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SSAC Report - Environmental Impacts of the Scottish Manufacturing Industry

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B1. GENERAL INFORMATION

B1.1. STANDARDS AND FIGURES

Annual Compendium of Scottish Energy Statistics. May 2019
https://www.gov.scot/binaries/content/documents/govscot/publications/statistics/2019/05/annual-compendium-of-scottish-energy-statistics/documents/annual-compendium-may-2019/annual-compendium-may-2019/govscot%3Adocument/Annual%2BCompendium%2Bof%2BScottish%2BEnergy%2BStatistics.pdf

Interactive Scotland Heat Map
https://www.gov.scot/collections/energy-statistics/#scotlandheatmap

Scottish Greenhouse Gas Emissions 2017
https://www.gov.scot/binaries/content/documents/govscot/publications/statistics/2019/06/scottish-greenhouse-gas-emissions-2017/documents/scottish-greenhouse-gas-emissions-2017/scottish-greenhouse-gas-emissions-2017/govscot%3Adocument/scottish-greenhouse-gas-emissions-2017.pdf?forceDownload=true

Scotland's Carbon Footprint: 1998-2016
http://www.gov.scot/ISBN/9781839604355

The basket of greenhouse gases consists of carbon dioxide, methane, nitrous oxide, and the four F-gases (hydrofluorocarbons - HFCs, perfluorocarbons – PFCs, sulphur hexafluoride - SF6 and nitrogen trifluoride - NF3).

These gases are weighted by Global Warming Potential (GWP), so that total greenhouse gas emissions can be reported on a consistent basis. The GWP for each gas is defined as its warming influence relative to that of carbon dioxide over a 100-year period. Greenhouse gas emissions are then presented in carbon dioxide equivalent (CO2e) units.

MtCO2e refers to million tonnes of carbon dioxide equivalent.

The Baseline Period uses 1990 for carbon dioxide, methane and nitrous oxide and 1995 for hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride and nitrogen trifluoride

The emissions reported are the combination of emissions minus removals from the atmosphere by carbon sinks. Carbon sinks are incorporated within the three sectors of agriculture and related land use, development, and forestry, which include both emissions and removals resulting from afforestation, reforestation, deforestation and forest management together with changes in land use. These are known as "removals" as they offset emissions.

For the purposes of reporting, greenhouse gas emissions are allocated into sectors aligned with those that were reported in the Scottish Government publication "Low Carbon Scotland - Meeting the Emissions Reductions Targets 2013-2027":

Energy supply - Emissions from fuel combustion for electricity and other energy production sources, and fugitive emissions from fuels (such as from mining or onshore oil and gas extraction activities). North Sea oil & gas emissions are not allocated to Scotland.

Business and industrial processes - Emissions from industry and from those in combustion in industrial/commercial sectors, industrial off-road machinery, process sources from decarbonisation of raw materials (such as from limestone use in cement plants) and refrigeration and air conditioning.

Transport (including International Aviation and Shipping) - Emissions from domestic aviation, road transport, railways, domestic navigation, fishing and aircraft support vehicles. It also includes international aviation and shipping emissions attributed to Scotland.

Public Sector Buildings - Emissions from combustion of fuel in public sector buildings.

Residential - Emissions from fuel combustion for heating/cooling and garden machinery and fluorinated gases released from aerosols/metered dose inhalers.

Agriculture and Related Land Use - Net emissions from cropland, grassland along with net emissions from land converted to cropland and grassland. It also covers emissions from livestock, agricultural soils, stationary combustion sources and off-road machinery.

Development - Net emissions from settlements and from land converted to settlements. This should not be confused with, for example, residential emissions; these relate to conversion of different land types to developed land, and changes in N2O and CO2 stocks from soils, urban trees.

Forestry - Changes in net emissions relating mainly to stock changes, resulting from afforestation, deforestation and harvested wood products.

Waste management - Emissions from waste disposed of to landfill sites, waste incineration, and the treatment of waste water.

When emissions are reported by source, emissions are attributed to the sector that emits them directly. These high-level sectors are made up of a number of more detailed sectors, which follow the definitions set out by the Intergovernmental Panel on Climate Change (IPCC), and which are used in international reporting tables that are submitted to the United Nations Framework Convention on Climate Change (UNFCCC) every year

Emissions of GHGs from offshore oil and gas exploration and production are classified within the Greenhouse Gas Inventory as “Unallocated” emissions and not attributed to any of the devolved administrations

SOURCE EMISSIONS

A measure of the actual emissions or removals in Scotland. Includes international aviation and shipping. Does not include North Sea Oil and Gas.

Used for UK and international comparisons.

40.5 MtCO2e in 2017
46.8% from 1990
3.3% from 2016

Scottish Greenhouse Gas Emissions, 1990 to 2017. Values in $MtCO_2e$

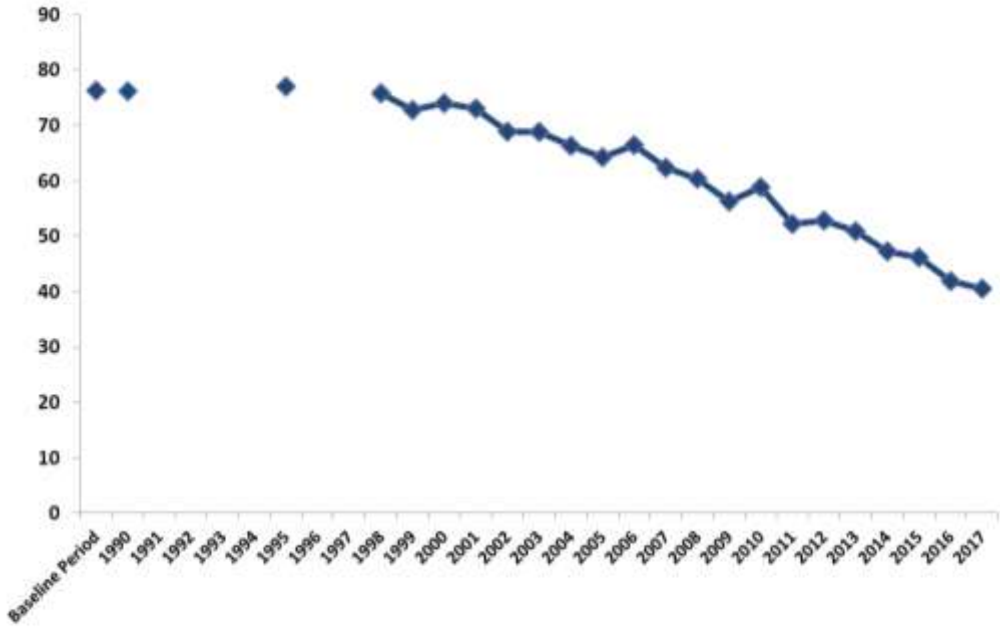
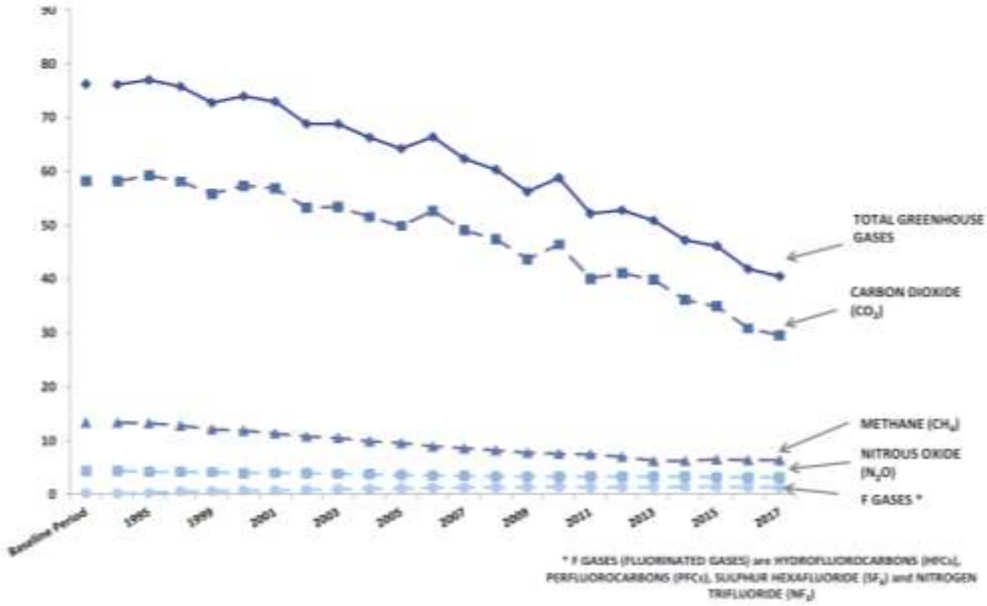


Chart B7. Scottish Greenhouse Gas Emissions, by Gas, 1990-2017. Values in $MtCO_2e$



Between 1990 and 2017, there was a 46.8 per cent reduction in estimated emissions, a 35.6 MtCO2e decrease.

The most significant contributors to this reduction were:

• Fall in Energy Supply emissions (such as power stations) (-16.7 MtCO2e; a 73.5 per cent reduction)
• Fall in Business and Industrial Process emissions (such as manufacturing) (-5.7 MtCO2e; a 39.7 per cent reduction)
• Fall in Waste Management emissions (such as Landfill) (-4.3 MtCO2e; a 72.0 per cent reduction)
• Fall in Agriculture and related Land Use emissions (-4.0 MtCO2e; a 29.4 per cent reduction)

ADJUSTED EMISSIONS: FOR REPORTING AGAINST TARGETS

Emissions adjusted to account for Scotland's participation in the EU Emissions Trading System (EU-ETS).

Cannot be used for UK and international comparison. Includes international aviation and shipping. Does not include North Sea Oil and Gas.

ETS Adjusted emissions, the indicator on which the Scottish Government's statutory targets are based, increased in 2017 even though actual source emissions fell.

46.410 MtCO2e in 2017
39.1% from Baseline Period
3.7% from 2016

SOURCES OF GHG EMISSIONS

Chart B1. Sources of Scottish Greenhouse Gas Emissions, 2017. Values in $MtCO_2e$

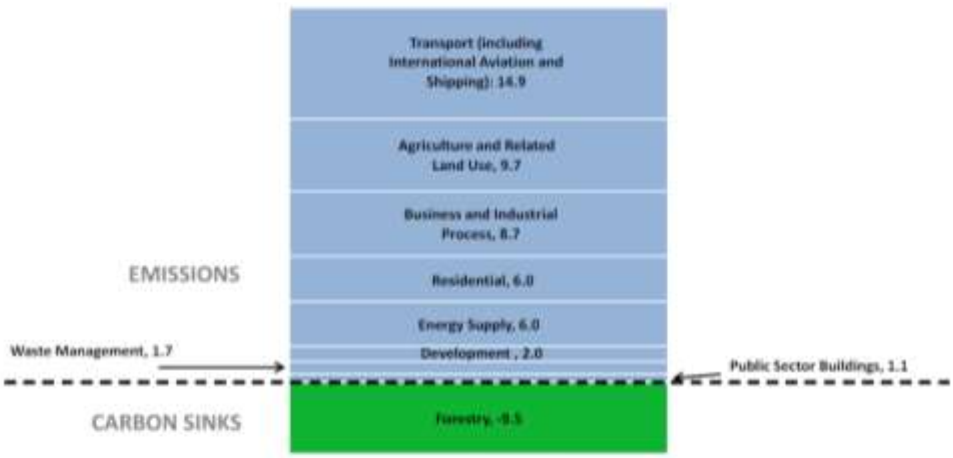
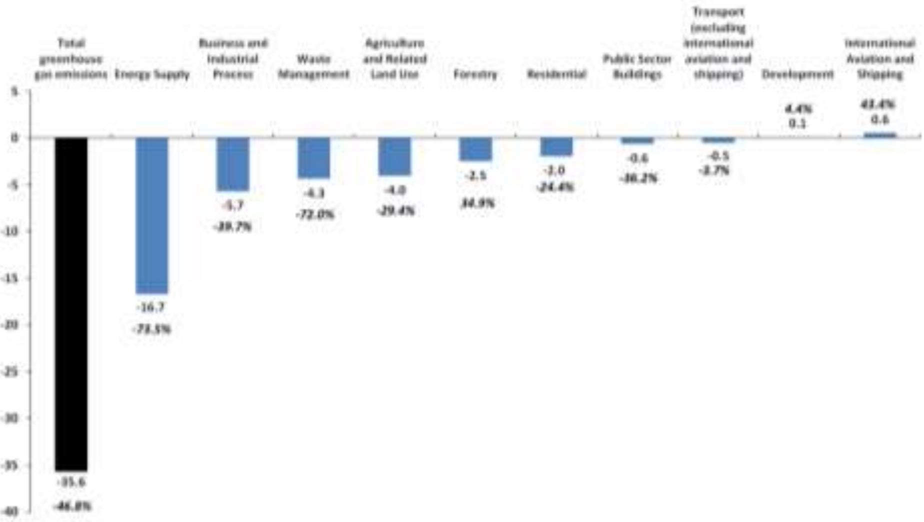


Table B1. Scottish Greenhouse Gas Emissions by Gas and by Scottish Government Source Sector, 2017. Values in $MtCO_2e$

	TOTAL	*Percentage share by sector*	Carbon dioxide	Methane	Nitrous oxide	Fluorinated gases
TOTAL	**40.5**	***100.0%***	**29.6**	**6.4**	**3.2**	**1.3**
Transport (including International Aviation and Shipping)	14.9	*36.8%*	14.7	0.0	0.2	0.0
Transport (excluding IA&S)	13.0	*32.1%*	12.9	0.0	0.1	0.0
International Aviation and Shipping (IA&S)	1.9	*4.6%*	1.9	0.0	0.0	0.0
Agriculture and Related Land Use	9.7	*23.9%*	2.8	4.3	2.6	0.0
Business and Industrial Process	8.7	*21.4%*	7.4	0.0	0.1	1.2
Residential	6.0	*14.9%*	5.8	0.1	0.0	0.1
Energy Supply	6.0	*14.9%*	5.6	0.4	0.1	0.0
Development	2.0	*4.9%*	1.8	0.0	0.1	0.0
Waste Management	1.7	*4.2%*	0.0	1.6	0.1	0.0
Public Sector Buildings	1.1	*2.7%*	1.1	0.0	0.0	0.0
Forestry	-9.5	*-23.6%*	-9.6	0.0	0.1	0.0

Chart B4. Change in Net Emissions by Scottish Government Sector Between 1990 and 2017 – in $MtCO_2e$, *and percentage changes* [6]



Air Quality Pollutant Inventories for England, Scotland, Wales, and Northern Ireland: 1990-2017
https://naei.beis.gov.uk/reports/reports?report_id=996

Eight priority air pollutants: NH_3, CO, NO_x, NMVOCs, PM10, PM2.5, SO_2, and Pb
Basic summary of PCDD/F and B[a]p emissions.
All pollutant emission levels are lower in 2017 than they were in 1990. The decline is relatively similar for PM10, PM2.5, NO_x, NMVOC, PCDD/Fs, SO_2 and CO.

Ammonia Emissions in Scotland
These emissions have declined by 15% since 1990 and accounted for 11% of the UK total in 2017. Agriculture sources have dominated with the trend largely driven by decreasing animal numbers and a decline in fertiliser use. However, an increased usage of urea-based fertilisers has had the opposite effect in recent years

Carbon Monoxide Emissions in Scotland
Emissions of carbon monoxide were estimated to be 107kt in 2017 and have declined by 84% since 1990. Emissions in Scotland accounted for 7% of the UK total in 2017. This decline in emissions stems from changes in transport sources, particularly in road transport.

Nitrogen Oxides Emissions in Scotland
Emissions of nitrogen oxides were estimated to be 93kt in 2017, representing 11% of the UK total. Emissions have declined by 71% since 1990, mainly due to changes in transport sources, particularly in road transport (passenger cars and other road transport). This decline is driven by the successive introduction of tighter emission standards for petrol cars and all types of new diesel vehicles over the last decade.

NMVOC Emissions in Scotland
Emissions of non-methane volatile organic compounds were estimated to be 136kt in 2017, representing 17% of the UK total. Emissions have declined by 65% since 1990. This reduction has been dominated by the 90% decrease in fugitive emissions since 1990. This is primarily due to the decrease in emissions from the exploration, production and transport of oil, specifically emissions from the onshore loading of oil. Emissions from the food and drink industry (which accounts for more than 99% of industrial processes emissions in 2017) have consistently increased since 2008 due to the increased production and storage of whisky, now contributing approximately 45% of NMVOC emissions in Scotland. Emissions from road transport sources, including evaporative losses of fuel vapour from petrol vehicles have also declined over time due to emission control technologies introduced in new petrol vehicles since the early 1990s. The reduction in emissions also occurs to a lesser extent due to the introduction of petrol vapour recovery systems at filling stations

PM10 Emissions in Scotland
Emissions of PM10 were estimated to be 15kt in 2017, declining by 63% since 1990. These emissions account for 9% of the UK total. Unlike most other pollutants, the emissions profile of PM10 is diverse: transport sources, residential and industrial processes each accounted for over 10% of total emissions in 2017.

PM2.5 Emissions in Scotland
Emissions of PM2.5 were estimated to be 8kt in 2017, declining by 68% since 1990. These emissions account for 8% of the UK total in 2017. As with PM10, PM2.5 emissions have a large number of significant sources. However, process emissions tend to produce coarser PM fractions and as such, combustion emissions are of greater importance for PM2.5 compared to PM10. The primary drivers

for the decline in emissions since 1990 are the switch in the fuel mix used in electricity generation away from coal and towards natural gas,

Sulphur Dioxide Emissions in Scotland
Emissions of sulphur dioxide were estimated to be 14kt in 2017, representing 8% of the UK total in 2017. Emissions have declined by 96% since 1990, dominated by the 98% reduction in energy industries emissions, coincident with large changes in the power generation sector.

Lead Emissions in Scotland
Emissions of lead were estimated to be 6.1 tonnes in 2017, representing 6% of the UK total. Emissions have declined by 97% since 1990 almost entirely due to changes in transport sources. Petrol with lead additives was phased out from general sale by the end of 1999.

B1.2. POLICIES

Climate Change Plan: third report on proposals and policies 2018-2032 (RPP3)
https://www.gov.scot/binaries/content/documents/govscot/publications/corporate-report/2018/02/scottish-governments-climate-change-plan-third-report-proposals-policies-2018/documents/00532096-pdf/00532096-pdf/govscot%3Adocument/00532096.pdf?forceDownload=true

By 2032, Scotland's electricity system will be largely decarbonised

- The electricity sector covers generation and the wider electricity system of Scotland.
- The system will be powered by a high penetration of renewables, with security of supply and system resilience aided by a range of flexible and responsive technologies
- Emissions reduction and security of supply will be ensured through diverse generation technologies, including gas generation, increased storage, smart grid technologies and improved interconnection. While Carbon Capture and Storage (CCS) is not a requirement until after 2030, it remains a key technology

We envisage significant decarbonisation of transport by 2032

- The transport sector covers all transport modes in Scotland, including public transport, freight, aviation, shipping, private motoring, active travel and the regulations, policies and infrastructure designed to support all of these.
- With our commitment to phase out the need to buy petrol and diesel cars and vans by 2032, low emission vehicles will be widespread and becoming the norm, and freight infrastructure will feature more efficient HGVs operating from out of town freight consolidation centres.

For the industrial sector our plans are broadly consistent with the existing EU and UK regulatory frameworks

- This sector includes all industrial activity in Scotland, including the energy-intensive industrial sectors covered by the EU Emissions Trading System
- We envisage a fall in industrial emissions of 21% over the lifetime of the Plan, through a combination of fuel diversification, cost saving energy efficiency and fuel recovery, and participation in the EU ETS

The Scottish Government offers specific support to accelerate low carbon infrastructure projects through our Low Carbon Infrastructure Transition Programme (LCITP)

The Scottish Government is committed to protecting domestic industries at risk of relocation overseas where climate or energy regulation is less stringent (referred to as 'carbon leakage')

1) By ensuring a continued level playing field for regulation through EU and UK frameworks for industrial decarbonisation

2) By providing a coordinated approach to incentives and business support that reflects our commitment to manage the transition toward decarbonising industry.
This includes:
• Our manufacturing action plan (MAP) – 'A Manufacturing Future for Scotland';
• Scotland's Energy Efficiency Programme (SEEP)
• Our circular economy strategy – 'Making Things Last'.

3) By continuing to consider emerging Carbon Capture and Storage (CCS), Carbon Capture and Utilisation (CCU) and hydrogen opportunities and supporting research and international collaboration.

DEFRA Clean Air Strategy 2019
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770715/clean-air-strategy-2019.pdf

Air pollution is the top environmental risk to human health in the UK, and the fourth greatest threat to public health after cancer, heart disease and obesity. It makes us more susceptible to respiratory infections and other illnesses.

Air pollution comes from many sources. Pollutants can travel long distances and combine with each other to create different pollutants. Emissions from distant and local sources can build up into high local concentrations of pollution.

Air pollution has direct impacts on the natural environment, contributing to climate change, reducing crop yields and polluting oceans.

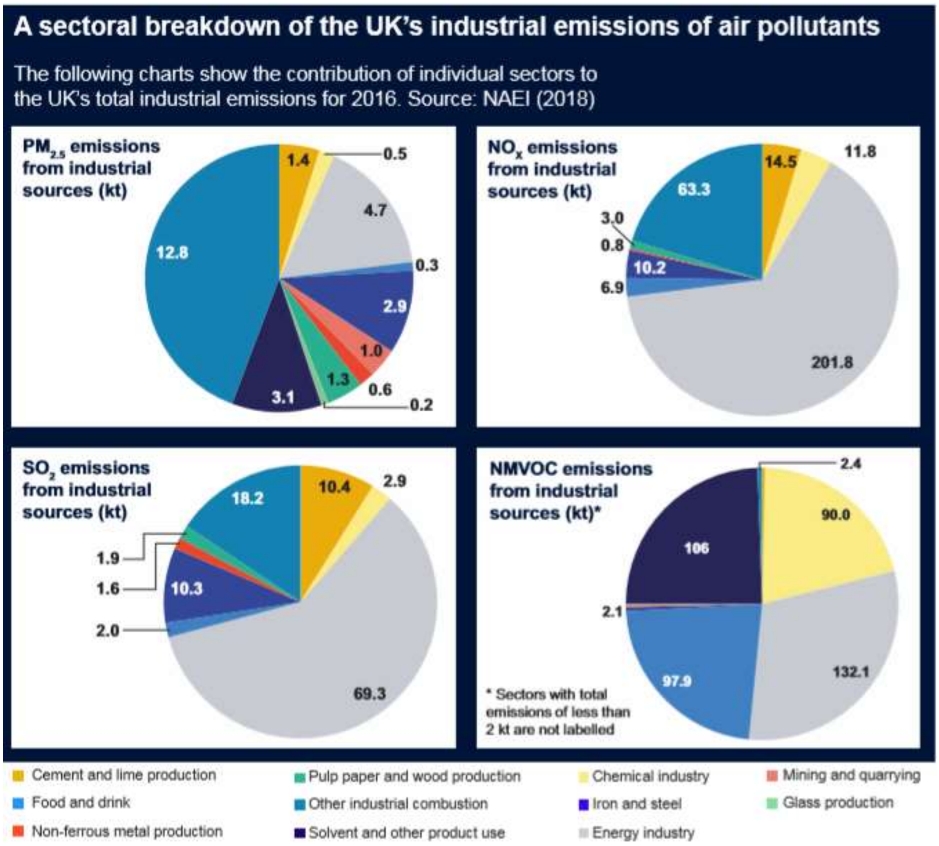
Transport is a significant source of emissions of air pollution.

Pollutants with ambient air quality standards in the UK.

● Nitrogen dioxide (NO2) / NOX (vegetation) ● Particulate Matter (PM10) ● Fine Particulate Matter (PM2.5) ● Ozone (O3) ● Sulphur dioxide (SO2) ● Benzene ● Lead (Pb) ● Carbon monoxide (CO) ● Benzo[a]pyrene (B[a]P) ● Nickel (Ni) ● Cadmium (Cd) ● Arsenic (As) ● 1,3-butadiene

Many technologies and solutions support multiple aspects of clean growth. For example, the move towards electric vehicles supports both decarbonisation and air quality.

However, there are some technologies that can create tension. For example, biomass burning can support decarbonisation but, without appropriate abatement, it will increase levels of air pollution, unless it involves a switch away from a dirtier fuel such as coal. This is particularly problematic when the burning takes place in or close to urban areas.



Cleaner Air for Scotland – The Road to a Healthier Future (CAFS)
https://www.gov.scot/binaries/content/documents/govscot/publications/report/2017/06/cleaner-air-scotland-road-healthier-future-annual-progress-report-2016/documents/00521031-pdf/00521031-pdf/govscot:document/

2019 Independent Review
https://www.gov.scot/binaries/content/documents/govscot/publications/independent-report/2019/08/cleaner-air-scotland-strategy-independent-review/documents/cleaner-air-scotland-strategy-independent-review/cleaner-air-scotland-strategy-independent-review/govscot%3Adocument/cleaner-air-scotland-strategy-independent-review.pdf?forceDownload=true

Scotland's first separate air quality strategy. CAFS sets out in detail how Scotland intends to deliver further air quality improvements over the coming years.

AIR QUALITY AND CLIMATE CHANGE – A JOINED-UP APPROACH
Commitments to decarbonise the Scottish economy should help reduce air pollution, but choices about the route taken to 2050 will influence the scale of additional improvements for air quality. Energy efficiency and demand management, as well as a shift towards low or zero emission energy sources and transport for example, should provide mutual benefits for air quality and climate change.

ENERGY AND AIR QUALITY
The use of fossil fuels to produce energy – mainly through gas and coal fired power stations, but also other methods such as waste incineration and the recovery of waste heat – contributes to air pollution.
The impacts on air quality and the climate could be minimised by:

• making energy use as efficient as possible;
• moving to renewable energy sources;
• using low emission fuels such as certain biofuels, liquid petroleum gas, biopropane and hydrogen.

Climate change actions noted in ‘Low Carbon Scotland: Meeting Our Emissions Reduction Targets 2013-2027 – The Second Report on Proposals and Policies’ that help to protect and enhance air quality include:

• a largely decarbonised electricity generation sector by 2030;
• a largely decarbonised heat sector by 2050 with significant progress by 2030;
• almost complete decarbonisation of road transport by 2050, with significant progress by 2030;
• significant modal shift from the private car to public transport and active travel.

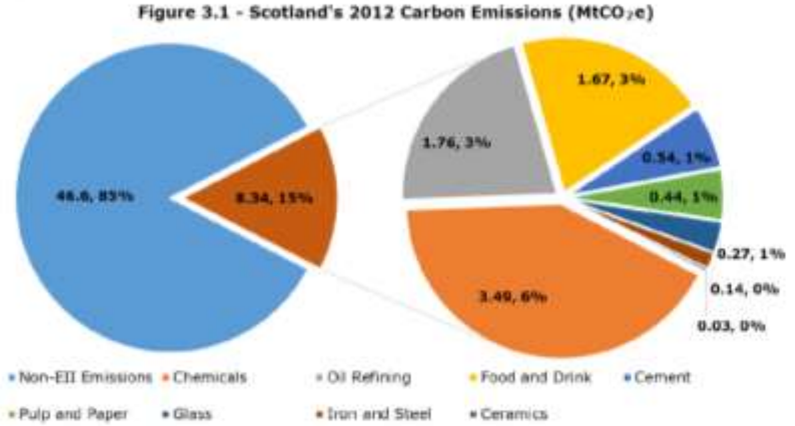
B1.3. CROSS-SECTOR REPORTS

Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=2ahUKEwilyb6ztszoAhWNZMAKHWKoCjMQFjABegQIBxAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

Energy Intensive Industries (EII) include: cement, ceramics, chemicals, food and drink, glass, iron and steel, paper and pulp and oil and gas refining.

Current Emissions Profile of Scotland’s Energy Intensive Industries (EII) 2012
In 2012, Scotland’s EII’s generated a combined 8.3 MtCO2 (15%) of all GHG emissions (54.9 MtCO2). Consistent with the UK IDEER, this study only considers CO2 emissions (no other GHGs) and excludes embedded carbon in materials and waste.
The largest single contributor to these industry emissions was the Scottish chemicals industry (42%), followed by oil refining (21%), and the food and drink industries (20%).

Figure 3.1 - Scotland's 2012 Carbon Emissions ($MtCO_2e$)



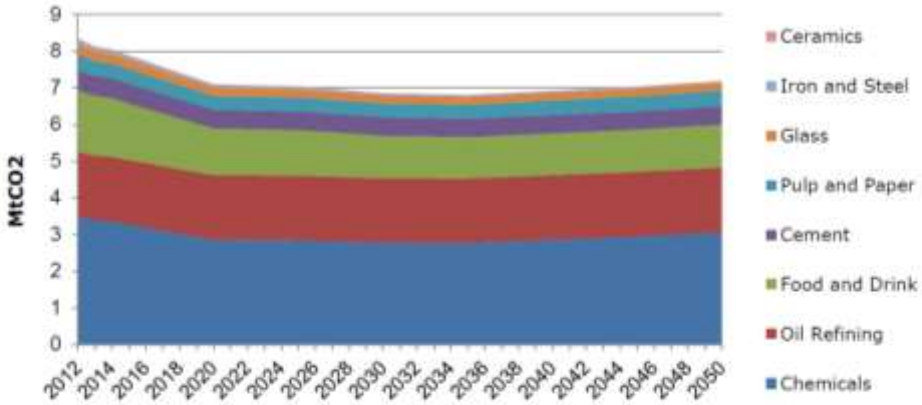
Scenarios Modelled

2050 Reference Scenario

The 2050 Reference Scenario represents a "do nothing approach" in which the EII take no direct action. However, Scotland's EII emissions do change over time as a result of two key parameters

Industrial Output
Future economic growth (estimated 0-1.25% p.a. depending on the industry) increases industrial output and, all else being equal, results in increased net emissions.

UK Grid Decarbonisation
UK continues to decarbonise the electricity grid along current trends, lowering Scotland's EII indirect emissions from electricity use.
Under the Reference Scenario, Scotland's EII emissions experience a general decline between 2012 and 2035, followed by a gradual increase until 2050. The rise in emissions beginning in 2035 occurs because emissions increases associated with projected economic growth exceed the emissions reductions resulting from grid decarbonisation.

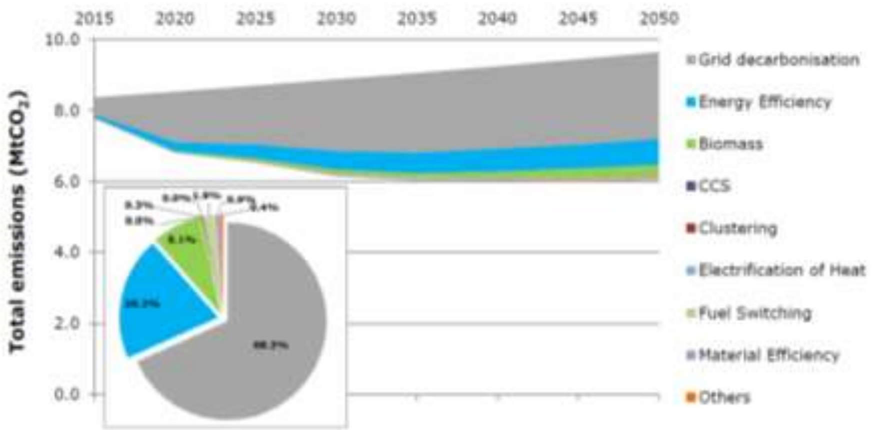


Under the Business as Usual (BAU) Scenario, Scotland's absolute annual EII emissions fall 27% by 2050 to 6.1 $MtCO_2$ from the 2012 baseline, at a cost to industry of £350 million.

This is primarily the result of progressive grid decarbonisation to 2050 (68%) and continuing incremental investment in energy efficiency and heat recovery measures (20%).

Biomass energy increases slowly to 2035, then more rapidly to 2050, contributing 8% to cumulative savings.

Other low-carbon technologies contribute less than 4% of total emissions savings.



Technologies

Carbon Capture & Storage/Utilisation (CCS/CCU)
Technology Overview – Carbon Capture (CC) technologies extract CO2 emissions from industrial processes and either use them as manufacturing feedstock (CCU), or store them in geological formations to remove them from the atmosphere (CCS).
Barriers and Enablers – CC technologies remain prohibitively expensive owing to their high capital investment requirements and operation costs, as well as the absence of return on investment opportunities. Another important factor is the energy penalty associated with their operation. Industries are unlikely to adopt CC without financial and policy incentives. Ongoing uncertainty about UK Government funding for CCS in the power sector is having a knock-on effect in undermining confidence for CCS in industry.

Electricity Grid Decarbonisation (EGD)
Technology Overview - EGD is the reduction of marginal CO2 emissions from electricity generation via low-carbon generation technologies, particularly renewables both on and off site. This is a UK policy objective that lies outside industry control, thus its impacts are constant across all scenarios in this study. Among the individual EII, EGD offers greatest annual emissions savings for industries where substantial process electrification is possible (food and drink, paper and pulp, glass and ceramics).
Barriers and Enablers – Scotland's EII remain uncertain as to whether government can reach its ambitious decarbonisation target while keeping energy prices affordable and a secure supply. Concerns include that incentives are only available at the start of operation of new projects and not at the investment decision stage. The rates associated with on-site renewable energy generation are inconsistent with energy generators.

Energy Efficiency and Heat Recovery (EEHR)
Technology Overview – Energy efficiency gains are typically made incrementally when old equipment is replaced with new, more efficient alternatives, however they can also result through energy management to improve automation, process control, monitoring, planning and maintenance. Heat Recovery is the capture of waste heat for use in industrial processes or distributed heat networks (e.g. district heating).
Barriers and Enablers – Improving energy efficiency lowers marginal production costs, providing direct financial paybacks for companies, however these often occur over long time period. As a result, energy efficiency projects, which must compete with limited company budgets, are often disadvantaged against other investments opportunities, typically focused on growth and output, with no carbon benefits and shorter payback periods.

Biomass
Technology Overview – Biomass are renewable resources (e.g. wood waste, sewage, slurry, organic household waste, energy crops, etc.) that can be used in combined heat and power, gasification and pyrolysis plants or anaerobic digesters to replace fossil fuel energy - or in bio-refining to replace conventional feedstock in the chemicals (e.g. pharmaceuticals), food and drink, cement, and paper and pulp sectors (The Biorefinery Roadmap for Scotland, 2015). Among the individual EII, biomass offers the greatest annual emissions savings for paper and pulp, cement, food and drink and chemicals.
Barriers and Enablers – Scottish Government firmly supports increased use of biomass. The use of biomass currently varies greatly among Scotland's EII, with the Scotch whisky industry leading the way. Greater use of biomass in the future will be challenged by competing demands, resource availability, security of supply, quality consistency, price, and policy support. Concerns surround the use of measures that may disadvantage some industries such as power generation.

Electrification of Heat (EoH)
Technology Overview – EoH involves transferring industrial processes from fossil fuel to electric power, provided the latter generates lower net emissions. EoH features most heavily in ceramics, food and drink and glass.
Barriers and Enablers – The economic viability of EoH is highly sensitive to relative price changes in grid electricity and fossil fuels. Since EoH involves "locking in" to electrified technology, companies must be confident that future electricity prices will remain competitive, and supply reliable, particularly if widespread adoption of EoH leads to increased electricity demand. Companies can insulate themselves from price and supply uncertainty and guarantee low-carbon electricity by developing on-site renewables
Concerns surround a lack of clear policy and lack of confidence that grid decarbonisation targets can be delivered at competitive costs since electricity costs are currently much higher than those of natural gas.

Clustering
Technology Overview – Clustering involves geographically concentrating industries to make use of underutilised resources (e.g. waste resources, industrial by-products and waste heat) and deliver energy and emissions savings. Clustering is not about moving businesses and jobs out of their communities; rather it is a long-term, gradual process in which existing plants seek local network opportunities (e.g. district heating), and new or replacement plants are encouraged to locate where clustering benefits can be realised. The direct emissions savings from clustering are very small.

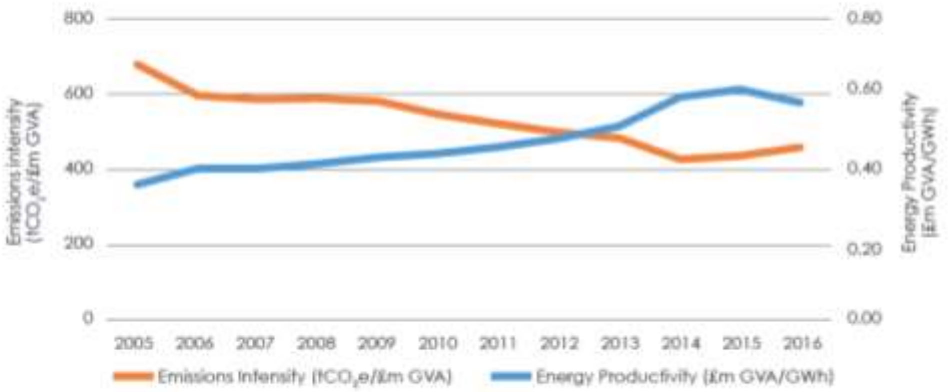
Barriers and Enablers – Clustering relies on inter-organisational collaboration that can lead to the perceived risk of dependency. Relocating large plants is unlikely due to the scale of operations and size of sites. Instead, smaller, cottage industries could be encouraged to locate themselves around these larger sites. Concerns surround regulations and how this is applied to clusters e.g. separate permits, waste receiving between cluster partners as well as the geographically diverse nature of industry. Some food and drink plants are very remote, and the sector counts many SMEs. Energy efficiency projects are more restricted to large enterprises.

Decarbonising Scotland's Industrial Sectors and Sites 2019
https://www.gov.scot/binaries/content/documents/govscot/publications/progress-report/2019/04/decarbonising-scotlands-industrial-sectors-sites-paper-discussion-scottish-energy-intensive-industries/documents/decarbonising-scotlands-industrial-sectors-sites/decarbonising-scotlands-industrial-sectors-sites/govscot%3Adocument/decarbonising-scotlands-industrial-sectors-sites.pdf?forceDownload=true

Our Climate Change Plan (CCP) and Energy Strategy (ES) contain two policy outcomes relevant to EII:
1. By 2032, industrial and commercial energy productivity will improve by at least 30%, from 2015 levels, through a combination of fuel diversification, energy efficiency improvements and heat recovery.
2. By 2032, industrial and commercial emissions intensity will fall by at least 30%, from 2015 levels, through a combination of fuel diversification, energy efficiency improvements and heat recovery.
Analysis shows these targets are consistent with the trajectory outlined in the CCP to reduce industrial emissions by 21% (or 2.2MtCO2e) over the plan's lifetime (2018-2032).

Trends

Figure 1: Comparison of historical (2005-2016) Energy Productivity (GVA/GWh) and Emissions Intensity (tCO_2e/£m GVA) in the Scottish Industrial sector

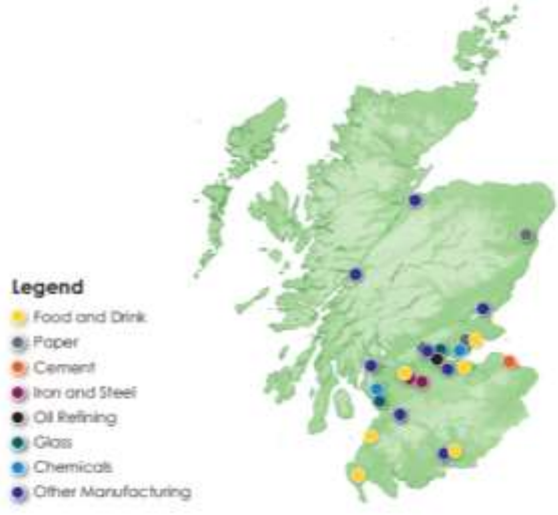


There has been a positive trend of increasing energy productivity and falling emissions intensity since 2005.
Support programmes and incentives currently exist but there remains a significant risk for EII that could lead to carbon leakage (which occurs when domestic industries relocate overseas, where climate or energy regulation may be less stringent).
The Scottish Government wants to support activity that incentivises investment in existing sectors and secure investment in new manufacturing sectors attracted by a low carbon energy supply, new fuels such as hydrogen, our R&D excellence, our high skilled labour force, and the locational advantages that clustering infrastructure can offer.

Our focus is on factors that we can influence, therefore we are working to:
• better target interventions that have an increased chance of industry take-up;
• maximise the effectiveness of public and private sector resources in overcoming barriers;
• prioritise support to where it can best influence outcomes and more directly connect with the delivery of our high level targets; and
• look at the wider economic and social impacts as EII adapt

What are, and where are, Scotland's energy intensive industries?
• Oil & Gas Refining • Iron & Steel
• Cement • Chemicals
• Pulp & Paper • Glass
• Food & Drink • Ceramics (No ceramics sites in Scotland large enough to be part of the EU ETS.)

Mapping high CO2 emitting sites illustrates where Scotland's industrial assets are. 'Clustered' industries, whether from the same sub-sector or not, will share infrastructure already, but there may be a case to consider development that makes more of proximity to improve efficiencies in energy productivity, material supply chains, or the local re-use of by-products such as excess heat.



Workshop Outcomes

Top cross sector barriers to investment and opportunities to decarbonise:

Top cross-sector barriers
• Unattractive payback periods on measures so investment is diverted to other areas
• The cost of energy (including rising costs as a result of policies on renewables)
• Policy uncertainty in some areas such as on bio-energy
• Limits to growth, change or decarbonisation, often due to constraints on network infrastructure
• Lack of long-term incentives

Top cross-sector opportunities
• Many potential resource efficiency projects, especially industrial heat recovery (IHR)21
• Potential to do more with products viewed as waste and use them more in processes
• Industry to support, and extract efficiency benefits from the distributed storage of energy
• With financial support, Scottish EII have an appetite for an ambitious low-carbon future

Chart of Opportunities and Challenges

Refining and oil products		Chemicals	
opportunities	challenges	opportunities	challenges
The financial environment for investment in proven technology. Waste heat recovery. Clustering.	Investment payback periods. Decline in demand. Low value of carbon counts against support to develop CO_2 capture technology.	Use devolved powers and coalesce Scottish development of networks to influence distributed energy storage and seek more competitive energy-related costs.	Energy costs vs Europe. Where is additional reserve generation capacity or storage infrastructure from?
Mineral products including cement		**Metals (steel and aluminium)**	
Waste potential. Potential for EII to go low-carbon if financially supported.	Reliable supply of waste. Cost pressures on EII are a barrier to invest.	Many potential projects, but payback too long without government support. Energy storage.	Energy costs vs Europe. Isolated thinking on infrastructure.
Food and Drink (in general)		**Scotch Whisky (specifically)**	
Finding use (or alternative uses) for low carbon heat.	Lack of clarity policy.	Increase in the generation, use and supply of renewable energy. Development of district heating networks.	Complex and changing policy framework. Infrastructure constraints, e.g. limited rural gas grid. Energy security & supply.
Paper and Pulp		**Glass**	
Finding suitable use for excess low-grade underutilised heat.	Investment payback periods.	Heat recovery. More recycled glass (cullet) input. Switch to electric melting.	Investment payback periods. Cullet availability. Cost of electricity.

Industrial energy use and carbon emissions reduction: a UK perspective
https://onlinelibrary.wiley.com/doi/epdf/10.1002/wene.212
Industry is very diverse in terms of manufacturing processes, ranging from highly energy intensive (EI) steel production and petrochemicals processing to low-energy electronics fabrication.
Around 350 separate combinations of subsectors, devices and technologies can be identified; each combination offers quite different prospects for energy efficiency improvements and carbon reductions, which are strongly dependent on the specific technological applications.

Energy Use and Emissions
Economy-wide emissions targets are likely to require a reduction from industry and a range of options will be required to make the necessary reductions.
The UK has seen a reduction in industrial energy use whilst continuing to increase output in economic terms.
The drop in aggregate energy intensity (defined as energy use per unit of economic output) is driven by different effects:
• Energy efficiency: A large part of the decline in industrial energy intensity can be attributed to energy efficiency improvements
• Structural change: The relative size of industrial subsectors has changed with a transition away from EI industries.
• Fuel switching: Coal and oil use has steadily declined in favour of ‘cleaner’ fuels, such as electricity and gas.
These ‘cleaner’ fuels can be used with a higher degree of control and so are more efficient than alternatives. Additionally, when examining primary energy demand, the increase in the efficiency of electricity generation (largely caused by fuel switching in favor of natural gas) will have the effect of lowering primary energy use
In addition to the energy use and emissions at a manufacturing site, a product will have upstream or ‘embodied’ energy and carbon emissions resulting from material extraction, transport, and the early stages of production.

An additional, related issue is that of 'carbon leakage.' By focusing only on UK energy use and GHG emissions, a national decrease may be seen that in reality corresponds to increased levels of imports

Drivers and Barriers to Industrial Energy Demand and GHG Emissions Reduction
There are two principal drivers in industry behind the adoption of energy demand management measures, namely costs and legislation. Energy costs represent a large proportion of operating expenditure (often as much as half) for EI subsector, whereas for NEI subsectors they are an order-of-magnitude smaller than this (only around 5%).

The Barriers to Change
Hidden costs, management focus on 'core business' issues (such as production output), lack of information, and (in some cases) the availability of capital.
Many result from a lack of specialist knowledge on the part of the firm. They include, inter alia, economic market and nonmarket failures, the investment costs associated with new plant, as well as a certain degree of management inertia.
The potential for energy saving opportunities in the NEI subsector of manufacturing is often underplayed by energy policy makers.
In contrast, the EI subsector is generally easier to analyze, but the NEI subsector comprises a significant proportion of overall energy use. Therefore, it is thought that the potential for relative savings in the latter subsector may be greater than in the rest of industry

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050. MARCH 2015
Cross Sector Summary Report and Plans
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/419912/Cross_Sector_Summary_Report.pdf
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651276/decarbonisation-action-plans-summary.pdf

Technology option groups and sectors applicable to Electricity grid decarbonisation.

All sectors

Grid decarbonisation impacts decarbonisation pathways in two ways: (i) through decarbonisation of imported electricity use from the base year and (ii) through deployment of options that involve electrification
While grid decarbonisation is outside the direct control of the industry, decarbonisation of the national electricity grid could provide a considerable contribution to the overall decarbonisation
Grid decarbonisation has a significant impact in all sectors that currently import large quantities of electricity, which is all sectors except refining. For sectors that include options that rely on increasing use of (low carbon) electricity (food and drink and pulp and paper for lower temperature heat and iron and steel, glass and ceramics for high temperature heat), grid decarbonisation is also a key part of the equation.

Biomass

All sectors: includes (either or both) biomass fuel and biomass feedstock

Biomass technology for decarbonisation is the use of biomaterials to provide a fuel or feedstock replacing current fossil fuel sources. Biomass absorbs CO2 during growth, so there is the potential to reduce emissions compared to fossil fuel sources. However, there are many different sources of biomass (including within waste streams) that will have different emissions factors linked to their processing and transport.

It is a key decarbonisation technology in six sectors: pulp and paper, cement, chemicals, glass, food and drink and ceramic. Biomass use was assessed in iron and steel in a sensitivity case only.
Three main uses of biomass as a fuel have been identified in this study: combined heat and power (CHP), gasification and pyrolysis. CHP is an existing well proven technology whereas both gasification and pyrolysis have a lower technology readiness level. Biomass can also be used as a feedstock replacement, for example in the chemicals and cement sectors.
There are a number of complexities regarding biomass use as a decarbonisation option, from an industrial perspective: availability of different resource streams (and the related issue of competing demand for land), consistency of quality, carbon emission factors, price and policy support. As biomass also serves as feedstock for pulp and paper and the food and drink sector, it adds complexity to the question at hand. In addition, biomass can be used in a range of applications outside of the eight sectors assessed here (e.g. electricity generation, transport and space heating).

Energy efficiency and heat recovery

All sectors: a range of improvements including energy management, utilities, heat recovery, improved process control, improved equipment and insulation (e.g. motors, pumps, compressors, fans), improved furnace design, compressed air to electric drives, maintenance.

This group includes a range of options to increase energy efficiency through investment in state-of-the-art equipment, improved energy management and increased heat recovery. There are opportunities for increased energy efficiency in all of the eight sectors.

Companies invest in new process equipment to stay competitive and new state-of-the-art equipment is typically more energy efficient than the equipment they replace. There are also opportunities to manage energy more systematically on sites. This includes improved automation and process control, monitoring, planning, and maintenance. As these interventions use highly developed technologies, they could be implemented in the short term, and since the investment costs can be low and energy efficiency saves operational costs, many of them can be funded locally. It is important that, with increasingly lean organisations and sometimes a lack of skilled labour, that when upgrading industrial plant, energy efficiency and decarbonisation are both considered as a high priority and suitably resourced in the project development process.

In addition to improved energy efficiency, increased heat recovery is an opportunity in all eight sectors. Most of the available heat to recover is lower grade heat16. To use it effectively, there needs to be either matched heat sinks near the plant or the heat needs to be upgraded to higher grade heat or electricity. Industrial clustering could help co-locate industries that use lower grade heat (food and drink, semiconductor manufacturing etc.) with industries that have low-grade heat available (iron and steel, pulp and paper, etc.). Low-grade industrial waste heat could also be used in district heating schemes to provide heat local housing or non-domestic buildings.

Electrification of heat

Low temperature applications in pulp and paper and food and drink and high temperature applications in glass (electric melting), ceramics (electric kilns) and iron and steel (increased use of electric arc furnaces)

Substantial electricity grid decarbonisation would provide a further opportunity to decarbonise UK industry through the electrification of processes that are currently powered by fossil fuel combustion. This will only provide overall emissions reductions where the use of electricity is a lower-carbon option than the current energy source, i.e. as the grid becomes decarbonised, more processes could have a reduced carbon impact through electrification.

It is a key decarbonisation technology in five sectors as follows: pulp and paper, food and drink, glass and ceramic. Increased use of electric arc furnaces in steel production was assessed as a sensitivity analysis.

Electric melting for glass manufacturing, electric kilns in the ceramic sector, and an increased proportion of steel production via electric arc furnaces, EAF, (although scrap price and availability constraints might limit this option) are key decarbonisation technologies. For the food and drink and pulp and paper sectors, electrification of heat is an important decarbonisation option. Compared to other sectors, the food and drink and pulp and paper sectors have a large part of their heat demand at fairly low temperatures and this could enable these sectors to shift towards electrification more easily. For other sectors, using electricity as their energy source is possible at higher temperatures but equipment (e.g. electric kilns) is not developed at scale and lower efficiencies can result compared to using other fuels. Electricity price projections relative to counterfactual fuels (e.g. gas) will be a key consideration in any investment decision.

Electrification of heat could be considered when replacing equipment, but the extent to which investments in electrified technologies are made will depend on firms' confidence that there will be secure, affordable decarbonised electricity in the future. The decision to electrify is an extremely significant step for companies to make, hence a clear plan will be needed that takes into account technology development, risks, costs and security/cost of supply.

DECC forecasts suggest substantial decarbonisation can be made from electrification, as long as prices are competitive to alternatives. Large-scale electrification of heat would increase overall electricity use, and therefore the impact of its deployment on the development of electricity generation, transmission and distribution capacity should be investigated.

Material efficiency
Food waste and packaging reduction, reducing yield losses, scrap densification/shredding and reuse of steel (steel), lighter bricks (ceramic), reduce product weight (ceramic), increased cullet use through recycling (glass)

Clustering
Chemicals and pulp and paper sectors – but possibilities in other sectors too.

Clustering is a long-term, gradual option that requires new or replacement plants to be encouraged to locate where clustering benefits can be realised, and existing plants to maximise local opportunities. The barriers to clustering are generally related to organisational collaboration and include the perceived risk of becoming reliant on a partner who may not be present in the long term. Relocating many plants within the eight sectors is unlikely due to the scale of operations and size of sites but other industries could locate themselves around them.

According to our analysis, clustering could result in significant decarbonisation in the pulp and paper and chemicals sectors, but most sectors could benefit from increased clustering.

Fuel switching

Includes pulverised coal injection (iron and steel) use of waste-derived fuels, hydrogen and oxygen enrichment technology and on site renewable generation of electricity. Excludes electrification and biomass.

Carbon capture

Other
Examples include substitution of materials and alternative cements, olefin catalytic cracking (chemicals), batch pelletisation and reformulation (glass), pre-calcining of clay (ceramic).

Life Cycle Accounting
All sectors use raw materials from and provide products to other parts of the economy. A standardised and quantifiable means of understanding the overall carbon impact of the entire product life-cycle could put a value on life-cycle (carbon) benefits of both the sector's manufacturing and product performance. This could better align industry incentives for generating revenue and maintaining competitiveness with societal incentives for decarbonisation by helping to build the case for investment in decarbonisation.

Sector	Pathway	Base year (2012) emissions (million tonnes CO_2)	Relative emissions reduction in 2050 (relative to 2012)	Absolute emissions reduction in 2050[3] (million tonnes CO_2)	Technology groups (in descending order of relative contribution)
Cement	BAU	7.5	12%	0.9	Others; Energy Efficiency
	Max Tech - with or without carbon capture		33-62%	2.5-4.7	(CCS); Biomass; Others; Energy Efficiency; Fuel Switching
Ceramics	BAU	1.3	27%	0.3	Energy Efficiency; Others; Material Efficiency; Fuel Switching; Biomass
	Max Tech		60%	0.8	Electrification of Heat; CCS; Energy Efficiency; Biomass; Others; Material Efficiency; Fuel Switching
Chemicals	BAU	18.4	31%	5.8	Biomass; Energy Efficiency; CCS; Fuel Switching; Clustering; Others
	Max Tech – with and without biomass		79-88%	14.6-16.1	CCS; (Biomass); Others; Energy Efficiency; Clustering; Fuel Switching
Food and Drink	BAU	9.5	40%	3.8	Energy Efficiency; Biomass; Electrification of Heat; Material Efficiency; CCS; Others; Fuel Switching
	Max Tech - with and without electrification of heat		66-75%	6.2-7.2	(Electrification of Heat); Energy Efficiency; Biomass; Others; Material Efficiency; CCS; Fuel Switching
Glass	BAU	2.2	36%	0.8	Energy Efficiency; Material Efficiency; Others; Fuel Switching
	Max Tech – with or without carbon capture		90-92%	2.0-2.0	(CCS); Electrification of Heat; Fuel Switching; Material Efficiency; Energy Efficiency; Others
Iron and Steel	BAU	23.1[4]	15%	3.4	Energy Efficiency; Material Efficiency; Fuel Switching
	Max Tech		60%	13.9	CCS; Energy Efficiency; Clustering; Material Efficiency; Fuel Switching
Oil Refining	BAU	16.3	44%	7.2	Energy Efficiency; Fuel Switching
	Max Tech		64%	10.4	Energy Efficiency; CCS; Fuel Switching
Pulp and Paper	BAU	3.3	32%	1.0	Energy Efficiency; Electrification of Heat
	Max Tech – clustering and electrification		98%	3.2	Energy Efficiency; Clustering; Electrification of Heat
	Max Tech - biomass		98%	3.2	Biomass; Energy Efficiency; Electrification of Heat

Table 2: Decarbonisation potential for the eight sectors

B1.4. MANUFACTURING AND INNOVATION

A Manufacturing Future for Scotland
https://www.gov.scot/binaries/content/documents/govscot/publications/corporate-report/2018/09/a-manufacturing-future-for-scotland-action-plan/documents/a-manufacturing-future-for-scotland/a-manufacturing-future-for-scotland/govscot%3Adocument/A%2Bmanufacturing%2Bfuture%2Bfor%2BScotland.pdf?forceDownload=true

Overall, manufacturers employ around 190,000 people in Scotland, produce over 50 per cent of Scotland's international exports and are Scotland's biggest investors in business research and development (R&D).

Analysis highlights that many SMEs need support and encouragement to prepare and submit investment cases to capital asset finance providers.

Public sector partners in Scotland are working together in a Decarbonisation of Industry Steering Group. This promotes and co-ordinates action to support energy intensive industries in making the transition to lower carbon forms of production.

Eight action plan themes (described below) each with an associated activity workstream. Collectively these form the Manufacturing Action Plan.

- Leadership
- Skills and Jobs
- Circular Economy. Includes a major focus on innovation: in product specification and design, product manufacturing and re-manufacturing, supply chains and product stewardship, business models and customer relationships.
- Energy Efficiency and Decarbonisation
- Competitive Infrastructure
- Investment in SMART Manufacturing
- Supply Chain Capability
- Technology and Innovation

The Future of Manufacturing
https://www.gov.uk/government/publications/future-of-manufacturing

The UK manufacturing sector is diverse, with activities ranging from aerospace, pharmaceuticals, chemicals and automotive to food and drink. It is characterised by a wide range of sizes of firm, with a disproportionate share of activity accounted for by a small number of large, often foreign owned multinational companies.

Manufacturing is and must continue to be an essential part of the UK economy. Its benefits include:

- Absolute value
- Research and Development (R&D): Manufacturing businesses are more likely to engage in R&D
- Innovation: Manufacturers are more likely to innovate.

- Productivity: The growth in total factor productivity for manufacturing has been 2.3% per year between 1980 and 2009, compared with 0.7% per year for the UK as a whole.
- Exports: Manufacturing businesses are more likely to engage in exporting.
- Highly skilled jobs
- Inter-industry linkages: Manufacturing performance affects other sectors through its wide range of input-output and other linkages
- Economic resilience: Economies with strong, export-led manufacturing sectors typically recover from recessions faster than those without equivalent manufacturing sectors.

However, in recent years, the relative share of manufacturing in the UK economy has declined while the service sector has grown at a faster rate. UK manufacturing performance has been weak relative to international competitors in some key areas:

- Expenditure on manufacturing R&D has been low, especially with regard to new products.
- The level of investment in capital equipment has been relatively low for many decades.
- The UK's share of global manufacturing exports has fallen.

Future sources of revenue for manufacturers will include:

- Increasingly extensive packaging of services with products;
- New sources of information on how products are used, drawing on embedded sensors and open data;
- Becoming a 'factoryless goods producer', capturing value by selling technological knowledge and leaving production to others;
- Becoming a 'remanufacturer' with end of life products remanufactured and returned to original specifications or better;
- Targeting 'collaborative consumption', where no one customer owns a product outright;
- Creating value from new forms of (competitive) strategic alliance within and across sectors;
- Exploiting new technologies more rapidly through greater operational capability coupled to entrepreneurial insight

Key future characteristics

Faster, more responsive and closer to customers
Technology will play a central role in driving change. Most important pervasive and secondary technologies including ICT, sensors, advanced materials and robotics. When integrated into future products and networks, these will collectively facilitate fundamental shifts in how products are designed, made, offered and ultimately used by consumers.

Mass personalisation of low-cost products, on demand
The historic split between cheap mass produced products creating value from economies of scale and more expensive customised products will be reduced across a wide range of product types. Technologies such as additive manufacturing, new materials, computer-controlled tools, biotechnology, and green chemistry will enable wholly new forms of personalisation. Direct customer input to design will increasingly enable companies to produce customised products with the shorter cycle-times and lower costs associated with standardisation and mass production. The producer and the customer will share in the new value created.

Distributed production
We will see a transformation in the nature of production itself, driven by trends such as new forms of modelling and additive manufacturing through to nanotechnologies and advanced robotics. The factories of the future will be more varied, and more distributed than those of today. The production landscape will include capital intensive super factories producing complex products; reconfigurable units integrated with the fluid requirements of their supply chain partners; and local, mobile and domestic production sites for some products. Urban sites will become common as factories reduce their environmental impacts28. The factory of the future may be at the bedside, in the home, in the field in the office, and on the battlefield.

Digitised manufacturing value chains
Pervasive computing, advanced software and sensor technologies have much further to go in transforming value chains. They will improve customer relationship management, process control, product verification, logistics, product traceability and safety systems. They will enable greater design freedom through the uses of simulation, and they will create new ways to bring customers into design and suppliers into complex production processes.

New market opportunities

Includes:

- Emergence of BRIC economies
- Continued importance of US and Europe for UK manufacturing exports
- Changing levels of personal wealth including larger and older populations in major markets

Risks to Foreign Direct Investment into Europe may affect the UK

High-tech likely to remain an area of UK advantage: Current high-tech sectoral strengths include pharmaceuticals, aerospace, chemicals, and the automotive sector.

Increasing foreign ownership

Continued global fragmentation of the value chain:
Fragmentation includes the outsourcing of functions and offshoring. It is driven by factors such as the costs and quality of labour and transport, security of provision, the opportunities created by trade liberalisation; the availability of data and information; and the integration of suppliers into product development processes. Many manufacturing value chains are likely to continue to fragment, with the operation of supply chains playing a major role in determining future changes.
May be some onshoring of production back to the UK

More sustainable

Driven by:

- Volatility of supply
- Climate change and the increased vulnerability of global supply chains:
- Greater use of regulation, potential 'pricing of the environment':
- Consumer pull for eco-products

Emergence of a 'circular economy'

End of life products are reused, remanufactured and recycled: Resource scarcity and higher costs for energy and waste disposal will shift manufacturing value creation to new models

Reuse: Redeploying a product without the need for refurbishment;

Remanufacturing: Returning a product to its original performance specification;

Cascaded use: Using a product for a lower value purpose, for example turning used clothes into pillow stuffing or redeploying computers within a business for less demanding applications;

Recycling: Extracting the raw materials and using them for new products;

Recovery: Re-using materials for a low value purpose such as road base or combustion to produce heat.

Quantifying domestic reserves of critical materials:
It is essential that the UK makes the most of any domestic supplies of key materials, where economically viable, such as sources of indium, widely used in the production of LCD displays and low-melting temperature alloys.

More integrated view of value creation
Manufacturing is no longer just about 'production' - making a product and then selling it. Manufacturers are increasingly using a wider 'value chain' to generate new and additional revenue from pre and post-production activities, with production playing a critical role in allowing these other activities to occur.

New metrics are needed to capture the new ways in which manufacturers are creating value, and to assess the scale and location of important changes within the sector.

Table 1: Important pervasive and secondary technologies for future manufacturing activities

PERVASIVE TECHNOLOGY	LIKELY FUTURE IMPACTS
Information and communications technology (ICT)	Modelling and simulation integrated into all design processes, together with virtual reality tools will allow complex products and processes to be assessed and optimised, with analysis of new data streams.
Sensors	The integration of sensors into networks of technology, such as products connected to the internet, will revolutionise manufacturing. New data streams from products will become available to support new services, enable self-checking inventories and products which self diagnose faults before failure, and reduced energy usage.
Advanced & functional materials	New materials, in which the UK has strong capabilities, will penetrate the mass market and will include reactive nanoparticles, lightweight composites, self-healing materials, carbon nanotubes, biomaterials and 'intelligent' materials providing user feedback.
Biotechnology	The range of biotechnology products is likely to increase, with greater use of fields of biology by industry. There is potential for new disease treatment strategies, bedside manufacturing of personalised drugs, personalised organ fabrication, wide availability of engineered leather and meat, and sustainable production of fuel and chemicals.
Sustainable / green technologies	These will be used to reduce the resources used in production including energy and water, produce clean energy technologies, and deliver improved environmental performance of products. Minimising the use of hazardous substances.
SECONDARY TECHNOLOGY	
Big data and knowledge based automation	These will be important in the on-going automation of many tasks that formerly required people. In addition, the volume and detail of information captured by businesses and the rise of multimedia, social media and the internet of things will fuel future increases in data, allowing firms to understand customer preferences and personalise products.
Internet of things	There is potential for major impacts in terms of business optimisation, resource management, energy minimisation, and remote healthcare. In factory and process environments, virtually everything is expected to be connected via central networks. Increasingly, new products will have embedded sensors and become autonomous.
Advanced and autonomous robotics	Advances are likely to make many routine manufacturing operations obsolete, including healthcare and surgery, food preparation and cleaning activities. Autonomous and near-autonomous vehicles will boost the development of computer vision, sensors including radar and GPS, and remote control algorithms. 3D measurement and vision will be able to adapt to conditions, and track human gestures.
Additive manufacturing (also known as 3D printing)	This is expected to have a profound impact on the way manufacturers make almost any product. It will become an essential 'tool' allowing designs to be optimised to reduce waste; products to be made as light as possible; inventories of spare parts to be reduced; greater flexibility in the location of manufacturing; products to be personalised to consumers; consumers to make some of their own products; and products to be made with new graded composition and bespoke properties.
Cloud computing	Computerised manufacturing execution systems (MES) will work increasingly in real time to enable the control of multiple elements of the production process. Opportunities will be created for enhanced productivity, supply chain management, resource and material planning and customer relationship management.
Mobile internet	Smart phones and similar devices are positioned to become ubiquitous, general purpose tools for managing supply chains, assets, maintenance and production. They will allow functions such as directed advertising, remote healthcare and personalisation of products. Linked technologies include battery technology, low energy displays, user interfaces, nano-miniaturisation of electronics, and plastic electronics.

MANUFACTURING AND THE NATURAL ENVIRONMENT

Future trends also influenced by 'environmental mega-trends'

1. Population growth

Increased demand for resources: energy, water, land, materials and food
Increased global demand for manufactured products. Manufacturers will need capabilities to understand the new, growing markets and how they are set to change
Urbanisation will mean that consumption will be concentrated in cities, which will influence the location decisions of manufacturing firms. Manufacturers will increasingly locate closer to the customer and this, for some, will involve setting up factories within cities. The implication of the need to locate in or near to cities will be that manufacturers will design their factories accordingly.
Greater integration. Manufacturers will need to Integrate with a greater diversity of players as part of the 'circular economy'.

2. Climate change

Climate change is likely to increase the vulnerability of global supply chains and increase the pressure on manufacturers to reduce their greenhouse gas (GHG) emission
Effects of climate change on food, water, health and general regional stability will also affect the supply of human resource and cost of labour around the world.

3. Resource demand

As demand increases for natural resources there is likely to be greater volatility in their prices with potential disruptions in their availability
The top four natural resources that are critical to manufacturing, which will see substantial increases in demand, are materials, water, energy and land.

Materials

Raw materials used for the manufacturing process, including ores, minerals and liquid fossil deposits, are unlikely to be depleted in the near future, but their extraction is predicted to become economically unattractive as easily exploited and high quality sources are used up
Many important manufacturing materials originate in a small number of locations outside of Europe. For example, about 40% of cobalt (uses include batteries, alloys and catalysts) is produced in the Democratic Republic of Congo and 92% of niobium (used in automotive and aerospace industries) is produced in Brazil, with most of it coming from a single mine.
To remain competitive, manufacturers will need to develop material-efficient processes and manage supply chain disruptions, as well as recovering precious materials with enhanced product stewardship.

Water

Future competition for water, driven by population growth, urbanisation and demographic shifts, may put the manufacturing sector in direct competition with food production and the basic needs of society.
Low-income countries will be particularly subject to future water scarcity
In the UK, over half of the water abstracted is used to supply electricity (55%), about one third is used for the public water supply (30%), and only 9% by industry. The manufacturing sector is the largest industrial consumer of water (using 27% of volume). UK consumption relies heavily on 'virtual water' imported and embedded in goods that are produced from water drawn in their countries of origin.

Energy

Energy prices, reliability of supply and market volatility may all affect future manufacturing

Land
Increased competition for land space with residential and agricultural sectors.

Pricing
An important future trend is likely to be 'pricing of the environment', which involves attaching an economic value to particular natural resources

Regulation
'Sustainability standards' and environmental regulations are likely to be used more widely

Consumer demand
Increasing demand for sustainable products, involving reduced energy and material use
Manufacturers will also increasingly need to consider the reputational risk of exposure to the consumption of energy and other issues throughout their value chains.

Opportunities

Improvements and efficiencies
Efficiency and reduced waste in the use of raw materials, for example metals, and other inputs such as energy, as a strategy to hedge against volatility in commodity prices and increasingly vulnerable supply chains.
Capital costs in factory design and infrastructure will constrain the magnitude of physical changes that are feasible. However, the UK manufacturing sector, particularly the aerospace and automotive subsectors, has strengths in adapting to best practice and making small adjustments.

Resource management
Manufacturers are likely to use a combination of approaches to resource management to remain competitive

Clean and resource efficient technologies
These are needed to drive re-manufacturing and recycling, and to enable more effective management of materials, energy and water.

Widespread integration of sensors into products and factories
These will generate vast amounts of information, 'big data', which leading manufacturers will use to analyse how their customers, factories and supply chains are operating. Sensors will also enable new products and processes which will provide opportunities to reduce material waste and increase the quantities of products that are monitored, repaired or refurbished before breakdown.
The key risk for the UK manufacturing sector is that it will be slow to adapt to these changes in resource management, making it vulnerable to supply chain shocks and rising resource costs.

Minimising material inputs – substitution
This involves replacing a critical material input to manufacturing with an alternative material
Most progress has been made in finding alternatives to petro-chemically-derived materials that are susceptible to strong price volatility, for example fibres for structural composites derived from sustainable bio-feedstocks, such as hemp and flax.
However, some materials used widely in UK manufacturing are not easily substitutable. Platinum, used in catalytic converters in motor vehicles is one such example. Reserves and production of platinum are concentrated in one country, South Africa.

In addition, some materials are becoming more expensive and difficult to dispose of, so there is a strong case for substituting them with materials derived from sustainable sources or materials that are readily biodegraded after use.

Minimising material inputs – dematerialisation
This involves using less material to achieve the same level of functionality in a product

Waste management (re-use, re-manufacturing and recycling):
Re-use and re-manufacturing tend to capture more value than recycling as they preserve much of the value created through the manufacturing process

Energy efficiency

Land use efficiency
Manufacturers may, for example, increasingly build vertically rather than horizontally, co-locate different parts of the value chain, and share resources with other firms and sectors. More changes can also be expected in the farming-industrial system in terms of cooperation between farms and supply chains.

Sustainability and manufacturing. Imperial College London October 2013
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjFxYGTs8zoAhWNURUIHRQrDQUQFjAAegQIBhAB&url=https%3A%2F%2Fassets.publishing.service.gov.uk%2Fgovernment%2Fuploads%2Fsystem%2Fuploads%2Fattachment_data%2Ffile%2F283909%2Fep35-sustainability-and-manufacturing.pdf&usg=AOvVaw0wxuJ4puB-Wmq8YCQUlu8S

The aim of this report is to outline the challenges and opportunities available to UK manufacturing in a future world that is projected to be resource- and carbon-constrained.

A number of environmental "megaforces" will be key drivers for business change to 2035 and beyond. These include climate change, population growth, energy and fuel, material resource scarcity, water scarcity, urbanization, wealth, food security, ecosystem decline and deforestation.

Megaforce: population growth & urbanisation
In 2050, there will be 3 billion more people in the world. The population will be older, richer and predominantly urban

Megaforce: climate change
Climate change is projected to result in an increase in average global temperatures, extreme weather events and a disruption of water availability

Megaforce: material security
Raw materials used for the manufacturing process, including ores, minerals and liquid fossil deposits, are unlikely to run out in the near future, but their extraction is predicted to become economically unattractive as easily exploited and high quality sources are depleted.

Demand for metals will increase by 30%-50% by 2020 and by up to 90% for steel and 60% for copper by 2030, compared to 2010.

Rare earth elements are important in renewable energy and clean efficiency technologies, including photovoltaic films, magnets used in wind turbines, batteries used in electric vehicles and phosphors used in low energy lighting. They have been identified as very high risk materials based on a number of criteria, including scarcity, production concentration, reserve distribution, recycling rate, substitutability and governance.

A "peak oil" scenario, estimated to occur before 2030 (Sorrell et al., 2010), will reduce supply of conventionally extracted oil and increase difficulty of discovery and extraction.
Materials based on renewable feedstocks, including wood, paper and bio-plastics rely on availability of favourable land.

Megaforce: water
The use of water is closely coupled with energy, food production and environmental integrity. Energy is used in the cleaning and movement of water.

Changes in diet will put added pressure on water supply as more meat and vegetable oils are consumed in place of grains and pulses.

Extreme weather events may influence the supply of blue water. The direct disruptions faced by the UK are likely to be less severe.

Predicted Impacts

Supply chain vulnerability
Due to cost and lack of capability, most UK manufacturers have part of their supply chain located overseas and 20% have half of their suppliers outside of the UK, with Asia supplying over half of manufacturers.

UK manufacturers have responded to the challenge of supply chain vulnerability by increasing collaboration; sourcing from multiple suppliers despite quality control issues and increased transaction costs; and on-shoring and increasing their use of local suppliers.

A resilient supply chain will have a number of characteristics that allow it to adapt to disturbances with minimal financial impact. Redundancy**,** having alternative distribution networks, including modes of transport and alternative suppliers, is an important characteristic. However, redundancy is ostensibly at odds with efficiency, where buffering capacity is removed to save costs.

Transportation efficiency
Increasing the efficiency of the global car fleet by 50% by 2050 is thought possible by deploying best practice across the sector and introducing effective demand-side pricing policies and some decarbonisation of the electricity supply.

Biofuels, as a strategy for reducing the carbon intensity of fuel, are predicted to have limited penetration due to population-driven competition for land for fuel.

There are sufficient material resources available to produce vehicles similar to those produced today to 2050, possibly with the exception of natural rubber.

Transformative initiatives in the automotive sectors are most at risk from the supply of rare earth metals, used currently in magnets and batteries in electric vehicles. This is seen as an issue of economics and politics rather than physical scarcity, but as oil is replaced by batteries this places extra demand on the rare earth supply chain.

Lightweighting powertrains could increase sector demand for rare earths from 15% of current global production to 55% by 220. The demand for carbon fibre could reach 20 times that of today and put the automotive sector in direct competition with aerospace.

Demand for aviation is projected to rise by over 200% between 2005 and 2050, especially linking the major urban centres that will exist. It is likely that the aircraft fleet in 2040 will comprise of similar aircraft to that seen today, although with improved performance.

Airlines are currently reliant on fossil fuels and assumed to be so to 2050
Carbon composites are seen as an attractive material that can be used to lightweight aircraft.

Agri-Tech
The demand for food is set to rise with world food production and predicted to increase 70% over 2005 levels by 2050. Demand for agricultural land is predicted to peak by 2030 and then decline as crop productivity increases.

Climate change will affect crop yields.

Agriculture is responsible for over 2/3 of all water used by humans.

New science and technology needs to be developed, including genetically modified crops; there must be widespread implementation of existing best practice; demand for resource-intensive food must be reduced; governance of the food system must be improved; and waste must be minimised.

Energy efficiency
A number of industries are now working at near maximum efficiency given the technology available. In order to meet 2050 climate targets new strategies for further substantial reduction will have to include the deployment of best practice across the industry; the capture and use of underutilised resources, such as recycling waste heat; developing cross-sector synergies; innovation in new materials and processes; development of carbon capture and storage systems; and the use of decarbonised electricity, all of which will require an increase in R&D activities.

A number of new technologies, including Ultra Low CO2 Steel, cement kiln processes and clinker replacement, are predicted to reach market maturity between 2010 and 2030

B2. PRECISION MANUFACTURING
(e.g. photonics; quantum; electronics (incl. medical devices))

B2.1. SECTOR OVERVIEW

This sector is difficult to define but vital for the UK's decarbonisation pathways. Several sub-sectors have been identified, including photonics, electronics, quantum and solar energy technologies.

Photonics is a major manufacturing and exporting sector built on four centuries of UK leadership but does not have a dedicated standard industrial classification (SIC) code, which makes it difficult to determine its size and to accurately define its environmental impacts.

Similarly, for quantum technologies, Scotland is a leading centre for research but its contribution to manufacturing output is undefined.

Solar energy is increasing in importance in the UK and therefore it may be anticipated that manufacture of solar cells will be required. There is currently no classification code and little information on this topic.

There is more information for electronics in the UK but there is an undefined amount of crossover with photonics and little information on environmental impacts of manufacturing processes.

The lack of detailed environmental information may be due to the fact that these are not energy intensive industries but they do represent enabling technologies when it comes to decarbonisation of other industries and therefore are important to consider.

Electronics Sub-Sector Overview
The Electronics sector has a presence across the UK. Scotland's GVA and turnover per region as % of UK are 9.3% and 8.7% respectively (1).
The UK electronics sector is diverse, producing a wide range of products. Broadly, what the sector makes can be split into eight segments (1).

1. ELECTRONICS COMPONENTS AND BOARDS
This class includes the manufacture of semiconductors and other components for electronics applications e.g. connectors, transistors and switches. Much of these products are used in the development of other electronics products and is an area where UK manufacturing is a key global player.

2. COMPUTERS AND PERIPHERAL EQUIPMENT
This segment refers to the production and/or assembly of electronics computers including desktops and laptops, and their complementary equipment such as printers, keyboards and monitors.

3. COMMUNICATION EQUIPMENT
Captured here are two broad strands: the manufacture of telegraph and telephone equipment (e.g. mobile phones, answering machines, pagers) and other non-telegraph and telephone communication equipment such as transmitting and receiving antenna used for television and radio .

4. CONSUMER ELECTRONICS
As the name suggests this segment includes the manufacture of electronic audio and video equipment for home entertainment e.g. televisions, stereo equipment, video game consoles. The manufacture of smart phones however are focused predominantly in Asia and the US

5. INSTRUMENTS AND APPLIANCES FOR MEASURING, TESTING AND NAVIGATION
The sector's largest segment makes up more than half of output. It includes the manufacture of measuring, testing and navigating equipment for various industrial and non-industrial purposes e.g. emission testing equipment, hydronic limit controls, consumption meters, radar and GPS equipment and motion detectors. It also includes time-based measuring devices such as watches and clocks and related devices.

6. IRRADIATION, ELECTRO-MEDICAL AND ELECTROTHERAPEUTIC EQUIPMENT
These instruments and appliances are predominately used in healthcare. They include a vast array of essential equipment including X-ray equipment, CT scanners, PET scanners, MRI equipment, pacemakers and electrocardiographs.

7. OPTICAL INSTRUMENTS AND PHOTOGRAPHIC EQUIPMENT
This class includes the manufacture of optical instruments and lenses (e.g. mirrors, magnifying instruments), and the manufacture of photographic equipment including both film and digital cameras.

8. MAGNETIC AND OPTICAL MEDIA
The manufacture of magnetic and optical recording media, such as blank magnetic audio and video tapes makes up a very small proportion of the sector's output.

Photonics Sub-Sector Overview
All science and technology related to the generation, transmission, detection and manipulation of light is known as 'photonics'. Photonics technologies range from basic optical lenses and optical fibre, to lasers, displays and cameras of all types, incorporated in products and high productivity manufacturing processes worldwide (3). Photonics manufacturing makes up around two thirds of the total reported output from the computing, electronics and optical products sectors (2).

Photonics manufacturing is distributed throughout the UK. The estimated UK photonics output in Scotland is £997m. Over 70% of photonics companies turn over less than £5m annually, with 170 mid- and large-sized firms employing 90% of the workforce, and generating 96% of the output (2).

Solar Energy Technologies Sub-Sector Overview

Solar Energy Technologies fall into two broad categories:

Photovoltaic (PV)
Photovoltaic cells convert sunlight into electric current

Concentrating solar power (CSP).
CSP uses reflective surfaces to focus sunlight into a beam to heat a working fluid in a receiver. Such mirrored surfaces include heliostat power towers (flat mirrors), parabolic troughs (parabolic mirrors), and dish Stirling (bowl-shaped mirrors) (4).

The size and location of a solar energy installation determines whether it is

Distributed.
Distributed solar energy systems are relatively small in capacity. They can function autonomously from the grid and are often integrated into the built environment (e.g., on rooftops).

Utility-scale.

Utility scale solar energy (USSE) enterprises have relatively larger economies of scale, high capacity (typically 41MW), and are geographically centralized —sometimes at great distances from where the energy will be consumed and away from population centres (4).

B2.2. ENVIRONMENTAL IMPACTS

There is little information on environmental impacts but some can be picked out from statistics or publications and are detailed below.

In anticipating the increase in solar energy requirements, the environmental impacts of large-scale installations was considered as these can be inferred from existing large scale operations (4). These represent possible scenarios rather than being specific to the UK solar sector and are linked to the use rather than production of solar cells. However, the environmental effects translate to other types of large construction projects and given the potential rise in large-scale data centres, it is worthy of note.

IMPACTS ON AIR

According to the Scottish Government's Scottish greenhouse gas emissions 2017, electronics produced 0.01482587MtCO2 equivalent of Hydrofluorocarbons and of 0.000371351MtCO2 equivalent of Nitrogen trifluoride but there is no information on direct CO2 emission from the sectors or sub-sectors.

This may be due to the fact that the main energy use is electricity which is derived from the National grid and thus emissions depend upon the source of that energy. Air conditioning and use of refrigerants to maintain the ambient temperatures required for fine-scale production is a source of GHGs and electricity use but this is not split out by sector.

IMPACTS ON WATER

Utility scale solar energy (USSE) technologies vary in their water withdrawal (total volume removed from a water source) and consumption (volume of withdrawn water not returned to the source) rates.

Photovoltaic energy systems have low rates (0.02m3/megawatt hours [MWh]), consuming water only for panel washing and dust suppression in places where dust deposition is problematic.

In the case of CSP, the water consumption depends on the cooling system adopted —wet cooling, dry cooling, or a combination of the two (hybrid cooling). The use of dry cooling reduces water consumption by 90% to 95%, is a viable option in water-limited ecosystems. Reduced efficiency and higher startup costs have been an economic deterrent to dry cooling.

Chemical spills of materials such as dust suppressants, coolant liquids, heat transfer fluids, and herbicides can pollute surface ground water and deep-water reservoirs.

IMPACTS ON LAND

The impacts of large-scale solar installations can have effects on biodiversity. In general, distributed and utility scale solar energy (USSE) installations integrated into the existing built environment (e.g., roof-top PVs) will likely have negligible direct effects that adversely impact biodiversity. USSE sites not integrated can affect endangered and vulnerable species.

Centralized USSE operations require transmission of generated electricity to population centres where consumption occurs. This necessitates the development of expanded transmission infrastructure. Landscape fragmentation due to transmission corridors may create barriers to the movement of species and specifically less mobile genres. However, the majority of UK is unlikely to suffer this due to its urban intensity and existing infrastructure. Rural Scotland may be affected though.

Environmental toxicants required for USSE operation (e.g., dust suppressants, rust inhibitors, antifreeze agents) and herbicides may have consequences on both local and regional biodiversity.

The fire hazard potential of both rooftop and ground-mounted USSE infrastructural materials (e.g., phosphine, diborane, cadmium), and their proper disposal, presents an additional challenge to minimizing the environmental impacts of USSE facilities.

The radiative balance at the land-atmosphere interface can shift when the albedo of a PV solar installation differs from the former background albedo. Given their absorptivity, PV panels have an effective albedo (averaging 0.18–0.23), a function of its inherent reflectivity and solar conversion efficiency.

During the decommissioning phase of solar installations, photovoltaic cells can be recycled to prevent environmental contamination due to toxic materials contained within the cell, including cadmium, arsenic, and silica dust

B2.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

These sub-sectors have opportunities to aid other industries to increase energy efficiency.
Key opportunities for the electronics and photonics sub-sectors to influence reduction of environmental impacts in the UK include:

Communication
The industrial application of 'the internet of things' allows machines and devices to "talk" to each other to improve performance and to reduce downtime. Suppliers are able to instantaneously schedule maintenance duties and minimise disruption to their production process.
Sensors embedded in production chains can provide real time information and reduce waste while increasing energy efficiency.

The fifth generation of mobile communication (5G) would allow virtual reality (VR) to improve and expand. The use of VR may help companies to reduce the impact of repair, maintenance and installation costs.
Fibre optic communication networks are fast and more energy efficient.

Efficiency in Manufacturing Processes
Digital design, simulation, and integration, enables companies to inspect and design objects at all conceivable scales at the design stage. This in theory should eliminate defects earlier on in the production process, preventing problems further down the line, which inevitably are more expensive and difficult to rectify. Digital holography is beneficial in production control.

Additive laser-based processes are beneficial in that even complex geometries can be produced and processed quickly, while the materials deployed can be used efficiently. This means that in industrial production, components with improved functions and properties can be produced, which significantly increase energy efficiency

'3D printing' offers new design freedom throughout production technology.

Environmental Monitoring
Satellite-based lasers can measure the distribution, creation and adsorption of greenhouse gases globally online. This opens up opportunities to record local climate change events in real time.
Land-based optical systems allow for the early detection of forest fires.
Preservation of traffic infrastructures through laser scanning.
Laser spectroscopy for the measurement of exhaust gas emissions.

Transport Efficiency
Electronics in hybrid and electric vehicles.
Unmanned aerial vehicle (UAV) production.
Laser technology in lightweight construction. Lightweight construction plays a central role in electromobility in particular to compensate for the weight of the batteries used.
The reduction of mass in space travel using additive processes
Efficient turbo engines for aviation technology through laser-based processes

Efficient Energy Generation
Photonic technologies contribute to efficient manufacture in energy generation, in increasing the efficiency of solar panels, in energy storage and conversion, in reliable and safe battery cells, as well as in compact electrical drives for electromobility.
When generating renewable energy such as wind power, Photonics based manufacturing processes allow for greater efficiencies and longer lifespans of wind turbines.
Combustion processes for both traditional fossil fuels and for the development of turbines for renewable energy can be optimised, particularly using additive laser processes of extreme temperature-resistant materials and precision drilling for optimised cooling. This allows CO2 emissions to be reduced systematically.

Recycling
The proportion of secondary production (recycling) of metals and other materials, such as from cars and mobile phones, can be increased using photonics based processes.
Lasers can be used to economically coat or repair components, increasing their shelf lives. In many cases, chemicals that are harmful to the environment are no longer required.

In the case of solar technologies, the substitution of carbon-intensive energy sources for solar energy has enormous potential to mitigate climate change by directly reducing greenhouse gas emissions
Additional environmental co-benefit opportunities include:

(1) Utilization of degraded lands,
(2) Co-location of solar panels with agriculture,
(3) Hybrid power systems,
(4) Photovoltaics
(5) Novel panel architecture and design that serves to concomitantly conserve water and land resources

B2.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

The UK may be slow to adapt to new technologies.

Brexit may create risks for access to R&D funding. The Precision sector has benefited from EU funding programs, specifically Horizon 2020.

Cybersecurity. The electronics sector is particularly exposed to this risk considering how their products may be affected by cybercriminals and it therefore needs to invest a conspicuous amount of money to provide safe products.

KEY REFERENCES

1. Make UK. Sector Bulletin Electronics
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-electronics.pdf

2. UK Photonics: The Hidden Economic Engine
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=2ahUKEwiNtbr8ifzoAhVJaRUIHUQhCAQQFjABegQICxAD&url=https%3A%2F%2Fphotonicsuk.org%2Fwp-content%2Fuploads%2F2018%2F05%2FUK_Photonics_The_Hidden_Economy.pdf&usg=AOvVaw1euqtHfdtHc6Kh2RgL5Pc1

3. Light as the key to global Sustainability
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=2ahUKEwjolPzn68noAhUQEcAKHfQyC7QQFjACegQIAhAB&url=https%3A%2F%2Fwww.photonics21.org%2Fdownload%2Fppp-services%2Fphotonics-downloads%2FStudy_GreenPhotonics_2020_final.pdf&usg=AOvVaw2KUF_GVNjLUoQLMscbyosm

4. Environmental impacts of utility-scale solar energy
https://doi.org/10.1016/j.rser.2013.08.041

B3. MEDIUM-SCALE / IN-FACTORY MANUFACTURING
(e.g. automotive; aerospace (incl. satellites))

B3.1. AUTOMOTIVE

B3.1.1. SECTOR OVERVIEW

The automotive sector manufactures a range of motor vehicles from cars, buses and commercial vehicles (vans, lorries etc.) to snowmobiles, golf carts and caravans. This is complemented by the production of bodies for motor vehicles and their parts and accessories, such as electrical and electronic components, gearboxes, brakes and airbags.

The automotive sector primarily produces final goods and 40% of what's made is consumed by domestic households, while another 29% travels to overseas markets (2).

B3.1.2. ENVIRONMENTAL IMPACTS

Most research into the environmental impacts surrounding the automotive industry focus on the opportunities for it to impact emissions from the products it manufactures through low-carbon designs and sustainable fuel types.

However, there is some information on the manufacturing process itself and the industry appears to have considered in detail its impacts on the environment.

IMPACTS ON AIR

The main energy use of the sector is from electricity and therefore this represents a source of greenhouse gas emissions depending on the makeup of the fuel used to generate it for the grid. Some processes are particularly energy intensive such as painting, which can account for almost half of the energy used by an average assembly plant (1).

Painting also results in VOC (solvent) emissions, which are considered one of the key environmental impacts of vehicle manufacturing. VOCs are a precursor to the formation of ground level ozone and photochemical smog (1).

Automotive manufacturers can have global supply chains but the industry has put effort into consolidating these. However, export and import of components and finished products is still energy intensive.

IMPACTS ON WATER

Water use and effluent also impacts the local environment as does waste sent to landfill such as sludge form paintshops (1).

IMPACTS ON LAND

<nothing noted>

B3.1.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

The sector appears committed to reducing its environmental impact and has made significant improvements. In addition, investment in R&D has historically been high in the sector (2) and this provides it with an ideal opportunity to lead in developing low carbon technologies and more advanced manufacturing processes.

Opportunities to reduce energy use in the manufacturing process include:

Investment in Renewables
Increased volume of power generated by wind turbines, onsite or local solar panels
Some manufacturers require their energy supplier to provide them with Renewable Energy Guarantees of Origin (REGO) certificates, which guarantees that their energy purchased comes from renewable sources (1).

Installation of combined heat and power (CHP)
Switching from using electricity to gas, which has a lower emission factor
In CHP plants, turbines combust natural gas to simultaneously generate electricity and recover what would otherwise be wasted heat. CHP can reach 90% efficiency, whereas conventional electricity generation converts only 30% of fuel into usable energy (1)

Efficiency improvements
Building insulation reduced space heating needed
Eliminating heat loss during non-production periods

Opportunities to reduce water use include:
Reducing effluent
Rinse waters in the paint shop cascaded in reverse so the dirtiest water is used for the first rinse and so on. This minimises fresh water usage and ensures that only the strongest effluent is discharged to the on-site effluent treatment plant (1)
Review of chemical dosing regime in painting processes (1).
Reducing water loss
Real time detection of leaks allows efficient water system repairs
Adjustment to water testing regime for the finished vehicle to minimise water loss through evaporation

Opportunities to reduce waste/hazardous waste include:
The volume of sludge from paintshops sent to landfill can be minimised by reducing the amount of water it contains and creating a dried residue, which can be used in the production of cement (1).
Utilisation of high calorific hazardous waste, such as paint sealer for thermal treatment with energy recovery (1).
Coolant can be cleaned and processed on site to enable its re-use, reducing the need for transportation of waste coolant and reducing the volume of new coolant brought in (1)
Foundry sand can be used by construction companies for road fill (1)

Opportunities to imperative automotive supply chain efficiency
Vehicle manufacturers have already worked to integrate delivery systems (2) but routes could be consolidated further.

Recycling/Re-use/Remanufacturing

Secondary material use could be increased.

Re-usable and dedicated packaging can be introduced to reduce damage and handling times. Smaller and lighter weight packaging would reduce loads.

Some products, such as machinery and engines, lend themselves naturally to remanufacturing (1), under certain conditions, such as when:

- the product has a high value
- the product is durable
- the product is designed for ease of disassembly
- the product is leased or delivered as a service instead of hardware.

The benefits of remanufacturing include reductions in raw material consumption, energy consumption and CO2 emissions and waste sent to landfill. In addition, remanufactured products can have longer durability than some original parts of lower quality. However, it needs to be noted that the original part must be of good quality (1).

B3.1.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

Brexit may lead to:

- Reduced trade channels
- Tariffs. About 80% of all parts and accessories imported for use in UK production are sourced from the EU (2).
- Access to skills
- Rising input costs
- Slowdown in consumer spending
- OEM investment decisions

Increased weight

Since 2008, vehicle weight increased by 18% on average and is expected to increase further in the future due to increased volumes of battery electric vehicles (BEVs) (1).

Some parts made from recycled material need to be reinforced to reach the same properties, therefore are heavier than those made form virgin sources, which adds to the vehicle weight and consequently leads to increased emissions (1).

Challenges in Reduction of VOCs

Installation of VOC abatement equipment can be a relatively quick solution, but can also be undesirable in the long run. For instance, additional energy is required to run the abatement plant and this is an ‘end of pipe’ remedy rather than minimising VOCs at source in the paint (1)

Reducing VOC emissions has had an adverse effect on energy consumption. For instance, moving to water-based paints requires longer drying times, so more energy and more space is needed to install drying ovens (1).

Challenges in recycling

Parts containing recycled content often differ visually to parts made with virgin material, so their use in vehicle surface applications is limited for aesthetic requirements (1).

Many recyclers are batch based, meaning they cannot guarantee larger industrial quantities of material to the same standard (1).

Secondary materials are often derived from products put on the market several years ago, using materials which are not necessarily used currently due to the availability of improved materials which are able to fulfil the latest technical requirements and contribute to vehicle light weighting (1).
The potential restriction on content of certain substances, such as lead and flame retardants, might hinder the use of some secondary materials in new products.
Suppliers charge a premium for materials that include recycled content, which makes the business case for using such materials more difficult.

Challenges in remanufacturing
Remanufacturing companies are usually small with limited resources to invest in the fast pace of change in alternative fuel technologies e.g. EV batteries and hydrogen vehicles etc.
A key barrier to the uptake of successful remanufacturing is the return of end of life products (or 'core') from the consumer back to the remanufacturer, although remanufactured products are sometimes sold at 30-70% of the cost of new products (1)
Although the remanufacturing sector has the potential for huge job creation, these jobs are skilled and the associated costs of training a new or existing workforce are high.
Access to test data or the ability to extrapolate test data is critical since products are becoming more complex and particularly in automotive are integrated into the overall vehicle management rather than being standalone parts (1).

KEY REFERENCES

1. SMMT Sustainability Report 2019
https://www.smmt.co.uk/wp-content/uploads/sites/2/Sustainability-energy.jpg

2. Make UK Automotive Sector Bulletin
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-automotive.pdf

B3.2. AEROSPACE

B3.2.1. SECTOR OVERVIEW

Note- includes manufacturing portion of space sector
The aerospace industry as defined in this study manufactures everything from aeroplanes and helicopters to spacecraft, rockets and satellites, airships, balloons and gliders.
Aircraft manufacturing in the UK is relatively evenly distributed, with no one region dominating. In Scotland, it is a mature and highly developed industry largely focused on maintenance, repair and overhaul activities in Prestwick and the surrounding areas (4). According to ADS, the trade organisation for companies in the UK Aerospace, Defence, Security and Space sectors, the Scottish aerospace sector has a turnover in 2017 of 2billionn and a GVA of 0.6billion (3).
The ADS figures for the Scottish space sector in 2017 reported a turnover of £2.5billion and a GVA of 1billion (3). The UK, including Scotland-based sites, have particular strengths in the manufacture of large telecommunications and weather satellites and small surveillance satellites and Scotland has also been chosen as the home for the UK's first vertical spaceport (5).
Space manufacturing is often bespoke or involves very limited production runs and it is an export-focused sector, and its manufacturing supply chains are typically integrated across borders and flexible (5).

B3.2.2. ENVIRONMENTAL IMPACTS

There is little information on the environmental impacts of the manufacture of aircraft and most research focuses on the impacts of the products it manufactures. The impact of aviation is notable and since air travel around the globe is expected to rise in the foreseeable future by between four and five percent annually, there is considerable opportunity for green innovations in aircraft manufacture to lead to reductions in Scotland's carbon budget (1, 2). Similarly, space travel and satellite launches are anticipated to become more frequent and for this reason, the environmental impacts of aviation and space travel are therefore also covered here, despite not being the focus of the study (which looks at the manufacture of products as opposed to their use).

IMPACTS ON AIR

Aviation impacts the environment in a number of ways; contributing to climate change through emitting greenhouse gases, causing noise pollution and generating derived emissions and congestion from travel to and from airports. Currently UK aviation gross emissions account for 7% of total UK carbon emissions and this has increased over time. In 1990 the gross emissions from flights departing the UK was 17MtCO2 and by 2017 it was 37 MtCO2 (6).

The environmental impacts of the manufacture of aircraft as previously stated, is not easily derived from existing literature although some studies have described the operations of specific manufacturers who have sought to reduce energy use (e.g. Levers, A. and Lunt, P. 2011. Reducing Energy Use in Aircraft Component Manufacture - Applying Best Practice in Sustainable Manufacturing. SAE AeroTech Congress, SAE Technical Paper. DOI: 10.4271/2011-01-2739). Electricity is the main energy source and many processes such as anodising and drying, are particularly high consumers. The demand for rare metals and composite materials leads to a global supply chain with associated environmental impacts

The impacts of space travel are less well documented, primarily because launches are relatively rare. However, they are anticipated to increase, especially in Scotland due to its new vertical spaceport. Rocket engines emit reactive gases that cause ozone molecules to break apart. They also discharge microscopic particles of soot and aluminum oxide and components are not generally recycled but rather left to burn up on re-entry.

The impacts of manufacture of satellites and other spacecraft is not well defined. From comparison with the aviation sector, it can be anticipated that sourcing and supply of the components required in manufacturing process such as rare metals and composites may have an environmental impact. Electricity is the main energy source.

IMPACTS ON WATER

<nothing noted>

IMPACTS ON LAND

<nothing noted>

B3.2.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

The opportunities for the sector to reduce its environmental impact are mainly focused on its ability to create more energy efficient products. Indirectly, this also has an impact on the energy efficiency of the manufacturing process itself through creating a greener global supply chain and more efficient telecommunications network.

The main opportunities that can be derived from the literature are:

Moving towards hybrid-electric

The move to more electric propulsion in aircraft is becoming more feasible with the development of new battery technologies driven by the automotive sector.

Sustainable/Alternative fuels

Summary Sustainable Aviation Fuel (SAF) creates an opportunity for aviation carbon reductions. (6) Research has found that second generation biofuels, rich in bio-derived oils, such as soybeans and algae can be chemically processed to make high quality jet fuel. For wide adoption and success of biofuels, they must be suitable for use in engines and aircraft fuel systems. They must also be able to be mass produced in a commercial environment, as well as being competitive on price to conventional kerosene Biofuels remain some way off replacing traditional kerosene in civil aviation (4).

Unmanned air systems

Digital technologies

Sensors that detect maintenance issues in real time and transmit the data to its engineers around the world or even fix them automatically (4).

Advanced sensing capability to securely gather data both onboard the air vehicle and associated ground infrastructure.

Advanced artificial intelligence approaches including machine learning and data analytics will enable the aviation system to deliver breakthroughs in future mobility and support priorities on clean growth.

Factory of the Future/3D Printing

Traditionally, component parts are made from a solid block of material, which is cut away at to form the required shape and dimensions. However 3D printing works in reverse, creating from the inside out. The process repeatedly prints very thin layers of material on top of each other until the layers form a solid object. As a result, components created by 3D printers have a natural and topologically optimised shape, greatly improving efficiency and performance. Furthermore such components are lighter yet still strong, have lower lead times and ultimately less expensive than conventional parts. There are still some limitations to the technology, including the size of component parts that can be created, a narrow range of printing materials and inconsistent quality. However as advances in the technology continue to be made, these challenges should be overcome, allowing widespread adoption of the technology and the associated benefits (4)

Use of Composites

Composite materials offer several advantages over conventional metallic materials, namely their excellent durability and high stiffness to density ratios. They are also much lighter, allowing for greater fuel efficiency and therefore travel distances. Moving to a composite primary structure also reduces the overall maintenance needed to be carried out on the aircraft (4).

Effective Market Based Policy Measures

In this model, carbon is given a value and airlines pay for emissions via carbon savings from projects on the ground, for example, efficiency, renewable and nature based solutions (6)

Airspace Modernisation

Air traffic management and operational improvements are likely to reduce CO_2 emissions from UK aviation (6)

Improvements in Aircraft and Engine Efficiency
Introduction of "known" aircraft types will improve fleet-average fuel efficiency of UK.
Introduction of "future" aircraft types from 2035 onwards (including conventional and hybrid-electric aircraft) and from 2040 onwards (pure-electric aircraft on shorter range flights) has the potential to further reduce fleet CO2 emissions within UK aviation, taking account of likely fleet penetration by that date
Post 2050, improvements in fleet-average fuel efficiency will continue due to the ongoing penetration into the fleet of "future" aircraft types (6).

Carbon Capture and Storage (CCS)

B3.2.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

UK exit from the EU (4) which may lead to

- Uncertainty on investment decisions
- Protectionist measures and tariffs may be introduced
- Loss of EU funding for R&D

Input cost pressure on margins
Weakness in the domestic supply chain
Impact of low oil price on key Middle East market for UK defence exports
Ageing satellites under threat from cyber attacks
Space policy is not a devolved matter, which constrains the impact Scotland can have on the sector
Prices for sustainable aviation fuels remain high and therefore volumes remain low. Aviation fuels are presently not prioritised and without greater government support, larger volumes of SAF are unlikely to be realised post 2035 (6).

KEY REFERENCES

1. BEIS Industrial Strategy- Sector Deal: Aerospace
https://www.gov.uk/government/publications/aerospace-sector-deal
ADS/ ADS Scotland.

2. UK Aerospace Outlook 2019
https://www.adsgroup.org.uk/wp-content/uploads/sites/21/2019/06/AD00046_2019_AerospaceOutlookBooklet-FINAL-soft-copy-single-pages.pdf

3. Facts and Figures 2017
https://www.adsgroup.org.uk/wp-content/uploads/sites/21/2017/12/ADS-Scotland-FactsFigures-2017.pdf

4. Make UK Aerospace Sector Bulletin
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-aerospace.pdf

5. UK Parliament- Space Sector Report
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=10&cad=rja&uact=8&ved=2ahUKEwjHvuWSyf7oAhWUilwKHdTjBlwQFjAJegQIChAB&url=https%3A%2F%2Fwww.parliament.uk%2Fdocuments%2Fcommons-committees%2FExiting-the-European-Union%2F17-19%2FSectoral%2520Analyses%2F34-Space-Report.pdf&usg=AOvVaw0_eygOs_tTdcJzY2DF02c6

6. Sustainable Aerospace. DECARBONISATION ROAD-MAP: A PATH TO NET ZERO A plan to decarbonise UK aviation
https://www.sustainableaviation.co.uk/wp-content/uploads/2020/02/SustainableAviation_CarbonReport_20200203.pdf

B4. LARGE-SCALE FABRICATION
(e.g. shipbuilding; mechanical equipment (including wind turbines))

B4.1. SECTOR OVERVIEW

The large-scale fabrication sector of this report covers shipbuilding and manufacture of mechanical equipment. Wind-turbine manufacture is included within mechanical equipment due to the anticipated demand for these products with the expansion of renewable energy.

Scotland is an important shipbuilding hub and hosts the only UK shipyards currently used to design build and commission sophisticated naval warships at Govan and Scotstoun sites (1).

When investigating environmental impacts, shipbuilding, like the construction of other transport equipment, is difficult to untangle from the use of its products. The maritime sector is key in forming the supply chain for many other industries covered in this report; the UK's major ports handled just under half a billion tonnes of commercial cargo and over 22 million passengers in 2017, accounting for around 95% of UK trade (1,2). It was therefore considered important to include some information on the impacts of shipping itself in the literature study despite the focus being on the manufacturing process.

The mechanical equipment sector encompasses a wide range of products and systems broadly split into five segments (4).

1. General purpose machinery e.g. turbines, engines, pumps and compressors
This segment refers to machines that transfer one type of work into another. This industry segment also produces diesel and other internal combustion engines and their components (such as gears), as well as air compressors and pumps.

2. Agricultural and forestry machinery e.g. tractors

3. Other general purpose machinery e.g. ventilation, heating and air conditioning equipment
Production of machines that are used across many different industries. Captured here include non-domestic cooling and ventilation equipment, ovens and furnaces, office equipment such as printers, and lifting and handling equipment e.g. fork lifts.

4. Metal forming machinery e.g. rollers and moulds
The segment encompasses the drills, moulds, presses, and rollers needed to form metal, as well as the accessories used by these machines.

5. Other special purpose machinery
This segment refers to machines used in specific sectors, including construction, mining, quarrying, rubber and plastics, food and drink, and textiles. These machines tend to be more bespoke systems, which are differentiated in order to carry out specific tasks related to their sector's needs. Examples include oil and gas extraction equipment.

The Scottish output and turnover in mechanical equipment as a % of the UK total is 7.6% and 7.3% respectively (4).

The chief process used through the mechanical equipment sector is assembly and the vast majority of goods it manufactures are finished capital goods, used in other sectors to deliver an action or product. Consequentially, 27% of the sector's demand is derived from the investment needs in the

UK market with the remainder consisting of components used in the production of these finished capital goods, as well as components used to make products in other sectors (4).

Trade is essential to the mechanical equipment sector's standing and performance. Imports are growing in order to satisfy demand needs across industrial sectors and the sector is one of the most export intensive in UK manufacturing (4).

B4.2. ENVIRONMENTAL IMPACTS

The environmental impacts of shipbuilding are difficult to assess at present day although there is information on past pollution. This may be because the sites in Scotland primarily make products for defence and there may be less public information available on the mechanisms of assembly. In the case of shipping, there is more information so this has been included as the opportunities for the sector to contribute to reducing environmental impact overall could lie in making more energy efficient ships.

Similarly, there is little information on a broad scale on the environmental impacts of the mechanical equipment manufacturing sector. This may be because it produces such a wide variety of products and there is likely more information on specific processes.

IMPACTS ON AIR

In terms of CO_2 emissions, shipping is considered one of the most efficient modes of transport. However, it also represents a substantial source of greenhouse gas emissions, as the fuel used has historically been some of the most polluting fuel used across all transport modes.

Shipping also generates emissions to air of several pollutants harmful to human health: nitrogen oxides (NO_x), sulphur dioxide (SO_2), particulate matter (PM2.5 & PM10), volatile organic compounds (VOCs) and ammonia (NH_3) (2,3). There is therefore opportunity in the manufacture of ships and other maritime transport, to switch to more energy efficient materials and greener fuels. However, this may conflict with the defence needs to ships build in Scotland.

In the mechanical equipment manufacturing sector, there are a huge variety of processes with differing energy consumption and environmental impact. However, there are some common processes used to generate different products that provide some insight.

The primary raw materials are metals and other composite materials (4) that are used to build the electrical system (windings), magnetic system, mechanical structure and insulation of the machine. Each of these steps requires energy, the majority of which is electricity. Environmental impacts stem from this electricity (to a greater or lesser extent depending on its source) and from the supply chain.

IMPACTS ON WATER

<*nothing noted*>

IMPACTS ON LAND

<*nothing noted*>

B4.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

The key opportunities from the literature in both the shipbuilding and mechanical equipment sectors are in producing more energy efficient and greener products rather than in the manufacturing operations themselves. That said, there is crossover between a more effective and environmentally conscious transport network and supply chain and a reduced impact for the manufacturing sector that produces it.

The shipbuilding sector has opportunities to aid decarbonisation of the maritime transport sector and benefits from government support under the policy commitments of the Clean Maritime Plan (3). These policy commitments include financial incentives to support innovations towards zero-emission shipping.

The shipbuilding sector also has opportuinities to investigate technologies and fuels on a path to net zero and to establish itself as a world leader.

Technologies/fuels could include the following (3):

	Technology/Fuel	Technology/fuel usage	Further detail
Alternative fuel propulsion	Methanol	Can be used directly in an internal combustion engine or fuel cell.	Can be used as a fuel itself or a store for hydrogen.
	Hydrogen		Can be used as an input to ammonia or methanol production as well as a fuel itself.
	Ammonia		Can either be used as a fuel itself, or as a carrier for hydrogen before the hydrogen is used as the fuel.
	Biofuels	Used directly in an internal combustion engine.	Various types of biofuels from different sources of biomass (e.g. crops, wastes) possible.
Non-fuel propulsion	Hybrid propulsion	A diesel engine acts as a power source, charging batteries, which power an electric motor, often in order to keep the diesel operating at its most efficient load point.	Diesel engine power converted to electric drive.
	Fully electric propulsion	No diesel engine. An electric motor is entirely powered by batteries, which are charged whilst the vessel is in port.	Batteries charged onshore.
	Shore-power (cold-ironing)	Use of an onshore power supply (rather than onboard diesel engines) to run auxiliary (non-propulsion) electric systems while the vessel is in port.	Does not substitute propulsion energy, only auxiliary loads and only when in port.
	Wind propulsion	Can take various forms, such as: – Sails – Flettner rotors – Kites	
	Solar power	Use of photovoltaic cells to covert solar radiation into electric power using the available space on deck.	Enhances primary propulsion or auxiliary supply.
Energy efficiency options	Various	Examples include: – Rudder Bulb – Air Lubrication Bubbles – Pre-Swirl propeller ducts – Vane wheel – Hull scrubbing – Trim optimisation	These are all options that have potential to improve energy efficiency of vessels[41].

In the mechanical equipment sector, opportunities lie in alternatives forms of business such as after-sales services. These focus on repair and maintenance and keep products in circulation longer, reducing waste (4).

The nature of mechanical equipment products – namely their role as a capital investment by other businesses – means they tend to have longer lifespans than products in other branches of manufacturing and customers are now increasingly not just wanting to pay for the sole piece of equipment or the "base level", but guarantees on the running of machines and "productive maintenance", given the impact to their business of failure (4).

New financial models such as leasing are also opportunities for the sector to reduce its environmental impact (4).

Renewable energy equipment is also expected to grow in importance – for example wind and hydro-electrical turbines, fuel cells and biomass systems (4).

The sector is well placed to take advantage of grid electrification.

The Internet of Things (IoT), big data analysis and automation/4IR technologies are all opportunities for the sector to increase operational and energy efficiency.

B4.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

Focus on environmental impacts of maritime transport rather than direct impacts of ship manufacture.

Inefficient contract and supply chain meaning that ships enter service later than planned and aging ships are retained in service beyond their planned lifespan. This means new technologies not in circulation and existing models subject to refit and maintenance costs (and reducing second hand export opportunities) (1).

Capital for shipbuilding projects not consistently assured.

Ageing workforce, and difficulty in recruiting appropriately skilled staff mid-career
Some of the maritime industry and shipbuilding for defence are not devolved areas making it difficult for Scotland to fully influence policy.

Threats to the three main global demand drivers in the mechanical equipment sector (4):

1. Capital investment demand
2. Commodity price fluctuations e.g. fossil fuels, metals
    - Exchange Rate Volatility
    - Oil price fluctuations
3. Trade performance
    - Brexit

    i) Tariff and non-tariff barriers: The mechanical equipment sector is a highly globalised industry, importing and exporting goods across the globe, with the EU its main trading partner
    ii) Regulation: As is the case with most sectors, the regulatory landscape for the mechanical equipment sector is designed at a European wide level, with the key piece of legislation being the Machinery Directive

KEY REFERENCES

1. National Shipbuilding Strategy
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/643873/NationalShipbuildingStrategy_lowres.pdf

2. Maritime 2050 and annexes
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/872194/Maritime_2050_Report.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/877630/technology-innovation-route-map-document.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815666/economic-opportunities-low-zero-emission-shipping.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815667/economic-opportunities-low-zero-emission-shipping-technical-annexes.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815671/identification-market-failures-other-barriers-of-commercial-deployment-of-emission-reduction-options.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816015/maritime-emission-reduction-options.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816017/potential_demands_on_UK_energy_system_from_port_shipping_notification.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816019/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs-technical-annexes.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815665/port-air-quality-strategies.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816020/potential-role-targets-economic-instruments.pdf

3. Clean Maritime Plan
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815664/clean-maritime-plan.pdf

4. Make UK Sector Bulletin Mechanical Equipment
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-mechanical-equipment.pdf

B5. FOOD AND DRINK
(including Scotch whisky)

B5.1. FOOD AND DRINK (GENERAL)

B5.1.1. SECTOR OVERVIEW

Food manufacturing involves the processing of agricultural and fishing products into food for humans or animals. Processing can take several different forms depending on the type of product being manufactured. Food processing also includes adding components to food, such as ingredients that extend shelf life or vitamins that improve nutritional quality. Similarly, the manufacturing process for beverages will differ based on the type of drink produced (6).

Food & drink does not qualify as manufacturing where the processing is minimal and does not lead to a real transformation. The packaging of food and bottling of beverages are also not considered part of the manufacturing process in official statistics (6).

The food and drink manufacturing industry is the single largest manufacturing sector in the UK and is dominated by SMEs (small and medium enterprises) with 86% of companies having fewer than 20 employees, which establishes competition and a strong innovation drive. The sector is highly heterogeneous, with a very broad diversity of businesses, which regardless of size, are often characterised by relatively low margins, making investment and development difficult (3).

The Scottish Food & Drink Industry (SFDI) is similarly large and diverse, with many significant subsectors including Scotch whisky and other spirits, seafood, bakeries, meat processing, breweries, bottled water and soft drinks. It is an important part of Scotland's economy, worth around £14 billion each year (1). However, it differs from the UK average by the dominance, particularly over exports, by the Scotch whisky subsector.

The food & drink industry is characterised by a complex value chain with manufacturing at its core. Over the past few years, the line between agriculture, manufacturing and retail has become increasingly blurred. The emergence of large retailers, such as supermarkets, with manufacturing operations, as well as small-scale farmers, microbreweries etc. with retail arms, has diversified the food & drink value chain into several overlapping layers of economic activity (6).

Despite this change, the key customers for the food and drink manufacturers are (often large) retailers who hold a strong position in the market and can exercise considerable bargaining power. Big retail chains seldom sign contracts for more than a year, adding to the uncertainty of the business environment. Consumer preferences have not gained enough traction for retailers in the UK to exert power over their food and drink suppliers (3).

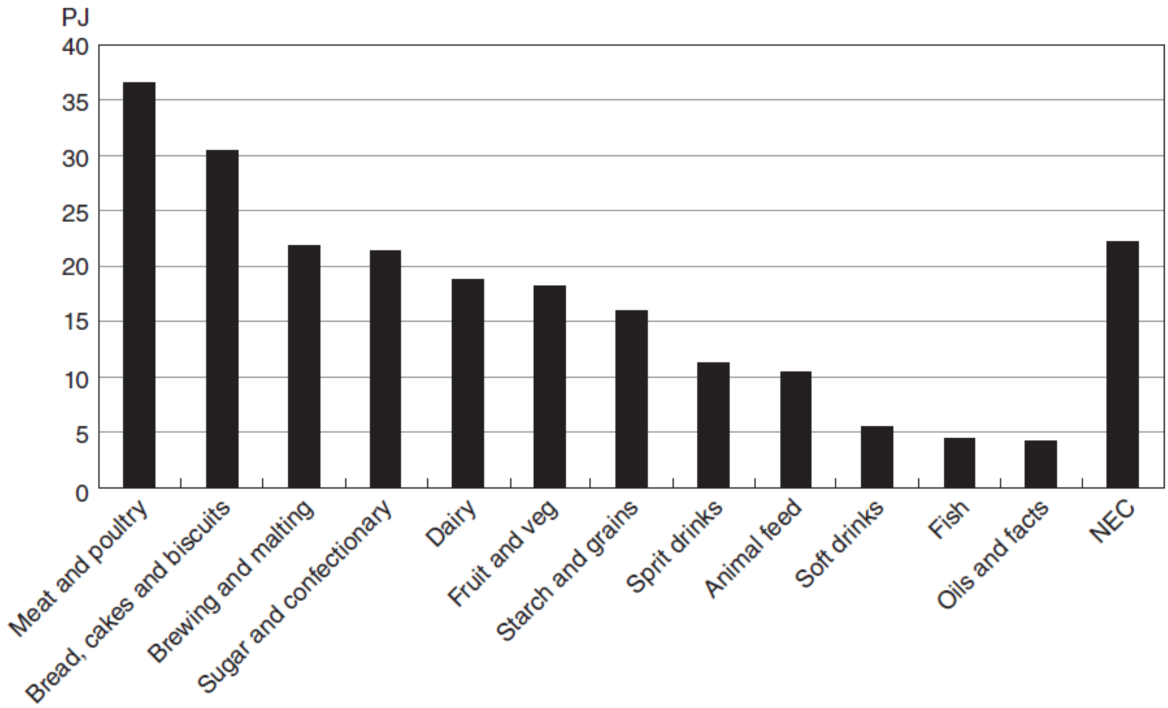
Innovation is a key focus of the industry, primarily because it is highly competitive and has significant scope for growth. UK population is expected to grow, presenting an opportunity for the food and drink sector to service the needs of a growing yet ageing consumer base. Export is another area of potential growth especially for products with longer shelf life, such as spirits (3).

Growth will also depend on the ability of the UK food and drink manufacturers to predict and satisfy the changing preferences of the diverse and complex consumer base in the UK. Change of diet and lifestyle is perceived to increase the demand for healthier and readily available options and expected to alter product mix, portion size and production routines (3).

B5.1.2. ENVIRONMENTAL IMPACTS

The food and drink manufacturing industry is the single largest manufacturing sector in the UK and the fourth-highest industrial energy user in the country (3). Due to its heterogeneity, there is significant variation between different subsectors in terms of their energy demand (1). The figure below (2) splits the UK food & drink subsector into thirteen product groups or subsectors and highlights this variation.

Primary energy demand (2002-2006)(2)



Despite the large range of processing techniques, the food and drink industry does some common energy intensive processes that can be considered. Food and drink manufacturing requires electrical and thermal energy for virtually every step of the process with the most common technologies (and their share in energy consumption) being: boilers (54%), direct-fired applications (21%), cooling and freezing (10%) and fans and pumps (7%) (3)

IMPACTS ON AIR

The main sources of greenhouse gas emissions from food and drink manufacturing sites relate this high heat demand together with indirect emissions from electricity consumption. The fuel use in the sector is dominated by natural gas (about two-thirds), followed by electricity, and a minor amount of oil and coal. For UK food and drink factories, the overall split of emissions between fossil fuels and grid electricity is approximately equal. Some processes also emit CO2 from fermentation (3). However, different subsectors have very varied emissions profiles.

The UK food and drink sector is also one of the largest users of refrigeration technology, making up a large part of the energy bill. The electricity consumption for refrigeration will vary for different subsectors. Both cooling and chilling are used in a variety of processes throughout the food and drink sector (3).

After the different processing stages, food undergoes some additional operations including packing and filling (using textile, wood, metal, glass, plastic, paper and board packaging materials under modified or vacuum atmosphere), and gas flushing (storage of products in an artificially produced atmosphere, mainly used for meat, bakery products and wine). These also require energy to undertaker, although at lower levels that heating and chilling (3).

Another major source of emissions is the transport of raw materials and finished goods.

Other minor amounts of greenhouse gas can originate from sources such as leaking refrigerants and methane from effluent treatment but these are generally accidental and hard to quantify.

IMPACTS ON WATER

<nothing noted>

IMPACTS ON LAND

<nothing noted>

B5.1.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

The heterogeneous nature of the Food and Drink industry can make consistent decarbonisation policies challenging but also provides a range of different mechanisms for reduction of environmental impacts that are more tailored to each subsector.

The opportunities can be classified under six headings: Research and Innovation, energy efficiency, low temperature heat generation, fuel switching, supply chain optimisation and internal/external support.

Research and Innovation

The UK food and drink sector is dominated by SMEs (small and medium enterprises) with 86% of companies having fewer than 20 employees, which establishes competition and a strong innovation drive (3).

Increased research and development investment could therefore lead to innovations with early adoption of new technologies providing scope to improve not only the production process, but also the development and introduction of new products to market.

The sector is looking to evolve and move towards a system of batch production and fully automated production lines, allowing food to be produced quicker, with less waste and greater precision (6). Factories of the future could produce new trends in food production, e.g. 3D-printing of food closer to the end-user while new technologies could improve efficiency of processes such as refrigeration, pasteurisation, cleaning, drying and heating (3)

Smart sensors implemented into food packaging, could provide a more accurate method for detecting food spoilage and help to minimise food waste and increase the UK's sustainable food supply (6)

Greener, more environmentally sustainable food packaging, such as bio-plastics derived from food waste streams is an opportunity, as is developing and increasing the adoption of packaging of greater durability that can be resealed or reused (6).

Energy Efficiency

Energy Efficiency is also a key opportunity and includes:

- Energy management and good maintenance practice: energy metering, process control and measurement, energy monitoring and targeting, process optimisation and pinch analysis, production scheduling, and avoiding idle equipment (3)
- Undertaking basic maintenance to preserve performance.
- Replacement of equipment such as with more efficient units could also be considered although factors such as availability of capital and windows of opportunity to retrofit technologies without disturbing production may form barriers to realizing the potential (2).
- Optimisation of motors, pumps and drives, lighting and HVAC: correct sizing and controls, maintenance, energy efficient motors, VSDs (variable speed drives), voltage optimisation, sequential air ventilation, and LED lighting (3).
- Optimal process design: improving layout and process flows through changing existing plant layout or when designing new plants (3).
- Waste heat recovery, CHP and avoiding heat loss: insulation of equipment and piping, and heat pumps (3).

Low Temperature Heat Generation

Although the food and drink industry is energy intensive, many processes demand low temperature heat (1) meaning that the food and drink industry is well placed to benefit from technologies such as:

Combined Heat and Power (CHP)
Conventional power generation—that is the combustion of fossil fuel to produce heat, raise steam, and drive a turbine—involves considerable inefficiencies. CHP makes use of the surplus or 'waste' heat that arises during power generation, so improving the overall energy efficiency of the plant. The thermal output of CHP plants is normally steam and/or hot water and these plants require a relatively constant heat demand to operate effectively. This makes them suited to many of the demands of the Food & Drink subsector (2).

However, if CHP is fired by fossil fuels it still leads to carbon emissions. It is therefore seen as a 'transitional,' low carbon technology being immediately available and economic in many cases (2).

Heat Pumps
Heat pumps use an external energy source (e.g., an electric motor) to 'upgrade' heat from a lower to a higher temperature. The greatest limitation in the use of heat pumps in industry is currently the temperature of the heat output, which may not be suited to some sub-sectors. Currently the most economic systems are based on mass-produced A/C systems (2).

The carbon savings offered by heat pumps are dependent on the emissions factor of electricity and the fuel supplying the alternative or competing (usually steam-based) system (2).

The increased reliance on electricity of these mechanisms of heat generation may also provide rebound benefits as grid decarbonisation progresses.

Fuel switching

Fuel-switching to replace the industry's latent reliance on fuel oil will also generate significant carbon savings, and plans to extend the gas grid are already underway (1).

Biomass clearly has significant potential as an alternative fuel for the food and drink industry, and provides an opportunity to decarbonise the sector. The sector can use a part of its own product flow to convert to green energy, and is already using biomass in this way (3).

The Scotch whisky industry in particular, is well positioned to make greater use of rural biomass feedstocks via combustion and anaerobic digestion (1).

Feedstock availability is considered less of a barrier than in other sectors, but it remains a very complex issue for the food and drink sector as the biomass it produces on site is often used as animal feed. Considering food waste as biomass source would require a full carbon accounting approach to understand the benefits and consequences (3).

Supply Chain Optimisation and Recycling

Options in these areas include:

- Food waste reduction (3)
- Ensuring packaging design is optimal and avoiding re-packaging (3)
- Use of renewable materials in packaging (3)
- Food-grade recycling of plastics and increased recycling (3)
- Supply chain collaboration (avoiding unnecessary handling, treatment, transport through improved collaboration with third parties such as clients, suppliers, etc.) (3).
- Online shopping provides greater scope to tailor pack and portion sizes to suit different demographics (6)
- Food & drink manufacturers may be able to set up online direct-to consumer sales platforms (6)

Internal/External Support

Internal support is important for the food and drink industry to implement mechanisms to reduce their environmental impact.

This is more likely when projects can be presented as:

- Strong, evidence-based business cases (3)
- Projects providing multiple benefits (3)
- Realistic commitments (3)

Internal support is also useful in making efficiency upgrades by ensuring mechanisms in place for sharing effective best practice within the organisation.

Collaboration in the value chain also improves efficiency (3).

Political buy-in is also important and compliance with regulation is a major driver for industry (3)

Scotland has a national food and drink policy that looks at the impact of food and drink on health, the environment and the economy in Scotland. Food and the bioeconomy is one of four priority areas in 'Making Things Last – A circular economy strategy for Scotland', because of the major scope for economic and environmental benefits, particularly emissions reductions. Scotland's new target to reduce food waste by 33% by 2025 is the focus for action across manufacturing, retail and household food waste. The strategy complements the Biorefinery Roadmap for Scotland and Scotland's Industrial Biotechnology Innovation Centre (IBioIC) (5).

Key actions include mapping of bio-resources in Scotland and helping SMEs scale up bioeconomy action through Scotland's Circular Economy Investment Fund (5).

Trade bodies can also play a role, especially in working across the highly disparate subsectors and in 2007, the Food and Drink Federation launched its Five-Fold Environmental Ambition to improve the food and drink sector's environmental performance. FDF members are working collectively to (i) reduce CO2 emissions by 35% by 2020 against a 1990 baseline; (ii) achieve zero waste to landfill by 2015; (iii) make a significant contribution to WRAP's Courtauld Commitment; (iv) reduce water use by 20% by 2020 compared to 2007; and (v) achieve fewer food transport miles and contribute to the Logistics Carbon Reduction Scheme target to reduce the carbon intensity of freight operations by 8% by 2015 compared to 2010 (3).

B5.1.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

The barriers to reducing environmental impacts arise from the characteristics of the sector, financial pressures, regulatory regimes, technology readiness and supply chain weakness

Characteristics of the Sector

The inherent characteristics of the sector such as its heterogeneity, fragmented nature and numerous SME's and risk aversion, can impact upon its ability to successfully evolve to mitigate its environmental impacts.

The heterogeneous nature of the Food and Drink sector makes it challenging to achieve economies of scale, which will allow the reduction of energy consumption overall and on a per-product basis (3) Furthermore, each of the industry's subsectors uses very specific processing technologies, limiting the ease with which successful decarbonisation measures can be replicated (1). Additionally, many food-processing sites are small with uptake of efficiency improvements tending to be slower (2).

Risk aversion arises from a focus on product quality and safety, as they are meant for human consumption. Innovation tends to be product rather than process-related (2).

Product life cycles can be short and so flexibility of equipment is vital, which will often harm efficiency (2).
The customer base of the subsector tends to be dominated by a few large retailers (e.g., 'supermarket' chains) (2) that hold a strong position in the market and can exercise bargaining power towards food and drink manufacturers. In most cases, this is focused on reducing retail prices, limiting contractual periods and extending payment periods (3). This is intensified as food is a 'non-growth industry,' although there is a move toward higher value added products (e.g., so-called 'ready meals') (2).

The process has driven down margins and reduced the ability of manufacturers, especially small ones, to invest in new more energy-efficient technologies.

Financial Pressures

Financial pressures can hinder the industry's ability to adopt carbon-saving measures.

Pressure for product innovation and differentiation, consumes most of the available financial resources (3).

Energy efficiency is perceived by industry as important, but decarbonisation is generally not yet a priority in the current investment climate, because energy presents only a low proportion (2-5%) of total production costs. The majority of companies select projects based on annual capital expenditure programmes, with a small number appraising projects on an ongoing basis, as they are identified (3).

Business cases are required at all levels and there is pressure from investors for immediate results (3).

Large upfront costs and long lifecycles of equipment (20-40 years) are other disincentives to regularly invest in new technologies. Food and drink plants and the process equipment tend to be built (or purchased) as complete plants through and typically have a life expectancy of over 30 years. In many sectors, the change in processing lines can be more frequent due to changes in product mix or because of new product development, but the utilities services equipment (such as boilers, ovens, refrigeration plants, etc.) can have long life cycles (3).

Currency Fluctuations form another potential barrier to investment in energy efficiency especially with respect to the supply chain (6).

Regulation

The industry is highly conscious of safety due to products being intended for human consumption. Increased hygiene requirements over recent years have led to increased energy use per tonne of product (2).

Current regulatory context is perceived by industry to be detrimental to decarbonisation in the long term as investors look for energy price stability, energy security and an indication of the direction in which the government would like to take the energy market (3).

There are concerns over losing competitive advantage to other EU markets and emerging economies with lower energy prices than in the UK (3).

UK sugar tax provides another disincentive to companies to invest in new carbon-saving technologies (6).

Technology Readiness

Conservatism is widespread in the industry with many companies only willing to invest in technologies that have already been proven to be successful (3).

Companies would not implement any technology that risks diminishing end product quality or character, key drivers for sales; nor would they risk potential production disruption, which would affect profit margins (3).

There is perceived to be a shortage of demonstrated technologies and lack of reliable and complete information can also be a barrier to early adoption of carbon saving measures.

Supply Chain weakness

Brexit is a major concern for the Food and Drink industry supply chain and impacts the willingness of companies to invest. Tariffs could hit the profit margins of export and impart intensive subsectors.

In addition, around 95% of detailed food & drink legislation across every aspect of the food supply chain - production, distribution, packaging, labelling and retail is currently in the form of EU regulations leading to increased uncertainty over the future requirements (6).

Shortage of skilled labour may also be a problem as the food & drink industry is more reliant on EU workers than any other sector of the UK economy (6).

KEY REFERENCES

1. Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses
Scottish Food & Drink Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

2. Industrial energy use and carbon emissions reduction: a UK perspective
Food and Drink Subsector
https://onlinelibrary.wiley.com/doi/epdf/10.1002/wene.212

3. Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Food and Drink Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416672/Food_and_Drink_Report.pdf

4. Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Food and Drink Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/415954/Food_and_Drink_Appendices.pdf

5. Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Food and Drink Action Plan
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651970/food-and-drink-decarbonisation-action-plan.pdf

6. MAKE UK. Food and Drink Sector Bulletin
https://www.makeuk.org/-/media/sector-bulletin-food-and-drink.pdf

B5.2. SCOTCH WHISKY SUB-SECTOR

B5.2.1. SECTOR OVERVIEW

Scotch whisky is the UK's largest food and drink sector and accounts for 80% of Scotland's food and drink exports, worth over £4bn per year. Whisky directly generates more than £5bn per year for the UK economy and the sector invests £1.7bn in its supply chain annually (1).

The sector is diverse in size and includes companies that operate a single distillery to large multinational organisations with several distilleries and associated support facilities such as bottling halls and bonded warehousing. Scotland has five distinct whisky regions: Highland, Speyside, Lowland, Islay and Campbeltown, each of which produces Scotch whisky with a character and flavour unique to that region. Recently there has been significant growth in micro distilleries (1).

Scotch whisky is directly exported to 182 countries. Established markets exist in Europe and North America (around £2.5bn), but major emerging markets are likely to grow significantly (1).

B5.2.2. ENVIRONMENTAL IMPACTS

Environmental impacts arise at different stages of the production of Scotch whisky and also in its supply chain.

IMPACTS ON AIR

At the earliest stages, raw materials have an environmental effect. Peat plays an important role in the production of Scotch whisky by providing a distinctive flavour. It is used in the malting process where the peat is burned to generate smoke to be infused into the malted barley and results in greenhouse gas emissions.

During the distillation and maturation stages, there are additional greenhouse gas emissions from fossil fuel use at distilleries and packaging manufacturers and emissions from the processing of by-products (1).

The Whisky industry is a producer of non-methane volatile organic compounds during bottling and packaging operations. These are involved in the photochemical production of ozone and secondary organic aerosols in the atmosphere over a large spatial scale (1).

Greenhouse gas emissions also arise from the production and transport of raw materials, products and by-products.

IMPACTS ON WATER

Production of cereal crops also caused diffuse pollution and requires water abstraction for irrigation (1).

Other environmental impacts arise from water abstraction for process and cooling and from controlled effluent discharge and accidental spillages (1).

IMPACTS ON LAND

Peat extraction creates additional impacts on biodiversity (1).

B5.2.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

Opportunities for the Scotch whisky industry to reduce its impacts include (3):

Producer Responsibility

The Scotch whisky industry has already taken steps to decrease its environmental impacts and had major successes in reducing emissions, water use and waste.

Regulation by SEPA provides incentives and covers different aspects of the value chain. For example, many of the distilleries, glass manufacturers and bottling plants have to be registered with SEPA under the Producers Responsibility Regulations, a market driven scheme to encourage packaging recycling (1).

Renewable Energy

Fossil fuel is still the primary source of energy for distilleries. The use of renewable energy and the switch from heavy fuel oil use to natural gas use are two steps to reducing emissions (1)

Around 85% of energy generation at a distillery is to produce heat (1), and the sector could reuse this.

Recycling

Glass accounts for around 86% of the packaging material inputs for Scotch whisky, (1) and the challenge for the industry is to find ways of producing lighter bottles made from fully recycled glass.

Packaging of the bottles could be made from recycled materials.

By-products from Scotch whisky distilling have long been reused by the agriculture sector as a valuable animal feed and fertiliser for agricultural land. Developments in renewable technologies have recently opened up new markets for these materials to produce energy and biofuels (1).

B5.2.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

The risks to decarbonisation for the Scotch whisky industry include:

Regulation: The industry is currently captured by a complex set of energy and emission reduction and energy efficiency measures, including: Climate Change Levy (CCL) and associated Climate Change Agreements (CCA), EU Emissions Trading System (EU ETS), Carbon Reduction Commitment (CRC) and the Energy Savings Opportunity Scheme (ESOS) and is required to meet the obligations under these schemes when designing any new measures for industry (1).

Location: Industry has collaborated to invest in and extend the gas grid in rural Scotland. However, in parts of Scotland, the grid is constrained and some companies have not been able to obtain a continuous supply throughout the year. This has led to some companies needing to install dual fuel boilers to burn higher emitting fuel oil (1).

Customer Demand: Packaging weight has increased by 2.4% since 2012 and the main driver is consumer demand for premium products (1). It is a challenge for the industry to reduce packaging weight in this environment.

KEY REFERENCES

1. SEPA Whisky Sector Plan
https://sectors.sepa.org.uk/scotch-whisky-sector-plan/

2. Scotch Whisky Association Environmental Strategy
2009, 2016 and 2018 Report
https://www.scotch-whisky.org.uk/media/1294/final_2018_environmental_strategy_report.pdf

3. Scotch Whisky Pathway to Net Zero: Report for Scotch Whisky Association (May 2020)
https://www.scotch-whisky.org.uk/newsroom/world-environment-day-industry-continues-to-take-steps-on-the-journey-to-net-zero/

B6. CHEMICAL / PHARMACEUTICAL

B6.1. SECTOR OVERVIEW

The chemical industry in the UK underpins UK manufacturing supply chains by providing chemical materials and products to a range of sectors such as aerospace, automotive, construction, pharmaceuticals and final consumers. The sector covers a wide range of diverse processes, ranging from complex continuous processes making large-volume basic chemicals to smaller scale batch processes producing speciality chemicals and pharmaceutical ingredients (1).

The sector is highly diverse and includes over 75 large players (employing more than 250 people) and circa 2,500 SMEs and micro enterprises. In 2016 the chemicals sector generated £11.3bn GVA (6.6% of total UK manufacturing GVA and 1% of GDP); employed around 99,000 people (predominantly across 4 main clusters in the North East (Teesside), Humberside, the North West (Runcorn and other locations), and Scotland); and it was one of the largest UK manufacturing export sector by value after automotive with £24.9bn of exports, comprising 9% of all UK exports (1).

Chemicals manufacturing within Scotland specifically produces a diverse range of output, ranging from research and development (R&D), base chemical manufacture, speciality chemicals and subsequent formulation into products. The sector has substantial growth potential across businesses that span small-scale laboratories to large industrial complexes, from small to medium enterprises (SMEs) to global entities. The majority of chemicals manufacturing sites are located in the central belt and on the west and east coasts of Scotland (2).

Scottish manufacture of chemicals (including pharmaceuticals) reported a turnover of £3.65bn and contributed £1.94bn of Scotland's GVA (gross value added) in 2016 (2).

Raw resource inputs into the sector are from a variety of sources, but principally petrochemicals from the transformation of crude oil and natural gas, and inorganic compounds from mined or quarried ores and salts. Additional inputs may arise from plants, vegetable oils and animal fats. These can range from locally sourced inputs such as fish for the production of omega 3, to glucose from European cornfields for the production of vitamin C to ethane feedstock from North Sea gas for ethylene production (2).

The main products the chemical industry manufactures are (3):

Dyestuffs and agro-chemicals GVA: £1.1bn 9.4% of total chemicals

Dyestuffs (also known as pigments) are substances that yield a dye or that can be used as a dye, while agro-chemicals are chemicals used in agriculture, excluding fertilisers. (They broadly refer to pesticides.)

Inorganic chemicals GVA: £1.5bn 12.6% of total chemicals

A broad class of substances encompassing all those that do not include carbon and its derivatives as their principal elements (unlike petrochemicals), including fertilisers.

Petrochemicals and their derivatives GVA: £3.5bn 29.0% of total chemicals

Petrochemicals are chemicals derived primarily from crude oil and natural gases. Once sourced, the petrochemicals can then be converted into their derivatives, namely plastics and rubber in their primary form.

Other chemical products GVA: £1.6bn 13.6% of total chemicals

These include explosives, glues and essential oils.

Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations GVA: £2.8bn 23.3% of total chemicals

These are the main consumer facing products of the sector, and are broadly sourced from animal and plant fat chemicals (oleo-chemicals).

Paints, varnishes and similar coatings, printing ink and mastics GVA: £1.5bn 12.1% of total chemicals

These products are derived from dyestuffs, or petrochemicals, depending on whether they are from natural or synthetic sources. They are the commercialised end use products for consumers.

The chemicals sector operates in a global market, and is reliant on global supply chains. It is intrinsically linked with the EU. Approximately 60% of UK chemical exports and 75% of imports (including raw materials) are from the EU (2).

The movement of product across the chemicals manufacturing chain can be complex, with chemicals at different stages in the production process moving between parts of a site, to storage areas, to different sites, different operators, manufacturers and potentially back to the originating site (2).

This chain can span significant distances and various countries before the final product reaches the point of sale. There is a movement towards more integrated supply chains, with operators completing more steps in the manufacturing chain on one site. No matter how simplified this process, there will still be a flow of resources through operations (2).

As with transportation, packaging is present throughout the production process and as part of the final product for sale (2).

The UK is a major centre, and key player, in the production of pharmaceuticals, mainly due to its reliable legal system and strong protection of intellectual property. As a result, the UK is home to two of the largest pharmaceutical manufacturers in the world in GSK and AstraZeneca, with all other leading pharmaceutical corporations holding a presence in the UK (4).

The sector is one of the most research intensive in the UK economy, along with other life science industries such as bio-tech and med-tech. It is dominated by a few large firms with a high degree of foreign ownership and regular mergers and acquisitions (4).

Inputs and Products

The pharmaceutical sector's products, while varying hugely and covering a wide range of medical needs, can be split into two broad categories (4):

1) Basic Pharmaceutical Products

This includes the manufacture of substances to be used for their pharmacological properties in medicaments i.e. substances used to produce medicines. Examples include antibiotics, basic vitamins and salicylic acids.

2) Pharmaceutical Preparations (Responsible for 95% of output)

This includes the broad production of medicaments. Examples include vaccines, antisera and blood fractions, homeopathic preparations and other diverse medicaments such as chemical contraceptive products, and hormonal contraceptive medicaments. This class also includes the manufacture of medical bandages, dressings and wadding

The main inputs to the pharmaceuticals sector are overwhelmingly basic pharmaceutical products and pharmaceutical preparations (54%) so its main raw materials come from itself.

Due to the fact that the sector does not interact much with other manufacturers, its growth is not driven by the same forces which move the rest of manufacturing and it therefore has a volatile growth performance, which is highly uncorrelated with total manufacturing growth (4).

This is also driven by the fact that the production of a new pharmaceutical product or treatment is the result of years of research, testing and development, with no guarantee of success. Patents also play a key role in the sector. The expiration of patents, while good for consumers as it means increased competition and lower prices, can result in the pharmaceuticals sector performing erratically (4).

B6.2. ENVIRONMENTAL IMPACTS

The chemicals sector is highly energy intensive. This reflects the energy-intensive nature of many chemical processes, which require high temperatures and consequently high-energy inputs. The thermodynamics of the sector's chemical processes mean it will always require a certain minimum amount of energy to achieve desired chemical reactions (although this is not automatically linked to direct carbon emissions) (1).

IMPACTS ON AIR

Energy use in the sector is characterised by the use of natural gas to generate steam or for direct heating, and the use of electricity for a range of activities. The chemicals sector is therefore responsible for greenhouse gas emissions either directly through emissions from chemical process plants, or indirectly through the use of electricity generated by others. Direct emissions can be further divided into combustion emissions (e.g. related to burning fuel in boilers) or process emissions (where a greenhouse gas is produced as a by-product of the chemical reaction) (1).
Thirteen UK sites were identified as producing 40% of total sector emissions, of which the largest are from sites with ammonia and hydrogen processes. There are however a large number of lower emitting operations which are still relatively energy intensive and collectively also account for significant CO_2 emissions (1).
Greenhouse gas and other emissions also arise from distribution and formulation and packaging operations and flaring (2).

IMPACTS ON WATER

The chemicals manufacturing sector is reliant on a consistent, quality water supply for use in industrial processes. The water use requirements across the sector vary depending on the scale and processes involved but the sector is generally considered water intensive (2).
Water use within the sector relates to process water, cooling water, generation of steam for heating, cleaning, and staff welfare. The sector also produces significant quantities of effluent, which is required to be discharged in a way that protects the water environment from potential harm. Operators within the sector may undertake water treatment on site and should be responsive to the management of leaks and spills (2).

IMPACTS ON LAND

Waste and by-product material is created during the manufacturing process, some of which can be hazardous. However, the UK regulatory regimes for hazardous waste are generally well complied with and the industry has also made efforts to reduce wastes. A significant volume of waste from chemicals sites is already being recovered rather than being disposed to landfill or incinerated (2). Land and groundwater contamination issues can arise accidently from spills but primarily this impact is restricted to legacy sites (2).

Single use packaging, which is often a regulatory requirement, leads to increased volume of waste (2).

B6.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

Significant progress has been made over recent decades to reduce energy consumption per unit of product (e.g., GJ of energy used to produce each tonne of product). It is also important to recognise that the sector itself is a vital enabler of low-carbon industries, for example providing coatings for solar panels, lightweight materials for planes and cars, catalysts for low-carbon vehicles and insulation for homes (1).

The main opportunities for decarbonisation identified in the literature can be categorised under the following headings: Low Carbon Alternatives, Energy Efficiency and Heat Recovery, Clustering, Policy and Regulation, Innovation, Financial, Resource Efficiency, Life-cycle Analysis and Value Chain Collaboration.

Lower Carbon Alternatives
The sector will benefit from electricity grid decarbonisation
Fuel substitution is also possible through use of biomass fuel and using low-carbon methane (1).
Feedstock switching options involve changing the feedstock (raw material) used for a process to a lower carbon alternative (1).

Energy Efficiency and Heat Recovery
Energy efficiency options are generally incremental in nature and use known technologies to reduce the amount of energy required to carry out current processes (e.g. by improving process control,

reducing heat losses). Since they are already well established and of low technical risk, they can provide operational cost savings as well as reducing emissions (1).
There is a need to improve the availability of resources to allow the potential of this option to be fully realised. However, the sector considers energy efficiency and decarbonisation to be important and many organisations report having strategies and goals in place. It is already the default position to identify whether there are more environmentally sustainable, commercially viable products and processes it can use (1).

Combined heat and power generators may also be used to provide energy
Development of new process technology options to carry out existing processes more efficiently (1).
Development of new chemical routes to produce existing products. Many of these options are at an early stage of development (1).

Clustering
The clustering option refers to chemical sites and processes (and sites from other sectors) that are located near to each other sharing energy and raw materials to increase efficiency and reduce overall emissions (1).
The UK has a number of chemicals clusters, which benefit from selling their by-products and waste streams to neighbouring sites, from shared infrastructure, and from developing a local supply chain (1). The concentration of the Scottish Chemicals Industry in the Grangemouth area presents clustering opportunities (5).
However, clustering of sites to optimise resource use can be a challenge given the need for collaboration across companies and the risk that cluster partners will exit, leaving a crucial gap in the supply chain. Stronger encouragement for increased clustering needs to be established, including a means for companies to reflect the benefits of clustering in business cases (1).

Policy and Regulation
The UK's decision to leave the EU has accelerated the need to realise competitive opportunities for the UK. In the context of the Paris Agreement and potentially increased energy carbon costs, any activities to support the sector to decarbonise and become more energy efficient will be advantageous for the competitiveness of UK plants (1).
Environmental policies may therefore provide both a push to achieve greater efficiency and productivity and opportunities in the development of new bio products, with more environmentally conscious customers increasingly demanding that their products do not impact on the environment (3).
A stable and predictable policy framework is also considered an enabler for the chemicals industry to invest in low carbon alternatives. Financial incentives to address the costs associated with adopting technologies is also a key area that could be considered (1).

Innovation
Digitalisation provides opportunities in optimisation
Smart manufacturing, for instance the introduction of closed loop sensors, have the ability to improve logistics, reduce waste and avoid delays. This is crucial for the chemicals sector, given its highly complex and interlinked structure, across the value chain (3).

Digitalisation also offers manufacturers the chance to mitigate rising energy prices. Big data analysis can be used to quantify large sums of data instantly, allowing manufacturers to "buy" energy at the most cost effective moment (3).
Digitalisation, machine learning and artificial intelligence can play a role in preliminary drug discovery and testing, while the role of technology in healthcare apps or wearables (such as smartwatches) is continuing to evolve at a rapid pace (4).
One of the most striking recent developments however is the emergence of digital medicine. Digital medicine, or digital pills, are drugs with an ingestible sensor embedded in them that records when the medication was taken (4).
Personalised medicine is another area of opportunity within the pharmaceutical sector, often coupled with use of 3D printers.
Research and innovation may also help capture emerging markets where current technology gaps hamper performance and growth. For instance, many Chinese firms do not invest significantly in R&D and rely primarily on imported technology (3).
Early adoption of other environmental impact mitigation technologies is another opportunity for the sector but less likely to be realised due to its risk aversion.
Carbon Capture options involve capturing CO2 and either storing it or re-using it as a feedstock for the sector. However, emissions from individual chemical plants in the UK are not considered to be of a sufficient scale to justify their own CO2 pipeline and storage infrastructure (1).
Other decarbonisation technologies have been identified such as generating hydrogen by electrolysis and the recycling of plastics to generate syngas feedstock. However, there is a need for further RD&D and production at a scale that invites cost-competitiveness (1).

Resource Efficiency, Life-cycle Analysis and Value Chain Collaboration

The sector uses raw materials from and provides its products to other parts of the economy and collaboration between different parties in the value chain can provide opportunities for decarbonisation beyond those related to individual sites. For the chemical sector, this could include clustering, collaborative RD&D, and the development of comprehensive carbon accounting (1).
The sector is already embracing efficiencies from economic and environmental perspectives and recognises the potential benefits of a circular economy. Increasing competition for materials of increasing scarcity will likely serve to embed further efficiency gains across the supply chain (2).
There could usefully be a common and quantifiable means of understanding the overall carbon impact of the entire product lifecycle.

B6.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

Barriers to decarbonisation include - regulation, financial disincentive, international competitiveness and technology readiness

Regulatory Barriers

Pharmaceutical manufacturing processes are guided by strict regulations based on various international regulations. Emissions reduction goals must be integrated into this regulatory framework to avoid hampering process changes and technological innovations that support

decarbonisation (1). Uncertainty in policy and regulation is therefore a factor in the willingness of companies to invest in environmental technologies (1).
The UK is currently part of the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). Retaining access to this system is a priority for chemicals manufacturers given the increased administrative, as well as infrastructure costs that would arise by leaving it. The nature of the REACH framework, and particularly how it was written, means it will be difficult to transpose directly into UK law (3).
UK's open takeover framework can leave pharmaceutical companies exposed (4).

<u>Financial</u>
The business environment also impacts upon the ability of the sector to reduce its environmental effects. The UK chemicals sector has suffered from the financial downturn as demand from other parts of the economy declined. New capacity in low-cost countries, particularly in the Middle East, has made it difficult for the UK to increase its market share over the past five years. Asian economies in the Far East have also rapidly expanded their capacity (1).
If poor economic performance continues, this will continue to impact on the ability of the chemicals sector to invest in decarbonisation and look beyond the short payback required. There are also challenges in relation to higher policy and energy costs, alongside differences in operational cost bases (1).
One of the most important barriers to decarbonisation and increased energy efficiency is lack of funding for investment projects. UK site managers often find that the return of investment is not attractive enough to meet their internal funding criteria or that they are competing for capital against sites in other countries where the return on investment (ROI) is more attractive (1).
High energy costs are also a financial hurdle. The initial stages of the manufacturing process are typically energy intensive, as large volumes of raw material are extracted and converted into primary products (3).
The UK is becoming increasingly reliant on imports of crude oil and natural gas and open to risks arising from political tensions and that market volatility (3).
Fluctuations in commodity prices, primarily crude oil, impact the supply and demand economics of international market (3).
The long lifetime of major equipment means that upgrades are expensive and rare and plants may be operating with aged and far less energy efficient equipment than is currently available (1).
Chemical plants are typically built and operated for at least 20 years, large plants producing basic chemicals can have typical lifetimes of 50 years, assuming some debottlenecking over time. These long lifetimes apply to major equipment items also (1).
However, overhauls take place at regular intervals, typically every few years, providing opportunities for incremental process improvements or upgrades and replacements to smaller equipment items. Major upgrades or refits may take place at less frequent intervals where more significant equipment modification or replacement takes place (1).
In the pharmaceutical sector, high costs of developing a drug and getting it to market are prohibitive factors for many manufacturers (4).

<u>Technology Readiness</u>
The research, development and demonstration of the new technologies required to deliver decarbonisation is difficult to achieve with current approaches in the sector. This includes early R&D

activity but also, crucially, progressing technology to successful commercial demonstration so that it is de-risked for future deployment (1).
Companies may not have the time, expertise and funding to identify if and how different options may be of benefit to them and so may not progress the R&D activity needed (1).

Competition
Competition from Asia and the US is an increasing challenge to UK production and it can be difficult to secure funding for investment in UK sites when better returns can be achieved elsewhere where feedstock and energy costs may be lower (1).
Brexit is another key concern to the industry who would be impacted financially by trade tariffs (3).
Cyber security is also an issue in the pharmaceutical sector whose competitiveness depends on confidential research (4).

KEY REFERENCES

(1) Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Chemicals Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416669/Chemicals_Report.pdf

(2) SEPA Sector Plan DRAFT Chemicals
https://consultation.sepa.org.uk/sector-plan/chemicals-manufacturing/

(3) Make UK Sector Bulletin: Chemicals
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-chemicals.pdf

(4) Make UK: Pharmaceutical Sector Bulletin
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-pharmaceutical.pdf

(5) Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses: Scottish Chemicals Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Chemicals Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/415948/Chemicals_Appendices.pdf

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Chemicals Action Plan
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651230/chemicals-decarbonisation-action-plan.pdf

B7. MATERIALS PRODUCTION
(incl. metals; cement; ceramics; glass; paper/pulp)

B7.1. METALS

B7.1.1. SECTOR OVERVIEW

The Metals Sector covers all activities involving the production of metal from raw materials and the manufacture of metal products (4).

The UK Metals Industry includes (5):

- Primary manufacture of metals such as aluminium and steel
- Provision of metals to industrial users through supply chain management
- Processing metals through casting, forging, forming, extrusion, rolling and other methods for use by industrial users
- Fabrication of high integrity structural components, such as steel frames for buildings
- Application of surface coatings to improve performance or appearance
- Recycling metals contained in end-of-life products or in off-cuts and scrap metals arising from the industrial supply chain

Regionally, the industry is strongest in the Midlands and North of England, and in Wales. Its importance has declined in Scotland and Northern Ireland, although some sectors continue to have a presence there (5). The number of Scottish sites producing metal and metal products has declined significantly. There are now only 20 specialised large metal foundry and casting sites, producing high specification components for manufacturing, building or infrastructure projects (4).

These include (4):

- The Dalzell steel plant in Motherwell, operated by Liberty Steel and part of the GFG Alliance, imports slab ingots, made from ore, for melting in their cast furnaces prior to rolling plate to customer specification.
- The GFG Alliance smelter near Fort William, which produces about 40,000 tonnes of aluminium each year, is powered by a SIMEC owned hydroelectric scheme, which is also part of the GFG Alliance, utilising rainwater from Ben Nevis and surrounding hills.
- Progress Rail, a Caterpillar company, located in South Queensferry, is one of the largest suppliers of railroad and transit system products and services worldwide. They recycle metal into new product and extend the life of viable components.

The UK metals sector is a highly capital intensive, mature and consolidated industry (2). Companies in the Metals Industry operate globally and many firms are themselves part of multinational, foreign-owned enterprises, which in some cases requires them to compete internally for investment (5).

Imports include raw materials such as ores, coal and unprocessed metals and products are exported around the world (5). Export from Scotland in 2016 of metals and metal products, computer and electrical equipment, machinery and equipment, and transport equipment accounted for 31% of the total manufacturing exports (4).

Competition is global too, often against the international suppliers who have come to dominate parts of the UK market making the sector's revenue is highly volatile. Metal is globally traded and increasing raw material prices, including gas and electricity prices, can affect profit margins per tonne, as manufacturers are unable to pass on the price increases to customers (2).

After several years of revenue contraction due to the recession, the gradual economic recovery of the automotive and construction sectors is holding a promise of resurgent global demand and increasing sales volumes (2).

B7.1.2. ENVIRONMENTAL IMPACTS

The metals sector is highly energy intensive and more than two-thirds of the sector's energy consumption is used to provide heat (often at very high temperatures over 1,000°C). The UK industry has a mix of technologies for delivering heat, including coke ovens, burners, boilers and turbines that burn fossil fuels (coal and natural gas) (2).

IMPACTS ON AIR

The reliance on carbon as a chemical reductant (resulting in significant amounts of process emissions for integrated sites), together with the combustion of fossil fuels, and the indirect emissions from electricity consumption result in emissions of greenhouses gases, mainly CO2 (2).

Compared to the UK as a whole, the Scottish industry emits considerably less CO2, as there are no upstream steel making sites in Scotland (1). However, aluminium smelting, which is undertaken in Scotland, also produces Perfluorocarbons which are potent greenhouse gases with high global warming potentials but they are emitted in very small quantities.

Transport emissions from transport of raw materials and metal products to market also add to the overall carbon budget (4).

IMPACTS ON WATER

The metal industry in Scotland is not a significant water user but has the potential to impact the water environment through poor site management. There may also be emissions to water from manufacture process (4).

IMPACTS ON LAND

Land pollution in the UK is highly regulated but there may be issues arising from illegal activity (fly-tipping) (4). Impacts associated with raw material extraction often arise in other countries but should be accounted for somewhere in the same way that transport emissions are.

B7.1.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

The metals industry has considerable potential to save energy and reduce carbon emissions in many areas since few investments have been made in the last decade (1). Several broad categories of mechanisms to reduce emissions can be distilled from the literature.

Low Carbon Alternatives

UK Grid decarbonisation coupled with electrification of heat can deliver emissions reductions in the sector and the Scottish industries are well-placed to take full advantage of this due the dominance of downstream processes (1).

Some iron and steel plants have significantly reduced gas flaring, and instead capture the gases arising from ovens and furnaces, using them to replace natural gas elsewhere, such as at reheating furnaces, to produce steam and to generate electricity (2).

Heat Recovery could also provide a viable mechanism to increase energy efficacy but this heat is low grade and hence difficult to use directly. Where there are no appropriate heat sinks on site though, it is possible to pass it for outside use such as district heating, provided there is a demand close by and the infrastructure can be provided (2). This also relies upon the heat being recovered and although modern furnaces are equipped with regenerators for heat recovery, some plants may use older equipment (2).

Biomass-based steam generation is another alternative fuel (2).

Efficiency Upgrades

Upgrading steam/power production systems, improving on-site energy management and process optimisation are all promising avenues for decarbonisation (1).

Smaller-scale energy efficiency projects are likely to have shorter payback periods and represent immediate cost savings although not all options are available or practical for certain grades of steel requiring specific treatment (2):

- Improved automation and process control
- Improved planning and efficiency of all stages of the production process
- Recovery of waste gases and heat
- Fuel switching
- Supply chain optimisation
- Value chain collaboration.

Larger scale options include breakthrough technologies such as rebuild or retrofit of integrated sites with advanced technologies (2).

Financial Enablers

The industry has declined and was hit by the economic recession. Decarbonisation and energy efficiency are considered as mechanisms for saving costs, especially if energy and carbon prices increase over the long term. Customers primarily make purchasing decisions based on cost for service delivery, rather than on carbon emissions but increased demand for materials used in renewable energy and energy efficiency products may change perspectives (2).

These options may be aided by a link between environmental and safety issues in investment projects

Recycling Opportunities

Metals and metal products could be at the heart of the new circular economy as they are endlessly reusable and recyclable, and become increasingly attractive from a life-cycle perspective the more times they are reused or recycled (5).

Keeping metal materials flowing through the economy at as high a value as possible creates environmental and economic gains. The biggest environmental gains are realised when products can be directly reused or repaired for reuse but recycling also provides energy savings. The production of metal is significantly more energy intensive than reprocessing and recycling. Re-melting scrap metal uses around 30% less energy and emits only 25% of the carbon dioxide emissions of compared to production from primary sources. Recycling aluminium uses up to 95% less energy than primary aluminium production (4).

Circular economy business models like remanufacture and product leasing could become a growing part of Scotland's economy and improving the quality and reducing contaminant levels of waste metals increases the opportunity for higher value uses and the potential to be supplied as feedstock to electric arc furnaces with lower carbon emissions than the use of ore in blast furnaces. Collecting alloys of the same type enables this material to retain the properties of the original alloy and reduces the carbon intensity of the material when compared to alloys created from virgin ore and metal (4).

In addition, certain metals are globally scarce and may present a risk to future Scottish manufacturing as they become difficult to source and increasingly expensive. Many of these materials can be recovered and recycled from end-of-life products reducing the need for extraction of raw material and energy (4).

Other Innovations
Changing technologies and product development is altering demand for metals and the associated economics and techniques that need to be used in reprocessing products. Examples include electric vehicles, renewable electricity generation infrastructure, WEEE and construction materials.

Life-Cycle Accounting and improvements in standardised carbon accounting methodologies would enable measurement, valuation and comparison of steel products, and facilitate the sector to differentiate their products produced using low carbon options (2).

The consolidated market structure enables R&D (research and development) and innovation to be a non-competitive area enabling good cooperation and cross-company learning (2).

However, for some highly energy intensive sites to realise decarbonisation, deployment of medium to longer term technology is needed such as clustering and Carbon Capture. Improved site and sector integration could deliver significant emissions reductions and could be enabled by further industrial clustering close to CCS/CCUS sites (2).

B7.1.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

Financial Barriers
The risks to decarbonisation of the sector are mainly financial as metals manufacture remains a very capital-intensive business (5) and as a result of the economic recession, mature market, and

increasing global competition, the current business strategies in place are focused on business continuity, value-added projects, investing in growing markets (such as India), and increasing production efficiency (2).

This can be explained by the fact that it is a low-profit industry (5) with global competition from lower-cost producers. Steel and other metals are cheaper to produce abroad for a variety of reasons. In recent years, steel from China has significantly displaced steel produced in the EU (4).
Global commodity markets are also are at the ebb and flow of commodity prices and it is difficult to invest or innovate when there is no security of supply or price. Loyalty between suppliers and customers can enable businesses to survive when commodity prices are challenging (4). Increasing electricity and gas prices and long investment cycles compound this issue and mean that decarbonisation and energy efficiency are not considered as strategic and high-priority business goals in their own right. There is a lack of demand for low-carbon steel products from customers through purchasing requirements as decisions are primarily made decisions on costs, not on carbon emissions (2).

Most companies in the sector do not see R&D as important due to the cost and perceived high rate of failure.

Many demand a very rapid payback from investments, which means R&D, cannot compete against other business improvements (5). The current business environment is therefore not conducive to large-scale demonstration projects as there is limited capital available, and companies are focusing on business continuity and cost savings (2). In Scotland, this can be evidenced by the lack of investment to date and additionally, many companies in Scotland have larger upstream operations elsewhere in the UK where far greater cost and energy savings can be made (1).

<u>Equipment costs</u>
There are very few newly built plants in the UK. The majority of the plants have equipment from different time periods. Equipment is continuously upgraded and/or retrofitted rather than replaced. Some of the equipment at the integrated sites have been in operation for 60 to 70 years. For the EAF sites, the main equipment age ranges from 4 to nearly 40 years (2).

Some of the most expensive equipment in the sector is expected to run almost continuously for up to 12 years before refurbishment and might not be replaced for more than 20 years. Once UK plants are closed, they are rarely re-opened or replaced (5).

<u>Regulatory Barriers</u>

Trade tariffs may also arise from EU exit

Government's innovation support mechanisms are patchy and poorly coordinated, and not well suited to smaller companies (5).

Small firms also find it difficult to participate in signature programmes such as Catapult (5).

<u>Raw Material Scarcity (4)</u>

Certain metals are globally scarce and may present a risk to future Scottish manufacturing as they become difficult to source and increasingly expensive. These include:

- Cobalt: Used in a number of important electronic components and products including batteries and pigments.
- Copper: Found in electrical cables, transformers and other electronic components.
- Lead: Used in the construction industry and in specialist applications such as batteries. Specialist battery applications are becoming increasingly important for electric vehicles and are expected to become more important.
- Lithium: An important component of electric vehicle manufacture.
- Rare earth elements: Used in small quantities in specialist metals and electronics applications.
- Tin: Widely used in the food and drink sector for packaging but also has important applications in electronics.

KEY REFERENCES

(1) Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses
Scottish Iron and Steel Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

(2) Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Iron and Steel Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416667/Iron_and_Steel_Report.pdf

(3) Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Iron and Steel Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416197/Iron_and_Steel_Appendices.pdf

(4) SEPA Sector Plans – Metals
https://sectors.sepa.org.uk/metals-sector-plan/

(5) UK Metals Council. Strategy 2030
https://www.ukmetalscouncil.org/uploads/files/p1a29r5d9h10f91j1dss17sq1jvi4.pdf

B7.2. CEMENT

B7.2.1. SECTOR OVERVIEW

Cement is a widely used construction material and is fundamental in the construction of buildings as cement (concrete) structures can last over 100 years. Concrete is also widely reused at end of life as a raw aggregate material (3).

The UK cement industry is highly concentrated (i.e. small number of manufacturing sites) industry. According to MPA, the UK cement production includes two semi-dry and one semi-wet kiln, with the rest comprising of a dry process. The sector has been consolidating over a long period of time and the recession has further exacerbated this trend (3). The Scottish Cement Industry consists of a single manufacturing site – the Tarmac plant in Dunbar, East Lothian (1).

The industry is highly regulated in the UK and represents a mature market, with high capital intensity requirements. It is dependent on trends in downstream construction and public sectors in particular. The companies operating within the cement sector are predominantly owned by international businesses (3).

An increasing market share is being taken by imports and although future UK cement production is projected to grow in the short term, longer-term production is uncertain and will be linked to the future economic environment in the UK, EU and beyond. Key drivers for growth include demand from building and construction. The public sector and government have a large market influence over the cement sector as one of the key drivers of construction of homes, public buildings and infrastructure. However, the UK is a mature market for construction. There will always be a certain amount of 'maintenance' of the existing building stock, e.g. replacing old buildings with new, infrastructure improvements (3).

B7.2.2. ENVIRONMENTAL IMPACTS

Cement is an energy intensive sector; energy is one of the largest operational costs in cement making. The cement industry is energy-intensive, mainly because of the fuel requirements of kilns (3). About 90% of on-site energy demand is used to raise the kiln firing temperature to 2000C (2). Currently, solid fuels constitute the large majority of fuel consumption, with coal on its own accounting for more than half of all fuel on an energy basis (3).

The primary fuel used at the Dunbar site is coal, with waste-derived fuels (including tyres and recycled liquid fuels) supplying up to 40% of net energy demand (1). The cement sector is a large consumer of these waste fuels, some of which are renewable or have a renewable component. The ability of the cement sector to combust a large proportion of waste fuel derives from the alkaline environment, very high temperature and long processing times of the clinkering process, whereby harmful species are broken down. Burning a large proportion of waste fuels has been accompanied by significant investments in the industry to comply with the Waste Incineration Directive. The final mineral product also allows the ash from a wide range of combustion products to be absorbed (3).

IMPACTS ON AIR

Fuel combustion produces greenhouses gases in the form of carbon dioxide (and others). However, most carbon dioxide (CO_2) emissions from the sector derive not from fuel combustion, but from the decomposition of limestone. These 'process emissions' account for 60% of carbon dioxide emissions related to cement manufacture, while just over 30% can be attributed to kiln fuel combustion. The remaining 10% is emitted indirectly via the production of electricity delivered to the cement plant for mainly grinding processes (2).

The UK cement industry has reduced absolute CO2 emissions by 55 per cent between 1990 and 2011. However, around half of this absolute reduction is a result of declining production, with the remainder resulting from decarbonisation and energy efficiency improvements. Kiln energy efficiency in particular has increased substantially (3).

The combustion of coal can also produce other gases such as sulphur dioxide, nitrogen oxides and particulate material. However, industrial combustion accounts for slightly more than 10% (respectively 10%, 13% and 8-15% depending on particle size) of Scotland's total of each of these gases with most resulting from emissions from commercial, residential and public sector combustion (Air Pollutant Inventories for England, Scotland, Wales, and Northern Ireland: 1990-2017).

Other environmental impacts include the impacts of raw material extraction. The limestone used to make cement at the Dunbar site is taken from Dunbar quarry where the rock is then extracted through controlled blasting, or shot-firing. This process causes impacts to the local environment but these were not recorded in detail in this study since they relate to a different process from cement making itself. It should also be noted that locally sourcing raw materials must be contrasted with the impacts of import over long distances and associated emissions and other impacts.

IMPACTS ON WATER

<nothing noted>

IMPACTS ON LAND

<nothing noted>

B7.2.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

Since the kiln is the dominant energy centre in the plant it represents by far the greatest opportunity for decarbonisation of the cement making process (3) and many opportunities surround the fuels and raw materials that are used as inputs as well as efficiency and recycling improvements. Other financial and market enablers can also be identified from the literature.

Fuel and Raw Material Options

The industry's latent reliance on coal presents an opportunity for significant decarbonisation (1). Over the past decade, the UK cement industry has focused on utilizing waste for fuel, and this trend is likely to continue into the medium term. Kilns can technically run on 100% waste fuel, but such high substitution rates require tailored pre-treatment and quality control of the waste supply (2). Already, the Dunbar site uses a considerable amount of waste derived fuels (1).

Fuel switching to natural gas or hydrogen fuel could also reduce CO2 emissions for cement production (3).

More carbon-neutral biomass fuels is considered a key opportunity for the sector. According to MPA, in 2018, waste derived fuels made up 43% of the thermal input with waste biomass fuels composing

17% of the thermal input to the cement manufacturing process. They assume that by 2050, 40 per cent of fuel use will comprise of biomass (6).

Raw Material substitution could also provide opportunities including:

Cementious substitution
Reducing the amount of clinker per unit of cement by substituting the clinker with other cementitious materials, such as pulverised fuel ash (a waste from coal fired power stations) or ground granulated blast furnace slag (a by-product from iron and steel manufacture), natural pozzolanic materials, fillers such as limestone (3).

Alternative raw materials (calcined)
Improves the energy efficiency of the thermal processes in the kiln and so their use leads to a reduction in the thermal requirement per unit of clinker produced (3).

Lower carbon cements
The sector hope that by 2050, low carbon non-Portland cements will be further developed, tested and potentially included in standards to allow them to be commercially produced for specific applications and markets. It is unclear at present which 'low carbon' cement(s) will make the break through to commercial production or the technical limitations they might have. Furthermore, the CO2 savings may differ between the various types of new cements (6).

<u>Efficiency improvements</u>

These opportunities include:

Plant efficiency improvements
The Best Available Techniques (BAT) conclusions for cement, lime and magnesium oxide manufacture indicate that the newest and most efficient cement plants in Europe are around 20% more efficient than the UK (6).

Electrical efficiency and decarbonisation of the electricity sector

Electricity from waste heat

The use of waste heat in order to reduce CO2 emissions by raw material drying, power generation (steam cycle, Kalina cycle, Organic Rankine Cycle) (3).

Oxygen enrichment technology
The use of oxygen enriched combustion air in the clinker burning process. This allows an increase of the fuel efficiency, production capacity or substitution of fossil fuels by low calorific value (or secondary fuels). This option includes oxygen enriched combustion and oxyfuel combustion (3).

Reduced transport emissions through consolidation of the supply chain.

<u>Recycling</u>

Cement (concrete) structures can last over 100 years and concrete is widely reused at end of life as a raw aggregate material. It can be recycled into cement and there is significant scope to extend this process by improving viability of collecting and transporting old cement (3).

The cement production process has a unique capability to recycle minerals and recover heat simultaneously (known as co-processing). Cement producers take low/zero value waste material from other sectors of the economy and turn it into an essential and strategic material, cement. In 2018, 1.4 million tonnes of waste and by-products from other industries were co-processed in cement production. This resulted in a recycled content of cement of almost 10% (6).

Cement companies also stress that the re-carbonisation properties of cement and concrete during their lifetime, and particularly when broken down and reused, are not being appropriately recognised or accounted for at present and therefore this represents an opportunity to improve (3).

Financial and Market Enablers

Energy efficiency helps reduce companies' operational costs through reducing exposure to fluctuating and increasing energy prices (3).

Management buy in is another great enabler and decarbonisation is becoming a more prominent issue for the sector. The UK cement sector has developed a decarbonisation roadmap, "MPA cement GHG Strategy: Roadmap to 2050" that sets out a clear vision and qualitative objectives for increased research into decarbonisation and specific work streams on decarbonisation. In the past few years the focus has mainly been on fuel switching to biomass and alternative fuels where possible – along with making incremental plant equipment improvements where commercially viable (3,4,5).

Cement companies are interested in decarbonisation from the lifecycle perspective and are promoting the thermal properties of concrete that can significantly reduce energy use throughout the lifetime of a building (3).

Cement companies have a further interest in the issue of climate change as the sector considers its product to be vital in the construction of UK low-carbon infrastructure such as nuclear and wind power installations as well as being important for climate change adaptation measures such as flood and coastal defences (3).

Technological feasibility

There is an opportunity to demonstrate that new technologies are proven and financially viable as this makes them more likely to be deployed (3).

The cement sector is very interested in Carbon capture technology and opportunities (3).

B7.2.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

Risks can be categorised as non-technical risk, financial and regulatory barriers and technological feasibility.

Non-Technical Risk

The meaning of this heading is that often the barriers to implementation of new techniques or use of new fuels is controlled by non-technical factors that are more diverse than those of other industries and can be separated from specific financial and regulatory barriers.

These risks include:

The unavoidable calcination process by which cement clinker is made represents almost half of the total emissions. There is therefore particularly low potential to reduce industrial emissions, as efficiency measures do not tend to dominate the incidence of process emissions (2).

The subsector is already very technically efficient. Indeed, nontechnological factors have an arguably more important influence. For example, market conditions that affect the kiln operation typically reduce efficiency (2).

Fossil fuel replacement from locally sourced alternative fuels that have been diverted from the waste stream is considered vital due to the reliance of the sector on coal but could be adversely affected if materials divert to other uses. Commercial pressures may also inhibit the use of waste derived fuels in the cement sector as other energy consumers seek new ways to generate heat/electricity or produce gas also using the limited locally sourced waste derived fuels (6). Competition with other industries for these alternative fuel sources, as well as the technical and engineering skills required to deploy them, is likely to increase over time (1).

Building new plants and kilns is seen as the critical point at which any major step changes can occur. The current generation of kilns, however, is relatively new with most being built or modified within the last 15 years (3).

Feedstock Substitution is made more challenging due to pressure on both the blast furnace route steel production and coal-fired power stations to shut down their operations which means that importing the equivalent raw materials (clinker) would dramatically extend the transport distance of substitute materials.
The extent to which clinker is substituted will affect the properties of the final cement product and is therefore sensitive to market barriers (2).

Clinker substitution rate in cement and concrete is ultimately determined by the end user in the construction industry and is consequently subject to constraints imposed by economic and safety factors (2).

Product Substitution alternatives will require years of further development before they can be considered serious candidates for substituting**.** The construction industry is characteristically wary about unfamiliar products and Europe is more restricted by regulation than other markets (2).

Concrete is widely reused at end of life as a raw aggregate material but is infrequently recycled into new cement. UK cement companies have stated that the logistical, financial and energy implications of collecting and transporting old concrete back to cement factories does not usually make this option viable (3).

<u>Financial/Regulatory Risks</u>

Requirement for short payback periods and high rates of return on energy efficiency projects (3).
Companies are less likely to finance investments in decarbonisation if the payback period is greater than three years and 1-2 year payback projects would be much more likely to be approved.
Financial Risk aversion (3)
Companies are wary of being locked in to the ‘wrong’ investment choices (in part due to high technology costs, long investment cycles and concerns over product quality impacts).

High capital costs for new plants or significant projects (3).

Competition for internal funds (3)
In multinational companies and from other projects more closely related to the core business.
Longevity of current equipment and investment cycle (3).
The production of cement clinker in cement plant takes place in kilns that are constructed to continuously produce large quantities of cement clinker over operational lifespans of 30-40 years according to MPA, after which they may undergo a partial rebuild. Typically, modifications and partial rebuilds are more frequent than completely new build.
Potential impact on production or product quality (3)
CO2 abatement opportunities will have to avoid interrupting production and associated downtime and production losses: renovating kilns and introducing decarbonising technologies hence has to wait for planned kiln replacement.
The implementation of opportunities requiring retrofit will either have to wait until planned shutdown periods or during unplanned downtime and lost production.

Market and Economy/Legislation (3)

UK demand for cement is lower and growth forecasting is difficult. In addition, there is a risk from low cost imports.

Uneven EU and global playing field with overseas competition due to differences in climate change and energy policies and pricing.

EU ETS – Risk induced by future uncertainty (unknown future carbon prices, caps, proportion of allocations).

Financial and Technological feasibility (3)

Industry perception that the UK government is not backing CCS and R&D as strongly as other countries.

CCS forms integral part of established sector roadmaps, but the technological feasibility or affordability is still highly uncertain.

Shortage of qualified engineers and specialists skills and knowledge.

KEY REFERENCES

1. Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses
Scottish Cement Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

2. Industrial energy use and carbon emissions reduction: a UK perspective
The Cement Subsector
https://onlinelibrary.wiley.com/doi/epdf/10.1002/wene.212

3. Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050

Cement Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416674/Cement_Report.pdf

4. Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050
Cement Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/415956/Cement_Appendices.pdf

5. Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050
Cement Sector Joint Industry - Government Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651222/cement-decarbonisation-action-plan.pdf

6. Mineral Products Association (MPA) 2050 Strategy
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjzrvj2nszoAhWHZMAKHRPJAzMQFjAAegQIBxAB&url=https%3A%2F%2Fmineralproducts.org%2Fdocuments%2FMPA_Cement_2050_Strategy.pdf&usg=AOvVaw0sI2R8q4hw3B_a82WZ9vNd

7. Mineral Products Association (MPA) Greenhouse Gas Reduction Strategy
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=2ahUKEwjzrvj2nszoAhWHZMAKHRPJAzMQFjABegQIBBAB&url=https%3A%2F%2Fcement.mineralproducts.org%2Fdocuments%2FMPA_Cement_GHG_Reduction_Strategy_Technical_Document_Dec_2015.pdf&usg=AOvVaw0ccKDDuj67Lkxs6YqfxFHF

B7.3. CERAMICS

B7.3.1. SECTOR OVERVIEW

The UK ceramics industry consists of around 160 sites located throughout the UK, with three quarters of companies being SMEs7 (2).

Four subsectors identified by British Ceramic Confederation (BCC) as having different scales of production and types of product (2):

- Heavy clay construction products (bricks, roofing tiles, clay drainage pipes etc.)
- Whitewares (sanitary ware, floor and wall tiles, tableware and giftware)
- Refractories (high temperature heat resistant materials vital in all high-temperature processes including metals making, the production of cement, petrochemical processes, glass and ceramic)
- Technical ceramics (special purpose ceramic components for electronics, medical, environmental protection, military and structural applications)

A fifth subsector, raw materials extraction and processing is related to ceramic sector as a supplier of some materials. It is not addressed in this study as it covers a diverse range of processes and supplies mineral products to numerous sectors in addition to ceramic (2).

The Scottish Ceramics Industry is small compared to the rest of the UK, comprised of 5 companies and 6 operational sites. Production is therefore limited to a few key products. The high proportion of specialist refractories and technical ceramics manufactures make Scotland's ceramics industry unusually dependent on grid electricity for extremely high temperature firing (1).

Competition in the sector is high, with small margins. Overall, the shrinking profit margins have resulted in a lower level of capital investment in new technologies. Future production for the UK ceramic sector is projected to grow somewhat, but with differing levels across the four subsectors (2).

The ceramic sector is a capital-intensive sector with long investment cycles; a ceramic production plant typically has a lifetime of over 40 years, although repair and partial replacement of refractories is common and upgrades to burners, control mechanisms and external components, such as fans and flue gas clean-up equipment may occur during the life (2).

B7.3.2. ENVIRONMENTAL IMPACTS

The UK ceramic sector is energy and heat-intensive.

IMPACTS ON AIR

In 2012 from ceramic production totalled 1.2 million tonnes of CO2 (including fuel emissions, indirect emissions and estimated process emissions) and this was associated with the production of 4.2 million tonnes of ceramic products (2).

Direct emissions originate from fuel combustion for firing kilns and dryers, and process emissions. Process emissions result from inherent chemical changes in the raw materials (decomposition of carbonates and oxidation of organic content) as they are converted to ceramic products. Indirect emissions arise from electricity imported from the grid for process machinery and in a limited number of cases for heating electric kilns and furnaces (2).

The emissions profile varies by product type. The heavy clay subsector dominates the emissions, but with its simpler processes, higher adoption of more-efficient continuous kilns and larger scale of production has lower emissions per tonne of product. White wares has substantial emissions due to the multiple firing steps, greater use of less-efficient batch firing and higher air to ware densities in the kiln. Refractories have an intermediate level of emissions per tonne due their simpler, but generally higher temperature, production of bulk products. Technical ceramic subsector has disproportionately large emissions due to the small scale of production coupled with the higher firing temperatures (2).

Energy can represent up to 35% of overall production costs and ceramic manufacturers have been driven to maximise the efficiency of their operations over several decades (2).

IMPACTS ON WATER

<nothing noted>

IMPACTS ON LAND

<nothing noted>

B7.3.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

The ceramic sector collectively is committed to contributing responsibly to a competitive low-carbon and resource-efficient economy. The European Ceramic Industry Association has already developed a 2050 ceramic industry roadmap 'Paving the Way to 2050'. This willingness to engage is positive but the basic drying and firing processes are energy intensive so, despite considerable innovation in recent decades, a radical further reduction in energy use is unlikely without fundamental improvements in materials and processes.
Hence, innovations to reduce carbon emissions need to build on process and energy efficiency improvements but must be focussed on providing the necessary heat with minimum carbon emissions (2).

Opportunities for the industry to do this arise from:

Alternative fuels

The Scottish Ceramics Industry's unusually high reliance on grid electricity means that the industry will benefit from UK grid decarbonisation (1).

One of the options is the development and application of 100% electrically heated brick kiln, which would result in increasing decarbonisation as the electricity grid reduces its carbon intensity (2).

Options to utilise a lower carbon fuel include the use of biomass gasification to generate gaseous fuels to replace fossil fuels and the application of electrically heated kilns for heavy clay products. Woody biomass is considered unsuitable for direct combustion as it adversely affects product quality and increase losses (2).

However, it appears that temperatures available from combined heat and power (CHP) limit its use to materials processing in the UK raw materials (2).

Efficiency Improvements

Improved process control, energy monitoring and minimisation of losses

Replacement of batch by continuous kilns (where product ranges and volumes allow this to be feasible and economic) and replacing kilns that are passed their life expectancy (2).

Ceramic process changes that reduce energy consumption in the kiln.

Significant process improvements such as heat recovery and regeneration, materials advances for insulation and refractories, improved combustion efficiency (2).

Significant materials chemistry and technology refinements allowing lower firing temperatures, reduced number of firings, and options such as pre-calcining of clay and reduced product weight (2).

The application of CC technology to large kilns (2).

Management Buy-in

Projects providing multiple benefits (energy, carbon and labour cost reduction, improved production yield, increased capacity to satisfy a growing market, etc.) are more likely to be invested in (2).

A strong, evidence-based business case for energy and decarbonisation measures that capture all benefits and cost. Ceramic manufacturers look to invest in new technologies or upgrade existing technologies in order to increase production capacity and improve efficiency to drive costs (including cost of energy) down and production yield up. This commercial approach is mostly driven by shrinking margins across all subsectors (2).

The need to replace obsolete equipment, expand production or reduce operational manpower can also represent an opportunity to invest in new efficient technologies (2).

B7.3.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

Barriers that hamper decarbonisation are mainly financial but also arise due to limitations in technical viability. In Scotland, the high reliance on electricity makes the industry sensitive to changing electricity prices and increases the need for finacial considerations when making investment decisions in decarbonisation (1).

Financial Barriers

Decarbonisation is generally a lower priority in the current investment climate for a variety of reasons, including:

- UK producers with headquarters overseas are also in competition for funding with their peers abroad, and corporate investment may be targeted on locations with higher returns associated with lower energy and wage costs (2).

- There is often requirement for very high rates of return or short payback time on all projects including energy efficiency (2).

- Large upfront costs and long life cycles of kilns (30-60 years) are disincentives to invest given the uncertain market conditions and UK regulatory environment, internationally disadvantageous energy and carbon prices and perceived long-term lack of support for UK manufacturing industry (2).

- Increasing concern about the security of energy supply where an interruption can cause major damage taking months to repair coupled with increasingly volatile electricity and gas prices (2).

- Conservatism so that companies are more willing to invest in financially viable technologies that have already been proven to be successful, to reduce commercial risks (2).

Limitations in Techological Viability

The equipment suppliers have little of their manufacturing or RD&D based in the UK and there is a lack of government support (e.g. financial) for sector RD&D and future implementation of emerging and breakthrough technologies. Limited access to affordable capital and adequate grants is also an issue (2).

This leads to a shortage of proven, financially viable and demonstrated energy-efficiency technologies and industry stakeholders also cite a lack of information about technical feasibility, costs and benefits of new technologies and lack of the technical and engineering skills required to confidently implement new processes and technologies (1)

There are concerns abou the current relative inefficiency of high temperature heat electrification technologies (e.g. electric kilns) (1).

Risks that an innovation would diminish product quality or cause production disruption also cause low appetite for new technologies (2).

KEY REFERENCES

1. Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses: Scottish Ceramics Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

2. Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050
Ceramics Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416676/Ceramic_Report.pdf

3. Ceramic Sector Joint Industry - Government Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan. October 2017
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651229/ceramics-decarbonisation-action-plan.pdf

4. Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050
Ceramic Sector Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416194/Ceramic_Appendices.pdf

B7.4. GLASS

B7.4.1. SECTOR OVERVIEW

The glass sector produces container glass (bottles and jars), flat glass (windows for construction automotive), fibreglass (e.g. for wind turbines), and domestic/specialty glass products. Production of container and flat glass accounts for 95% of all glass production (2). Emissions from other glass sector product manufacturers, such as glass beads and insulation, have been excluded, however key recommendations may still be relevant.
The Scottish Glass Industry is limited to Scotland's two large container glass (bottles and jars) plants located at Alloa and Irvine (1).

The UK glass industry is a mature market, with high capital intensity requirements (2). Future production for the UK glass sector is projected to grow somewhat. The sector's growth is reliant on trends in downstream construction, automotive, wind energy, beverage, and fruit and vegetable processing sectors as these are the primary customers of glass (2).

The growth prospects differ between flat, container glass and fibreglass. For flat glass, growth depends on the sector's ability to compete with import competition and expanding into downstream shaped and processed flat glass products. Key drivers for growth include demand from building and construction and automotive sectors (2). During the recession, due to the depression of the construction industry, demand for flat glass fell sharply. The economic recovery is seeing an increase in the demand for flat glass.

The long-term growth prospects for the container glass industry hinges on the continued capability of bottle and jar manufacturers to compete against alternative packaging materials. Key drivers for growth include demand from food and beverage packagers and retailers (2).

The growth of the wind energy market, electronics, and bathroom industries will directly impact on the growth prospects of fibre glass in the UK (2).

B7.4.2. ENVIRONMENTAL IMPACTS

Glass manufacturing processes depend highly on the final product, but all manufacturing processes have a common origin: glass first needs to be melted. Glass is therefore an energy-intensive sector and energy is one of the largest operational costs. The sector is characterised by the use of high-temperature melting furnaces and other heat-intensive processing equipment (like forehearths and lehrs), accounting for ca. 85% of all the fuels used. Overall energy consumption in the UK glass sector (excluding fibre) is split to approximately 70% for container glass and 30% for flat glass production (2).

The energy use in the sector is dominated by natural gas (81%). Electricity use is 13% and other fossil fuels make up 6%. Most furnaces are fired with natural gas (with fuel oil as standby fuel) (2). Both plants (Alloa and Irvine) use natural gas as their fuel source (1).

IMPACTS ON AIR

The combustion of fossil fuel, raw material degradation and indirect emissions from electricity consumption makes up the glass sector carbon footprint. Direct emissions originate largely from fossil fuel combustion and raw material degradation in the furnace (process emissions), and indirect

emissions from electricity from the grid, with the melting furnace accounting for about three quarters of all energy use in a typical UK glass plant.
Additional CO_2 is released from the actual glass making process: for each tonne of glass produced from virgin raw materials, 185 kg of CO_2 is produced (2). The CO_2 emissions released from glass manufacturing can be split into 18% from raw materials, 58% from fossil fuel combustion and 24% from primary electricity generation (5).

The majority of electricity used in the UK glass industry is currently supplied from the national electricity grid, although a very small amount of on-site generation from CHP or private wire supply is available too (2).

IMPACTS ON WATER

<nothing noted>

IMPACTS ON LAND

<nothing noted>

B7.4.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

It should be noted that glass already makes a significant contribution to building a sustainable society – for example through developing high performance glazing, lightweighting of products and, most significantly, being a 100% recyclable material that meets circular economy principles (4). However, it is still a major emitter of GHG's and there are opportunities for both increasing levels of recycling to contribute to the sustainability of products and reducing emissions resulting from the manufacturing process.

Fuel and Raw Materials

Melting furnaces are the major energy users in the glass manufacturing and are hence the most important areas for energy improvements. The largest users of electricity in a container glass plant - after the furnaces - are the compressors used to provide air for the glass-forming processes, the many fans used to cool the glass-forming machines and certain parts of the furnace (2).

Fuel Switching: fuel switch to electricity (electric melting and electrification or boosting), fuel switching to biogas (bio-SNG) or hydrogen, and renewables generation (2).

Electric melting is a key decarbonisation technology (2).
The main barriers to implementation include late state research and development needs including scale-up, the current carbon intensity of the UK electricity supply meaning that electric melting has a higher carbon impact than conventional natural-gas fired furnaces and the current and projected high cost of electricity compared to natural gas.

Furnace Improvements

Traditional burners are air-fuel fired, but an increased use of oxygen will increase fuel efficiency and reduce NOx emissions. Air can therefore be enriched with oxygen, or burners can be 100% oxygen-fuel fired. However, the additional energy required to make oxygen must be included in emissions calculations (2). Evolutionary and revolutionary modifications to furnaces to improve energy efficiency.

Cullet addition. In the production of container glass, cullet is added to the melt, giving significant energy savings and does not result in 'process' CO2 emissions. Cullet can arise within the factory as a result from breakage or rejected ware (domestic cullet), having the advantage of an identical composition to the glass being melted. The cullet can also be brought into the factory from external sources (foreign cullet), which is now a major source of raw material (4).

Pelletisation: Each pellet contains the correct proportion of mixed, powdered raw materials in close contact improving efficiency (5).

Improved Process Control and monitoring systems can be implemented.

Heat Recovery: To increase energy efficiency, furnaces today are equipped with regenerators for primary heat recovery which pre-heat air. Secondary waste heat recovery van be installed to generate electricity, to pre-heat batch and cullet, and to generate steam in a waste-heat recovery boiler (e.g. for space heating). When plants are located in built-up and established industrial areas, there is also potential for 'over the fence' heat recovery for district heating (2).

Optimise Product Design: To further reduce material required or facilitate recycling.

<u>Public/Government Engagement</u>
The Scottish Government and its agencies are working with the glass sector to support progress against the key policy objectives of decarbonisation, energy efficiency and circular economy contained in the Scottish Manufacturing Action Plan.

Scottish Enterprise has supported furnace rebuilds, achieving energy reduction through the economic development route. As part of 'Making Things Last – A circular economy strategy for Scotland', the Scottish Government is working to improve the quality and quantity of glass reprocessed in Scotland by harmonising Local Authority collections under the Household Recycling Charter and amalgamating contracts for the sale of glass cullet through the Scottish Materials Brokerage Service (4).

Customer demand for more sustainable products would benefit the glass industry.
Creating markets for low carbon glass products: The majority of customers and consumers would not preferentially choose a low carbon product over a similar product manufactured to lower environmental standards (2).

Regulations encouraging energy efficiency in downstream sectors may also aid the sector. The interaction between sectors is significant, with the carbon emissions of the glass sector being necessary to make products that reduce carbon emissions in other sectors (2).

<u>Increase Glass Recycling</u>

The recycling industry comprises the collecting organisations and the cullet processors. Processors sort the glass to remove unwanted materials (metals, stones, paper, plastics, etc.). Glass destined for re-melting at container plants additionally undergoes some colour separation. Glass recycling is aided by the bottle bank system (glass collection points) which incorporates colour segregation. Availability of recycled glass depends on bottle banks, kerbside collection, other waste separation processes, and glass collected via the drinks trade from pubs and clubs (2).

There is an opportunity for the sector to reduce carbon emissions by increasing the use of recycled glass (cullet). Closed loop recycling (recycling glass back to glass) is preferred as it results in greater energy savings and CO_2 reduction than using recycled glass as aggregate (2).

Education, Training & Skills

The glass industry wants to be involved in the search for solutions. The industry can provide ideas, appropriate data and expert advice and are best placed to lead change. Suggestions include (5):

- Promotion of the environmental and economic benefits of glass and glass products
- Strengthening of dialogue on environmental issues and find out what others are interested in
- Create Delivery Structures such as long-term sector R&D and technology plans. Options include a centre of glass research and a glass knowledge transfer network.
- Identify and put in place funding to support industry plans for R&D and innovation.
- Fully utilise training provided by the Glass Academy (such as 'making the business case for energy efficiency improvements') and establish a training centre for the UK glass sector.

Emissions Offsetting

Carbon Capture: Emerging technology that separates CO_2 from other exhaust gases to be utilised or permanently stored.

Carbon Offsetting: A carbon offset is a reduction in emissions in one area, made in order to compensate for an emission created elsewhere e.g. planting trees to compensate for CO_2 emitting activities. Offsetting should be considered in addition to direct reductions (5).

B7.4.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

Demand

Lack of demand for low carbon products (2).

Clear glass is predominantly produced in Scotland, being the preferred colour for the food and drink sector, however much of this is exported (e.g. Scotch whisky). At the same time, the majority of domestic consumption is brown and green glass. This incompatibility between supply and demand, along with low glass recycling rates, hampers the industry's ability to increase use of recycled glass cullet and consequent decarbonisation benefits (1).

Existing recycling systems could be improved, new glass streams (e.g. building glass) could be recycled, and technologies could be improved to aid processing. The limiting factor is the availability of competitively priced, uncontaminated recycled glass (2).

Financial

High and fluctuating energy prices

Long payback periods and high costs (2)
Energy efficiency is perceived as important, but decarbonisation is generally not a priority in the current investment climate, as it is currently perceived as additional business cost. Companies may also face difficulty finding external financing.

Uneven playing field with overseas competition (2)
The views of the sector is that increased competition from other countries with, what are perceived to be, lower environmental regulations and energy costs is perceived to be making it more challenging for UK glass companies to remain competitive and obtain internal funding for investment across the sector, due to a reduction in profits, and investments going to other countries rather than the UK.

Risk of production disruption, hassle and inconvenience (2)
The production of glass takes place in furnaces that are constructed to continuously melt large quantities of glass over extended campaigns of 10-15 years for container glass. Flat glass furnaces, however, have a campaign life of approximately 20 years, after which they undergo a partial rebuild. CO2 abatement opportunities will have to avoid interrupting the melting campaign and associated downtime and production losses.
Not all decarbonisation measures need to be delayed until complete rebuild but can be temporarily bypassed on existing furnaces, but opportunities to finance large-scale disruptive technologies are at specific times.

Technical Viability

Chemical and process efficiency limitations (2)

There is a limited number of staff with specialised skills in energy and furnace engineering in the sector (2).

Lack of clarity on the long-term availability, cost and technical viability of resources such as biomass and the degree to which it can be considered low carbon (2).

KEY REFERENCES

1. Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses: Scottish Glass Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

2. Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050.
Glass Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416675/Glass_Report.pdf

3. Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050.
Glass Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/415958/Glass_Appendices.pdf

4. Glass Sector Joint Industry - Government Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan. October 2017
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652080/glass-decarbonisation-action-plan.pdf

5. A clear future: UK glass manufacturing sector decarbonisation roadmap to 2050
https://www.britglass.org.uk/system/files/UK%20Glass%20Decarbonisation%20Roadmap_Full%20report.pdf
https://www.britglass.org.uk/sites/default/files/A%20clear%20future%20-%20UK%20glass%20manufacturing%20sector%20decarbonisation%20roadmap%20to%202050_summary.pdf

B7.5. PAPER / PULP

B7.5.1. SECTOR OVERVIEW

The pulp and paper sector in the UK is dominated by 17 companies representing 80% of the sector emissions in the UK with a mix of national and international companies, where the latter represent the majority of the production (2). In Scotland, there are only 4 paper and pulp mills with an additional 4 facilities involved in the manufacture of wood products (1).

The sector can be divided into the following subsectors (2):

- Specialist paper mills
- Tissue and hygiene paper mills
- Packaging paper mills using recycled fibre
- Specialist packaging paper mills
- Printing and writing mills including newsprint

There are a large number of smaller mills in the specialist packaging paper subsector compared to packaging paper mills using recycled fibre that are generally larger, producing 37% of all the paper products produced in the UK (2).

In the papermaking process, either paper for recycling or wood fibres (or on occasion other types of fibres) serves as the raw material to the pulp production (2). Overall, UK paper mills use approximately 75% recovered fibre and 25% virgin fibre. The virgin fibre used in UK paper manufacturing is mostly imported, as virgin fibre production in the UK is limited to two sites, both of which use all the virgin fibre they produce for their own paper products (5).

The sector is mature and capital intensive, with long investment cycles. The level of competition is high in general though to some extent this varies depending on the end product (2).
The UK is the biggest net importer of paper in the world and future production for the UK pulp and paper sector is projected to grow somewhat and certain subsectors will either grow or decline (2):

- Tissue and Hygiene is likely to grow;
- Speciality will either grow slightly or stay the same;
- Printing and Writing, including Newsprint and Packaging, is expected stay the same or decline.

Due to the high level of imports to the UK market, it could technically be possible for UK production to increase, even if overall UK consumption were to fall.

B7.5.2. ENVIRONMENTAL IMPACTS

The UK pulp and paper industry is a considerable consumer of heat. The paper machine, and in particular the drying process, accounts for about two thirds of all energy use in a typical UK pulp and paper mill, using mainly steam produced by natural gas or biomass (2).

IMPACTS ON AIR

Direct emissions of greenhouse gases originate largely from steam-producing boilers and gas turbines, and indirect emissions from electricity from the grid, with the paper machine –- and in particular the drying process –- accounting for about two thirds of all energy use in a typical UK pulp and paper mill (2). The amount of energy consumed by each mill depends on its products and on the processes employed.

The fuel use in the sector is dominated by natural gas with 17% of the fuel used being biomass (2). The energy source within a mill is a key factor in determining its overall environmental impact. The principal energy sources for papermaking in the UK are natural gas and electricity, although other sources such as coal, oil and biomass are also used to generate energy on site (5).
Biomass is mostly used by four installed biomass CHP plants. Sludge from wastewater treatment plants is also used as fuel in some mills (2).

The gross energy demand for the production of paper from virgin fibre is generally higher than for the production of RCF, but the production of virgin pulps can result in a net gain of energy as process by-products are normally used to produce energy (and surplus energy is exported to the grid). Energy from waste is becoming important for recovered mills as well, with RCF residues being used for energy production (5).

IMPACTS ON WATER

Whilst water abstraction is high, the paper industry's water consumption is relatively low as most of the water that is abstracted is re-circulated within the mills before being cleaned up and discharged. What is actually consumed by the industry is water that evaporates or water that is incorporated into the product (5). Cooling, which is mainly achieved by using cooling water, is also not a large energy consumer in the pulp and paper industry (2).

IMPACTS ON LAND

Production met 43% of domestic consumption, and 81% of domestic consumption was recovered. The fact that UK production only supplies 43% of the domestic consumption is a cause for concern as the carbon emissions for the additional paper used are not accounted for in the UK (2). Over half of the UK RCF is sent abroad for recycling, mostly to China and this is associated with increased emissions arising from the transport of material and with uncertainty in emissions from Chinese paper mills. WRAP work suggests that recycling of paper is preferable to landfill even if this means shipping the material to China. Furthermore, since most of the material is now being reprocessed in new Chinese mills using state of the art technology, processing emissions are also reduced (5).

B7.5.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

The Scottish mills have already improved energy efficiency, reducing energy consumption by almost 40%. Its decades of success improving energy efficiency provides valuable experience and expertise that can be drawn and built upon going forward. It is also well placed to take advantage of grid decarbonisation and increased heat and recycling recovery mechanisms and uptake (1).

Alternative Fuels and Heat Recovery

Pulp and paper production is inherently energy intensive the need for both heat and power in paper production means the sector is well suited to deploy CHP with its inherent higher efficiencies compared to stand alone electricity generation and steam boilers (5).
However, the latent heat in the dryer section is currently quite difficult to reuse as it is wet exhaust air and of too low quality. In addition, additional CHP power in the future may be limited, mainly due

to the fact that the pulp and paper Industry is no longer growing and many mills already have CHP installed. Investment in CHP is only feasible if there is a sufficient gap between fuel price and electricity price (2).

The industry is also adopting mechanisms such as biomass cogeneration and increasing use of recyclate feedstocks (1). The processes in a mill do not require energy supplied at a higher temperature than can be provided by steam. Today, on average, two thirds of the energy used in a mill is steam and the rest is electricity. If the fuel used to produce the steam is replaced by a low carbon fuel, two-thirds of the carbon emissions could be reduced. Today, 17% of the fuel used in the sector is provided by biomass (2).

Biomass Carbon can also be used by the pulp and paper industry to provide energy. This energy biomass is either a waste stream from production processes or purchased biomass (either waste or non-waste), often from closely associated forests or commercial waste streams (2).

Energy Efficiency

Small-scale changes could be made to operations across mills to improve energy efficiency. There include (2):

- Energy monitoring and management
- Improved process control
- Maintenance

Larger scale options include Paper machine upgrades to more modern technologies and looking for opportunities for industrial clustering and heat networking. However, clustering opportunities are limited for existing installations and there can be significant local planning difficulties (2).

Increasing Recycling

There is a practical limit to the amount of paper that can be collected for recycling, due to the fact that much of the uncollected paper either remains in circulation (e.g. banknotes and in libraries) or is unrecoverable for hygienic or practical reasons (e.g. tissue paper) (5).

It could be possible to increase the UK‟s paper collection rate by focusing efforts on historically difficult to reach sources such as recycling on the go, SMEs, densely populated areas such as high rise flats etc. By ensuring that high quality RCF is collected (e.g. minimising contamination by non-target material), UK exports will become more competitive in the international paper market (5).

Advancements in the printing industry often involve the use of hard to remove inks that can lead to increased use of energy and water for cleaning of the RCF pulp and also to a likely loss of valuable fibre. Research is being carried out to identify easier ways to remove these inks during the recycling process, but it could be worthwhile promoting the use of more traditional and less environmentally challenging inks (5).

Financial Enablers

Decarbonisation is not a priority in the current investment environment but two business drivers contribute to decarbonisation; the need to reduce energy costs and the cyclic investment in new equipment. Despite decarbonisation not being a priority, most companies have decarbonisation targets for 2025. The drivers behind these strategies are twofold – all companies are seeking reduced operating costs, which drive energy and therefore carbon emissions. The second driver, albeit weaker, is the adaptation of corporate wide sustainability strategies. These have a much wider remit than carbon, and are about much more than decarbonisation, yet the vast majority steer organisations into setting and working towards decarbonisation targets (2).

Collaboration in the value chain is also an opportunity for the sector.
Partnerships with machine suppliers are needed to refine existing and develop new technologies, as well as collaboration between different paper companies. If customers put a premium on low-carbon paper products then a differential pricing approach would be possible. The challenge for the pulp and paper sector is that it rarely has a relationship with the end customer as it typically sells its products to a distributor of some sort.
As a sector that has uses biomaterials, paper companies have the knowledge and experience to contribute towards the development of a Bio-refinery. In collaboration with other sectors, such a facility could covert biomass to high-quality products for the evolving bio-economy (e.g. bio-polymers and composites with new functionalities) (2).

B7.5.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

The risks for decarbonisation in the pulp and paper sector mainly relate to financial concerns and the fact that overall, generally poor profit margins have resulted in a low level of recent capital investment in new machinery and technologies. Limits on recycling are also a risk, as is a low level of research and development.

Financial Concerns

The pulp and paper industry operates in a competitive marketplace with lowering profit margins. Rising UK energy prices and recent regulatory uncertainty leads to uncertainty about return on capital (2).

Companies that have international owners may face global competition for funding from group headquarters (2).

The investment cycles are long (typically 30-60 years). Modern machines run more efficiently at higher speeds and produce higher quality paper – but at significant capital cost at the investment stage. Older machines gradually become obsolete, prompting a cyclic nature to step changes in the sector. Paper machine investments drive associated site investment, such as power equipment – which in turn deliver efficiency improvements and, in most cases, a decarbonisation benefit. Essentially, a mill must continue to invest to remain competitive; those lacking investment risk falling behind peers in the sector, become uncompetitive, and eventually close (2).

There are few newly built mills in the UK and, although a number of mills have been making serious investments over the past years, the majority of the mills have equipment from different time periods and major items of equipment have typically been rebuilt over the lifespan of the equipment. The lifespan of both process technology and utility equipment is typically 25 to 40 years (2).
Uncertainty regarding impact of new technology on machine operability also reduces the willingness of the industry to invest in new technologies (2).

Recycling Limitations

Virgin paper production and paper recycling are fully dependent on each other for paper production to remain sustainable. There is a minimum fibre length requirement for recycling of paper to be feasible and since the re-pulping process shortens the paper fibre, virgin fibre or high quality recovered fibre (RCF) must be introduced to the paper loop to compensate for the loss of fibre (5).

Newsprint manufacturing uses the highest percentage of RCF, with almost 100% of newsprint produced in the UK made from recovered fibre. The lowest recycled contents, on the other hand, are found in printings and writings (P& W) and tissue paper, mostly because of customer perceptions and requirements. Although virgin fibre in P&W can be recycled, virgin fibre used in tissue and other hygienic products is lost after its first use. Therefore, an opportunity exists to work with industry and the public to promote the greater use of RCF in these products (5).

To further increase paper recycling the industry must overcome the important barrier of contamination. While paper contamination can occur either before or after use of the paper product, post-consumer contamination is most easily avoidable. The most important paper contaminants are glass and grease/food. Glass is broken down to an abrasive dust causing wear and tear of the mill equipment whereas grease and food contamination impacts on the strength and presentation of the finished product. Other contaminants include difficult to remove inks and integral additives used to make paper and paper products (5).

Lack of R& D Activities

There is a general lack of Research, Development and Demonstration (RD& D) projects taking place in the UK pulp and paper sector, meaning that the sector could fall behind other regions with regards to strategy and leadership, knowledge, expertise, training and skills, technologies, and the supply chain. There is a lack of awareness and information imperfections with regards to new technologies that could aid energy efficiency (2).

KEY REFERENCES

1. Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses: Scottish Paper & Pulp Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

2. Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Pulp and Paper Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416673/Pulp_and_Paper_Report.pdf

3. Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Pulp and Paper Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416200/Pulp_and_Paper_Appendices.pdf

4. Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Pulp and Paper Action Plan
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652141/pulp-paper-decarbonisation-action-plan.pdf

5. DEFRA
How can paper be made more sustainable? A desk-based review of available information on sustainability practices in the UK paper industry
http://sciencesearch.defra.gov.uk/Document.aspx?Document=WR1210SustainablePaper-FinalReport-PublishedFeb2012.pdf

B8. TEXTILES (incl. Leather)

B8.1. SECTOR OVERVIEW

The Fashion and Textile sector includes manufacturing processes such as weaving, knitting but also covers design and supply chain aspects. Across the EU and UK, clothing is the eighth largest sector in terms of household spending (1). In 2016, based mainly on Her Majesty's Revenue and Customs data, it is estimated that 1,130,000 tonnes of clothing was purchased in the UK (1).

It also has a large export market and Scotland exports textiles worth £360 million and representing around 1.1% of Scotland's total international exports to more than 150 countries worldwide (Scottish Economic Statistics, Scottish Enterprise February 2020).

Leather in particular, is an important part of the Scottish economy and in 2016, the Scottish leather sector contributed £40 million to the economy (2). Scottish organisations manufacture leather from bovine hides and range from manufacturers considered micro-scale through to those exporting to a global market (2).

B8.2. ENVIRONMENTAL IMPACTS

Despite improvements, the carbon footprint of clothing in use in the UK has risen to 26.2 million tonnes CO_2e in 2016, up from 24 million tonnes in 2012 due to a combination of relatively low prices and increased population (1).

The carbon footprint of clothing bought in the UK includes contributions from a variety of sources (1), many of which are not specific to the manufacture of the garments in Scotland. However, it is difficult to separate the part of the process and its impacts that can be assigned to Scotland and so all of the impacts are covered.

The environmental impacts of leather manufacture are easier to separate out to specific sites in Scotland since it has a less extensive global supply chain. However, leather tanning is a multi-stage process turning raw into a suitable leather that can be used for many purposes and throughout each stage of the processes, energy is used and by-products and waste are produced. Each part of the process therefore may give rise to specific environmental impacts (2).

IMPACTS ON AIR

The highest contributor to the carbon footprint of textiles in the form of clothing is the production of fibre through polymer extrusion or agriculture. Other fibre preparation and processing such as spinning to make yarn, fabric printing and dyeing, all add to the carbon footprint. In particular, the heat setting in chemical and mechanical finishing has a significant effect (1).

Re-use and recycling offer some carbon savings by extending the lifetime of clothing and displacing sale of new garments thus avoiding the effects on the environment from fibre extraction and processing.

Very low levels of carbon emissions are associated with transport and disposal of clothing via landfill and incineration (1).

The raw material (bovine production) for leather production is resource intensive and has impacts on water, soil and air quality. Greenhouse gas emissions arise from energy use in bovine production alongside other impacts on air, water and land from raw material production for hide preservation. Greenhouse gas emissions and air quality impacts also arise from transportation and preservation of raw materials. However, raw hides in the UK are largely a by-product of the meat and dairy industry and thus the impacts of production are offset in some ways due to re-use of otherwise waste products (2).

Leather production affects the environment through greenhouse gas emissions from the fossil fuels used to power the manufacturing processes and also from transportation of finished products.

Greenhouse gas emissions also arise from waste treatment in the leather industry (2).

IMPACTS ON WATER

The greatest quantity of water is used during the growing and production of fibres. Processing, including spinning, weaving, knitting, colouration and finishing, or setting of the dye, also adds to the water footprint of clothing (1).

Water is used most intensively in agriculture, particularly in cotton growing. Cotton production accounts for 69% of the water footprint of textiles' fibre production and 65% of the total water footprint with much of this water burden placed on overseas locations (1).

Large quantities of water are used in the production of silk fibre. Kilogram for kilogram, silk has a higher water footprint than cotton (1).

Cellulosic fibres also use a large quantity of water in their production. With viscose, this occurs when raw material is made into fibre ready for spinning into yarn (1).

Synthetic fibres affect the water footprint mostly during dyeing and finishing because a high amount of dye and processing is needed for synthetic fibres (1).

Leather production impacts upon water quality and ecology from indirect emissions to the water environment and from water abstraction (2).

Waste from leather manufacturing can also have an impact on water quality and ecology from liquid effluent containing chromium and other chemicals used in tanning and finishing processes and from sludge effluent dewatering (2).

IMPACTS ON LAND

Supply chain waste arises in the country where the fibres or fabrics are processed and the amount of supply chain waste varies by fabric and fibre type. The majority arises during preparation of fibres to make yarn and during garment production (1).

The production of natural fibres produces large amounts of by-products some of which will arise as waste.

In garment production, all fabrics are likely to create waste during cutting (1).

B8.3. OPPORTUNITIES FOR REDUCING ENVIRONMENTAL IMPACTS

For the textiles industry (1), opportunities lie in:

- Switching to sustainable cotton;
- Increasing the adoption of sustainable fibre;
- Fibre to fibre recycling;
- Using lower-impact processes in the production of garments;
- Focusing on specific garments that will deliver the largest reductions in carbon, water and waste footprints;
- Informing and enabling customers to improve clothing care, repair, and re-use;
- Colouration technologies offer environmental savings by using fewer resources and causing less pollution, offer great potential;
- Designing for durability;
- Increasing use of hire and repair service.

For the leather sector (2) opportunities arise from:

- Water reuse through the manufacturing process means demand is reduced;
- Recovery and reuse of process residues and wastes resulting in a decrease in resource requirements e.g. recycling end of life leather products;
- Energy recovery initiatives which reduce reliance on traditional energy supplies and reduce the carbon footprint of leather production while maximising resource recovery;
- Resource efficiency can improve productivity and reduce costs for the leather sector. It can bring environmental improvements and reduce reliance on virgin raw materials;
- Fats and greaves can be removed and passed on for further processing in a side process which results in a grease like substance, which is used as a raw material in other industries (e.g. biofuel manufacture);
- When leather products have come to the end of their life they are still a high value material. There may be potential for leather clothing banks and the infrastructure to support this;
- Use of leather manufacturer's high protein content material residues as a raw material within the pet food industry and other sectors.

B8.4. BARRIERS TO REDUCING ENVIRONMENTAL IMPACTS

- Global market access / trade tariffs;
- Competition from foreign producers with lower environmental standards and overheads;
- Competition from leather alternatives;
- Changing fashion trends;
- Increased regulation.

KEY REFERENCES

[1] WRAP- Valuing our Clothes: The cost of UK fashion
http://www.wrap.org.uk/sites/files/wrap/valuing-our-clothes-the-cost-of-uk-fashion_WRAP.pdf

[2] SEPA Sector Plans: Leather
https://sectors.sepa.org.uk/leather-sector-plan/

B9. INFORMATION SOURCES

B9.1. STANDARDS AND FIGURES

Annual Compendium of Scottish Energy Statistics May 2019
https://www.gov.scot/binaries/content/documents/govscot/publications/statistics/2019/05/annual-compendium-of-scottish-energy-statistics/documents/annual-compendium-may-2019/annual-compendium-may-2019/govscot%3Adocument/Annual%2BCompendium%2Bof%2BScottish%2BEnergy%2BStatistics.pdf

Interactive Scotland Heat Map
https://www.gov.scot/collections/energy-statistics/#scotlandheatmap

Scottish Greenhouse Gas Emissions 2017
https://www.gov.scot/binaries/content/documents/govscot/publications/statistics/2019/06/scottish-greenhouse-gas-emissions-2017/documents/scottish-greenhouse-gas-emissions-2017/scottish-greenhouse-gas-emissions-2017/govscot%3Adocument/scottish-greenhouse-gas-emissions-2017.pdf?forceDownload=true

Scotland's Carbon Footprint: 1998-2016
http://www.gov.scot/ISBN/9781839604355

Air Quality Pollutant Inventories for England, Scotland, Wales, and Northern Ireland: 1990-2017
https://naei.beis.gov.uk/reports/reports?report_id=996

B9.2. POLICIES

Climate Change Plan: third report on proposals and policies 2018-2032 (RPP3)
https://www.gov.scot/binaries/content/documents/govscot/publications/corporate-report/2018/02/scottish-governments-climate-change-plan-third-report-proposals-policies-2018/documents/00532096-pdf/00532096-pdf/govscot%3Adocument/00532096.pdf?forceDownload=true

DEFRA Clean Air Strategy 2019
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770715/clean-air-strategy-2019.pdf

Cleaner Air for Scotland – The Road to a Healthier Future (CAFS)
https://www.gov.scot/binaries/content/documents/govscot/publications/report/2017/06/cleaner-air-scotland-road-healthier-future-annual-progress-report-2016/documents/00521031-pdf/00521031-pdf/govscot:document/

Cleaner Air For Scotland 2019 Independent Review
https://www.gov.scot/binaries/content/documents/govscot/publications/independent-report/2019/08/cleaner-air-scotland-strategy-independent-review/documents/cleaner-air-scotland-strategy-independent-review/cleaner-air-scotland-strategy-independent-review/govscot%3Adocument/cleaner-air-scotland-strategy-independent-review.pdf?forceDownload=true

B9.3. CROSS-SECTOR SUMMARIES

Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=2ahUKEwilyb6ztszoAhWNZMAKHWKoCjMQFjABegQIBxAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

Decarbonising Scotland's Industrial Sectors and Sites 2019
https://www.gov.scot/binaries/content/documents/govscot/publications/progress-report/2019/04/decarbonising-scotlands-industrial-sectors-sites-paper-discussion-scottish-energy-intensive-industries/documents/decarbonising-scotlands-industrial-sectors-sites/decarbonising-scotlands-industrial-sectors-sites/govscot%3Adocument/decarbonising-scotlands-industrial-sectors-sites.pdf?forceDownload=true

Industrial energy use and carbon emissions reduction: a UK perspective
https://onlinelibrary.wiley.com/doi/epdf/10.1002/wene.212

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050. MARCH 2015
Cross Sector Summary Report and Plans
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/419912/Cross_Sector_Summary_Report.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651276/decarbonisation-action-plans-summary.pdf

B9.4. MANUFACTURING AND INNOVATION

A Manufacturing Future for Scotland
https://www.gov.scot/binaries/content/documents/govscot/publications/corporate-report/2018/09/a-manufacturing-future-for-scotland-action-plan/documents/a-manufacturing-future-for-scotland/a-manufacturing-future-for-scotland/govscot%3Adocument/A%2Bmanufacturing%2Bfuture%2Bfor%2BScotland.pdf?forceDownload=true

The Future of Manufacturing
https://www.gov.uk/government/publications/future-of-manufacturing

Sustainability and manufacturing. Imperial College London October 2013
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjFxYGTs8zoAhWNURUIHRQrDQUQFjAAegQIBhAB&url=https%3A%2F%2Fassets.publishing.service.gov.uk%2Fgovernment%2Fuploads%2Fsystem%2Fuploads%2Fattachment_data%2Ffile%2F283909%2Fep35-sustainability-and-manufacturing.pdf&usg=AOvVaw0wxuJ4puB-Wmq8YCQUlu8S

B9.5. PRECISION MANUFACTURING (e.g. photonics; quantum; electronics (incl. medical devices))

Make UK. Sector Bulletin Electronics
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-electronics.pdf

UK Photonics: The Hidden Economic Engine
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=2ahUKEwiNtbr8ifzoAhVJaRUIHUQhCAQQFjABegQICxAD&url=https%3A%2F%2Fphotonicsuk.org%2Fwp-content%2Fuploads%2F2018%2F05%2FUK_Photonics_The_Hidden_Economy.pdf&usg=AOvVaw1euqtHfdtHc6Kh2RgL5Pc1
Light as the key to global Sustainability
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=2ahUKEwjolPzn68noAhUQEcAKHfQyC7QQFjACegQIAhAB&url=https%3A%2F%2Fwww.photonics21.org%2Fdownload%2Fppp-services%2Fphotonics-downloads%2FStudy_GreenPhotonics_2020_final.pdf&usg=AOvVaw2KUF_GVNjLUoQLMscbyosm

Environmental impacts of utility-scale solar energy
https://doi.org/10.1016/j.rser.2013.08.041

B9.6. MEDIUM-SCALE / IN-FACTORY MANUFACTURING (e.g. automotive; aerospace (incl. satellites))

Aerospace

BEIS Industrial Strategy- Sector Deal: Aerospace
https://www.gov.uk/government/publications/aerospace-sector-deal

ADS/ ADS Scotland. UK Aerospace Outlook 2019
https://www.adsgroup.org.uk/wp-content/uploads/sites/21/2019/06/AD00046_2019_AerospaceOutlookBooklet-FINAL-soft-copy-single-pages.pdf
Facts and Figures 2017
https://www.adsgroup.org.uk/wp-content/uploads/sites/21/2017/12/ADS-Scotland-FactsFigures-2017.pdf
Make UK Aerospace Sector Bulletin
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-aerospace.pdf
UK Parliament- Space Sector Report
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=10&cad=rja&uact=8&ved=2ahUKEwjHvuWSyf7oAhWUilwKHdTjBlwQFjAJegQIChAB&url=https%3A%2F%2Fwww.parliament.uk%2Fdocuments%2Fcommons-committees%2FExiting-the-European-Union%2F17-19%2FSectoral%2520Analyses%2F34-Space-Report.pdf&usg=AOvVaw0_eygOs_tTdcJzY2DF02c6
Sustainable Aerospace. DECARBONISATION ROAD-MAP: A PATH TO NET ZERO A plan to decarbonise UK aviation
https://www.sustainableaviation.co.uk/wp-content/uploads/2020/02/SustainableAviation_CarbonReport_20200203.pdf

Automotive

SMMT Sustainability Report 2019
https://www.smmt.co.uk/wp-content/uploads/sites/2/Sustainability-energy.jpg

Make UK Automotive Sector Bulletin
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-automotive.pdf

B9.7. LARGE-SCALE FABRICATION (e.g. shipbuilding; mechanical equipment (incl. wind turbines)

National Shipbuilding Strategy
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/643873/NationalShipbuildingStrategy_lowres.pdf

Maritime 2050 and annexes
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/872194/Maritime_2050_Report.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/877630/technology-innovation-route-map-document.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815666/economic-opportunities-low-zero-emission-shipping.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815667/economic-opportunities-low-zero-emission-shipping-technical-annexes.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815671/identification-market-failures-other-barriers-of-commercial-deployment-of-emission-reduction-options.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816015/maritime-emission-reduction-options.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815665/port-air-quality-strategies.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816017/potential_demands_on_UK_energy_system_from_port_shipping_notification.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816019/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs-technical-annexes.pdf

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816020/potential-role-targets-economic-instruments.pdf

Clean Maritime Plan
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815664/clean-maritime-plan.pdf

Make UK Sector Bulletin Mechanical equipment
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-mechanical-equipment.pdf

B9.8. FOOD AND DRINK (incl. Scotch whisky)

All

Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses: Scottish Food & Drink Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

Industrial energy use and carbon emissions reduction: a UK perspective

Food and Drink Subsector
https://onlinelibrary.wiley.com/doi/epdf/10.1002/wene.212

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Food and Drink Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416672/Food_and_Drink_Report.pdf

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Food and Drink Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/415954/Food_and_Drink_Appendices.pdf

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Food and Drink Action Plan
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651970/food-and-drink-decarbonisation-action-plan.pdf

MAKE UK. Food and Drink Sector Bulletin
https://www.makeuk.org/-/media/sector-bulletin-food-and-drink.pdf

Scotch Whisky

SEPA Whisky Sector Plan
https://sectors.sepa.org.uk/scotch-whisky-sector-plan/

Scotch Whisky Association Environmental Strategy
2009, 2016 and 2018 Report
https://www.scotch-whisky.org.uk/media/1294/final_2018_environmental_strategy_report.pdf

B9.9. CHEMICAL / PHARMACEUTICAL

Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses: Scottish Chemicals Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Chemicals Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416669/Chemicals_Report.pdf

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Chemicals Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/415948/Chemicals_Appendices.pdf

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Chemicals Action Plan
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651230/chemicals-decarbonisation-action-plan.pdf

SEPA Sector Plan DRAFT Chemicals
https://consultation.sepa.org.uk/sector-plan/chemicals-manufacturing/

Make UK Sector Bulletin: Chemicals
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-chemicals.pdf

Make UK: Pharmaceutical Sector Bulletin
https://www.makeuk.org/-/media/eef/files/reports/industry-reports/sector-bulletin-pharmaceutical.pdf

B9.10. MATERIALS PRODUCTION (incl. metals; cement; ceramics; glass; paper/pulp)

Metals

Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses: Scottish Iron and Steel Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX
Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Iron and Steel Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416667/Iron_and_Steel_Report.pdf

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Iron and Steel Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416197/Iron_and_Steel_Appendices.pdf

SEPA Sector Plans – Metals
https://sectors.sepa.org.uk/metals-sector-plan/

UK Metals Council. Strategy 2030
https://www.ukmetalscouncil.org/uploads/files/p1a29r5d9h10f91j1dss17sq1jvi4.pdf

Cement

Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses: Scottish Cement Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

Industrial energy use and carbon emissions reduction: a UK perspective
The Cement Subsector
https://onlinelibrary.wiley.com/doi/epdf/10.1002/wene.212

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050
Cement Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416674/Cement_Report.pdf

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050
Cement Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/415956/Cement_Appendices.pdf

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050
Cement Sector Joint Industry - Government Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651222/cement-decarbonisation-action-plan.pdf

Mineral Products Association 2050 Strategy
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjzrvj2nszoAhWHZMAKHRPJAzMQFjAAegQIBxAB&url=https%3A%2F%2Fmineralproducts.org%2Fdocuments%2FMPA_Cement_2050_Strategy.pdf&usg=AOvVaw0sI2R8q4hw3B_a82WZ9vNd

MPA Greenhouse Gas Reduction Strategy
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=2ahUKEwjzrvj2nszoAhWHZMAKHRPJAzMQFjABegQIBBAB&url=https%3A%2F%2Fcement.mineralprodu

cts.org%2Fdocuments%2FMPA_Cement_GHG_Reduction_Strategy_Technical_Document_Dec_2015.pdf&usg=AOvVaw0ccKDDuj67Lkxs6YqfxFHF

Ceramics

Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses: Scottish Ceramics Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050
Ceramics Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416676/Ceramic_Report.pdf

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050
Ceramic Sector Joint Industry - Government Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan. October 2017
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651229/ceramics-decarbonisation-action-plan.pdf

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050
Ceramic Sector Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416194/Ceramic_Appendices.pdf

Glass

Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses: Scottish Glass Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050.
Glass Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416675/Glass_Report.pdf

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050.
Glass Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/415958/Glass_Appendices.pdf

Glass Sector Joint Industry - Government Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan. October 2017

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652080/glass-decarbonisation-action-plan.pdf
A clear future: UK glass manufacturing sector decarbonisation roadmap to 2050
https://www.britglass.org.uk/system/files/UK%20Glass%20Decarbonisation%20Roadmap_Full%20report.pdf

https://www.britglass.org.uk/sites/default/files/A%20clear%20future%20-%20UK%20glass%20manufacturing%20sector%20decarbonisation%20roadmap%20to%202050_summary.pdf

Pulp/Paper

Industrial Decarbonisation and Energy Efficiency Roadmaps: Scottish Assessment
Industry-Specific Profiles and Pathway Analyses: Scottish Pulp and Paper Industry
https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwiSuqir8cnoAhURm1wKHT1ICmkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.resourceefficientscotland.com%2Fsites%2Fdefault%2Ffiles%2Fdownloadable-files%2FIndustrial%2520Decarbonisation%2520and%2520Energy%2520Efficiency%2520Roadmaps%2520Scottish%2520Assessment.pdf&usg=AOvVaw0M9aAvjwOpkwhaKFpGMCZX

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Pulp and Paper Report
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416673/Pulp_and_Paper_Report.pdf

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Pulp and Paper Appendices
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/416200/Pulp_and_Paper_Appendices.pdf

Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050
Pulp and Paper Action Plan
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652141/pulp-paper-decarbonisation-action-plan.pdf

DEFRA: How can paper be made more sustainable? A desk-based review of available information on sustainability practices in the UK paper industry
http://sciencesearch.defra.gov.uk/Document.aspx?Document=WR1210SustainablePaper-FinalReport-PublishedFeb2012.pdf

B9.11. TEXTILES (including Leather)

WRAP- Valuing our Clothes: The cost of UK fashion
http://www.wrap.org.uk/sites/files/wrap/valuing-our-clothes-the-cost-of-uk-fashion_WRAP.pdf

SEPA Sector Plans: Leather
https://sectors.sepa.org.uk/leather-sector-plan/