green alliance…

A new formula

Cutting the UK chemical industry’s climate impact

A new formula: cutting the UK chemical industry's climate impact

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Summary

> “The inevitable transition to a net zero economy will be a major challenge for this sector.”

Although a sector that has so far received little attention in the climate debate, most of modern life relies on the chemical industry and the products derived from it. From the toothpaste used to clean our teeth and the agrochemicals to grow our breakfast cereals, to the loft insulation in our homes and the fuel additives, batteries, rubber, plastic and paints used in our cars, the majority of the chemicals in these products come from fossil fuels. Their production creates greenhouse gas emissions and the embedded carbon in them is likely to be released as they degrade. As the use of fossil fuels for energy and transport diminishes, the chemical industry will feature as an increasingly important part of oil and gas companies’ business models.

This industry is a small share of the UK economy but policy makers will still be wary of allowing it to shrink, especially in light of growing security concerns around overseas supply chains. Along with the European industry, the UK’s chemical industry generates lower emissions than the global average. This should be a selling point as customers demand greener products. However, the inevitable transition to a net zero economy will be a major challenge for this sector.

Some chemical companies have net zero plans. There are those which are, for instance, members of the planned industrial carbon capture and storage (CCS) clusters around the UK. But the industry lacks

> “There is uncertainty as to which technological solutions offer the best direction.”

an overarching agreed pathway to net zero carbon emissions, and it has tended towards incremental, conservative investment in solutions. The industry is waiting for the government to build infrastructure like CCS, rather than embracing other radical changes in its operations. This is, in part, due to soaring energy prices. But there is uncertainty as to which technological solutions offer the best direction. This is particularly unclear for processes requiring high temperature heat.

As changes to the whole economy need to be well underway to avoid devastating climate impacts, a clearer direction for this industry is urgently needed.

We suggest three under explored areas where greater focus and policy support would put the industry on track. We make the case for why these should be prioritised and outline each in detail at the end of this report. In summary, they are:

Electrification

Current government policy underplays the opportunity for industrial electrification. Heat pumps and electric boilers can meet the low and medium heat needs (up to 600°C) responsible for most of the chemical sector’s heat demand and greenhouse gas emissions. Electrification is the lowest carbon option, is more suited to dispersed sites and, particularly in the case of heat pumps, is a much more efficient use of energy.

Our recommendations to the government to accelerate electrification in this industry are:

- provide long term access to cheap renewable electricity;
- phase out financial incentives for new combined heat and power plants and replace them with incentives for electric boilers and heat pumps;

- provide innovation funding to scale up and derisk high temperature electric heat technologies and thermal batteries, and support the commercial scale roll out of industrial heat pumps.

> “Circular economy approaches reduce the need for virgin chemicals.”

Resource efficiency

Circular economy approaches reduce the need for virgin chemicals through demand reduction, reuse and recycling of chemicals and products containing them. But policy in this area has been slow to develop. Government strategies for designing out waste and improving recycling have stalled. For example, there has been a failure to impose carbon taxes on waste incinerators, in line with the polluter pays principle, and important opportunities have been missed to support new circular business models for chemicals and their downstream products.

To address these issues and improve resource efficiency in the chemical industry, we recommend the following:

- require companies to report their upstream and downstream emissions (scope 3);
- align the tax framework with the optimal resource use hierarchy;
- extend existing approaches to encourage lower emissions products, such as mandatory standards and producer responsibility schemes;
- create incentives to reduce and optimise the use of nitrogen-based fertilisers.

Alternatives to fossil fuel feedstocks

Biomass (from dedicated crops or forestry and agricultural residues) and synthetic chemicals could together replace most fossil fuel feedstocks, but the trade offs between the alternatives and the significant risk of new and increasing impacts on nature must be properly examined and managed.

To avoid unforeseen consequences from the use of alternative feedstocks, we recommend the following to the government:

- outline a clear hierarchy for the use of different types of biomass in the government's upcoming Biomass Strategy, as well as for other potential feedstocks, like green hydrogen and captured carbon, recognising the risks and trade offs;
- begin a wider discussion with all relevant stakeholders on how to drive innovation, which could include mandates for alternative feedstocks, buyers' clubs or product standards;
- scale up innovation funding for new, lower emission technologies, such as green methanol.

Introduction

> **"The sector is often overlooked as a major source of greenhouse emissions."**

Chemicals and their derivatives are ubiquitous in modern life and are used in over 90 per cent of manufactured products and materials. This includes plastics, fertilisers, detergents, rubbers, pharmaceuticals and more.[1]

The industry underpins many critical technologies in the transition to a more sustainable economy, including batteries, heat pumps, insulation and wind turbines. It has a turnover of around £70 billion and supports around 160,000 direct jobs.[2] Chemical industry workers are highly skilled, and jobs are primarily located outside London and the South East, meaning it has an important role in more economically disadvantaged areas.

Of the ten largest economies in the world, the UK has the second smallest chemicals industry by sales value.[3] Retention of a diverse domestic chemicals industry, able to support a range of downstream businesses, should be part of a UK industrial strategy to maintain economic resilience.

However, the sector is often overlooked as a major source of greenhouse emissions. It is one of the largest industrial emitters alongside the steel industry. It contributes 19 per cent of UK industrial emissions and two per cent of all UK emissions.[4] These figures do not factor in its significance as a consumer of fossil fuels, which are used as a feedstock as well as a fuel source for the industry. The sector is, therefore, an indirect as well as direct driver of emissions. Chemical products are also a source of greenhouse gas emissions in other parts of the economy, including from plastic incineration and fertiliser use.

In this industry, the use of the word 'decarbonisation' is not helpful as many of these chemical products will continue to contain carbon, the focus should be their net impact on the climate.

Which chemicals are we talking about?

We consider ‘high value chemicals’ made from carbon and hydrogen, as well as ammonia. Along with methanol, these are known as ‘primary’ chemicals. The two groups of high value chemicals are:

- Olefins: eg ethylene, propylene and butene
- Aromatics: eg benzene, toluene and xylene

Ethylene is the main high value chemical produced in the UK.

These are the building blocks of nearly all chemicals and the source of half of the industry’s greenhouse gas emissions.

Methanol is not currently made in the UK.

“This is an opportunity for UK leadership and early mover advantage.”

Cutting emissions from this sector is essential if the UK is to meet its net zero carbon goal. It will also become increasingly important to meet the demands of the major brands in its value chain, like Unilever, which have net zero targets covering their whole supply chains.

As with other aspects of the green economy, this is an opportunity for UK leadership and early mover advantage. UK produced chemicals already have lower emissions associated with them than those produced in many other countries, due to the choice of feedstock used. With the right policy framework in place the UK could move faster towards a net zero compatible chemical industry.[5]

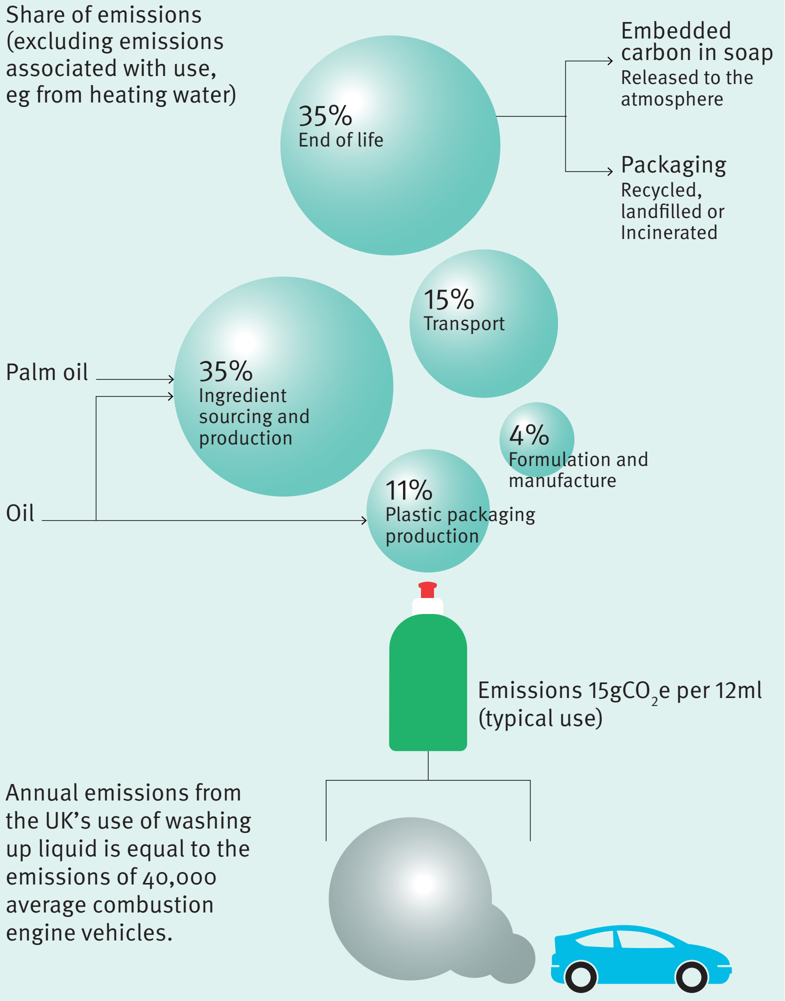
Chemical manufacturing is complex, with thousands of different products, hundreds of manufacturing sites across the UK and no ‘one size fits all’ solution to eliminate greenhouse gas emissions. There are also deep and historic connections with the fossil fuel industry that will be hard to untangle. In fact, as it faces declining demand in the energy and transport sectors, the fossil fuel industry is relying more on the chemical industry as part of its business model.[6]

Many companies operate processes across the supply chain, including oil and gas extraction, refining and the production of primary and secondary chemicals. It is also a challenging time for operators. High gas prices have led to temporary shutdowns of production plants across Europe.[7]

Based on a wide review of existing studies and our interviews with industry experts, we map some of the main sources of emissions from chemical production in the UK and identify where new government policy could reduce them. We focus particularly on production emissions but also explore options for addressing the sector's wider environmental footprint in relation to the fossil fuel feedstocks it uses.

It is worth noting that we do not specifically address the issue of chemical safety and the environment in this report but this is an important aspect of the long term sustainability of the industry and the products derived from it.

The climate impact of a bottle of washing up liquid[8]



Washing up liquid contains chemicals in both its contents (soap) and its packaging (bottle and cap). These have emissions associated with their production and end of life. Among other ingredients, soap contains surfactant as its active ingredient, typically made from a combination of fossil fuels (via ethylene oxide) and biological sources like palm or coconut oils. The bottle is made from polyethylene terephthalate (PET) and the cap is made from polypropylene.

All the ethylene and propylene used, if made from fossil fuels, originally started life in a 'steam cracker'. At the end of life, carbon embedded in the soap is released to the atmosphere as carbon dioxide through the wastewater stream. The packaging will be recycled, landfilled or incinerated, each with associated emissions.

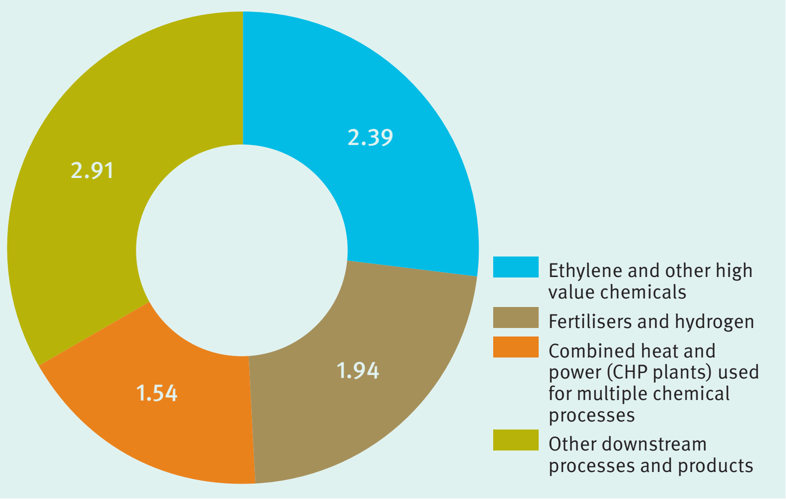
Where do the chemical industry's emissions come from?

> **"Much of the emissions from the sector come from the production of primary chemicals."**

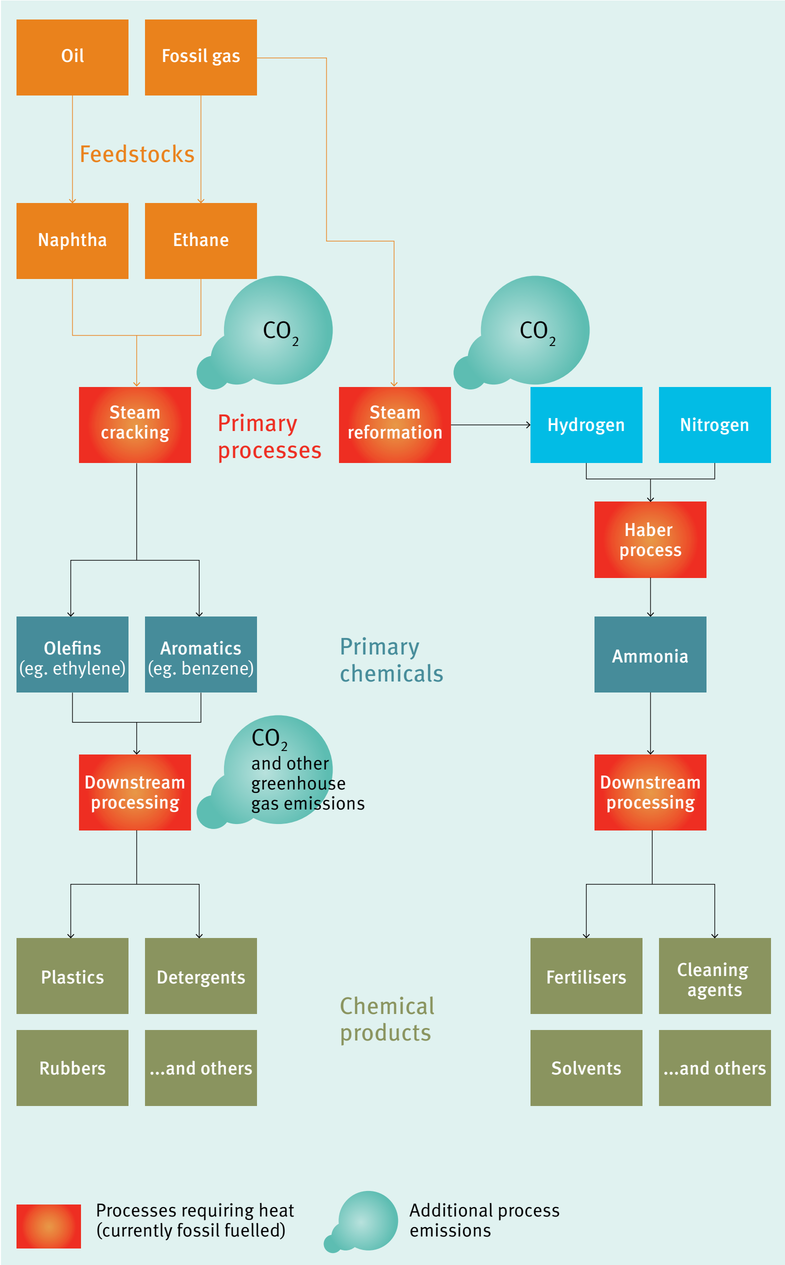
UK chemical plants make primary chemicals, which are the building blocks for other substances, as well as an array of secondary downstream products, including polymers used for the manufacture of plastics, paints, detergents, personal care products, agrochemicals, adhesives, flavours and fragrances, lubricants, fuel additives, construction chemicals and catalysts.

A large fraction of the emissions from the sector come from primary chemical production. Globally, three receive the most attention: ethylene, methanol and ammonia. Ethylene production is the largest source of chemical industry emissions in the UK, and the production of hydrogen for ammonia is the second largest. The UK does not produce methanol, but it is often highlighted as a potential future 'keystone chemical', used as a stepping stone in the production of ethylene and other primary chemicals, without needing fossil fuel feedstock.[9]

UK chemical industry direct greenhouse gas emissions, 2020 (total: 8.8 million tonnes CO_2e)[10]



The UK chemical industry and its emissions simplified



> The production of hydrogen via steam reformation is a major source of emissions."

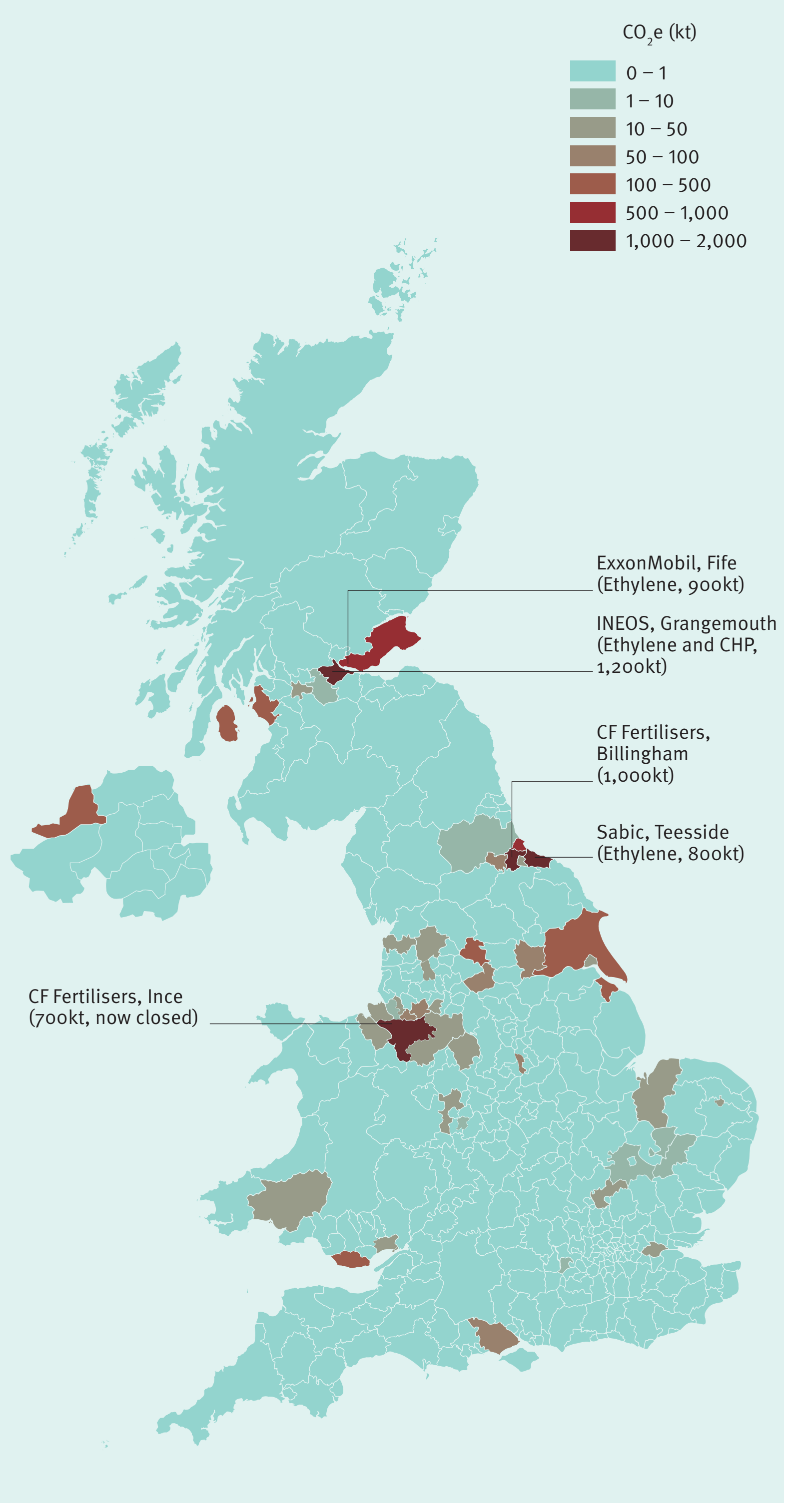
Ethylene (C_2H_4) is a precursor to many downstream products, including plastics, rubbers and detergents. It is considered one of several 'high value chemicals', alongside other olefins such as propylene (C_3H_6) and aromatics like benzene (C_6H_6), which are also important building blocks for making products like plastics, fibres and solvents.

In the UK, these chemicals are produced in large furnaces called 'steam crackers', at three locations (Teesside, Grangemouth and Fife). These operate at temperatures up to around 850°C, to break down either ethane (a by-product of extracting fossil gas, typically obtained from US fracking operations) or naphtha (a by-product of oil refining) into high value chemicals. Eighty to 90 per cent of the resulting emissions come from burning fossil fuels to generate the temperatures necessary for steam crackers, with the rest coming from the chemical reaction itself.[11]

Ammonia (NH_3) is a building block for many pharmaceutical and cleaning products but most of it is turned into fertiliser. It is made by combining nitrogen, separated from the air, with hydrogen produced through the steam reformation of fossil gas. Known as the Haber-Bosch process, this is done at temperatures of around 450°C. The production of hydrogen via steam reformation is a major source of emissions, partly due to the level of heat required (800 to 900°C) but mostly from the CO_2 by-product of the reaction. As this is relatively pure, a small amount is supplied as an input to other sectors like the food and drinks industry.

As the map opposite shows, most of the chemical sector's emissions originate from a limited number of regions of the UK. (The now closed CF Fertilisers plant in Ince is included in the data from 2020, but some production from the company's Ince plant has since moved to Billingham.)

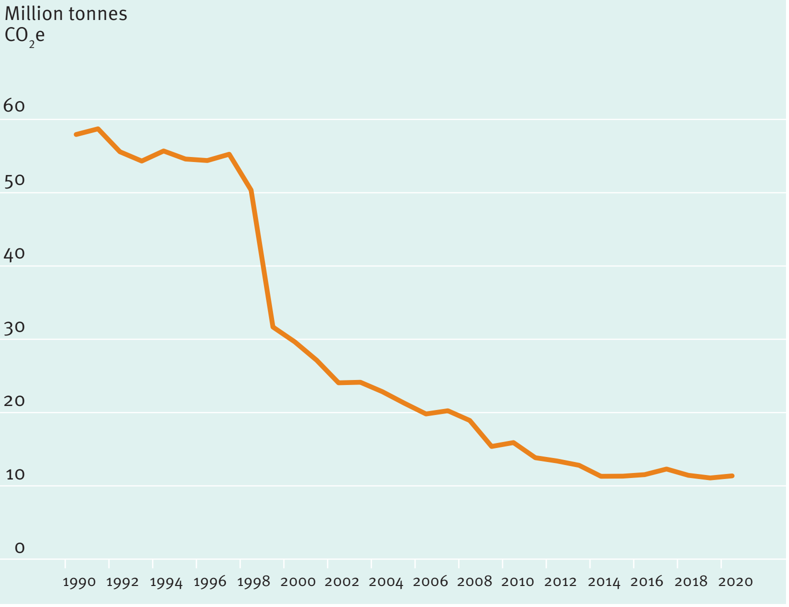
The chemical industry is regionally concentrated[12]



In the late 1990s, retrofitting equipment at UK chemical plants reduced emissions of nitrous oxide and ozone depleting hydrofluorocarbons significantly. Plants moving overseas, energy efficiency improvements and fuel switching reduced emissions further in the 2000s. However, progress in cutting the sector's climate impact has stalled over the past decade.

> **"Progress in cutting the sector's climate impact has stalled over the past decade."**

Greenhouse gas emissions from the UK chemicals industry[13]



The UK's position globally

> **"The UK was the world's largest net exporter of ethylene in 2020."**

The UK is home to global chemical companies, such as INEOS and Croda, as well as notable downstream users, like Unilever. It also houses production sites for overseas companies, such as ExxonMobil and CF Fertilisers.

Although the UK still plays a role in the global market and has produced the same total volume of chemicals for the past three decades, its share of this market declined from around seven per cent in 1990 to one per cent in 2020.[14]

Before the European gas crisis, the UK had around £55 billion in imports and exports of chemicals, while producing a little over half of that total domestically.[15,16] Most of the export content is ethylene and the UK was the world's largest net exporter in 2020, exporting 20 times as much as it imports.[17] The full impact on import and export trends from the recent high gas prices is not yet known.

For plastics, UK and European production has a carbon intensity roughly half the global average. Countries that use coal as a feedstock and energy source, like China, India and South Africa, have much higher associated emissions.[18] However, the UK imports more plastic than it produces, so it is importing high emissions.[19] Similarly, for fertiliser production, European (including UK) emissions are lower than other regions of the world.[20]

CF Fertilisers: the economics of production in the UK

CF Fertilisers produce ammonia and ammonia-based fertilisers. Until recently, the company operated two sites in the UK, one at Ince in Merseyside and the other at Billingham in Teesside.

High gas prices forced the Ince plant to close permanently in 2022, with production now concentrated at the Billingham site.[21]

The company's headquarters are in the US, where gas is cheaper and the government heavily supports carbon capture and storage (CCS) infrastructure. In deciding where to make future investments to expand production, there is a risk that the company may find other locations more appealing than the UK.

The CF Fertilisers plant at Billingham, Teesside

Reducing the sector's climate impact

> **"The UK is in a relatively strong position to improve the climate impact of its chemicals sector."**

The UK is in a relatively strong position to improve the climate impact of its chemicals sector, with access to a very large offshore wind resource in the North Sea and extensive CO_2 storage potential in now empty oil and gas reservoirs. With the right investment, policy framework and markets, it could capitalise on these and lead in the domestic production of lower emission chemicals, which would create more skilled jobs.

Ammonia production, in particular, is highlighted as a possible growth sector, where low carbon supplies, produced using so called 'green hydrogen', could be used as a shipping fuel or for energy storage. A potential drawback is that leaked ammonia from storage and transport facilities could lead to increased climate impacts.[22] But, if the leaks can be contained, then the UK's large renewable energy capacity could eventually allow for growth in this industry.

There has also been discussion about starting domestic methanol production, powered by green hydrogen or sustainable biomass. Indeed, this has the potential to provide a lower environmental impact route to producing a range of high value chemicals.[23]

Short term solutions are being sought

However, for now, the sector is looking at quick solutions and maximising the use of its existing assets and resources, rather than investing in more radical change. For example, SABIC reportedly spent hundreds of millions in converting its Teesside steam cracker to use lower emission ethane gas rather than naphtha, taking advantage of cheaper shale gas from the US.[24]

The UK trade body, the Chemical Industries Association, and its members, have committed to reducing the sector's greenhouse gas emissions by 90 per cent by 2050.[25]

However, details are slim, beyond an intention to follow the government's planned trajectory for industry. In addition, these plans are reliant on government providing the necessary infrastructure and funding. Of the major UK-based chemicals companies, Croda, Linde, Johnson Matthey and Tata Chemicals have accredited science-based emission reduction targets, while SABIC, INEOS, Dow, CF Fertilisers and BOC do not.[26]

> **"There are powerful and viable climate solutions for the chemical industry that have received less attention."**

In the case of ammonia, CF Fertilisers' Billingham site has plans, and in principle government support, to capture CO_2 from its steam reformation process. But this means it will replace 'grey hydrogen' with 'blue hydrogen' as the feedstock, instead of switching to green hydrogen, which in the longer term will have lower emissions.[27]

For ethylene production, the favoured solutions at present are CCS, even though it is unlikely to capture all the emissions, and hydrogen as a heat source instead of fossil gas.[28,29]

In the rest of the sector, hydrogen is seen as an important way to reduce emissions from heat, once it is available at scale. Existing boilers and combined heat and power plants (where gas is used to create steam for heat and electricity generation), could be used with hydrogen as a fuel, although they would need some modification.

As we discuss later, these options are reflected in the UK's wider policy framework to cut the carbon emissions of industry. But there are powerful and viable climate solutions for the chemical industry that have received less attention, particularly the electrification of heat, resource efficiency and alternatives to fossil fuel feedstocks. These could help drive down production emissions and address the sector's wider environmental footprint (see opposite). Below, we outline these solutions briefly, but the context, issues and potential of each are discussed in more detail at the end of this report (see page 30).

Heat electrification

The direct electrification of heat could be a more efficient alternative to hydrogen or CCS, particularly for low and medium heat applications. Most greenhouse gas emissions from chemical production are from burning fossil gas to

Addressing the sector's wider carbon footprint

Emissions released from the chemical industry's related upstream oil and gas operations and refining are lower than its production emissions but are still significant. And downstream emissions, released during the use or end of life of chemical products (often the carbon released from the original fossil fuel feedstock), are usually higher than production emissions (as we illustrate below).

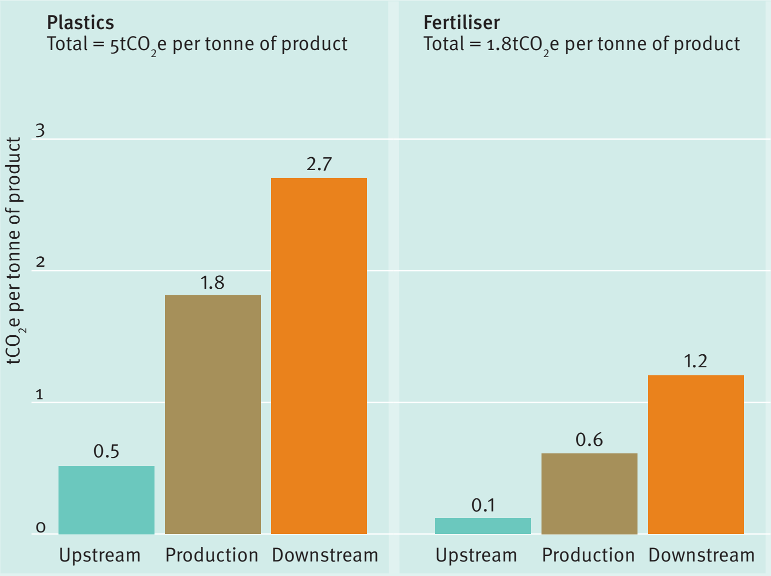
For detergents and personal care products, embedded carbon is released when they are used, or it may flow into wastewater facilities. For plastics and other polymers, the downstream emissions depend on the waste treatment route, with incineration now the most common and highest emitting option.[30]

Fertilisers also have significant emissions in use. In particular, nitrogen based fertilisers produce nitrous oxide (N_2O) when they are applied. This is an extremely potent greenhouse gas, around 300 times more powerful than CO_2.

Although the choice about how to handle chemical products after they have been used is not principally for the chemical industry, product design affects end of life options. Toxicity and contamination affects the potential for recycling and reuse.

Most emissions related to plastics and fertiliser are released during use and at end of life

European lifecycle emissions[31]



> It will be possible, in time, to electrify high temperature processes, including steam crackers."

generate heat. Although steam crackers and other high temperature processes are the biggest individual sources of emissions, the demand for low and medium temperature heat (below around 500°C) makes up the bulk of total energy use and this is simpler to electrify. For these lower temperature demands, more established technology such as heat pumps and electric boilers could be deployed.

It will also be possible, in time, to electrify high temperature processes, including steam crackers. Several companies including BASF, SABIC, Linde, Shell and Dow are investing in electric steam crackers, although further work is needed to derisk these new technologies and scale them up.

Resource efficiency

Increased resource efficiency, through better design and extending product lifetimes, can reduce overall demand for chemicals, bringing down sector emissions. In addition, at the end of life, chemicals, in particular plastics, may need to be treated differently to other types of waste to reduce carbon emissions, and adjustments to the established waste hierarchy should be considered. For example, where plastic waste is of such low quality that it cannot be reused or recycled by any means, it may be better to dispose of it in well managed landfill rather than incinerate it.

Chemical (or 'advanced') recycling is a controversial topic due to its high energy use and the tendency to use it to produce fuels rather than new chemical products, but it should have a place in the waste hierarchy. This may be a preferred option for low grade plastic waste that cannot be mechanically recycled if the high emissions associated with the process can be brought down.

Alternatives to fossil fuel feedstocks

Considering the wider climate impact of the industry is due to its use of fossil fuels as chemical feedstocks, a net zero chemicals sector is impossible to achieve without switching a significant proportion of these to other sources. There are environmental risks with using biomass feedstocks, and other options have technical or economic downsides that will take time to overcome, but the conversation should nevertheless start now so the industry has a clear pathway to move away from fossil fuels.

Policy support to cut emissions

“Little visible effort is being made to move away from fossil fuel feedstocks in the chemicals sector.”

In its Industrial Decarbonisation Strategy, published in March 2021, the UK government set out its plan to cut greenhouse gas emissions from industrial sectors, including chemicals, to meet its legally binding target of net zero by 2050.[32] The strategy acknowledges the range of likely measures needed and promises a suite of policies to support them.

This was a big step forward. Previous industrial climate policy was developed before hydrogen looked like a possible solution, and when the UK was aiming for an 80 per cent reduction in emissions, anticipating that industry might be one of the areas where widespread elimination of greenhouse gas emissions was not achievable. As in most other countries, the UK’s main policy focus in cutting carbon emissions until then had been energy efficiency.

However, infrastructure decisions are taking time and high energy prices have diverted attention away from the climate agenda. Even measures that seem straightforward have been slow coming, such as revising the UK emissions trading scheme (ETS) to align with the national net zero goal and measures to stimulate the market for lower carbon products.

Despite its obvious advantages, electrification has received little attention or funding from the government in recent years, across all industrial sectors. Little visible effort is being made to move away from fossil fuel feedstocks in the chemicals sector. And measures to encourage greater resource efficiency have been patchy.

“Support for resource efficiency has been highlighted by the Climate Change Committee as a major policy gap.”

Current government industrial policy leans heavily on CCS and hydrogen for industrial emissions reductions, with comparatively less support for electrification and resource efficiency. For example, the government has committed £1 billion and £240 million respectively for capital support for CCS and hydrogen.[33,34] This is while also establishing generous subsidised business models to reduce the operating costs of such projects over their lifetimes.[35,36]

In contrast, no equivalent business model or specific capital fund for electrification have been proposed (the Industrial Energy Transformation and Industrial Fuel Switching funds are open to other technologies, including hydrogen). Similarly, support for resource efficiency has been highlighted by the Climate Change Committee (CCC) as a major policy gap in its 2022 progress report to government.[37]

This lack of government support is despite electrification and resource efficiency being identified as important pillars of successful climate policy by independent experts. According to the CCC's balanced net zero pathway, electrification could deliver more cumulative emissions savings for UK industry (as a whole, not just in the chemicals sector) between now and 2050 than hydrogen or CCS.[38] Similarly, the CCC suggests that resource efficiency, along with demand reduction, could save more cumulative emissions than CCS, though a little less than is expected for hydrogen.

The absence of policy around electrification and resource efficiency could steer companies towards less optimal solutions. While this is better than taking no action at all, it could lead to the inefficient use of public funds or slow down the adoption of more effective measures over the longer term. At the very least, looking beyond hydrogen and CCS would help to mitigate the risk that one or both of these new technologies may not deliver results as hoped.

A more neutral approach, providing equivalent funding across a range of technologies, would allow chemical companies to make informed decisions about what works best for them. This could be done, for instance, with a carbon contract for difference, funding all emissions

> The government could provide more financial and policy support for electrification.”

reductions equally, which could support the difference between the cost of an action and the carbon price in the UK ETS.[39] However, this would be a major change of course and would need to account for the fact that the UK ETS only covers electricity use indirectly.

Alternatively, the government could provide more financial and policy support for electrification and set a time limit for support for CCS and hydrogen, as they may not be the optimal choices to bring down emissions over the longer term.

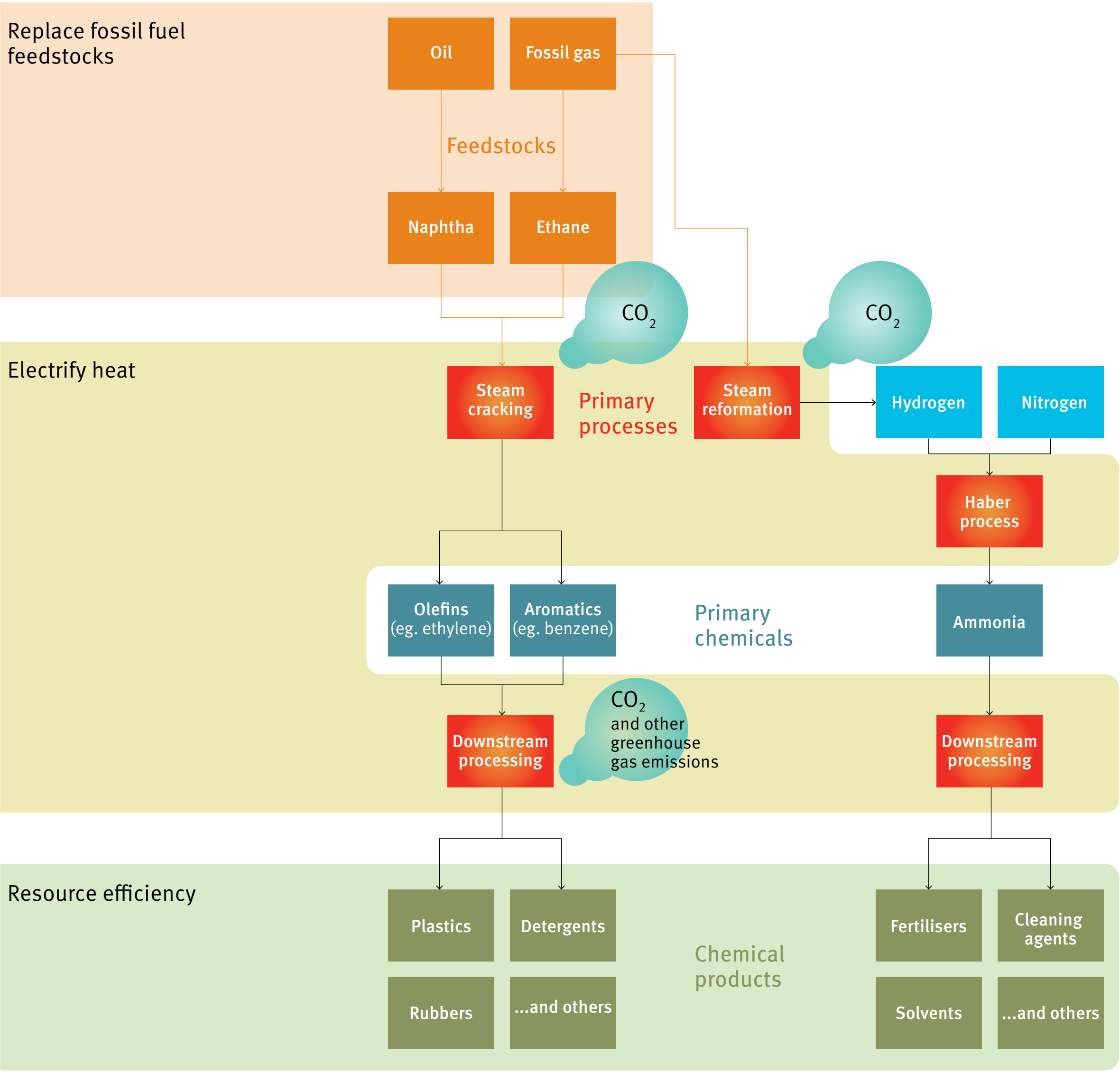
Our deep dives section on page 30 discusses some of the barriers to electrification of heat supply, resource efficiency and circularity, and the use of alternatives to fossil fuel feedstocks. We also offer suggestions as to how these obstacles might be overcome.

Measure	Support needed	Existing policy	Limitations and planned policies
Energy efficiency	Capital support	Funding through schemes like the Industrial Energy Transition Fund (IETF); UK emissions trading scheme (UK ETS) also shortens the payback period on investment	This will not get the sector to net zero alone; funding for IETF expired in February 2023
Resource efficiency and markets for low carbon products	Product labelling, standards and other means of creating value for lower carbon or recycled materials; better product design and business models that reduce the amount of material required	Metrics and voluntary standards are promised for some low carbon products in some sectors; a range of recycling targets and incentives for plastic packaging and other household plastics are coming	This will not get the sector to net zero alone; progress has been slow in a number of areas and responsibility is split between government departments; there is a tendency to use voluntary measures and end-of-pipe solutions, like recycling, over addressing product demand
Switch fuel to hydrogen	R&D support; capital support; affordable and locally available hydrogen	Funding available includes the Net Zero Hydrogen Fund (£240 million), the Low Carbon Hydrogen Supply Competition (£90 million) and the Industrial Fuel Switching Competition (£50 million); a business model for hydrogen will mean hydrogen is offered at the same price as fossil gas; another business model being developed is for the transportation and storage of hydrogen; reduced emissions costs from the UK ETS	'Blue hydrogen' is not net zero carbon compatible and 'green hydrogen' roll out is limited by renewables capacity in the short term; hydrogen might not be most energy efficient solution, adding to system costs; subsidies for hydrogen production may be passed on as costs to energy bill payers
Carbon capture and storage (CCS)	Capital expenditure (capex) support; operational expenditure (opex) support to cover ongoing costs of capture and fees for transport and storage	The Carbon Capture and Storage Infrastructure Fund (£1 billion); a business model for carbon capture will provide subsidies; loans to cover capex; reduced emissions costs from the UK ETS	Not all production emissions can be captured and this does not address upstream emissions; CCS will be an ongoing cost

Measure	Support needed	Existing policy	Limitations and planned policies
Capture and utilise carbon (at scale)	R&D support, in the form of some capex support for early plant; opex support will depend on likely profitability of the capture and resale of waste gases	Receiving R&D support; reduced emissions costs from the UK ETS	Still being developed; no policy in place
Electrification	R&D support for some applications; capex support for network upgrades and site changes; competitively priced electricity	Funding for fuel switching (limited); commitment (not yet realised) to equalise the costs of gas and electricity; reduced emissions costs from the UK ETS	There is little funding available for fuel switching; slow development of promised measures to equalise the costs of gas and electricity; combined heat and power (CHP), by contrast, benefits from significant capital allowances and tax breaks
Changing feedstocks	Initial R&D support; possible capex support for site changes; a market for lower carbon products or mandates for use of alternative feedstocks, as in aviation; policy to avoid the possible negative impacts of some feedstock choices	Very limited consideration in climate policy, except for biomass, where there have been separate discussions about a bioeconomy and mention of feedstocks for chemicals have been discussed in the biomass policy statement[40]	This is at the early stages of development but needs to be considered with more urgency
Carbon pricing	Carbon leakage protection (to enable UK investment without being undercut by global competitors), ideally while still creating an effective carbon price for the chemicals sector	The sector receives free allocations for most emissions included in the UK ETS; carbon border measures are under consideration for some products (including fertilisers) which could enable the removal of free allocation; moves are underway to align the UK ETS with the net zero goal	UK progress on removing free allocation has been slower than in the EU, potentially putting UK industry at disadvantage; the EU carbon border scheme only covers hydrogen and fertilisers (not all chemicals)

Conclusion: how to achieve a more resilient UK chemical industry

Where best to target climate action in the chemical industry



> “There is potential for the UK to lead the move to a net zero compatible chemicals industry.”

The UK chemical sector is important to regional economies outside London and the South East, and it will continue to supply a broad range of other industries, from construction and transport to healthcare. The importance of retaining and supporting it through the transition to a low carbon economy has become more apparent since the war in Ukraine has threatened energy supplies, with a new focus on securing UK supply chains. There is potential for the UK to lead the move to a net zero compatible chemicals industry, making it more resilient for the future, with the right policies and market conditions.

Although the government’s Industrial Decarbonisation Strategy has some useful signals for this sector, the underlying serious issues it faces are not addressed, particularly the recent steep rise in energy prices. The strategy is currently skewed towards hydrogen and CCS as the main solutions to achieve emissions reductions. If these technologies could be delivered rapidly, they could be effective. However, both come with inherent risks around scaling up and they will not result in a net zero chemicals industry on their own. More government support is needed for other supportive strategies, particularly, as we describe, for heat electrification, resource efficiency and the use of alternative feedstocks.

Action in these three areas would do more to address the emissions associated with the production and lifecycle of a typical product of the chemical industry like washing up liquid (see page 9), apart from those generated in its transportation. Electrification could, in time, help to reduce its production emissions. Resource efficiency and circularity could mean changes to its product and process design. For example, it could mean an even more concentrated liquid and refillable packaging becoming the norm. Using alternatives to fossil fuel feedstocks could neutralise emissions from the liquid as it breaks down during and after its use.

In addition, as the EU is doing for some products, border standards should be introduced to ensure that UK producers are not disadvantaged by higher carbon product imports.

Our recommendations

Below are the steps we recommend to take the UK chemical industry into a new era, as part of a greener economy:

1. Heat electrification

A package of policies should support the electrification of heat which at least matches support given to other options with higher residual emissions, such as hydrogen and CCS. This should include:

- **A green power pool** for energy intensive industries, or similar measures, to provide long term access to low cost clean electricity, in return for firm commitments from industry to act on its greenhouse gas emissions. This would have very limited costs for government, beyond administration and underwriting costs.[41]
- **Phase out incentives for new combined heat and power (CHP) plants powered by fossil gas**, which benefit from exemption from the climate change levy, carbon price support and discounted business rates.
- **Introduce new incentives for electrification** that reduce costs and increase the uptake of electric boilers and industrial heat pumps, such as by;
  - extending 130 per cent capital allowances beyond March 2023 for investment in electrified heat generation equipment, such as electric boilers and heat pumps;
  - replacing the Industrial Fuel Switching competition with a more ambitious capital fund to support the electrification of processes, including the cost of grid upgrades.
- **Innovation funding** to scale up and derisk electrified high temperature technologies and thermal battery technology, and support the commercial scale roll out of industrial heat pumps.

2. Resource efficiency

This would involve a suite of policies to encourage resource efficiency and greater circularity in the chemicals industry and downstream associated sectors, such as plastics and fertiliser production, including:

- **Make reporting of upstream and downstream (scope 3) emissions mandatory** under financial reporting requirements, to accelerate resource efficiency measures and alternative business models.
- **Align the tax framework with an optimal resource use hierarchy (see page 37).**
- **Extend existing approaches to encourage lower emissions products,** such as mandatory standards and producer responsibility schemes.
- **Provide incentives to reduce and optimise the use of nitrogen based fertilisers.**

3. Alternatives to fossil fuel feedstocks

The government should consider the following to support chemical companies' investment in alternatives to fossil fuels:

- **Set out a clear hierarchy for the use of virgin and waste biomass** in the government's upcoming Biomass Strategy, that considers whole life carbon impacts and availability, and provide a similar cross sector analysis on the best use of other possible feedstocks, like green hydrogen and direct air captured carbon.
- **Begin a wider discussion among industry stakeholders**, with a clear timeline for policy development, including considering mandates for alternatives that increase over time, buyers' clubs or product labelling and standards. Any policy should avoid a heavy reliance on scarce biomass in the short term and may favour a long term shift towards synthetic chemicals.
- **Scale up innovation support for alternative technologies** such as biorefineries, direct air capture, emissions free chemicals recycling, green methanol production and methanol to olefins and aromatics processes.

Deep dives

Three climate solutions for the chemicals industry

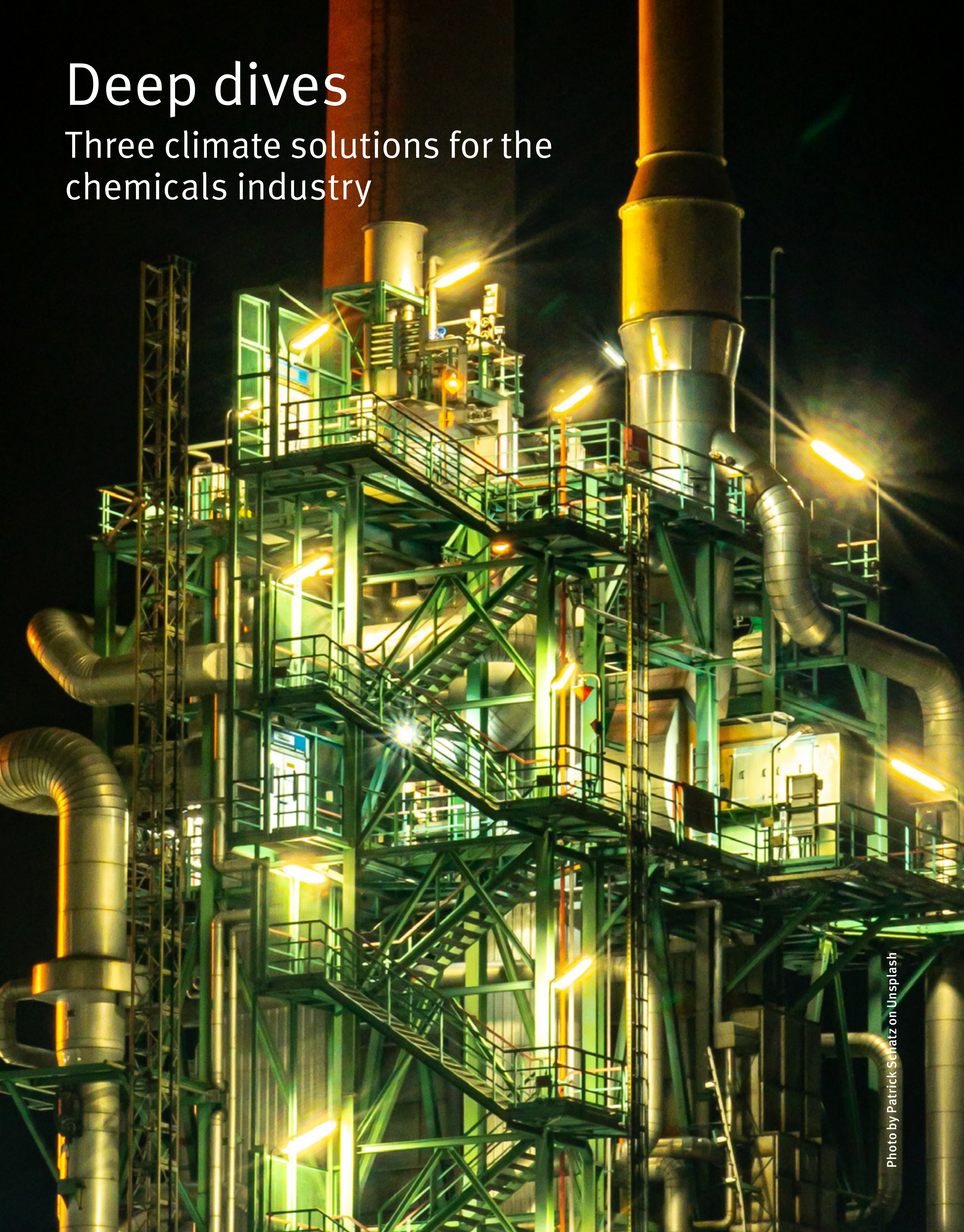


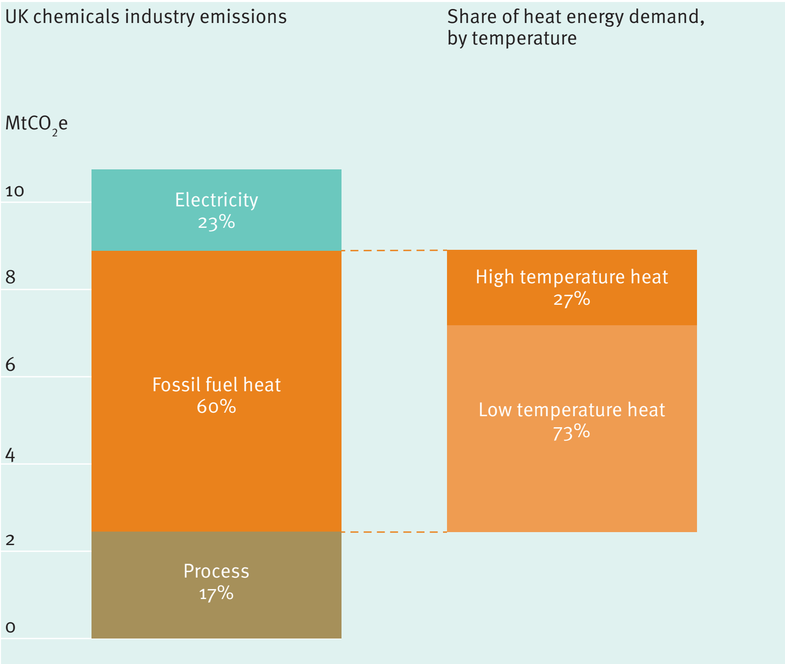
Photo by Patrick Schatz on Unsplash

1.
Heat electrification

> **Low temperature heat processes should be a priority.”**

As we illustrate below, the largest share of emissions across the UK chemical industry comes from burning fossil fuels onsite to create heat (this was the source of around 60 per cent of the industry's emissions in 2021). Although high temperature processes, such as steam cracking, are the biggest individual sources, government energy consumption statistics suggest around 73 per cent of the heat demand for chemical processing not yet electrified is for low temperature processes (below around 500°C).[42,43] This mostly comes from combined heat and power plants (CHPs, which burn gas to provide both heat and electricity) and gas boilers.[44] Therefore, low temperature heat processes should be a priority.

Heat's share of emissions and energy use[45]



Options at different temperatures

> **“Direct electrification of low temperature heat has many benefits over either hydrogen or CCS.”**

To reduce heat related emissions, chemical plants can either electrify heat generation using industrial heat pumps and electric boilers, switch from natural gas to an alternative low carbon fuel, like hydrogen, or capture emissions from fuel combustion using CCS. We compare these options below, including both ‘green hydrogen’, produced by splitting water using electrolysis, and ‘blue hydrogen’, produced from natural gas via steam reformation with CCS.

Direct electrification of low temperature heat has many benefits over either hydrogen or CCS. Heat pumps, which are useful up to 200°C, can be two to seven times more efficient than gas boilers or CHP.[46]

Electric boilers, which provide heat up to 600°C, are slightly more efficient than gas boilers.[47] Using hydrogen as a fuel would not significantly affect the underlying efficiencies of boilers or CHP plants, but producing hydrogen to then generate heat is inherently more inefficient than using electricity or gas directly.[48,49] Adding CCS processes also increases the energy demand.[50]

Both hydrogen and CCS are difficult to apply to smaller and more dispersed emissions sources.[51] The efficiency of electrification, combined with a rapidly decarbonising electricity system, mean heat pumps and electric boilers are the lowest emission solutions. A more electrified industry would be more resilient to future geopolitical shocks than if it continues to depend on natural gas.

Solutions are also being developed for the electrification of high temperature heat (see page 35).

There are some parts of the industry where heat electrification may not make sense because of the emissions from chemicals processes. In the production of hydrogen as a chemical feedstock for example, around 70 per cent of the CO_2 emissions from the steam reformation process arise from the chemical reaction itself, not from the combustion of fuel for heat.[52] In this case, while electrification could be coupled with CCS, it might be better to avoid steam reformation and use electrolysis to produce green hydrogen instead.

Heat for the chemicals industry: electrification, hydrogen and CCS compared[53]

Category	Direct electrification	Green hydrogen	Blue hydrogen	Carbon capture and storage
Energy efficiency	High	Low	Low	Low
Emissions	Medium but decreasing (via the grid)	High but decreasing (via the grid)	Low-medium + upstream emissions	Low-medium + upstream emissions
	Low (with renewables)	Low (with renewables)		
Capital cost	Medium	High (produced onsite)	Low (produced offsite)	High
		Low (produced offsite)		
Operational cost	High (via the grid)	Medium (with subsidy or renewables)	Medium (with subsidy)	Medium (with subsidy)
	Low (with renewables)			
Scale of operation	Variable	Variable	Variable	Large
Suitable for dispersed sites?	Yes	Yes	No	No
Fossil gas utilisation	No	No	Yes	Yes
Electricity utilisation	Medium	High	Low	Low
Can reduce process emissions?	No	No	No	Yes
Infrastructure required	Access to the grid	On site electrolyser and renewables	Hydrogen storage and transport infrastructure	CO_2 storage and transport infrastructure
	On site or direct wire transmission of renewable generated energy supply	Hydrogen storage and transport infrastructure		

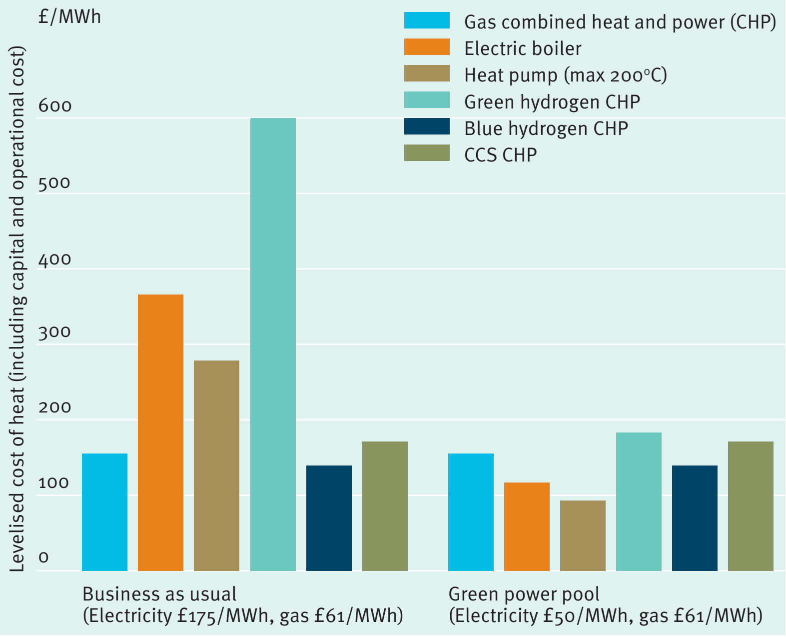
Scaling up

> **"The government has committed to align industrial gas and electricity prices but has taken no steps to do so."**

The main limitations of electrifying heat are the high costs of capital and of electricity relative to gas. Despite cheaper renewables making up over 40 per cent of the grid supply, electricity prices are mostly set in relation to the cost of gas, which increased over five fold in the UK between December 2020 and December 2022.[54] As shown in the graph below, if the cost of electricity (predicted to be around £175 per MWh on average in 2023) was brought down to a level reflecting the true cost of newer sources of renewable electricity (£50 per MWh) while gas prices stay constant at the predicted 2023 rate of £61 per MWh, both heat pumps and electric boilers would be cheaper to run than CHP plants (including the additional electricity that CHPs generate).[55]

The government has committed to align industrial gas and electricity prices but has taken limited steps to do so. A sustained reduction in electricity prices for specific sectors like chemicals could be achieved using a green power pool, originally conceived by UCL and the Aldersgate Group, as we have described in relation to steel production.[56,57]

What would the effect of a green power pool be on the overall cost of heat generation up to 500°C?[58]



> “The potential scale of emissions reductions through steam cracker electrification is significant.”

Innovation in high temperature heat

The cost of electrifying heat has been prohibitively expensive, particularly for high temperature processes, leading to a lack of investment and a perception that electricity is not suitable for such applications. However, trials are now underway at a number of sites in Europe which are looking at electrification as a solution for the chemicals industry.

BASF, SABIC and Linde are constructing the world’s first demonstrator level electric steam cracker furnace at BASF’s main steam cracker site in Ludwigshaven in Germany, due to open in 2023.[59] Shell and Dow have also embarked on a project with the Dutch government to develop electric cracker technology.[60] The Finnish-Dutch startup Coolbrook has developed an electrified technology that can be retrofitted onto existing plants, to eliminate process emissions and potentially enable the use of alternative feedstocks.

The potential scale of emissions reductions through steam cracker electrification is significant. For example, BASF expects a 90 per cent reduction in direct emissions.[61] However, as some of the undesirable by-products from crackers are also burned to add heat, to achieve targeted emissions reductions and operate the cracker economically, electrification should completely replace the heat derived from these by-products as well. Other uses should be found for the by-products to avoid increasing waste.[62] Electrified steam crackers would need to be carefully monitored to ensure they achieve the emissions reductions claimed.

Emissions reductions from the direct electrification of heat can be achieved even faster if the electricity comes from renewable energy and not the wider grid. For this, innovative thermal storage could bridge the gap between intermittent renewables and the need for a constant heat supply for many types of chemicals production. Technologies for this are being developed, such as the heat battery developed by a company called Rondo, which stores thermal energy in heated bricks at 1,500°C and releases it on demand via superheated steam or air.[63] Such technologies need to be proven at scale which may require further support from government.

2.
Resource efficiency

> **Decisions made about how and which chemicals are produced have an impact, such as on the ease of recycling.”**

Even if the chemical sector’s production emissions could be eliminated, there would still be significant emissions from the use and end of life of chemical-based products. The CCC explicitly relies on demand reduction and improved resource efficiency in its plan for the chemicals industry to meet the economy’s 2050 net zero target.[64] This is reflected in the Industrial Decarbonisation Strategy too, but with no policy detail around how it will be achieved.

The chemical industry is not directly responsible for the emissions of its products once they leave its plants, but decisions made about how and which chemicals are produced have an impact, such as on the ease of recycling. And some business models allow it to retain control over products. Equally, recycling carbon-based chemical products can provide a supply of carbon feedstock for new primary chemical production.

Reducing demand for primary chemicals and the products they are used in, as well as greater circularity, thus increasing the availability of recycled chemicals, will reduce the need for fossil fuel feedstocks. This would enhance the UK’s resource security.

Predicted global demand for chemicals varies considerably. Some experts imagine a substantial increase in demand for plastics, for instance.[65] Whereas, others suggest that ambitious efforts to eliminate, reuse and substitute chemicals and downstream products, as well as improve recycling rates could lead to a 40 per cent reduction in global demand for high value chemicals between 2020 and 2050.[66]

There are predictions of a boom in hydrogen demand, driven by its use in ammonia production, both as a potential energy storage medium and as a shipping fuel.[67]

In contrast, a UK study finds potential demand reduction of seven per cent for ammonia and eight per cent for high value chemicals.[68]

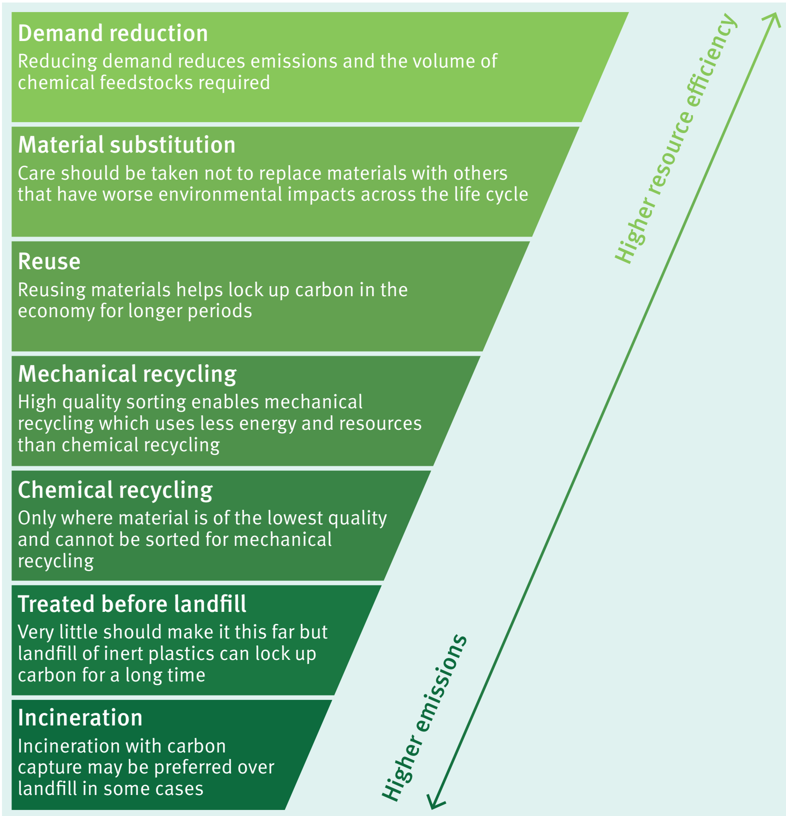
Where does the carbon go?

> **"Where carbon is embedded in products, reusing and retaining them in use can provide a temporary carbon store."**

Fertilisers, detergents and personal care products are examples of chemical products which release greenhouse gas emissions during or after their use, and these emissions cannot effectively be recovered, except by capturing carbon in wastewater facilities. For these products, cutting demand, exploring alternative products to fulfil the same needs, or replacing fossil fuel feedstocks with carbon drawn directly from the air (via biomass or direct capture), are the only ways to eliminate emissions from the entire lifecycle.

Where carbon is embedded in products, reusing and retaining them in use can provide a temporary carbon store. Reusing products also reduces the demand for virgin chemical feedstocks.

An optimal resource use hierarchy for plastics



A resource use hierarchy should guide decisions on the end of life treatment of chemical products, especially plastics. On the previous page we illustrate a preferable hierarchy for plastics, which differs from the government's established hierarchy, based on ongoing work started by Zero Waste Europe and our own proposals.[69,70]

"A resource use hierarchy should guide decisions on the end of life treatment of chemical products."

Where mechanical recycling is not possible, due to collection and sorting limits, toxicity or contamination, chemical recycling should be the next step. Chemical recycling includes different techniques to return waste plastics to a virgin-like monomer or into fuels that can be used as a feedstock for new chemical production.[71]

Different chemical recycling techniques have pros and cons and we and others have provided an overview.[72,73,74] In general, policies to encourage more circularity for chemical production should never provide incentives for chemical recycling over the upper tiers of the hierarchy, which have lower emissions and are more efficient uses of resources.[75] But chemical recycling could play a role in reducing fossil feedstock demand.

At the bottom of the hierarchy, analysis suggests properly treated waste sent to well managed landfill might be better than incineration, from both emissions and resource efficiency perspectives, although there are also land use considerations.[76] In contrast, the UK's Landfill Tax has encouraged incineration, with contracts for incineration in some areas lowering recycling rates.[77] While neither incineration nor landfill are desirable, landfill does not lock in an ongoing need for waste as a fuel in the same way as incineration.[78]

Carbon capture technology could change incineration's position in the hierarchy, if its emissions are captured and used as a feedstock along with hydrogen to produce new carbon-based chemicals (carbon capture and utilisation), or if they can be locked away in permanent underground storage (CCS).[79] However, capture rates are unlikely ever to reach 100 per cent, and recombining CO_2 with hydrogen to make feedstock requires a significant amount of energy. Despite this, itmakes sense to use captured carbon to displace virgin fossil fuel-based feedstocks. Even if this is the case, incineration with CCS will still sit lower in the hierarchy than mechanical or chemical recycling, on the basis of efficiency and emissions, so incentives should not be designed that encourage it over other routes.

A lower demand, more circular chemicals sector

A wide range of policy approaches could help to create a more circular economy for chemicals, above and beyond continued support for recycling.

Apart from policy, alternative business models can boost circular systems and provide more revenue for chemicals companies. The 'chemicals as a service' approach could shift value creation to focus on the function and performance of the chemical, rather than the volume sold. This would be an incentive for producers to take responsibility for more of the product lifecycle.[80] Examples include outcome-based smart agriculture models and fertiliser use, take back schemes where suppliers recover products at end of life, and chemical leasing schemes where payments are made for functions performed by the chemicals and more collaborative working optimises their use. This approach may also fit well with the UK's tendency to manufacture hi-tech products at lower volumes.

We describe a number of policy options below. Some of these are being considered under the government's draft waste prevention programme, but others could be considered as this is finalised.[81] Unfortunately, the momentum behind the programme seems to have stalled since the consultation closed in June 2021. The government should reassert its ambitions for a circular economy by driving this forward at pace, including in the chemicals value chain. It could also make use, across most of these areas, of its power as a procurer of a wide range of products and services.

Better design and extended producer responsibility

Improving the design and extending the useful life of products, while phasing out wasteful products such as single use packaging, would reduce resource use and minimise waste. This could be encouraged by applying further standards to products, along with extended producer responsibility schemes.[82,83] The EU is drawing up

> Better emissions reporting by the chemical industry and its customers would help decision making."

Safe and Sustainable by Design frameworks as part of a chemicals strategy for sustainability.[84] The UK should do the same, ideally without further delaying its much anticipated UK Chemicals Strategy.

Farming improvements

Incentives for farmers to reduce the use of ammonia-based fertilisers and optimise application would help to cut nitrous oxide emissions. This is particularly important in the face of rising fertiliser costs following Russia's invasion of Ukraine.[85] Alternative farming practices that reduce reliance on fertilisers and improved soil health will also help, alongside technological improvements to fertilisers that reduce greenhouse gas emissions.[86,87] The UK has a nitrogen use efficiency of around 60 per cent. This means that smarter application of ammonia-based fertilisers could reduce demand by 40 per cent without any loss in yield.[88]

Enhanced reporting

Better emissions reporting by the chemical industry and its customers would help decision making. Since a large share of the total emissions associated with the industry comes from upstream and downstream (scope 3) emissions, it is important to make tracking these in financial reporting requirements compulsory, rather than voluntary.[89,90] This would also encourage the uptake of alternative business models.

Aligning tax and regulation

Regulation and a comprehensive, integrated tax framework should be aligned with the resource use hierarchy we have proposed, and approaches may be different for different types of waste. This should aim to avoid locking in incineration through infrastructure, or encouraging chemical recycling over mechanical recycling.

3.
Alternatives to fossil fuel feedstocks

> **"Several types of feedstock could be used instead of fossil fuels."**

Ninety eight per cent of chemicals globally are produced using fossil fuel feedstocks.[91] This means the sector is directly responsible for a portion of the oil and gas industry's emissions upstream and also the products they are used to make are largely composed of fossil carbon, much of which is released to the atmosphere at the end of their lives. Studies show that a net zero chemicals sector is impossible to achieve without switching a significant proportion of the industry's feedstocks away from virgin fossil fuels.[92]

What are the alternatives?

Several types of feedstock could be used instead of fossil fuels, as we show below. None are like for like replacements for fossil fuels and all have trade offs. They all warrant further investigation, as a diverse range of feedstocks is likely to be required as fossil fuels are reduced.

Some companies propose a 'mass balance' approach in which a proportion of their feedstock is switched to alternative sources. However, it is unlikely that existing plants optimised for fossil fuel use will be able to fully switch over to alternatives so this will only be a partial solution.

Biomass

Biomass, ie either newly harvested or waste plant matter, is the most established option to replace fossil fuels as a feedstock. Globally, ethylene was primarily made from biomass prior to the introduction of steam crackers in the 1940s, and bioethylene production is still dominant in Brazil.[93] In the case of long lived chemical products, using biomass can also be an opportunity to capture and store carbon from the atmosphere.

However, concerns about land demand and competition from other sectors mean that supply is limited. It is also important to consider the whole lifecycle to ensure there is a net carbon benefit. This includes, for instance, making sure that emissions from land use changes and the processing and transport of resources do not exceed emissions savings, and accounting for the time taken for a forest to regrow after being cleared. Without careful regulation, using poorly sourced biomass results in higher emissions than using fossil fuels. Extensive biomass use is also likely to increase biodiversity loss.

> "Using direct air capture with green hydrogen is the best long term approach to emissions reduction."

Carbon capture and utilisation

Industrial carbon capture and utilisation could be an intermediate, and potentially cost effective, solution for synthetic chemicals before direct air capture (DAC) technology is scaled up. This captured carbon would need to be combined with hydrogen to create synthetic chemicals, except in some cases where sources of carbon dioxide also contain hydrogen. These waste gases could be more easily synthesized into chemicals, such as green methanol, without additional hydrogen production.[94] There is a risk that carbon capture and utilisation will lead to perverse incentives, for instance by encouraging the continuation of other high carbon industries and processes that should be winding down or switching to zero carbon operations, or perpetuating the incineration of waste rather than reduction or recycling.

Using DAC with green hydrogen to allow the manufacture of a full range of products is the best long term approach to emissions reduction, but there are concerns about how quickly the technology can be scaled up and it will be very expensive, at least initially. This process relies on first producing green methanol and converting it into ethylene and other primary chemicals, through energy intensive processes known as 'methanol to olefins' and 'methanol to aromatics'.

Chemical recycling

Chemical recycling could replace some virgin fossil fuel feedstock by turning mixed waste plastic into a naphtha-like input, but this should not replace mechanical recycling where that is possible as it is the lower emissions route. Emissions from chemical recycling processes need to fall significantly for this to be considered a viable alternative to fossil fuel feedstocks.

Comparison of feedstock options[95]

	Feedstocks				
	Fossil fuels	Biomass	Direct air capture + green hydrogen	Industrial carbon capture and use	Waste materials
Emissions intensity trajectory	High	Potentially low but with risks	Low	Medium, depends on original carbon source	Medium, potential to reduce
Cost	Low	Medium	High	Low	Medium
Energy demand	Low	Medium	High	Low	Medium
Supply and abundance	Abundant now but limited later	Limited	Limited now but abundant later	Abundant now but limited later	Limited and declining
Industry competitors for supply	Aviation, power, transport and building sectors; other industries	Aviation, power sector, timber products, other land uses, including food production, nature and negative emissions	Aviation, power sector, other industries, long term CO_2 storage	Other industries (including food and drink), long term CO_2 storage	Recycling, incineration
Technological readiness (1-low to 9-high)	9	9	7	7	8
Wider considerations	Air and water pollution. Continued use linked to considerable climate and environmental damage	Risk of encouraging land degradation, habitat destruction, and food scarcity	Risk of technology not scaling up quickly enough	Risk of locking in suboptimal technology in other industries. Requires suitable co-location	Risk of locking in resource inefficiencies

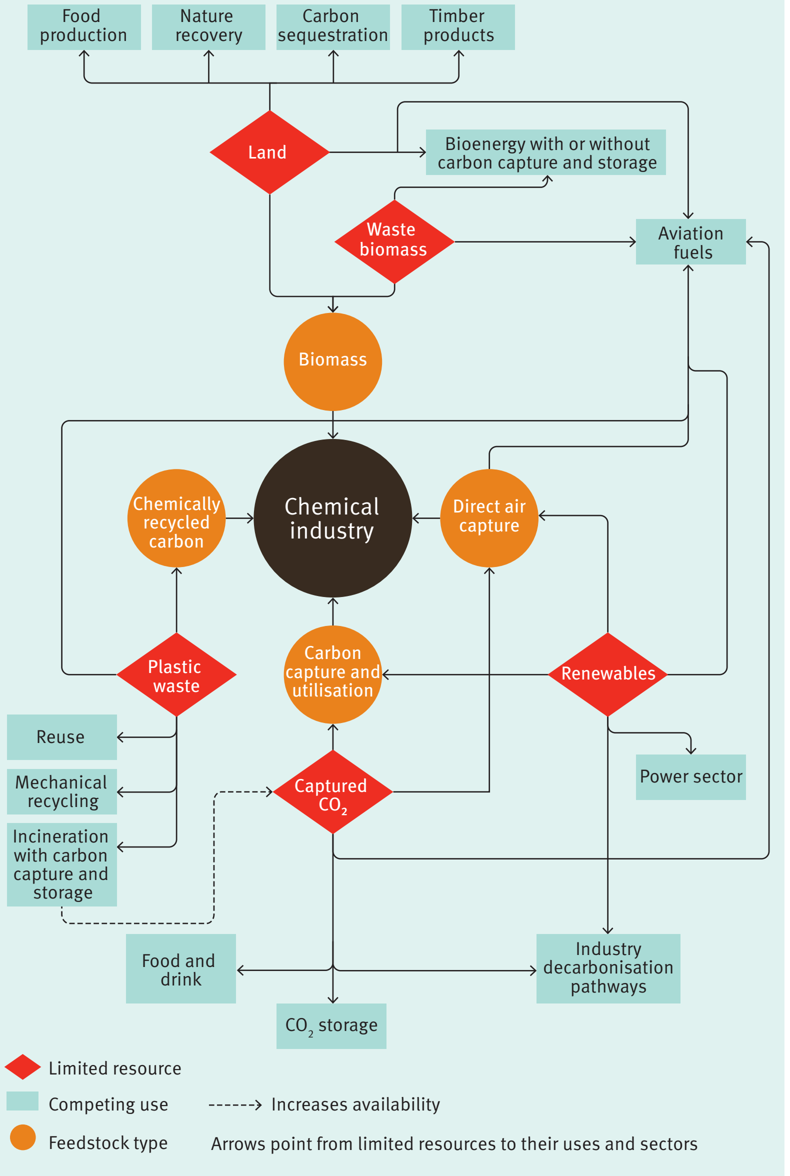
Competing demands

As demonstrated in the diagram on page 44, the availability of almost all alternative feedstocks is restricted, at least in the short term, by limited resources, ie land for biomass, suitable plastic waste for chemically recycled feedstocks, renewables capacity and captured carbon for synthetic feedstocks.

There will also be competition with other sectors like aviation for biomass, captured carbon, renewables and plastic waste.

These limitations mean that none of the alternatives, on their own, can realistically replace fossil feedstocks on a like for like basis and so the best use of each should be prioritised. This has been discussed by the government for some resources but not comprehensively and across sectors. Principles to consider include lifecycle carbon savings, the availability of alternatives and technological readiness.

Competing demands for alternatives to fossil fuel feedstocks in the chemical industry



NB This does not include ammonia production for fertilisers as no carbon is required, only hydrogen. Hydrogen can be produced in many ways but the cleanest method is using renewable energy in the electrolysis of water (known as 'green hydrogen')

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