Policy insight
April 2024

green alliance...

The last use of fossil fuels?

Making chemicals without oil and gas

Summary

“We make the case for a green carbon mandate on chemical products.”

In this policy insight we explore the need for the chemical industry to shift towards alternative feedstocks, ie ingredients not based on coal, oil or gas. This is a major challenge to greening the industry, in part because fossil resources remain more economical than others under current market conditions and, in part, because none of the alternatives are guaranteed to be greener

The most promising alternatives to fossil resources are biomass, plastic wastes and captured carbon. However, all of these have significant downsides; either on costs, availability or wider environmental impacts. All alternative feedstocks will be subject to scarcity and competition in an economy moving to net zero.

We make the case for a green carbon mandate on chemical products. Without this, or something similar, chemical manufacturers will continue to rely on fossil resources, and the embedded carbon in some chemical products will continue to end up in the atmosphere, in the form of CO_2.

This report follows our previous work exploring the UK chemical sector and its broader climate challenges.[1]

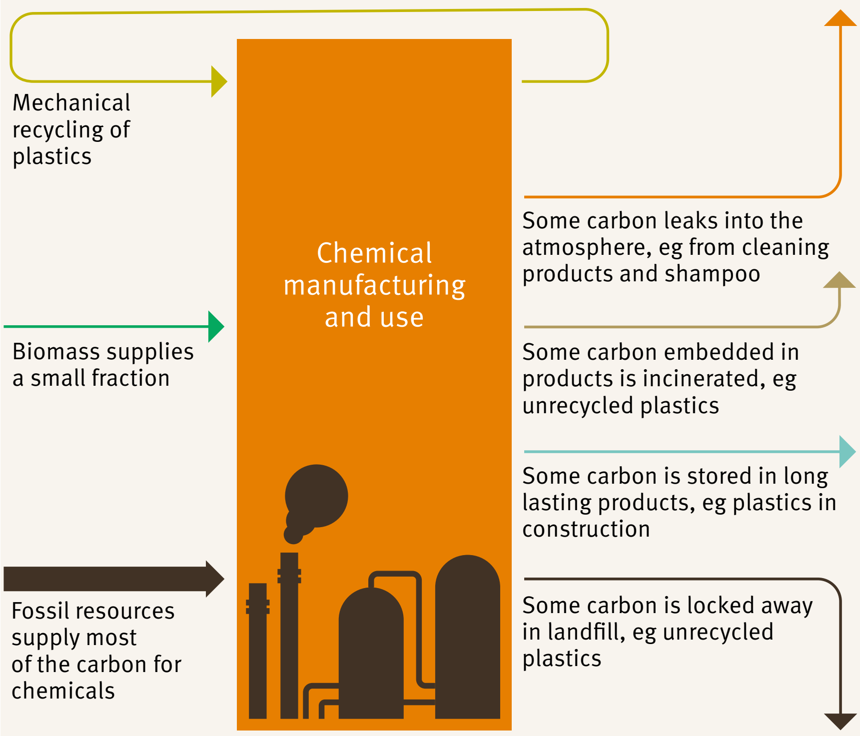
Our analysis and projections are estimations. There may, of course, be significant variation in impacts depending on how technologies develop and how policies and practices change in the period up to 2050 and beyond.[2] Our figures are intended to give a sense of the scale of the challenge ahead.

Most chemicals are made with fossil carbon

Over
90%
of carbon-based chemical products contain carbon from fossil resources

By mass, over 90 per cent of today's carbon-based chemical products contain carbon from fossil resources, including everyday items like plastics, polymers, detergents and rubbers.[3] These are 63 per cent of all the chemicals produced. Fertilisers and ammonia do not contain carbon, although they still have climate impacts. While it will be impossible to eliminate all these uses, efforts should be made to reduce the fossil resource inputs into these products because some of their embedded carbon will eventually end up in the atmosphere.

Where does the carbon in chemical products come from, and where does it go?



Three major steam crackers operate in the UK. These are large furnaces that turn fossil resources, in this case gas, into carbon-based bulk chemicals, primarily ethylene. The UK's steam crackers produce about one per cent of the world's ethylene.[4]

Embedded carbon in the ethylene the UK produces is equivalent to around two per cent of the UK's greenhouse gas emissions, which is similar to the amount generated by the UK's cement industry.[5] This does not include the emissions from the steam cracking process itself.

> The chemical industry’s needs should not justify the indefinite extraction of fossil resources.”

Chemicals made from alternatives to fossil resources, including biomass (plant material), carbon captured from the air and recycled plastics, all come with their own challenges and trade-offs. Although there are some established and commercialised ‘biomass to chemical’ routes, and commercialised recycling processes, many of the alternatives are still unproven at a commercial scale.

It is possible that chemicals could turn out to be one of very few sectors where the claim that “oil and gas will continue to play an important role” is true, at least in some specialist areas. But alternatives should be sought wherever possible, and meeting the chemical industry’s needs should not justify the indefinite extraction of fossil resources, or at anything like the current scale.

Assets like steam crackers have very long lifetimes but, as the UK is ahead of many other countries in phasing out oil and gas in other areas of its economy, it should also be moving early to phase down the use of oil and gas in chemical manufacturing.

The UK has a long history of chemical manufacturing and a highly skilled workforce, although the required skills are evolving as the industry changes.[6] Moving early would allow the domestic chemical industry to be maintained with the knowledge and capacity to make the products of the future, and avoid stranded assets in the decades to come.

Forward looking industry players are working to accelerate the transition towards greener feedstocks, but gaps in government policy are holding them back. Alternative feedstocks are more expensive, so companies need a price incentive to scale up greener practices.

Reducing demand for chemicals is critical

Globally

35%

of all polymers produced go into making single use plastics

Carbon derived from biomass or captured from the air will always be a limited resource. Reducing demand for chemicals will make the use of alternative feedstocks easier, by curbing demand for scarce resources. In their 2022 report 'Planet positive chemicals', environmental consultants SystemIQ calculated a maximum possible reduction of 19 per cent in total global demand for carbon-based chemicals.[7]

Plastic is an obvious and powerful example. Approximately 35 per cent of all the polymers produced in the world (14 per cent of all chemical products) go into making single use plastics.[8] Drastically reducing this subset of plastic production as part of the move away from throwaway culture could cut global demand for polymers by a third.

But, in the UK, progress on constraining the use of unnecessary plastics is too slow and the approach so far has been simplistic. The government has banned some single use plastics and introduced a plastics tax for packaging that contains less than 30 per cent recycled content. However, without comprehensive policy around single use culture, such initiatives can result in businesses directly substituting plastic for other materials such as glass and wood, which also have significant environmental impacts.

A higher rate of recycling also reduces the need for virgin polymers, but the UK lags behind the EU in not yet banning oxo-degradable plastics, which contaminate plastic recycling streams and, when littered, are widely regarded as being more harmful than helpful.[9] The deposit return scheme designed to stimulate greater collection for recycling and reuse, first consulted on in 2018, has not yet been implemented. Overall, progress on the government's resources and waste strategy, published in 2018, has been extremely slow, drawing recent criticism from the National Audit Office.[10]

However we choose to make chemicals, and acknowledging that demand for them will never disappear, using as few of them as possible should be a first principle for better environmental outcomes. Industry should develop new business models that do more with less, and the government should accelerate its policy efforts to aid this.

Chemicals of the future will be made of carbon from multiple sources

Below and in the following sections, we assess the advantages and challenges of the four main routes to providing carbon for chemical products. We compare hypothetical examples in which the UK's entire ethylene production via steam crackers is replaced with another process relying on different feedstocks. This exercise is for comparative and illustrative purposes only, and we do not expect UK ethylene production to be entirely replaced by any single alternative.

We estimate the energy required, and any residual greenhouse gas emissions, for the different feedstocks and production routes. Where relevant, we also estimate the potential impact on UK land use, for example if biomass feedstocks were to be supplied from domestic sources. Over time, some impacts may grow while others may shrink.

Making ethylene from different feedstocks comes with trade-offs

	Fossil resources, with carbon capture and storage	**Chemically recycled plastics**	**Biomass**	**Captured carbon and green hydrogen**
Land use impacts	Low	Low	High	Low
Cost	Moderate, and trending higher	High, but could trend lower	High, could rise with competition	Very high, but trending lower
Energy use	Moderate	Moderate	Moderate	Very high
Residual emissions	High	High	Low, but with risks	Low

“Ten per cent of current fossil carbon is used in chemicals.”

Chemicals could be the last use of fossil fuels

Given the long lifetimes of existing industrial assets, the UK is unlikely to stop using fossil resources entirely for chemical production before 2050. But that does not justify continued widespread fossil resource extraction, especially of oil. Only ten per cent of current fossil carbon is used in chemicals, and efforts to cut demand and create a circular economy for chemicals could prevent this growing extensively.[11] It is also worth noting that all three UK steam crackers now use only ethane gas imported from the US, rather than oil-based naphtha from the North Sea.

In theory, the UK could electrify its steam crackers, remove process emissions with carbon capture and storage technology (CCS) and lock away 65 per cent or more of the embedded carbon in long lasting products or landfill.[12] Even after this, the process would still be left with emissions of 3MtCO_2 per year due to embedded fossil carbon and energy consumption, which is equivalent to the carbon footprint of around 400,000 average UK citizens.

Ultimately, the remaining carbon emissions would need to be addressed, and will amount to about three per cent of the total UK residual emissions that will require removal in 2050. This volume could be reduced with greater recycling of plastic products and a shift away from waste incineration.

In the tables on page five and below, we note that the land use impacts of continued use of fossil feedstocks are low, but wider environmental impacts are likely. There will be a loss of nature and biodiversity near areas of fossil resource extraction, although the area affected will be smaller than that needed for the equivalent amount of carbon supplied from biomass.

Finally, it is important to emphasise that chemical manufacturing from fossil resources is an extremely efficient and fine tuned process, developed over many decades. Alternative routes, using biomass, captured carbon dioxide or plastic wastes, are much newer and, therefore, less optimised.

Impacts of continuing to use fossil feedstocks (with carbon capture and storage)

Land use impacts	Low in the UK, current feedstock is ethane imported from US fracking wells
Cost	Moderate, when the costs of CCS and electrification are included, and trending higher as demand for heavier oil fractions dissipates
Energy use	2-4% of expected UK electricity demand in 2050, if steam crackers are electrified
Residual emissions	3MtCO2 per year, 3% of residual UK emissions requiring removal in 2050

Recycled plastic waste is a source of carbon

> **"Reusing carbon already present in waste plastics makes the best use of the resource."**

Reusing carbon already present in waste plastics makes the best use of the resource, even if it originally comes from fossil sources. This can either be through mechanical recycling, which preserves the molecular structure of plastics, or through a range of chemical recycling processes, that break plastics up into very basic hydrocarbons that look a lot like conventional oil and gas.

Mechanical recycling can create new plastic products, but chemical recycling is required to produce base chemicals like ethylene, which can then be used to make chemical products other than plastics.

Increasing recycling rates and expanding chemical recycling lowers the demand for virgin fossil carbon, but the energy requirements of, and emissions from, chemical recycling are significant. We estimate that replacing the UK's ethylene production with recycled plastics as a feedstock could result in emissions of around $4MtCO_2$, or four per cent of the UK's expected residual emissions in 2050. This would be higher than the use of fossil resources in electric steam crackers with CCS, but much lower than current business as usual emissions.

However, there are different types of chemical recycling process, with quite different emissions intensities. In addition, chemical recycling could avoid some emissions from the fraction of plastic waste that otherwise gets incinerated, and cutting the amount of feedstock inputs would reduce associated upstream emissions from fossil resources.

An ambitious estimate for a theoretical global maximum plastic recycling rate, through both mechanical and chemical recycling, taking into account lost and unsuitable materials, is 70 per cent, providing enough carbon to meet about half of global demand for chemicals.[13]

If effective environmental policies to prevent the overconsumption of plastic and its toxic pollution are successful, the supply of waste should decline. Therefore, it will be imperative that any policy to use it as a carbon input for industry does not act as an incentive to generate more waste, and always prioritises mechanical over chemical recycling where possible, because it is a more efficient use of resources.

As mentioned above, we do not expect all UK ethylene production to be replaced by any single alternative, and would not suggest that would even be desirable. For example, to supply enough material for all UK ethylene production, it would be necessary to import some low grade plastic waste, or the 'oil' produced from plastic waste processed elsewhere, which is unlikely to be optimal in terms of costs or emissions.

Impacts of replacing fossil feedstocks with chemically recycled plastics

Land use impacts	Low
Cost	High, could trend lower with cheaper energy and advanced technologies
Energy use	1-4% of expected UK electricity demand in 2050
Residual emissions	Up to 4MtCO_2, or 4% of residual UK emissions requiring removal in 2050, excluding emissions savings from reduced waste incineration

> **"Extensive use of biomass carries the risk of wider impacts, primarily through competition for other land uses."**

Biomass is an alternative but has impacts

Biomass (plant material) as a source of carbon and hydrogen in chemical production receives a lot of attention from within the chemical sector. Many see it as a drop-in solution, or champion it as being well suited to producing certain downstream or 'speciality' chemicals, such as ethanol and organic acids.[14,15]

Its use as a chemical feedstock is often ignored in wider conversations about the best uses and competition for bioresources. The government's 2023 biomass strategy only delves into its use for the chemical industry in any detail in its final few pages.

Extensive use of biomass carries the risk of wider impacts, primarily through competition for other land uses (for food, nature and carbon sequestration). Confidence in sustainable biomass certification schemes is low, especially following well documented failures, such as in voluntary carbon markets.[16,17]

It is unlikely there will be sufficient domestically sourced biomass to supply all UK chemical production, especially as demand for it is rising in many other areas of the economy, including for carbon dioxide removal. However, chemical production is a better use of biomass than some uses, like powering surface transport, which is more effectively decarbonised through electrification.

In energy terms (the common unit for biomass and bioenergy), roughly 19-37TWh a year is needed to replace all UK ethylene production. That is equivalent to about seven to 35 per cent of UK domestic biomass supply in 2050, or up to 23 per cent of all arable land in the UK, if supplied only from crops.

Using agricultural residues and biomass wastes would need much less land for growing virgin biomass, but there are still trade-offs. Biomass wastes tend to have seasonal variations in supply and often need more extensive processing before use. UK agricultural policy is also evolving to encourage farmers to retain and reuse more nutrients on their farms, which may mean a smaller overall supply of agricultural residues available for other uses.

> E-chemicals are appealing, but their cost and energy requirements are extremely high."

Replacing UK ethylene production would take 20-40 per cent of the UK's expected domestic biogenic wastes and residues in 2050. But competition for these supplies will be fierce, especially from other sectors which have difficulty decarbonising, like aviation and shipping. Some studies expect electricity generation to use twice this amount of bioenergy, and transport as a whole could need up to three times as much by 2050.

Chemicals made from biomass should not be confused with biodegradable chemicals, such as cleaning and personal care products and so-called 'biodegradable plastic' goods. These can be made from fossil feedstocks, or from biomass but, either way, when they degrade their embedded carbon is released to the atmosphere. Cleaning and personal care products typically breakdown before they reach the municipal waste stream, so their embedded emissions cannot be avoided, for instance from being locked away in landfills or incinerated with CCS.

Impacts of replacing fossil feedstocks with biomass

Land use impacts	Up to 13-22% of UK arable land
Cost	High, could trend higher with competition for bioresources
Energy use	4-7% of expected UK electricity demand in 2050
Residual emissions	Low, 0.1-1% of residual UK emissions requiring removal in 2050, but risks from land use change and the overuse of fertiliser remain

E-chemicals may be greener, but at a price

Touted as the 'cleanest' way to make chemicals, using nothing but electricity, water and air, so called e-chemicals are appealing, but their cost and energy requirements are extremely high.

Combining hydrogen with CO_2 from industrial off-gases, or direct air capture (DAC), can produce methanol. Established methanol-to-olefins or methanol-to-aromatics production routes can then be followed to make other platform chemicals. This is common practice in China where methanol is made from coal.

Industrially captured CO_2 could be used at first, while a transition to using carbon from DAC could come later, when the costs of this technology fall. Similarly, blue hydrogen (produced using fossil gas with CCS) could be used initially, while green hydrogen production (produced using clean electricity and water) scales up. But these can only be part of a transition phase, and policy must not lock in assets and supply chains still reliant on fossil resources that have to be phased out eventually in a green economy.

E-chemical production would require

120TWh

of clean electricity a year

E-chemical production would require 120TWh of clean electricity a year to replace the equivalent ethylene production capacity of the UK's three steam crackers. That is a very high energy requirement, at 13-23 per cent of the UK's expected total electricity demand in 2050. Although, compared to biomass, the land use impacts would be minimal. Even if all the power needed came from onshore wind alone, it would only require 0.01-0.06 per cent of the UK's agricultural land.

Even wind power has a carbon footprint, from the manufacture, installation and maintenance of turbines, which can add up at this scale of demand (to 1.3MtCO_2e). Over time, the carbon intensity of wind power will decrease as the wider economy decarbonises, so this number may drop to perhaps 0.2MtCO_2e by 2050. At present, using electricity to create e-chemicals would not result in lower emissions compared to steam cracking. For that, the electricity supply would need a carbon intensity under 100gCO_2e per kWh. Current UK grid carbon intensity is around 150gCO_2e per kWh, but it is expected to drop to below 10gCO_2e per kWh by 2050, so if enough clean electricity can be generated, e-chemicals would be the lowest emission option.

If most of the embedded carbon in products made with e-chemicals were locked away through recycling, in long lasting products or in landfill, this production route could be considered to be net carbon negative. Assuming 65 per cent of the embedded carbon is locked away, as discussed above, this could, in theory, take care of four to five per cent of the UK greenhouse gas removals needed in 2050.

Impacts of replacing fossil feedstocks with captured carbon and green hydrogen to make e-chemicals

Land use impacts	0.01-0.06% of UK agricultural land to provide onshore wind power
Cost	High, trending lower with cheaper electricity and technology maturation
Energy use	13-23% of expected UK electricity demand in 2050
Residual emissions	Potential to be net negative, sequestering 4-5% of residual UK emissions requiring removal in 2050, but this is only possible with clean electricity

Can the UK chemical industry be ‘de-fossilised’?

> **“There is no simple, single solution, and change is likely to happen via a variety of routes.”**

Completely eradicating greenhouse gas emissions from the chemical industry is hard but, to address climate change, efforts must be made to move away from using virgin fossil resources as feedstock. Our analysis shows that, although alternatives to fossil feedstocks exist and can have lower emissions, there is no simple, single solution, and change is likely to happen via a variety of routes.

It is also important to note that our analysis focuses specifically on replacing the UK’s ethylene production, currently produced in three steam crackers. The inputs required to replace all of the UK chemical manufacturing sector’s use of fossil resources would be larger. Some alternative feedstocks may be better suited for particular products, and the optimal choice may change over time, depending on technological developments.

Better collection and segregation of waste is needed for mechanical recycling to reach its full potential. Where plastic waste is not suitable for mechanical recycling back into useable plastics, chemical recycling to extract its carbon and hydrogen is likely to be a worthwhile alternative so long as it reduces overall emissions compared to fossil resources. However, this will never provide enough input to replace fossil resources entirely, and there is a danger it will deter waste prevention.

There is also a risk that chemical recycling facilities could be used to produce fuel for combustion rather than feedstocks for chemicals. In fact, alternative fuel is the only product that currently has policy support, via the renewable transport fuel obligation. Policy makers must be wary of this, and research to bring down the high energy requirements for chemical recycling must continue. This option could grow in significance over time if these issues are addressed.

Chemical production is a good use of biomass wastes and residues. That said, there are caveats around this as it could increase pressure on other essential uses of land, especially as there is competition from other sectors needing to reduce their climate impacts. With strict sustainability criteria, the use of waste biomass could be a good medium term option for the industry, but this will become less positive over the longer term as other demands on land and for biomass rise. Biomass might be best used for speciality chemical production.

E-chemical production currently requires so much energy that it is unlikely to be viable until clean energy becomes much more abundant. But the UK has good access to sources of clean energy and some of the most ambitious clean electricity targets in the world. The long term potential of e-chemical production in the UK is promising, and R&D efforts should be expanded to improve these nascent processes.

Competition for, and scarcity of, resources will affect all options. A particular risk is that demand for sustainable aviation fuels (SAFs), especially once the SAF mandate is implemented, could swallow up supplies of green chemical feedstocks, like biomass and hydrogen.

> **"Sectoral policies need to reflect the requirements of the chemical industry, but without exaggerating them."**

Sectoral policies (eg for electricity, biomass, hydrogen, waste, oil and gas) need to reflect the requirements of the chemical industry, but without exaggerating them. The needs of the chemical sector should not be used to justify continued high levels of fossil resource extraction. Less than ten per cent of current fossil resource production is used for chemical feedstocks.

Alternatives to fossil feedstocks are still costly, and although consumers want 'green' products, they are often unwilling to pay the cost premium. As it uses the low cost by-products of the oil industry, the fossil resourced chemical industry effectively receives a 'subsidy' that may be substantial. As oil use diminishes, that benefit will shrink and alternative feedstocks may become more cost competitive. But this is not guaranteed and may take several decades, with an oversupply of virgin plastic currently squeezing prices downwards.[18]

Policy is needed now which empowers the industry to begin scaling up alternatives. Full lifecycle analyses are still crude and technologies are evolving, so it is not yet possible to say exactly which solutions will be optimal from a cost and environmental perspective. There are also many complex value judgments to be made around the best uses of scarce resources, and how recycled fossil carbon compares to carbon sourced from plants. Strong sustainability criteria and some flexibility regarding the different routes taken will be needed.

A ‘green carbon mandate’ for chemicals would kickstart change

> **“Qualifying feedstocks should meet strict sustainability standards.”**

The government has made slow progress on resource efficiency across the economy. It should accelerate efforts to reduce demand for chemical products and increase recycling, to cut the use of virgin resources.

To encourage the development of alternative feedstocks we suggest a ‘green carbon mandate’ on chemical products. Like mandates to stimulate sales of zero emission vehicles (ZEV) and sustainable aviation fuel (SAF), this would require chemical manufacturers, and possibly importers of equivalent products, to source a gradually increasing percentage of carbon input from non-fossil or recycled sources.

As with the ZEV mandate and plans for the SAF mandate, it could involve tradeable credits. This would allow manufacturers using a higher proportion of non-virgin fossil feedstocks to sell surplus credits to others that need them to comply with the mandate.

Qualifying feedstocks should meet strict sustainability standards that cover all supply chain impacts. Impacts should be included from land use change and upstream energy use, as well as damage to biodiversity and harms from unintended consequences, like higher demand for waste plastics and biomass residues.

The most effective route to implementation would need to be decided, including how the minimum green carbon fraction should be applied over time, how it would interact with policies like the plastic packaging tax, and where in the value chain the mandate should come in. For instance, it could be applied when finished products are sold, automatically covering imports as well as domestic production, although accounting and traceability could be challenging. Or it could apply to bulk chemical production, with border adjustment measures to ensure that UK producers were not disadvantaged as a result. Lessons should be drawn from the failure of the plastics packaging tax to drive change.

A green carbon mandate may increase the cost of bulk chemicals but, in most cases, the impact on consumer prices is likely to be minimal. Doubling the cost of bulk chemicals is expected to increase end prices by only one to three per cent.[19] The non-fossil resource fraction should increase slowly, allowing time for the costs of any new processes to come down, with the target reviewed over time. A subsidy for alternative feedstocks could also be considered to support faster progress and avoid any negative impacts for consumers.

Endnotes

1 V Viisainen, L Hardy, S Greacen and R Bulleid, 2023, *A new formula: cutting the UK chemical industry's climate impact*, Green Alliance

2 Details of supporting calculations for these statistics, and all in depth analysis included in this report are available in the separate methodology document at bit.ly/3VApLdO

3 SystemIQ, 2022, *Planet positive chemicals*, see: figure 15, page 61. The estimated '63 per cent of all chemicals' considers ammonia-based products which, although usually made from coal or gas, do not ultimately contain any carbon. The ammonia-based fraction of total chemical production is estimated to be 33 per cent, taken from figure 1 in P G Levi and J M Cullen, 2018, *Environmental science & technology,* vol 51, pp 1,725-1,734.

4 The three UK steam crackers have a combined capacity of 2.695 million tonnes per year according to: C Hill, December 2018, *Biopolymers (bio-based plastics) – an overview*, a report for the Climate Change Committee. The global ethylene production capacity was 223.9 million tonnes in 2022, according to: GlobalData, 27 April 2023, *Ethylene Industry installed capacity and capital expenditure forecasts including active and planned plants to 2027*. The UK's share of global capacity is therefore 1.2 per cent.

5 The estimated embedded carbon in the ethylene produced by the UK's three steam crackers is 8.5MtCO_2 per year (see the 'fossil fuel' section of the methodology document at bit.ly/3VApLdO). Total UK greenhouse gas emissions in 2022 were 417MtCO_2. Therefore, this embedded carbon is equivalent to approximately two per cent of UK emissions. The UK's cement and lime industry produced a little over 9MtCO_2 in 2021, according to: 'Final UK greenhouse gas emissions national statistics: 1990 to 2021', supplementary table 8.1, Department for Energy Security and Net Zero.

6 Royal Society of Chemistry, 2023, *The future chemistry workforce and educational pathways*

7 This 19 per cent reduction is relative to a business as usual scenario in which chemical demand grows between 50 and 100 per cent. See: SystemIQ, 2022, *Planet positive chemicals*, which estimates that circularity measures could reduce demand for virgin feedstocks of non-ammonia primary chemicals by up to 51 per cent overall (page 33). Of this, 38 per cent is from measures that directly reduce demand through elimination (figure 6, 134Mt of elimination savings from a total of 354Mt in the low circularity ambition example shown). We assume the same balance between different levers in the high circularity ambition scenario. Therefore, 19 per cent is the overall modelled reduction in demand.

8 Minderoo Foundation, 2023, *Plastic waste makers index 2023*, the basis of preparation notes that 139Mt of global plastic polymers produced are for single use plastics, from a total of 402Mt (figure 2, page 12). This suggests that 35 per cent of polymers are made for single use plastics.

In figure 1 of PG Levi and JM Cullen, 2018, op cit, thermoplastics and other fibres totalled 40 per cent of production in 2013. Assuming the ratio of production of different chemical products remains roughly the same as in 2013 (more recent and comprehensive data is very difficult to access, as noted by PG Levi and JM Cullen), then 14 per cent of all chemical products are single use plastics.

9 Royal Society of Chemistry explainer, 'Additives for degradable plastics', retrieved February 2024

10 National Audit Office, June 2023, 'The government's resources and waste reforms for England'

11 J-P Lange, 2021, 'Towards circular carbo-chemicals – the metamorphosis of petrochemicals', *Energy & environmental science*, vol 14, p 4,358

12 See our methodology at bit.ly/3VApLdO for further details on how this 65 per cent is calculated.

13 R Meys, et al, 2021, 'Achieving net-zero greenhouse gas emission plastics by a circular carbon economy', *Science*, vol 373, pp 71-76

14 K Huang, et al, 2021, 'Greenhouse gas emission mitigation potential of chemicals produced from biomass', *ACS sustainable chemical engineering*, vol 9, p 14,480

15 UKBioChem10, 2019, 'The ten green chemicals which can create growth, jobs and trade for the UK'

16 Biofuelwatch and Global Forest Coalition, March 2020, 'Can sustainability and greenhouse gas standards protect the climate, forests and communities from the harmful impacts of wood-based bioenergy?'

17 Greenpeace UK investor briefing, January 2021, 'Net expectations – assessing the role of carbon dioxide removal in companies' climate plans'

18 *Financial Times*, 15 January 2024, 'Petrochemical glut makes new plastic cheaper than recycled'

19 SystemIQ, 2022, op cit, page 93

Green Alliance
18th Floor
Millbank Tower
21-24 Millbank
London SW1P 4QP

020 7233 7433
ga@green-alliance.org.uk

www.green-alliance.org.uk
@GreenAllianceUK
blog: www.greenallianceblog.org.uk

Title
The last use of fossil fuels? Making chemicals without oil and gas

Authors
Liam Hardy and Roz Bulleid

Acknowledgements
Thanks to Dustin Benton, Will Carr and Libby Peake of Green Alliance for their helpful comments. We also thank industry experts, academics and other policy researchers for their insights and feedback, including Aidan Shilson-Thomas, Alex Mackaness, Dan Quiggin, Euan Casey, Joanna Sparks, Lydia Heinrichs, Matthew Davidson, Rich Woolley, Sarah Davidson and Tony Heslop.

We are grateful to the European Climate Foundation for supporting this work.

Green Alliance
Green Alliance is an independent think tank and charity focused on ambitious leadership for the environment. Since 1979, we have been working with the most influential leaders in business, NGOs and politics to accelerate political action and create transformative policy for a green and prosperous UK.

The Green Alliance Trust
Registered charity no 1045395
Company limited by guarantee
(England and Wales) no. 3037633

Published by Green Alliance
April 2024

ISBN: 978-1-915754-35-6

Designed by Howdy

Cover photo by Chris LeBoutillier on Unsplash