers related installation services. As with the export analysis, the domestic analysis is based on technology deployment profiles under the 2050 Roadmaps. This assessment excludes technologies related to CCS, bioenergy and hydrogen as they are covered in other EINA subtheme reports. For each technology, the domestic analysis covers the entire value chain: R&D, Engineering and Design, Manufacturing and Fabrication, and Installation services. This differs from the export analysis, where installation services are considered inaccessible to UK firms as they tend to be provided by local contractors. O&M services are not considered because they tend to occur in conjunction with the broader O&M of plants rather than emerge from low carbon innovations.

Overall, UK firms could capture 60% of the domestic market in 2050. This is based on the ambition that UK market shares across R&D, engineering and manufacturing for each technology could reach similar market shares that UK firms currently enjoy over proximate equipment types in the domestic market (see Methodology Notes for details). This varies substantially across technologies. As for installation services, the market is mainly served by local UK suppliers.[84] The potential 2050 market shares aggregated at the sectoral level are presented in Table 9.

Domestic business opportunities in industrial decarbonisation technologies could support £520 million in GVA per annum and 6,000 jobs by 2050. Domestic opportunities are split across alternative processes (38%), low carbon substitutes (29%), efficiency improvements (25%), heat recovery and reuse (5%), and recovery and recycling (3%), as shown in Figure 10 and Figure 11. The primary driver for both the size and composition of business opportunities is the deployment of technologies. If biomass were included in this assessment, the opportunities in the 'low carbon substitutes' category would be substantially higher. Alignment with the CCC's latest recommendations for a net zero target would also imply significantly increased use of hydrogen within industry, another low carbon substitute.

[82] Parsons Brinckerhoff and DNV GL (2015) Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050 - report for DECC and BIS: https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050
[83] Both the Max Tech scenario in the 2050 Roadmaps and the CCC's core options describe pathways in line with the existing 80% target. The CCC's core options draw on the energy efficiency options described under the Max Tech scenario in the 2050 Roadmaps. Both scenarios feature the use of CCS, electrification with industrial heat pumps, and a range of energy efficiency improvements. However, the Max Tech scenario offers greater analytical detail in terms of deployment and associated costs, thus is more convenient for this analysis.
[84] Some installation services in industry are provided by specialised suppliers. Unlike normal, low-value installation services, these specialised installation services are highly tradeable. Due to their tradeability, they are regarded as engineering services instead for the purpose of estimation.

Technology deployment in the food and drink sector accounts for up to 82% of the domestic business opportunities, contributing £420 million annually to GVA and 4,800 jobs. This result is driven by two factors. First, the UK food and drink sector is much larger in economic size: it has an annual GVA of over £30 billion, larger than the combined size of the other six carbon-intensive sectors in this report (cement, iron and steel, pulp and paper, chemicals, glass and ceramics). Second, several major decarbonisation technologies for other sectors, such as CCS and biomass, are considered in other EINA sub-themes. As a result, the food and drink sector's share of domestic opportunities in the scenario analysis is significantly higher than the other sectors, as shown in Figure 12, 13 and 14. Several decarbonisation technologies are particularly important in creating these opportunities within the food and drink sector: electrification of heat (30%), improved process design (19%), improved air compression (15%), and vapour re-compression (14%).

Of the total business opportunities, domestic opportunities within industrial decarbonisation support only 25% of jobs by 2050, with 75% supported by exports. This difference is explained by the relatively small size of UK industrial sectors. For instance, global expenditure on industrial decarbonisation technologies in the cement and glass sectors could be as large as 400 times that of corresponding domestic expenditure.[85] Although UK firms may acquire a large share of the domestic market, the absolute size of domestic opportunities is outweighed by opportunities driven by the much larger market in rest of the world, as shown in Figure 15 and Figure 16. This illustrates a broader challenge for industrial innovation: beyond the food and drink sector, capturing a meaningful market share in the global market would require substantial effort to innovate in technologies for which there is limited domestic demand.

It should be noted that industrial decarbonisation technologies can further create spillover effects beyond the scope of this assessment. The business opportunities quantified in this domestic analysis narrowly focuses on GVA and jobs supported by supplying the equipment and services required for industrial decarbonisation. In other words, this assessment focuses on opportunities available for equipment manufacturers and related EPCm service providers, rather than the carbon intensive industries that demand them. On the one hand, the adoption of these technologies may lead to energy savings, improve productivity and help maintain industrial competitiveness. On the other hand, the significant upfront costs required in retrofits and facility upgrades can be a burden for some companies. These spillover effects should be carefully considered on a sector-by-sector basis. The joint work between government and industry to develop the industrial decarbonisation and energy efficiency action plans is a step in this direction.[86]

[85] According to data in the underlying model for the 2050 Roadmaps
[86] BEIS (2017) Industrial decarbonisation and energy efficiency action plans: https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-action-plans

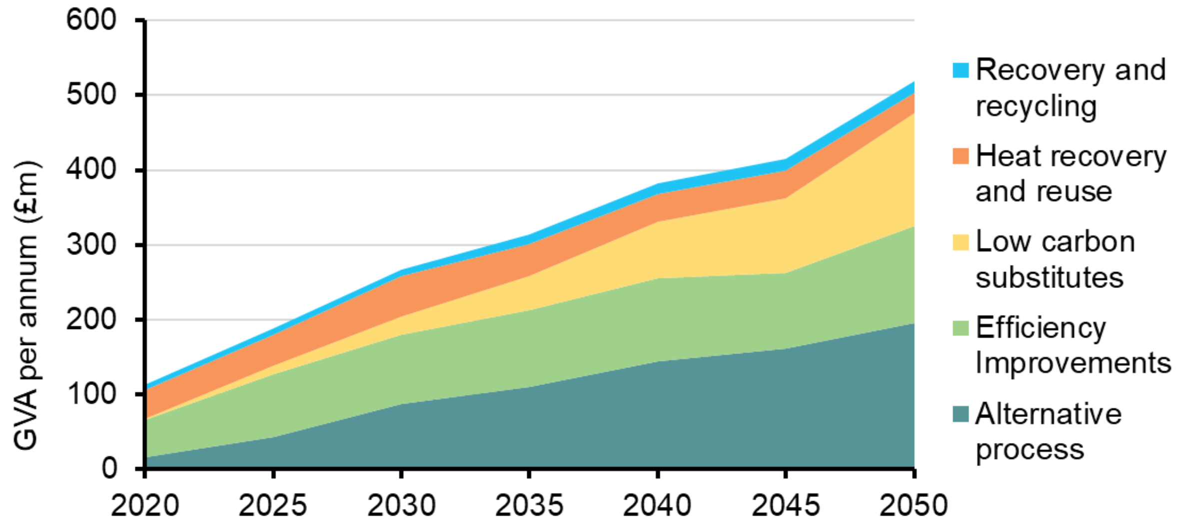
Table 9. **Domestic market shares and innovation impact – Industry**

Technology deployed in	Domestic market 2050 (£m)	Current market share of related goods and services	2050 outlook with strong learning by research			
			Market share* (%)	Domestic turnover captured (£m)	GVA (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
Cement	110	N/A	71%	80	30	**R&D; engineering & design; manufacturing & fabrication:** UK market shares in 2050 would be in line with the UK's current domestic market share in similar equipment types. **Installation services:** This market is treated as non-tradeable hence captured by UK firms. Specialised installation services are an exception to this pattern because they tend to be tradeable. However, they are accounted for within the engineering component above for the purpose of this estimation.
Ceramics	55	N/A	70%	40	20	
Chemicals	120	N/A	63%	70	30	
Food & drink	1,600	N/A	62%	1,000	420	
Glass	20	N/A	70%	10	6	
Iron & steel	25	N/A	67%	20	7	
Pulp & Paper	17	N/A	44%	8	3	

Note: ** Future market shares are not a forecast, but what UK business opportunities could be potentially in the context of the EINAs. The possible market share of the UK, and rationale for the impact of innovation, are based on PRODCOM analysis and additional market research. N/A indicates data is not available.*

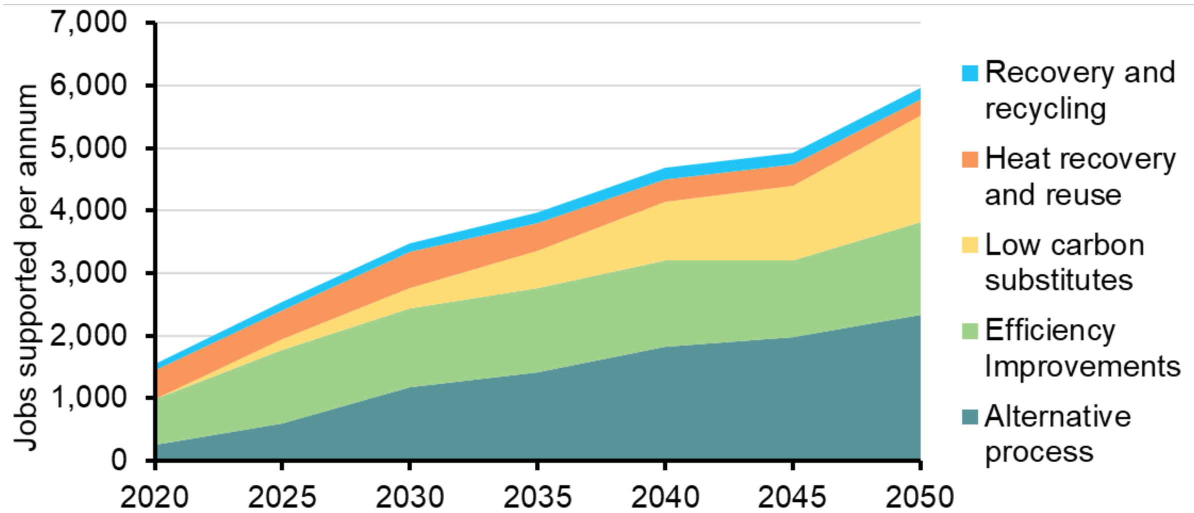
Source: *Vivid Economics*

Figure 10 **GVA per annum from domestic markets by innovation type – Industry**



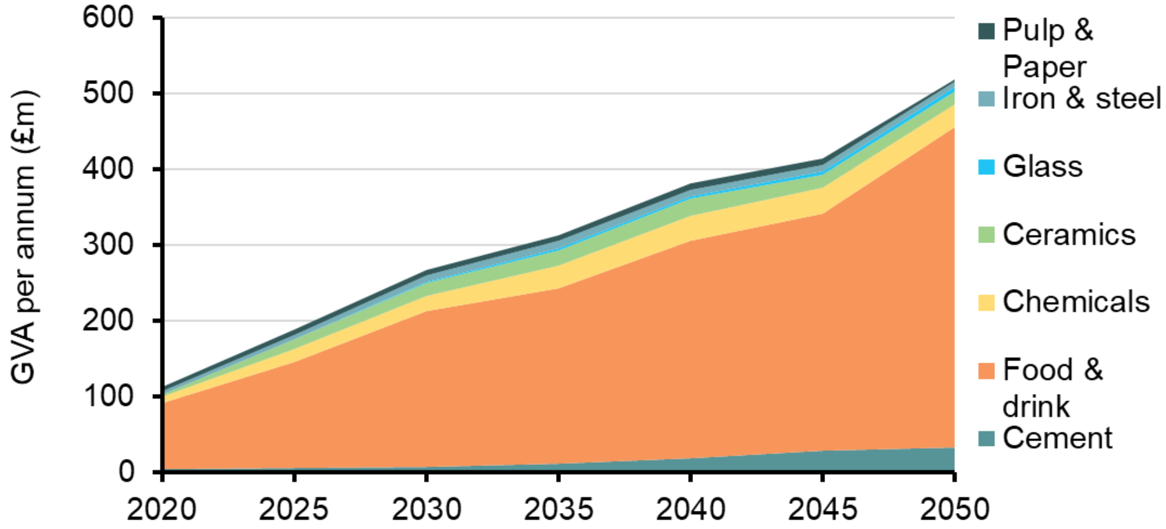
Source: *Vivid Economics*
Note: *The assessment considers only the subset of industrial decarbonisation technologies that are relevant to the 7 carbon intensive sectors within the scope of this report, and notably excludes CCS, and fuel switching to biomass and hydrogen.*

Figure 11 **Jobs supported per annum from domestic markets by innovation type – Industry**



Source: *Vivid Economics*
Note: *The assessment considers only the subset of industrial decarbonisation technologies that are relevant to the 7 carbon intensive sectors within the scope of this report, and notably excludes CCS, and fuel switching to biomass and hydrogen.*

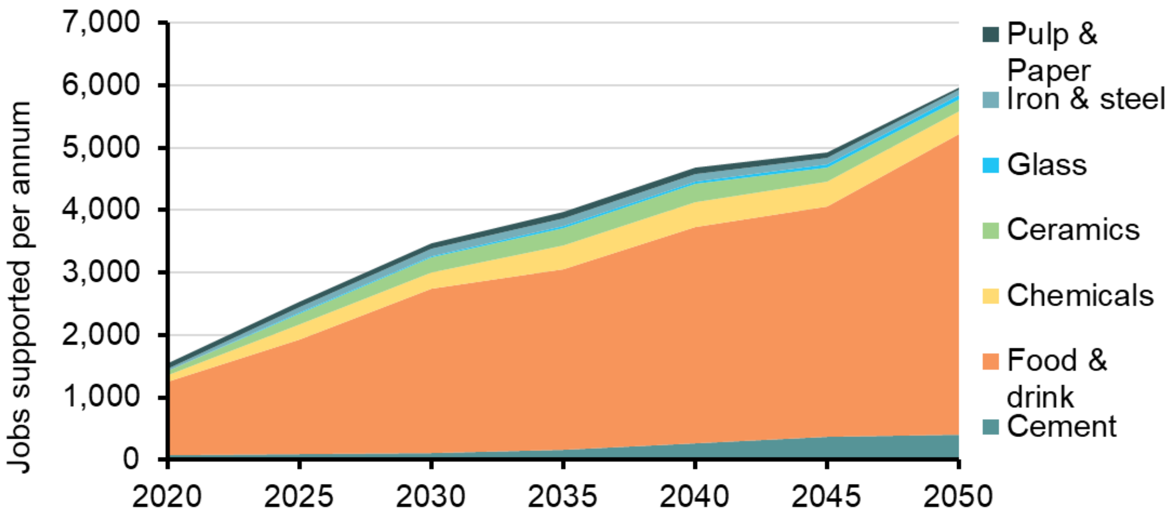
Figure 12 **GVA per annum from domestic markets by sector – Industry**



Source: *Vivid Economics*

Note: *The assessment considers only the subset of industrial decarbonisation technologies that are relevant to the 7 carbon intensive sectors within the scope of this report, and notably excludes CCS, and fuel switching to biomass and hydrogen. For reference, the GVA from the 7 sectors combined is currently £55 billion. These opportunities are captured by equipment manufacturers and EPCm service suppliers, rather than companies within the 7 sectors.*

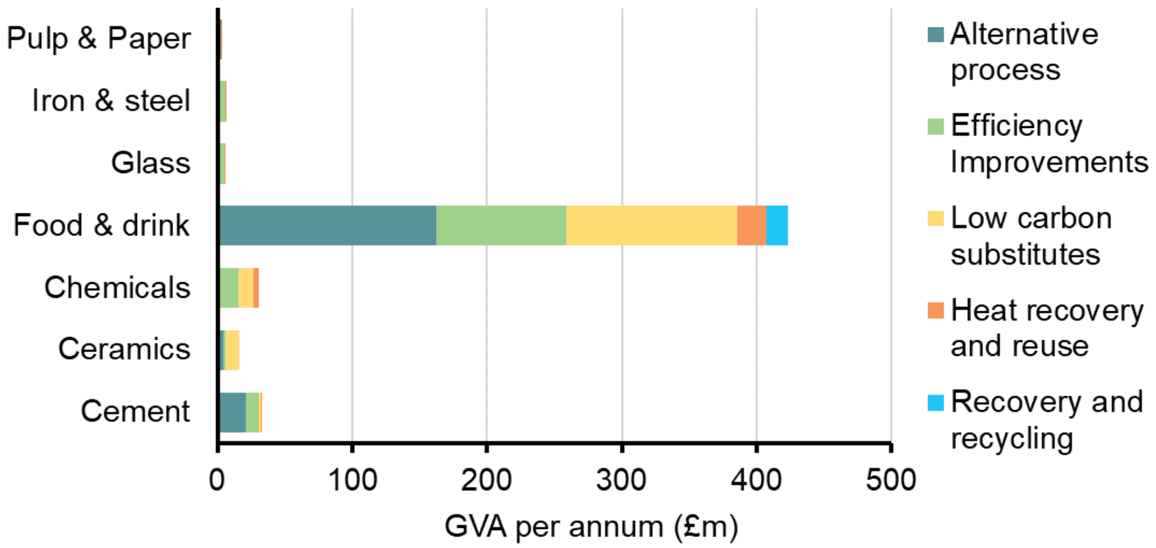
Figure 13 **Jobs supported per annum from domestic markets by sector – Industry**



Source: *Vivid Economics*

Note: *The assessment considers only the subset of industrial decarbonisation technologies that are relevant to the 7 carbon intensive sectors within the scope of this report, and notably excludes CCS, and fuel switching to biomass and hydrogen. These opportunities are captured by equipment manufacturers and EPCm service suppliers, rather than companies within the 7 sectors.*

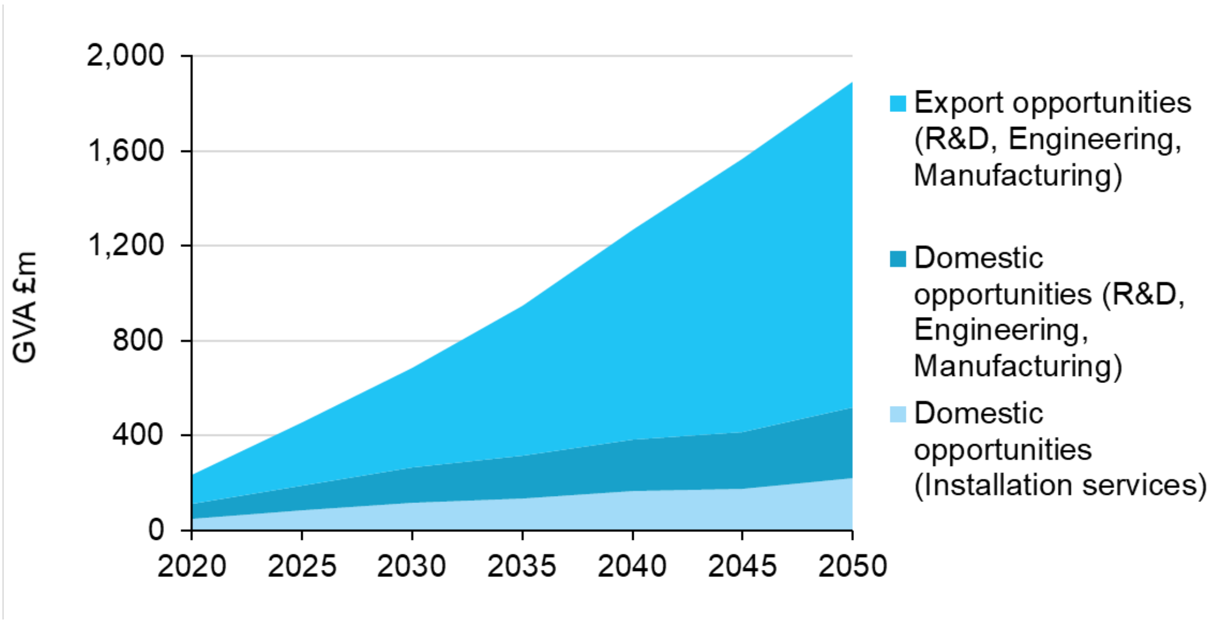
Figure 14 **GVA per annum from domestic markets by sector and innovation type in 2050 – Industry**



Source: *Vivid Economics*

Note: *The assessment considers only the subset of industrial decarbonisation technologies that are relevant to the 7 carbon intensive sectors within the scope of this report, and notably excludes CCS, and fuel switching to biomass and hydrogen. These opportunities are captured by equipment manufacturers and EPCm service suppliers, rather than companies within the 7 sectors.*

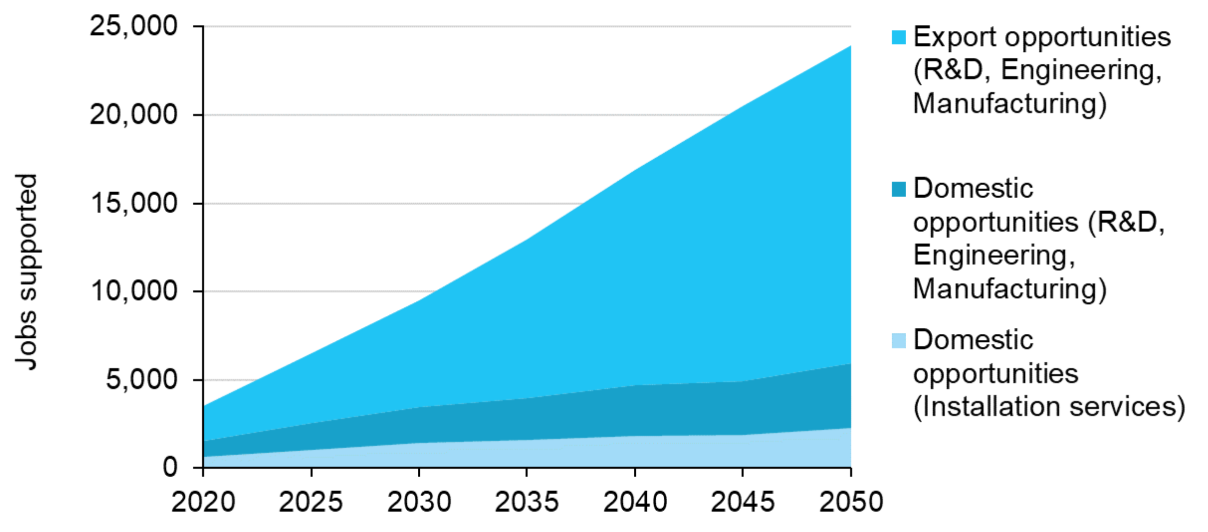
Figure 15 **GVA per annum from export and domestic markets – Industry**



Source: *Vivid Economics*

Note: *The assessment considers only the subset of industrial decarbonisation technologies that are relevant to the 7 carbon intensive sectors within the scope of this report, and notably excludes CCS, and fuel switching to biomass and hydrogen.*

Figure 16 **Jobs supported per annum from export and domestic markets – Industry**



Source: *Vivid Economics*

Note: *The assessment considers only the subset of industrial decarbonisation technologies that are relevant to the 7 carbon intensive sectors within the scope of this report, and notably excludes CCS, and fuel switching to biomass and hydrogen.*

Market barriers to innovation within industry

Introduction

Box 11. **Objective of the market barrier analysis**

Market barriers prevent firms from innovating in areas that could have significant UK system benefits or unlock large business opportunities. Market barriers can either increase the private cost of innovation to levels that prevent innovation or limit the ability of private sector players to capture the benefits of their innovation, reducing the incentive to innovate.

Government support is needed when market barriers are significant, and they cannot be overcome by the private sector or international partners. The main market barriers identified by industry are listed in Table 10, along with an assessment of whether HMG needs to intervene.

Market barriers for industry

Globally, direct industrial CO_2 emissions grew by 1.3% per year between 2010 and 2016, when they made up 24% of total global emissions. However, the rate of growth in industrial emissions has slowed in recent years, including in the UK.[87] Due to high upfront costs, long payback periods, and significant first-mover disadvantage for innovation in low-carbon industrial processes, government support is needed to drive innovation. This is the case globally, and the proportion of industrial total energy use covered by mandatory policies in the UK is like most countries (under 10%, only China and India have significantly wider coverage) .[88] In the Industrial Strategy, HMG commits to helping industry improve productivity and competitiveness, including through unlocking energy savings.[89] The Clean Growth Strategy states that HMG's goal is to improve energy efficiency for industry by at least 20% by 2030, enabled by a simpler, more ambitious and long-term policy and

[87] EIA (2018). Industry Tracking Clean Energy Progress https://www.iea.org/tcep/industry/
[88] Ibid.
[89] HMG (2017). Industrial Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664563/industrial-strategy-white-paper-web-ready-version.pdf

regulatory framework.[90] Funding opportunities for industry include, for example, the Clean Growth Fund, the Industrial Energy Efficiency Accelerator, and the Industrial Energy Transformation Fund.[91]

Table 10 lists the main market barriers in industry, along with an assessment of whether the government needs to intervene. For each identified market barrier, an assessment of the need for government intervention is provided. The assessment categories are low, moderate, severe, and critical.

- **Low** implies that without government intervention, innovation, investment, and deployment will continue at the same levels, driven by a well-functioning industry and international partners.
- **Moderate** implies that without government intervention, innovation, investment, and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
- **Severe** implies that without government intervention, innovation, investment, and deployment are significantly constrained and will only occur in certain market segments or must be adjusted for the UK market.
- **Critical** implies that without government intervention, innovation, investment, and deployment will not occur in the UK.

[90] BEIS (2017). The Clean Growth Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf
[91] For an overview of HMG funding see HMG (2017). Funding for low-carbon industry https://www.gov.uk/guidance/funding-for-low-carbon-industry ; HMG (2019) Designing the Industrial Energy Transformation Fund https://www.gov.uk/government/consultations/designing-the-industrial-energy-transformation-fund

Box 12. **Industry workshop feedback**

Industry experts raised additional challenges, which are not covered in Table 10:

- Retrofitting new technologies can require production downtime, which adds to the cost of innovation. This varies greatly across technologies; the paper industry suffers substantially from this barrier.
- SMEs drive a large share of innovation. The first-mover disadvantage is more severe for smaller firms, and by taking on a pioneering role they expose themselves to financial risk. Consumers are increasingly aware of this risk and can be reluctant to use newly introduced products from SMEs because the company might suffer financially and therefore will not be able to provide the needed support or updates in the future.
- The skills gap may become a severe barrier when the UK leaves the EU, as many skilled workers in the UK are nationals in other EU countries. Substantial time and investment would be needed to upskill the local workforce to retain current levels of innovation and deployment.

Table 10. **Market barriers**

Market barriers to innovation in low-carbon industry	Relevant for	Need for HMG support
Payback periods of decarbonisation technologies are often longer than the private sector is willing to accommodate. Private funding generally requires short life spans with payback in the first three years, which cannot be achieved by the innovations considered. Decarbonisation technologies are often high capex, and firms cannot recoup investment in the short term.	Capex	Critical
Early movers are not compensated for the technical risk of innovation and face the reputational risk of delivering lower quality products as a result of failed innovations or unforeseen impacts. Subsequent innovators can build on earlier iterations and experiences to better target market needs. As a result, firms take a 'wait and see' approach, slowing the progress of innovation. Larger firms can balance innovation risk more easily because they can diversify their investments and recoup potential losses.	Capex	Critical
Industry is not sufficiently compensated to commercialise new technologies and bring new innovations to market. New technologies are not commercially tested, making firms reluctant to implement them as they may cause disruptions now or in the future. As a result, innovations are not deployed and the returns to innovation are not achieved. Government support is currently focussed on early stage innovation. Industry stated that further funding support is needed to commercialise low-carbon alternatives, particularly to pilot and upscale them in the production process.	Low-carbon substitutes	Severe
Lack of access to required infrastructure. This includes hydrogen distribution networks, low-carbon electricity, and CO_2 transport and storage infrastructure. Due to the large upfront cost, shared revenues, and long lifetime of infrastructure, investment in it requires a high degree of coordination. Coordination failure of industry actors means there is a role for the government to support or take on the provision of shared infrastructure.	Low-carbon substitutes	Severe

Market barriers to innovation in low-carbon industry	Relevant for	Need for HMG support
The planning system generally supports industry, for example by providing timeframes and reducing risk, but regulation is not always sufficiently aligned. This is the case when various players are involved on the national and local levels. For example, utilising waste as input requires a complex set of licensing and other criteria due to the many players involved in designing the regulation. A simplified but effective system would reduce the cost of innovating.	Efficiency improvement; recovery and recycling	Moderate
Lack of required skills, and difficulty retaining knowledge, in advanced engineering, digitisation, and robotics. This is made considerably worse by a lack of training and accreditation requirements. High turnover results in loss of corporate memory and makes the innovation process less efficient. Digitisation and robotics require entirely new skillsets, which are very different from the traditional skills used in industry.	Efficiency improvement; recovery & recycling	Moderate
Uncertainty in the biomass supply chain reduces incentives for industry to innovate in processes using biomass. Key factors are the uncertainty of availability, resilience, quality, affordability, and sustainability of biomass and biogenic waste.	Low-carbon substitutes	Moderate
Very long-life spans of equipment mean alternative process technologies only have one chance to be adopted before 2050.	Alternative process technologies; Recovery & recycling	Moderate

Source: Vivid Economics analysis and stakeholder input

International opportunities for collaboration

There are potential international opportunities to innovate collaboratively. While being competitors, the UK can learn from countries that have a sound policy for promoting innovation in clean industrial technologies. In this area, Germany established a 'High-tech Strategy' across the economy in 2014, supporting the internationalisation of regional innovation clusters in priority areas such as Industry 4.0. SMEs are also very much the focus of Germany's innovation policy through efforts such as the Central Innovation Programme for SMEs and the programme for Joint Industrial Research.[92]

Opportunities for UK industry to collaborate with global platforms include Mission Innovation,[93] which is focussed on accelerating global clean energy innovation and affordability. Recently, the IEA and the UK began a partnership to drive international initiatives for industrial CCS.[94]

At a sectoral level, there are leading trade associations that are actively working to support innovation for industrial decarbonisation internationally. The Cement Sustainability Initiative (CSI) facilitates research and develops partnerships with key stakeholders in the industry, supporting basic research, funding, and advocacy.[95]

[92] German Federal Ministry for Economic Affairs and Energy (n.d.) New High-tech Strategy - Innovation for Germany https://www.bmwi.de/Redaktion/EN/Artikel/Technology/high-tech-strategy-for-germany.html
[93] Mission Innovation Website: http://mission-innovation.net/
[94] IEA (2018) IEA and UK kick-start a new global era for CCUS https://www.iea.org/newsroom/news/2018/november/iea-and-uk-kick-start-a-new-global-era-for-ccus.html
[95] The Cement Sustainability Initiative has now been transferred to the Global Cement and Concrete Association (GCCA). For more information see GCCA website: https://gccassociation.org/

Appendix 1: Organisations at expert workshop

- Department of Business Energy and Industrial Strategy
- Mineral Products Association
- Tarmac
- CEMEX
- Hanson
- Paper Industry Technical Association
- Confederation of Paper Industries
- DS Smith
- Smurfit Kappa
- Kimberley Clark
- British Glass
- Heatcatcher
- Glass Futures
- The Manufacturers' Organisation
- Society of Chemical Industry
- Food & Drink Federation
- Lucozade Ribena Suntory
- Macquarie
- British Ceramic Confederation

Tata Steel were unable to attend the workshop but were subsequently able to contribute to the key activities through a follow-up meeting.

Appendix 2: Innovation mapping

An indicative timeframe for each innovation is provided. The timeframe given relates to the year the technology is deployed commercially at scale (gaining 10-20% market share).

Table 11. **Innovation mapping for the chemicals industry**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Efficiency improvements	Improved controls and automation through digitization, for example simulated factory 'digital twins'	4	4	2030-2050
	Material innovations for: wear resistance, thermal conductivity, high temperature resistance, cool temperature performance, and better surface properties (e.g. graphene and new alloys)	4	4	2030-2050
Low-carbon substitutes	Fuel switching: electrification	4	4	2025-2030
	Fuel switching: biomass	2	2	2025-2030
	Fuel switching: hydrogen	3	4	2030
	New raw materials: bio-based feedstock, including biologically derived monomers/polymers and enzymes	1	3	2030-2040

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Heat recovery and reuse	Process waste heat recovery and reuse, avoiding heat loss: insulation of equipment and piping, and heat pumps	2	1	2020-2050+
	Improving combined heat and power (CHP) e.g. material innovation to improve thermal conductivity and high temperature	1	1	2020-2050+
Recovery and recycling	Recovery and reuse of materials, equipment, and other resources	2	2	2020-2040
Energy systems	Renewable integration, flexibility and DSR, electricity and thermal storage, electrification	2	2	2020-2030
Alternative process technologies	New technologies to carry out existing processes more efficiently, such as membrane separation, bio-processing catalytic processes etc.	4	3	2030-2040
Clustering	Sharing of resources, infrastructure, and knowledge among proximal industrial sites. Identification of symbiotic opportunities to optimise operations	3	3	2025-2030
All	Tools to identify the optimum decarbonisation routes for a factory, along with options on technology and business models to reduce transition costs and deployment barriers	4	4	2020-2030

Source: Carbon Trust research and workshops with industry experts (list of participants in Appendix 1).

Table 12. **Innovation mapping for the food & drink industry**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Efficiency improvements	Material innovations: wear resistance, thermal conductivity, high-temperature resistance and cool-temperature performance, surface properties (e.g. graphene and new alloys)	4	4	2030-2050
	Improved controls and optimisation tools through digitisation (e.g. simulated factory ‘digital twins’)	4	4	2030-2050
	Robotics for greater automation of mechanical processes	4	4	2030-2050
	Improved industrial refrigeration technologies through systems integration and smart controls	4	3	2030-2040
Low-carbon substitutes	Fuel switching: hydrogen	3	4	2030
	Fuel switching: biomass	2	2	2025-2030
	Fuel switching: electrification	4	4	2020-2030
Heat recovery and reuse	Waste-heat recovery; avoiding heat loss: insulation of equipment and piping, and heat pumps	2	1	2030-2050+

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Recovery and recycling	Packaging reduction: optimal packaging (design, efficiency) and reduction of resources, use of renewable materials in packaging, avoiding re-packaging, food-grade recycling of plastics, and increased recycling)	3	3	2020-2040
Energy systems	Renewable integration, flexibility and DSRM, electricity and thermal storage	2	2	2020-2030
Alternative process technologies	Technical study to identify and pilot the greatest opportunities for alternative processes across the industry	4	4	2020-2025
Clustering	Sharing of resources, infrastructure, and knowledge among proximal industrial sites. Identification of symbiotic opportunities to optimise operations	3	3	2025-2050

Source: Carbon Trust research and workshops with industry experts (list of participants in Appendix 1)

Table 13. **Innovation mapping for iron & steel industry**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Efficiency improvements	Industry 4.0 innovations (e.g. increased automation through digitisation) for process optimisation, improved scheduling, and detecting defects in coil	2	2	2015-2030
	Equipment efficiency improvements including variable speed drives on all electrical motors, steam or power production system upgrades, lighting and HVAC upgrades etc.	2	1	2015-2025
	Improved furnace and re-heating furnace performance and optimisation; new systems and retrofit upgrades	2	2	2020-2030
Low-carbon substitutes	Fuel switching: hydrogen	3	4	2025-2050+
Heat recovery and reuse	Technologies to increase low-grade waste heat/waste water temperatures to facilitate electricity generation or other heating capabilities (e.g. using industrial heat pumps)	3	4	2020-2035
	Hydrogen-fuelled combined heat and power (CHP) (and reversible fuel cells)	1	1	2035-2050+
Recovery and recycling	Design innovations for durability and deconstruction to facilitate increased reuse of products at the end of their life cycle	4	4	2025
	R&D into production of higher quality steel in electric arc furnaces (which use scrap steel) and increase scrap use in basic oxygen furnace steelmaking	4	4	2030

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Energy systems	Renewable integration, flexibility and DSRM, electricity and thermal storage	3	3	2020-2030
Alternative process technologies	Pulverised coal injection (PCI); better understanding of performance, costs, wider impacts, and suitability for biomass replacement and alternative reductants	3	3	2015-2050+
	Blast furnace process alternative: reduction of iron ore using hydrogen	3	3	2050+
	New refractories to enable other innovative technologies (e.g. hydrogen use)	2	2	2030
Clustering	Industrial symbiosis; shared generation and use of waste heat; and shared development of alternative energies (e.g. hydrogen use in high-temperature industries)	3	4	2025-2050

Source: Carbon Trust research and workshops with industry experts (list of participants in Appendix 1.

Table 14. **Innovation mapping for the cement industry**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Efficiency improvements	Industry 4.0 – digitisation and automation of processes	2	2	2020-2045
	Electrical efficiency improvements (e.g. motor management plan, maintenance, voltage and power optimisation, strategic motor selection)	1	2	2020-2045
Low-carbon substitutes	Electrification of processes	3	4	2030s
	Fuel substitution: Biomass	3	3	2020-2030
	Fuel substitution: Hydrogen	2	4	2025-2035
	Alternative cement constituents (e.g. natural pozzolanic materials, ground limestone, calcined clay, and pulverised fuel ash)	3	4	2030s
	Alternative binding materials (e.g. belite and calcium sulfuraluminate and geopolymers) instead of ordinary Portland Cement clinker	2	5	2020s
Heat recovery and reuse	Recovery, reuse, and integration of waste heat	1	4	2020-2030
Recovery and recycling	Recovery and reuse of materials, equipment, and other resources (e.g. productive use of kiln dust)	1	1	2020-2030

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Energy systems	Renewable integration, flexibility and DSRM, electricity and thermal storage	2	2	2020-2030
Alternative process technologies	Completely new technologies across processes (e.g. contact-free grinding)	3	3	2030-2050+
Clustering	Collection of by-products which can be used in other industries; shared generation and use of waste heat; and shared development of technologies (e.g. hydrogen and CCUS)	2	2	2025-2050

Source: Carbon Trust research and workshops with industry experts (list of participants in Appendix 1)

Table 15. **Innovation mapping for the pulp & paper industry**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Efficiency improvements	Improved process control across the entire mill (use of smart controls, valves, measuring and sensing machines) for improved diagnostics and maintenance	2	2	2015-2030
	Hood usage and control optimisation (e.g. closed hoods to reduce electricity/air demand)	1	2	2015-2020
	Improved energy management and controls including; installing meters for steam, electricity, air, and gas to allow for online energy balances	2	3	2015-2020
	Industry 4.0 innovations (digitisation, automation, process optimisation etc.)	2	2	2020-2040
	Supply chain and value chain improvements and new models/approaches	1	1	2030-2050
	Paper machine and dryer improvements; including extended nip press/improved pressing, high consistency forming, hot pressing, and improved dewatering	3	3	2015-2030
Low-carbon substitutes	Fuel switching: Electrification	5	5	2030-2050+
	Fuel switching: Biomass (including biomass CHP or boiler)	4	3	2020-2040
	Fuel switching: Hydrogen	4	4	2030-2050+
	Fuel switching: Waste-as-fuel	3	3	2020-2050

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Heat recovery and reuse	Waste heat recovery technologies (e.g. heat recovery on hoods) and integration systems (e.g. connection to heat pumps)	1	1	2030-2050
	Use of efficient combined heat and power (CHP) with different fuel source options	3	3	2015-2040
Recovery and recycling	Improved quality of recyclate, fibre collection, and supply logistics and more efficient recycling handling, storage, and processing	3	2	2020-2030
Energy systems	Renewable integration, flexibility and DSR, electricity and thermal storage	3	3	2020-2050
Alternative process technologies	Entirely new process technologies (e.g. deep eutectic solvents, flash condensing with steam) and new products that are not conventional paper	3	3	2050+
	Fibre supply processes and technologies; efficient screening, high consistency pulping alternatives, sludge drying	2	2	2015-2030
Clustering	Industrial symbiosis, sharing of energy networks and infrastructure, creation of ‘wider clusters’ (such as including local authorities, supermarkets etc.)	2	2	2025-2050

Source: Carbon Trust research and workshops with industry experts (list of participants in Appendix 1).

Table 16. **Innovation mapping for the glass industry**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Efficiency improvements	Equipment efficiency, control and general utility improvements (e.g. variable speed drives on motors, steam/power production upgrades, lighting & HVAC upgrades etc.)	2	1	2020-2050
	Furnace and combustion efficiency improvements including improved furnace design and construction, oxy-fuel firing/oxygen enrichment for improved fuel combustion	3	5	2030-2050
	Industry 4.0 innovations: development of sensors; advanced monitoring and process control; data modelling through AI and big data for faster feedback loops, operation to narrower tolerances	4	4	2020-2040
Low-carbon substitutes	Fuel switching: electrification and hybrid furnaces (hydrogen)	2	2	2030-2050+
	Use of new raw materials not based on carbonates to avoid process CO_2 emissions	3	4	2030-2050+
	Using alternative batch materials to make glass with lower melting temperatures (such as biomass or lithium) and save energy	3	2	2030
Heat recovery and reuse	Batch and cullet pre-heating to allow for reliable designs of heat recovery equipment	3	4	2020-2030
Recovery and recycling	Increased use of recycled glass for flat glass production and technology to improve glass separation (such as from double glazed windows)	2	3	2030-2050+

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Energy systems	Thermal storage and hybrid systems	4	3	2020-2050
Alternative process technologies	Development of new products with improved features. For example, 'light weight' bottles in the container glass subsector, which require less energy to produce and transport	4	5	2020-2050
	Batch reformulation and pelletisation of raw materials	2	4	2025
	New windows to improve energy efficiency of buildings (e.g. smart coatings and improved seals for double glazing)	5	4	2030
Clustering	Industrial symbiosis, sharing of energy networks and infrastructure, creation of 'wider clusters' (such as including local authorities, supermarkets etc.)	2	2	2025-2050

Source: Carbon Trust research and workshops with industry experts (list of participants in Appendix 1).

Table 17. **Innovation mapping for the ceramics industry**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Efficiency improvements	Industry 4.0 (digitisation and automation) - Development of sensors; advanced monitoring and process control; data modelling through AI and big data for faster feedback loops, operation to narrower tolerances	4	4	2020-2040
	Product improvements including increased pack density and reduction of product weight	4	5	2020-2030
	Kiln improvements and upgrades (such as pulse firing of kilns, optimisation of kiln circulation, low-mass kiln furniture and kiln cars)	4	4	2030-2050
Low-carbon substitutes	Addition of biomass to clay	2	2	2030-2050+
	Reduced process temperature from use of new materials	3	5	2030-2050
	Fuel switching (opportunities in decarbonised methane, biomass, and syngas)	2	2	2030-2050+
Heat recovery and reuse	Heat recovery technology	2	2	2025-2040
Recovery and recycling	More use of waste within ceramic products	2	2	2020-2040
Energy systems	Thermal storage and hybrid systems	4	3	2020-2030

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Timeframe
Alternative process technologies	Precalcining of clay	2	2	2025
	Alternative drying processes such as vacuum drying and steam drying	3	5	2030-2050
	Field-assisted sintering techniques (microwave, ultrasonic etc) currently in early TRL	4	3	2030
Clustering	Sharing of resources, infrastructure, and knowledge among proximal industrial sites Identification of symbiotic opportunities to optimise operations	2	2	2025-2050

Source: Carbon Trust research and workshops with industry experts (list of participants in Appendix 1).

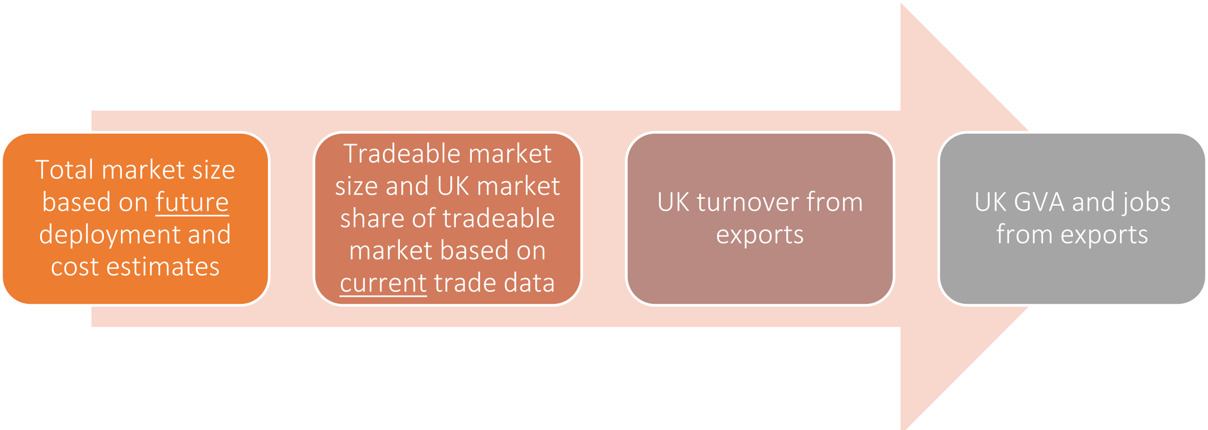
Appendix 3: Business opportunities methodology

Methodology for export business opportunity analysis

In identifying export opportunities for the UK, the EINA process uses a common methodology to ensure comparability of results:

- The **global and regional markets** to 2050 are sized based on deployment forecasts, which come from the IEA when available. For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market.
- The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs created**.

Figure 17 **Methodology for assessing export opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Export business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade data, where available. If the technology is immature or export levels are low, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to reach a market share in the EU and RoW by 2050. The potential future market share is intended as an ambitious, but realistic, scenario. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.
- Market share assumptions are validated at a workshop with expert stakeholders and adjusted based on stakeholder input.

Export business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The EINA methodology does not quantify opportunities associated with installation and operation and maintenance as these are typically performed locally. Exceptions are made if these types of services are specialised, such as in offshore wind.
- The key services to consider are based on desk research and verified through an expert workshop.
- The services considered in the CCUS EINA export analysis are EPCm services, transport and storage services.

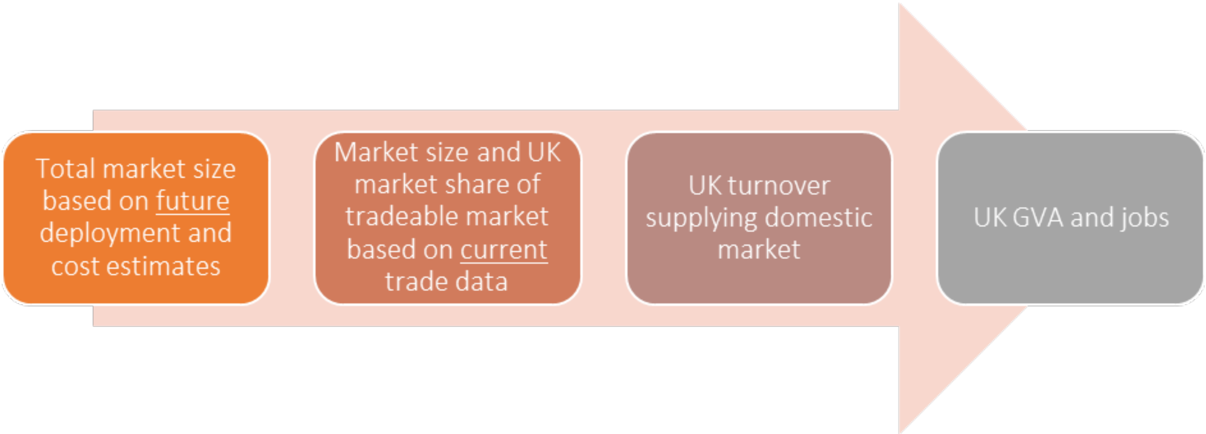
Methodology for domestic business opportunity analysis

To estimate the size of domestic business opportunities for the UK, the EINA methodology, as developed to size export opportunities, is adapted. The domestic analysis leans heavily on insight gleaned from the export analysis, particularly in estimating UK competitiveness and ability to capture market share in its domestic market. To estimate the domestic opportunity, the following methodology is used:

- The **domestic market** to 2050 is sized based on deployment and cost estimates. Deployment estimates are based on ESME modelling used for the EINAs and cost estimates are equal to those from the export work, and based on analysis for each of the EINA sub-themes.[96] For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the UK's market is likely accessible for foreign firms (e.g. electric vehicles), and how much is likely to be exclusively provided by UK companies (e.g. heat pump installation).
- For the traded share of the UK market, the UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- To estimate **UK captured turnover** the traded and non-traded markets are summed.
    - The UK's captured turnover of the UK traded market is estimated by multiplying the tradeable market by the UK's market share.
    - The UK's turnover from the non-traded market is equal to the size of the non-traded market.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs supported**.

[96] For detail on cost estimates used, please refer to the Excel calculators provided for each sub-theme, and the individual sub-theme reports.

Figure 18 **Methodology for assessing domestic business opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Domestic business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade (import) and domestic production data, where available. If the technology is immature, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to potentially increase its market share in its domestic market. This estimate is informed by the previously performed export analysis. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.

Domestic business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The domestic assessment explicitly quantifies services such as O&M and installation, which are typically not traded but can support a large number of

jobs associated with e.g. heat pumps. For these services, the estimate of potential service jobs supported is based on:
  - An estimate of the total turnover and GVA associated with the service
  - A ratio of GVA/jobs (adjusted for productivity increases) in analogous existing service sectors based on ONS data.
- The key services to consider are based on desk research, verified through stakeholder workshops.

Worked example

1. The **global and regional markets** to 2050 are sized based on illustrative deployment forecasts, which come from ESME when available.[97] For example, deployment of nuclear power (37 GW by 2050) is multiplied by O&M costs (~12% of total plant costs) to obtain annual turnover for the nuclear O&M market (~£2.5 billion by 2050).
2. The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market. In the case of nuclear O&M, tradability is 0% being as it is not tradeable. For the domestic analysis, tradability does not directly feed into our model, but is vital to provide insight on the share of the domestic market UK firms will capture.
3. The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below. For example, for nuclear O&M the UK domestic market share is 100% because the component is not tradeable and therefore foreign firms do not capture some of the value.
4. The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**. For nuclear O&M, market turnover (~£2.5 billion) is multiplied by the UK market share (95%) of O&M to obtain UK-captured turnover (~£2.5 billion by 2050).
5. The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by labour productivity figures for that sector to obtain **jobs supported**. For example, appropriate Standard Industrial Classification (SIC) codes are chosen for nuclear O&M. This leads to a GVA / turnover multiplier (49%) that is multiplied by market turnover (~£2.5 billion) to isolate GVA (~£1 billion by 2050), which is then divided by labour productivity (~70,000 GVA / worker by 2050) to isolate jobs supported (~16,000 jobs by 2050).

[97] If deployment information is not available from the IEA, alternative projections from, for example, Bloomberg are used. Please see individual sub-theme reports for further detail.

Additional notes

The below lists areas where the analysis under the EINA Industry subtheme deviates from the general approach and highlights any major caveats.

Deployment & turnover: Annual turnover associated with each technology is taken directly from the sectoral models underlying the 2050 Roadmaps, which provide technology deployment scenarios and corresponding capital expenditures.[98]

Technology categories: The 74 technologies within scope are grouped into 9 *categories* based on the machineries involved (e.g. furnaces and kilns, industrial control equipment, etc.). See Box 13 for details of this selection and categorisation.

UK market shares: For each *category*, an estimate of current UK market share in the proximate types of machinery is obtained from trade and production data of corresponding HS codes, following the general EINA approach (COMTRADE data for export analysis and PRODCOM data for domestic analysis).

- **Ambition for export market share:** estimates of 2050 export market shares for each category are informed by comments received from an industry workshop. It is generally agreed that it is conceivable, albeit highly ambitious, for the UK to meet half of Germany's current market share for equipment, and to meet the UK's current market share in oilfield services for EPCm services. Market shares are then assumed to grow linearly from current levels to the ambitious level set out for 2050.
- **Ambition for domestic market share:** the estimated UK market share in each category is then used as a reference point for the ambition for future market shares across R&D, Engineering & Design, and Manufacturing & Fabrication of the technologies within the category. Installation services are considered separately as a non-tradeable component of turnover. The sectoral market shares reported in Table 9 are weighted averages across the two types of market shares and across the multiple technologies within each sector.

GVA/worker and GVA/turnover ratios: This is estimated for each *category* following the general EINA approach by choosing proximate SIC codes. These ratios are then assumed to hold true across technologies within each category. [99]

[98] The 2050 Roadmaps identify UK deployment profiles in several scenarios, including a 'Max Tech' (High) scenario and a 'BAU' (Low) scenario. The UK deployment profiles are scaled up to global deployment profiles by applying sector-specific factors that account for the relative size of UK versus global industrial production and generally faster uptake within OECD countries. Multiplying this global deployment profile with capex figures of each technology results in the annual capex, which is the global turnover.

[99] It is recognised that there are significant differentiating aspects in each technology. However, given the difficulty in estimating market shares and GVA multipliers in each of these 74 technologies separately, a simple categorisation is preferred for this assessment. Nevertheless, the sensitivity of resulting GVA and job estimates to this categorisation is limited.

Box 13. **Selection and categorisation of industrial decarbonisation technologies**

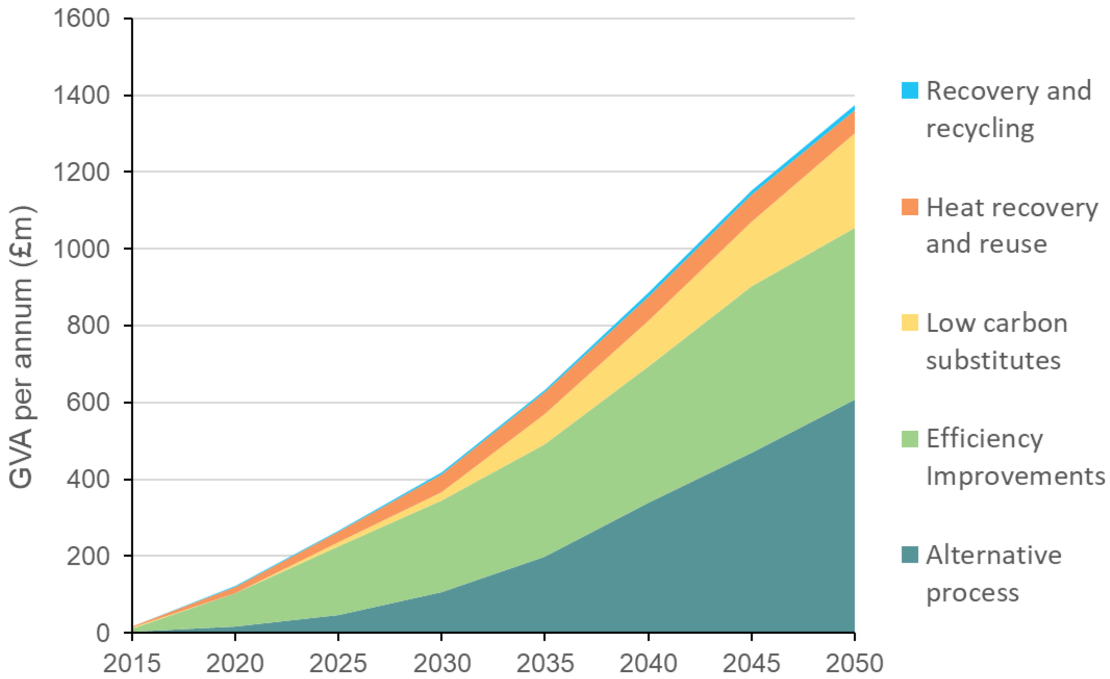
- Global turnovers of 216 technologies from seven industrial sectors are taken from an external model behind the “2050 Industrial Decarbonisation & Energy Efficiency Roadmaps” published by DECC and BIS in 2015. Turnover is calculated by multiplying capital expenditure and deployment profiles.
- Technologies with negligible global turnover are excluded from subsequent analysis. Technologies relating to CCUS and biomass are also excluded as they are covered in separate EINAs. A total of 74 technologies remain for the analysis of business opportunities.[100]
- All technologies are assumed to take a ‘typical’ value chain breakdown for capex, comprising: R&D, Engineering and Design, Manufacturing and Fabrication, and Installation. These four components return a weighted average tradability of 46% in the EU and 22% in the rest of the world. Tradeable turnover in export markets is estimated by multiplying tradability with global turnover.
- The 74 technologies are grouped into 9 categories based on the machineries involved (shown in *Appendix 5: Summary estimates from business opportunities analysis*). For example, the category ‘furnaces and kilns’ consist of 23 technologies such as BAT kilns in the cement sector, and furnace optimisation in the iron & steel sector. Each category is linked to several proximate HS codes and SIC codes.

[100] Therefore, *some* innovations mentioned in other sections of this report are *not* included in the business opportunity analysis.

Appendix 4: GVA from exports

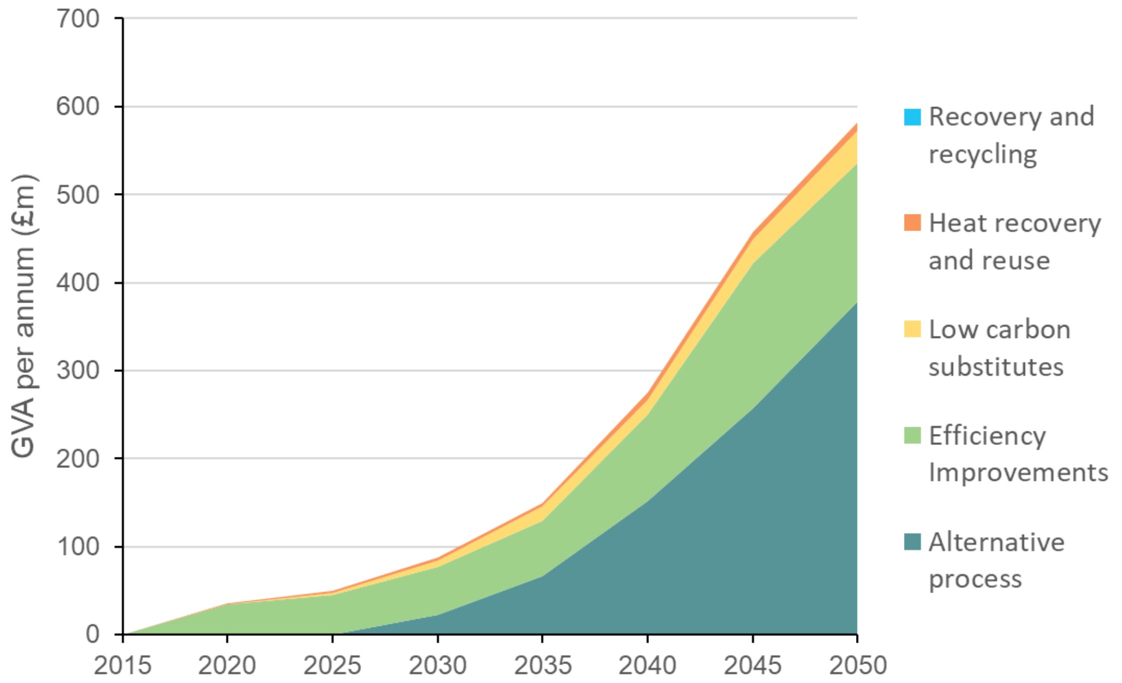
The following figures present disaggregated estimates of GVA from exports.

Figure 19 **Total in industry: GVA per annum from exports by type of innovations**



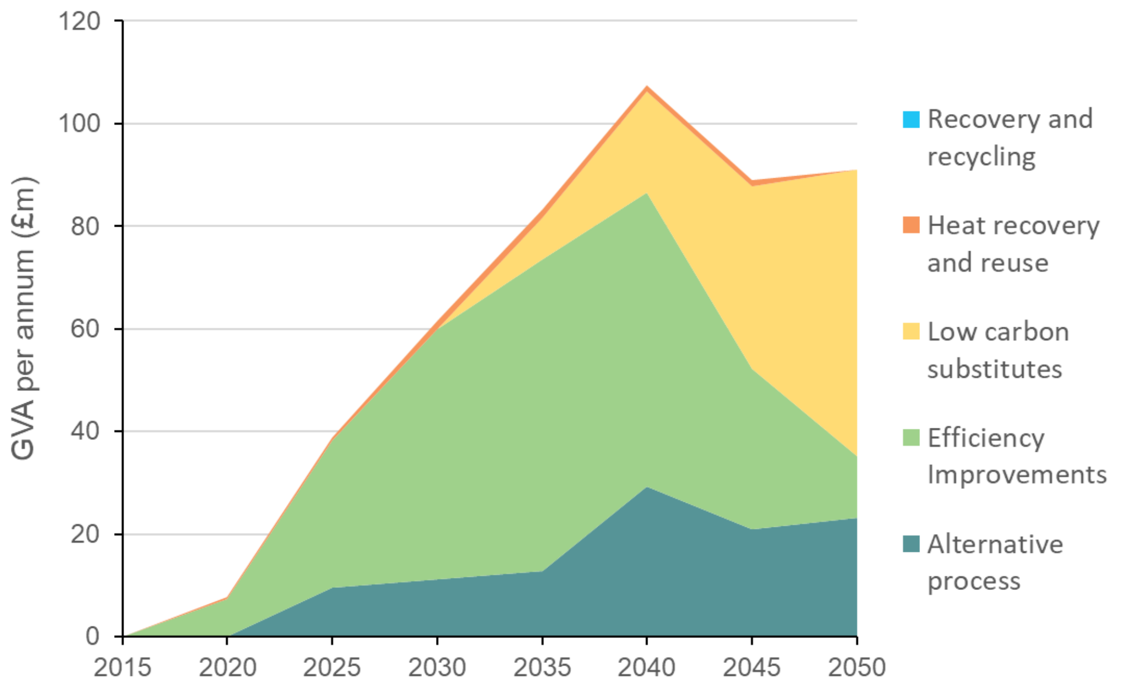
Source: *Vivid Economics*

Figure 20 **Cement sector: GVA per annum from exports by type of innovations**



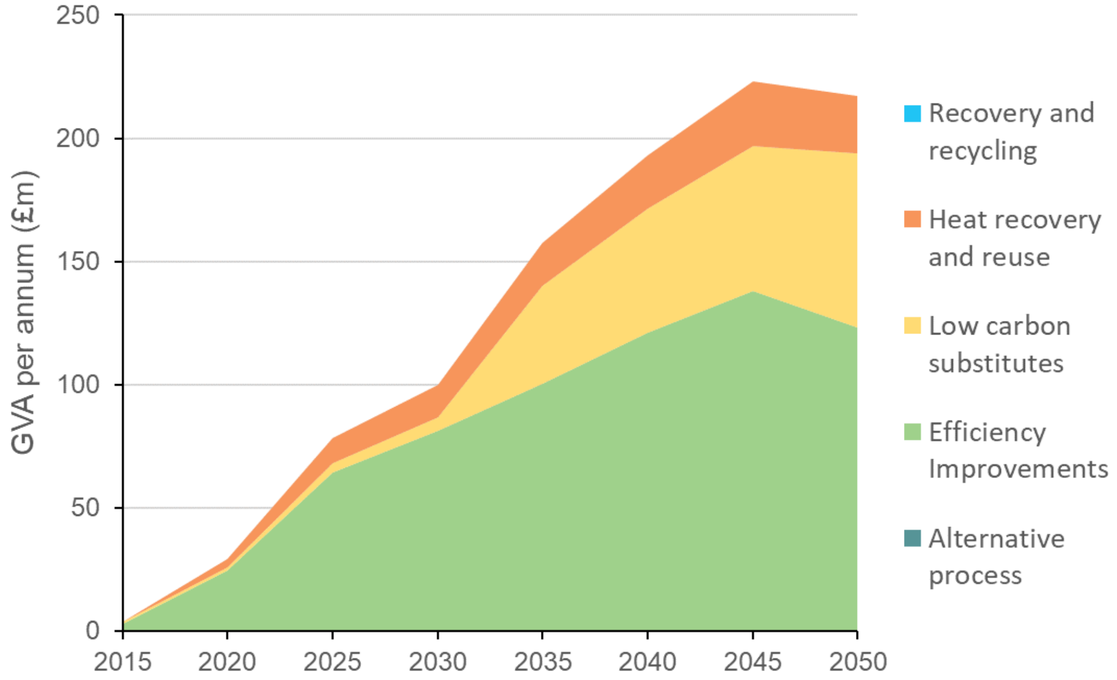
Source: *Vivid Economics*

Figure 21 **Ceramics sector: GVA per annum from exports by type of innovations**



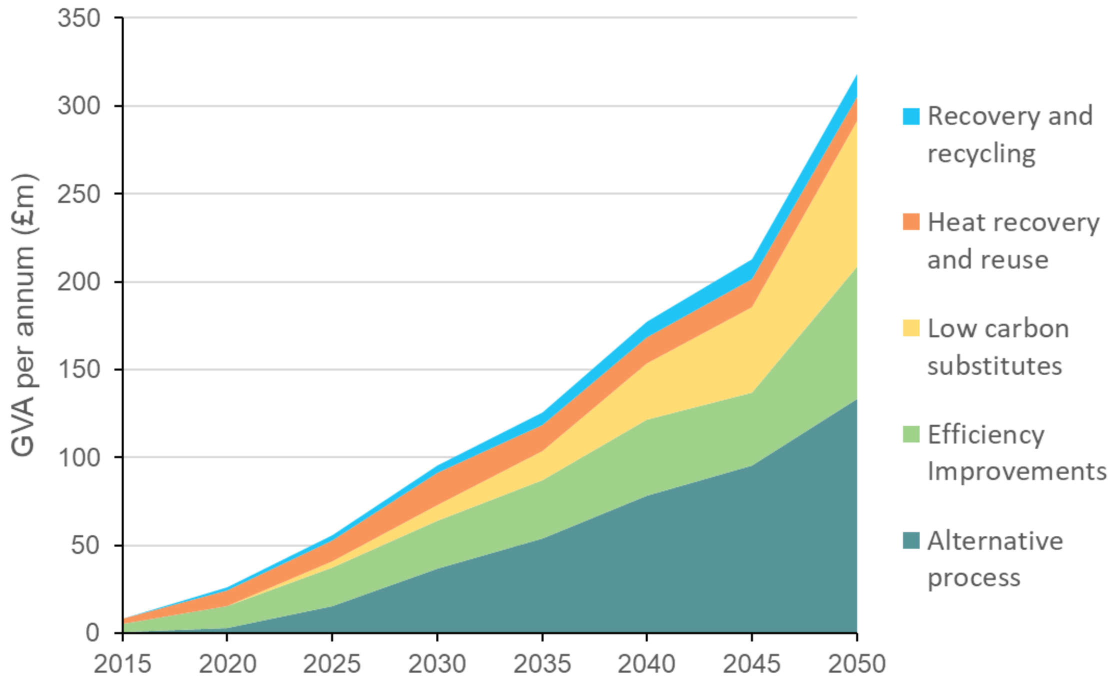
Source: *Vivid Economics*

Figure 22 **Chemicals sector: GVA per annum from exports by type of innovations**



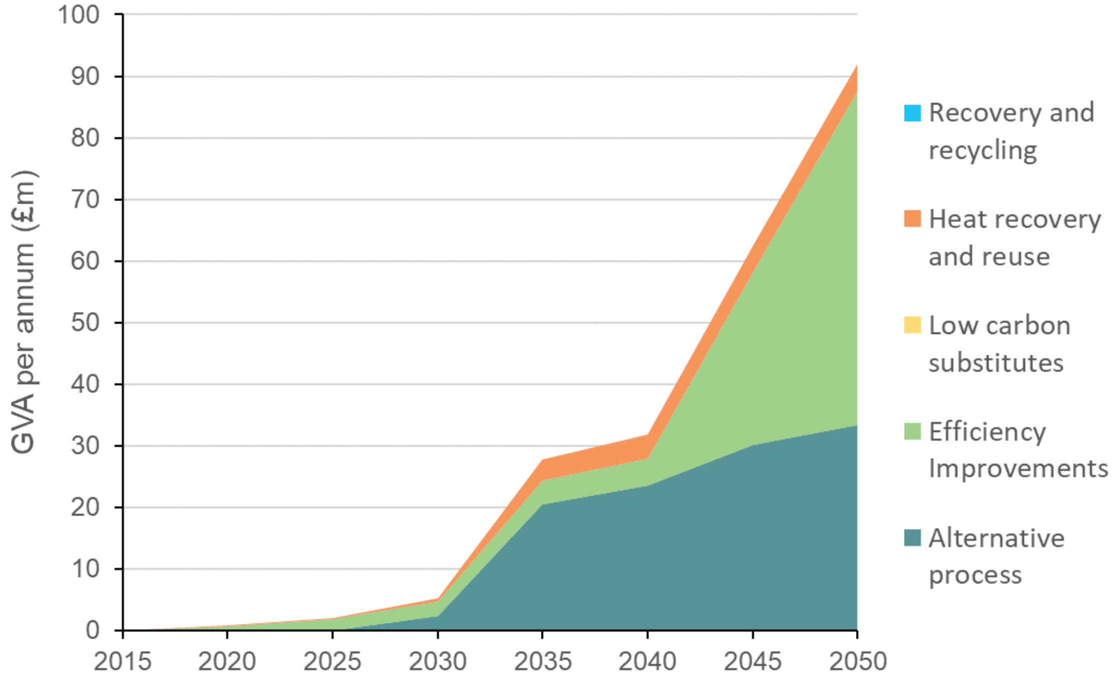
Source: *Vivid Economics*

Figure 23 **Food & drink sector: GVA per annum from exports by type of innovation**



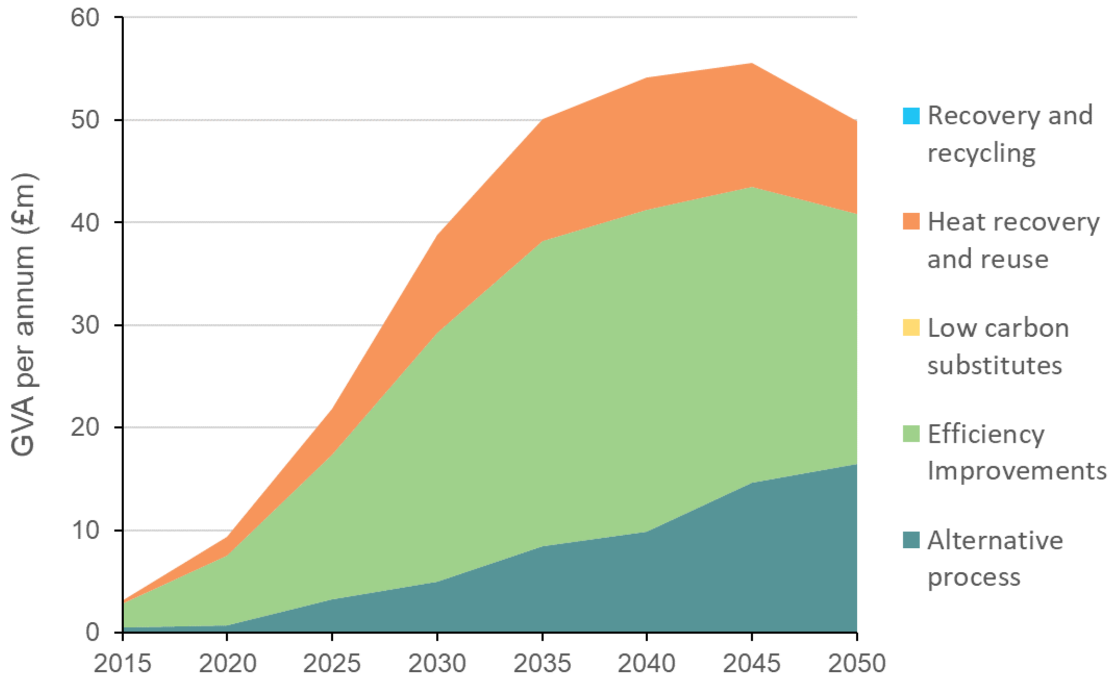
Source: *Vivid Economics*

Figure 24 **Glass sector: GVA per annum from exports by type of innovations**



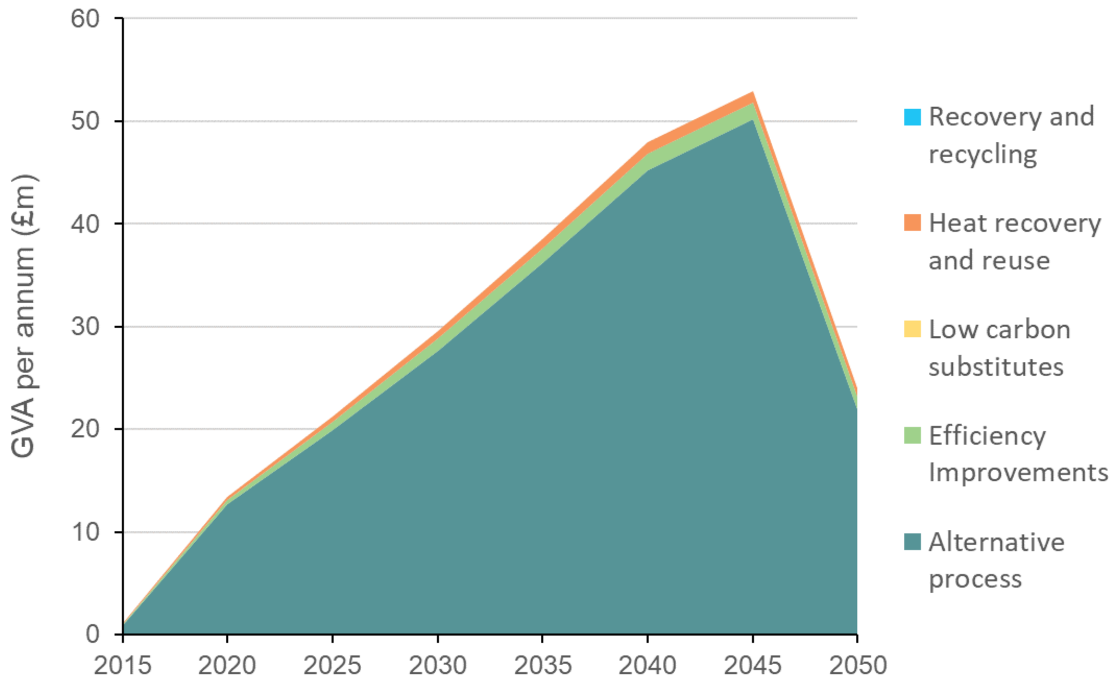
Source: *Vivid Economics*

Figure 25 **Iron & steel sector: GVA per annum from exports by type of innovations**



Source: *Vivid Economics*

Figure 26 **Pulp & paper sector: GVA per annum from exports by type of innovations**



Source: *Vivid Economics*

Appendix 5: Summary estimates from business opportunities analysis

Table 18. **GVA per annum from exports for each sector in 2050, by type of innovations (£m)**

	Low carbon substitutes	Alternative process	Efficiency Improvements	Heat recovery and reuse	Recovery and recycling
Cement	7	22	54	4	-
Ceramics	-	11	49	1	-
Chemicals	6	0	81	13	-
Food & drink	9	37	27	18	4
Glass	-	2	2	0	-
Iron & steel	-	5	24	10	-
Pulp & Paper	-	28	1	1	-

Source: Vivid Economics analysis and stakeholder input

Table 19. **Gross value added per annum from exports to each sector (£m)**

	2015	2020	2025	2030	2035	2040	2045	2050
Cement	-	36	49	88	150	275	457	582
Ceramics	-	8	39	62	83	107	89	91
Chemicals	4	29	78	100	157	193	223	217
Food & drink	8	26	56	95	126	177	213	318
Glass	0	1	2	5	28	32	63	92
Iron & steel	3	9	22	39	50	54	56	50
Pulp & Paper	1	13	21	30	39	48	53	24
Total	**16**	**122**	**267**	**418**	**633**	**886**	**1,153**	**1,374**

Source: Vivid Economics analysis and stakeholder input

Table 20. **Jobs supported per annum from exports to each sector**

	2015	2020	2025	2030	2035	2040	2045	2050
Cement	-	629	824	1388	2282	4072	6550	8007
Ceramics	-	128	600	934	1232	1492	1209	1191
Chemicals	58	422	1,085	1,335	2,116	2,496	2,775	2,633
Food & drink	123	361	747	1264	1631	2267	2673	3899
Glass	0	15	34	81	417	460	890	1270
Iron & steel	56	151	341	571	714	744	748	659
Pulp & Paper	19	231	350	468	586	702	745	321
Total	**256**	**1,937**	**3,980**	**6,040**	**8,979**	**12,233**	**15,591**	**17,981**

Source: Vivid Economics analysis and stakeholder input

Appendix 6: Technologies included for business opportunities analysis

The following list of 74 technologies is a subset chosen from the 2050 Roadmaps. See Appendix 3: Business opportunities for methodology behind the selection and categorisation.

Table 21. **Technologies included in the business opportunities analysis**

	Technology (74)	Category (9)	Innovation type (5)
Cement	Kiln process technology (BAT kiln)	Furnaces and kilns	Alternative process
	Electrical efficiency improvements	Furnaces and kilns	Efficiency Improvements
	Electricity from waste heat	Waste heat recovery and/or reuse	Heat recovery and reuse
	Alternative cements	Machinery for processing stones, ceramics, cement	Low-carbon substitutes
	Oxygen enrichment technology	Furnaces and kilns	Efficiency Improvements
Ceramics	Electric Kiln	Furnaces and kilns	Low-carbon substitutes
	Improve control of process	Industrial control equipment	Efficiency Improvements
	Reduce radiant, convective, and hot gas losses and leakage	Furnaces and kilns	Efficiency Improvements
	Heavy clay subsector: Adopt available lowest-carbon process (BAT, new kilns)	Furnaces and kilns	Efficiency Improvements
	Heavy clay subsector: CHP heat into dryer	Waste heat recovery and/or reuse	Heat recovery and reuse
	Heavy clay subsector: Improve heat use by regenerative processes	Waste heat recovery and/or reuse	Efficiency Improvements
	Heavy clay subsector: Low mass refractory for kiln cars	Furnaces and kilns	Efficiency Improvements
	Heavy clay subsector: Precalcining of clay	Machinery for processing stones, ceramics, cement	Alternative process
	Technical ceramics subsector: Adopt available lowest-carbon process (BAT, new kilns)	Furnaces and kilns	Efficiency Improvements
	White wares subsector: Adopt available lowest-carbon process (BAT, new kilns)	Furnaces and kilns	Efficiency Improvements

	Technology (74)	Category (9)	Innovation type (5)
	White wares subsector: Low mass refractory on kiln cars	Furnaces and kilns	Efficiency Improvements
Chemicals	Waste as fuel	Furnaces and kilns	Low-carbon substitutes
	Decarbonised methane as fuel	Furnaces and kilns	Low-carbon substitutes
	Improved insulation	Industrial control equipment	Efficiency Improvements
	Improved waste heat recovery	Waste heat recovery and/or reuse	Heat recovery and reuse
	Improved process control	Industrial control equipment	Efficiency Improvements
	More efficient equipment	Industrial control equipment	Efficiency Improvements
	Improved steam system efficiency	Steam production and distribution	Efficiency Improvements
Food & drink	Electrification of heat	Pumps, compressors, motors	Low-carbon substitutes
	Energy management & good manufacturing practice	Industrial control equipment	Efficiency Improvements
	Waste heat recovery / CHP / no heat losses	Waste heat recovery and/or reuse	Heat recovery and reuse
	Food waste reduction	Food processing machinery	Recovery and recycling
	Packaging reduction	Food processing machinery	Recovery and recycling
	Motors, pumps & drives, HVAC & lighting	Pumps, compressors, motors	Efficiency Improvements
	Process design	Industrial control equipment	Efficiency Improvements
	Factories of the future	Food processing machinery	Alternative process
	Compressed air	Food processing machinery	Efficiency Improvements
	Mechanical vapor recompression and thermal vapor recompression	Food processing machinery	Alternative process
	Ultrasonic homogenisation	Food processing machinery	Alternative process
	Increased use of enzymes to prepare food	Bioprocessing and catalysts	Alternative process
	New refrigeration technologies	Pumps, compressors, motors	Alternative process
	Pasteurisation	Food processing machinery	Alternative process
	Cleaning (Clean-in-place)	Food processing machinery	Alternative process
	Steam production, distribution, & end use	Steam production and distribution	Efficiency Improvements

	Technology (74)	Category (9)	Innovation type (5)
	Microwave drying and heating	Food processing machinery	Alternative process
	Advanced oven technology	Food processing machinery	Alternative process
	Dewatering before drying	Food processing machinery	Alternative process
	New drying technologies	Food processing machinery	Alternative process
	Fluidised bed dryers	Food processing machinery	Alternative process
Glass	Electric melting	Furnaces and kilns	Alternative process
Glass	Waste heat recovery - electricity from waste heat	Waste heat recovery and/or reuse	Heat recovery and reuse
Glass	General utilities {from 2012 level}	Furnaces and kilns	Efficiency Improvements
Glass	Improved furnace construction - conventional {from 2012 level}	Furnaces and kilns	Efficiency Improvements
Glass	Improved furnace design - innovative	Furnaces and kilns	Efficiency Improvements
Glass	Improved process control {from 2012 level}	Industrial control equipment	Efficiency Improvements
Glass	Oxy-fuel combustion	Furnaces and kilns	Alternative process
Glass	Waste heat recovery- raw materials pre-heating	Waste heat recovery and/or reuse	Heat recovery and reuse
Glass	Waste heat recovery - other	Waste heat recovery and/or reuse	Heat recovery and reuse
Iron & steel	Hot Charging	Furnaces and kilns	Efficiency Improvements
Iron & steel	Installing Variable Speed Drives on Electrical Motors (Pumps & Fans)	Pumps, compressors, motors	Efficiency Improvements
Iron & steel	Pulverised Coal Injection (PCI)	Furnaces and kilns	Alternative process
Iron & steel	Compressed Air System Optimisation	Industrial control equipment	Efficiency Improvements
Iron & steel	Reheating Furnace Optimisation	Furnaces and kilns	Efficiency Improvements
Iron & steel	Near Net Shape Casting	Furnaces and kilns	Alternative process
Iron & steel	Use of premium efficiency electrical motors	Pumps, compressors, motors	Efficiency Improvements
Iron & steel	Waste Heat Recovery - sintering	Waste heat recovery and/or reuse	Heat recovery and reuse
Iron & steel	BOF Heat & Gas Recovery	Waste heat recovery and/or reuse	Heat recovery and reuse
Iron & steel	Endless Strip Production (ESP)	Furnaces and kilns	Alternative process
Iron & steel	Heat Recovery from Cooling Water	Waste heat recovery and/or reuse	Heat recovery and reuse
Iron & steel	Steam / Power Production System Upgrades	Steam production and distribution	Efficiency Improvements

	Technology (74)	Category (9)	Innovation type (5)
	Regenerative / recuperative burners - sec processes	Furnaces and kilns	Heat recovery and reuse
Pulp & paper	Energy management including installing meters for steam, electricity, air, and gas to allow for online energy balances	Industrial control equipment	Efficiency Improvements
	Improved process control across the entire mill (process & utilities)	Industrial control equipment	Efficiency Improvements
	(Waste) heat recovery and heat integration	Waste heat recovery and/or reuse	Heat recovery and reuse
	Improved dewatering in press section beyond extended Nip Press	Paper-making machinery	Alternative process
	Impulse drying	Paper-making machinery	Alternative process
	Infrared profiling	Paper-making machinery	Alternative process
	Efficient screening	Paper-making machinery	Alternative process
	Sludge dryer	Paper-making machinery	Alternative process

Source: Vivid Economics analysis and stakeholder input

Appendix 7: Assessment of business opportunities uncertainty

The assessment of business opportunities in the long term, associated with new technologies is uncertain. This assessment does not attempt to forecast what *will* happen. Instead, the business opportunity assessment attempts to provide a realistic and consistent assessment, based on current information, on the business opportunities that *could* be captured by the UK. Whether these opportunities are indeed realised depends on domestic and international developments, political decisions, macro-economic conditions, and numerous other complex variables.

As this assessment is not intended as a full forecast, a formal quantitative sensitivity analysis has not been performed. the below provides a high-level qualitative assessment of the uncertainty associated with the sized opportunity. Note, this is *not* an assessment of how likely the UK is to capture the opportunity, rather it is an assessment of the uncertainty range around the size of the opportunity. The assessment is based on three key factors driving the assessment

1. *The level of future deployment of the technology*. Technologies such as offshore wind are deployed at scale across different energy system modelling scenarios and hence considered relatively certain. In contrast, there is more uncertainty for e.g. hydrogen related technologies. The export analysis is based on 3 IEA scenarios (with numbers provided for the IEA ETP 2 degree scenario). Domestic analysis is based on a single ESME run used across the EINA process.
2. *The potential domestic market share* the UK can capture. This assessment attempts to estimate a plausible market share for the UK across relevant markets. Where this can be based on longstanding trade relationships and industries, this assessment is considered more robust.
3. *Future technology costs and production techniques* are a key driver of the future turnover, gross value added and jobs associated with a technology. For immature technologies for which manufacturing techniques may, for example, become highly automated in future, future costs and jobs supported by the technology may be significantly lower than assessed.

The ratings in the table below are the judgement of Vivid analysts based on the above considerations. The analysts have worked across all sub-themes and the ratings should be considered as a judgement of the uncertainty around the size of the opportunity relative to other sub-themes. As a rough guide, we judge the uncertainty bands around the opportunity estimates as follows:

- **Green**: Size of the opportunity is clear (+/- 20%). Note, this does not imply the UK will indeed capture the opportunity.
- **Amber:** Size of the opportunity is clear, but there are significant uncertainties (+/- 50%).
- **Red:** There are large uncertainties around market structure and whether the technology will be taken up at all in major markets. The opportunity could be a factor 2-3 larger or smaller than presented.

Table 1. **Assessment of uncertainty in business opportunities across sub-themes**

Sub-theme	Uncertainty rating	Comments
Biomass and bioenergy		• **Deployment**: Moderate deployment uncertainty; BECCS can produce negative emissions that have high value to the energy system under a deep decarbonisation pathway; there is moderate uncertainty as to whether BECCS will be used for hydrogen production, as in the ESME modelling, or for power generation. • **UK market share:** Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services and feedstocks. • **Costs and production techniques:** Relatively certain costs with most opportunities associated with labour input rather than immature technologies.
Building fabric		• **Deployment:** Depends on levels of retrofit that greatly exceed those seen to date. • **Market share:** Speculative for traded. However, majority of market untraded, highly likely captured domestically. • **Costs and production techniques:** High share of labour costs (independent of uncertain tech cost).
CCUS		• **Deployment:** Moderate deployment uncertainty; decarbonisation scenarios anticipate rapid uptake of CCUS, though there are few large-scale facilities today. • **Market share:** Moderate market share uncertainty; the UK is likely to be competitive in the storage of CO2 and EPCm services while component market shares are less certain given numerous technology choices and lack of clear competitors. • **Costs and production techniques:** Moderate cost uncertainty; the lack of large-scale facilities today makes estimating future costs difficult.
Heating and cooling		• **Deployment**: Expected to be deployed in most UK buildings by 2050. • **Market share:** some uncertainties, immaturity in markets such as for hydrogen boilers. • **Costs and production techniques:** Relatively certain given relative maturity of boilers and heat pumps. • **Deployment of hydrogen boilers or heat pumps** lead to similar opportunities for UK businesses, while heat networks present a 50 per cent smaller opportunity per household.

Hydrogen and fuel cells		• **Deployment**: Highly uncertain future deployment with a wide-range of 2050 hydrogen demand estimates across scenarios, particularly for export markets. • **UK market share**: Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services. • **Costs and production techniques:** Although deep uncertainty in future hydrogen production costs, for example electrolysis, most domestic costs are associated with labour input rather than equipment.
Industry		• **Deployment**: Relative certainty in deployment as it is based on the 2050 Roadmaps • **UK market share**: Some uncertainty due to poor quality of trade data that may not be representative of technologies within scope. • **Costs and production techniques:** Some uncertainty in costs, particularly for less mature technologies.
Light duty transport		• **Deployment**: Certainty in deployment; low-carbon vehicles will be required in any deep decarbonisation scenario. • **UK market share**: Speculative market share for a relatively immature market; a small number of uncertain future FDI investment decisions generates high uncertainty in overall business opportunities. • **Costs and production techniques:** Highly uncertain future costs, with substantial falls in battery costs a key enabler of BEV uptake.
Nuclear fission		• **Deployment**: Moderate uncertainty in future deployment with some proposed nuclear plants recently cancelled • **UK market share**: Relatively certain market shares based on robust estimates of current nuclear activity; market share growth is dependent on uncertain development of UK reactor IP; however, most business opportunities are associated with untraded activity or areas where the UK has existing strength • **Costs and production techniques:** Uncertain costs for nuclear new build, with dangers of construction overrun; deep uncertainty in costs for immature nuclear technologies, for example SMRs and AMRs.
Offshore wind		• **Deployment**: Offshore wind will be required in any deep decarbonisation scenario, with clear government commitments. • **UK market share**: Expected growth in current market shares given commitments and progress to date. • **Costs and production techniques:** Costs are relatively certain, with clear pathways to 2050.
Tidal stream		• **Deployment**: Global sites for tidal stream are relatively limited, and hence the potential market size well established. • **UK market share**: Although the market is immature, the UK has a an established (and competitive) position. • **Costs and production techniques:** Costs are relatively certain, although the impact of potential scale production is hard to anticipate.
Smart systems		• **Deployment**: High deployment uncertainty given immaturity of smart system market today and evolving business models and regulatory framework. • **UK market share**: Moderate uncertainty given immaturity of the market today and scalable nature of digital smart

		technologies, though there is UK leadership in aggregation services and V2G charging. • **Costs and production techniques**: Moderate uncertainty of cost reductions of batteries and V2G and smart chargers, though costs are expected to continue to fall.

Source: Vivid Economics

Contact us if you have any enquiries about this publication, including requests for alternative formats, at:

Department for Business, Energy and Industrial Strategy
1 Victoria Street
London SW1H 0ET
Tel: 020 7215 5000

Email: enquiries@beis.gov.uk