FINANCING A CIRCULAR CHEMICAL ECONOMY

Key findings and recommendations from policy workshops discussing how to finance a transition to a circular economy in the UK chemical manufacturing sector. Senior representatives from academia, industry, special interest groups and learned societies were invited to contribute their views, requirements and perceived challenges.

Moving to a circular economy is imperative not only for environmental reasons. It has potential for wide-ranging economic and societal benefits, giving the capacity to grow and thrive, create green jobs, upskill the workforce, increase self-sufficiency by reducing import reliance, improving infrastructure and providing a brighter outlook for future generations.

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CO_2 is currently viewed as a waste product, but it is a valuable commodity resource to reduce costs for many industries within the chemical sector and beyond.

Current UK policies place an **over-importance on biomass for fuels**. Sustainable aviation fuel (SAF) and similar methods are not sustainable in the long-term and there are valuable chemical feedstocks to be extracted before conversion into fuel.

Accessing resources and facilities for **scaling-up early-stage research and building demonstrator units** is extremely difficult. A portfolio of demonstrator units would help to boost investor confidence and de-risk these new technologies.

Finance & Fiscal

UK-based finance opportunities are severely lacking which poses a significant barrier to developing and scaling innovation. Increasingly, funding of the scale required is being sought and obtained overseas leading to an outward flow of UK innovations.

Investment risk remains a significant challenge, particularly with business-as-usual activities having greater stability and return on investment. Limited investor understanding of this sector further adds to the perceived degree of risk.

Sector funding requirements are far greater than in other areas, in the billions of GBP, with considerably high seed funding costs and a large gap between the early and pre-commercial stages requiring additional support.

Government collaboration, both inter-administration and with industry and financial institutions, is needed urgently.

General

The utilisation value of carbon should be recognised. There should be a product-focus on waste generation to create efficiencies in the supply chain, such as **incentivising Carbon Capture & Utilisation (CCU) over Carbon Capture & Storage (CCS)** (which is economically unproductive and likened to landfilling).

While intellectual property (IP) generation is generally strong **the transition to commercialisation and retention of IP is weak**. **The UK is not seen as an attractive investment for scaled infrastructure**, which is compounded by high manufacturing and labour costs. In turn this creates an **outward flow of manufacturing** meaning emissions of embodied carbon are overseas.

A longer-term outlook is needed to prioritise environment over profit, facilitated by increasing profit potential and decreasing risk to invest in such areas. An over-focus on return on investment under short timeframes is a barrier to change.

Further education is needed to help investors and policymakers understand this technical space. If the risks are not fully understood, investor confidence will be low.

Competing priorities and strategies of government departments are hindering progress. A unified, multi-department approach is needed, with clear, attainable sustainability targets.

The sole focus on Net Zero can hinder broader sustainability achievements. A more holistic view is required to address overall environmental issues, of which emissions reduction is one aspect.

An impediment to change is that **understanding of the chemical industry and circular business models are underdeveloped and different across UK administrations**.

Key Recommendations

Technology

1. **Support industrial symbiosis clusters.** Initiatives that use the waste from one sector as feedstocks for another will help to accelerate circular businesses.
2. **Create national, collaborative public sector research institutions operating as a commercial business with industry and academia.** To incentivise partnerships and commercialisation and support early-stage research scale-up, plus the added benefits of employment opportunities and revenue generation.
3. **Support novel technologies and early-stage research through all TRL levels to de-risk investment opportunities.** Greater access to financial support and resources to assess and minimise risk in building demonstrator units should enable quicker scale-up and growth.
4. **CCU must be prioritised over CCS.** CCU can be revenue generating and give rise to economic growth and jobs creation. A longer-term vision for CCU must be realised with investment in infrastructure.

> ***"There are a lot of 'stick' approaches but not a lot of 'carrot' in the UK… at the moment everything that we're doing is very much a 'stick' approach. There's going to be emissions taxes… but we don't have any incentives."***
>
> *Industrial representative*

Financial & Fiscal

1. **Carbon taxes should be of a sufficient scale to actively disincentivise poor behaviour not simply act as a punitive charge.** Consider the carbon emission efficiencies and only subsidise the actual carbon savings – see **Box 1** (pg. 28).
2. **Greater appreciation of the value of the chemical industry** from an economic and political perspective.
3. **Oil and gas tax relief refocussed towards re-skilling and training.** Ensuring minimal job losses and

continued sector growth - see **Box 2** (pg. 29).

4. **Additional support for investment opportunities.** Investment funding guarantees should be offered more frequently and include a requirement of independent investment review to de-risk and boost investor confidence. Public equity, private funds and wider debt and equity instruments are needed to develop and scale CE interventions and technologies.[3]

5. **A stronger and clearer carbon credit framework** will help to incentivise further emissions reductions and the CE transition. Carbon offsetting is permitted greenwashing and should not be encouraged.

> ***"The UK is not seen as an attractive place for investment in green tech. It is behind the curve in terms of investment into technology and business growth."***
>
> *Academic Representative*

General

1. **Recognise the value of typical waste products, such as carbon dioxide.** Current 'waste' streams contain valuable resources and feedstocks for many chemical industries, helping to reduce environmental damage and boost economic growth.

2. **Adopt a unified industrial strategy for a CE transition.** Government departments need to develop a robust, unified, cross-cutting intra-departmental strategy with industry collaboration.

3. **Refocus the current biomass strategy on value extraction before fuel generation.** Valuable commodities and chemical compounds should be extracted first before any remainder is turned into biofuel, thus generating new revenue streams and jobs.

4. **Implement a standardised Life Cycle Assessment (LCA) framework** to assist in determining the degree of risk for investment, but current approaches do not fully consider the whole system and related boundaries.

5. **Embrace longer-term thinking to achieving positive impact.** Sustainable initiatives typically require longer investment and return periods to have measurable impact.

> ***"We do need to have a more collaborative approach in terms of how the financial institutions and the government could work together."***
>
> *Industry Representative*

Chapter 1

Introduction

The CircularChem Centre

The National Interdisciplinary Centre for the Circular Chemical Economy (CircularChem) brings together stakeholders from academia, industry, government, NGOs and general public to transform the UK's chemical industry into a fossil-independent, climate-positive and environmentally-friendly circular economy. As part of a £30 million strategic government investment, it will play a key role in helping the UK to reduce waste and the environmental impacts of production and consumption and creating opportunities for new UK industries.

Our Vision

To transform the sector's current linear supply chain model into a fossil-independent, climate positive and environmentally friendly circular economy.

The UK Chemical Industry

The UK chemical industry makes a significant contribution to the UK economy. With revenue of £75.2 billion in 2021, corresponding to a gross value added (GVA) of £30.7 billion and 141,000 direct jobs,[1] it is one of the largest export sectors with demand predicted to double in the next 10 years.

However, business as usual is no longer an option. The sector is one of the largest consumers of energy and resources and, consequently, one of the largest producers of waste and emitters of CO_2. Carbon-based chemistries are integral to the majority of chemical sectors.

Therefore, we need to *decarbonise* our energy supplies and *defossilise* our carbon sources. Alternative, non-fossil derived sources of carbon are needed urgently to achieve our vision.

A group of chemicals called *olefins*, and their complementary feedstocks such as ethylene and propylene (which can be used to form the common plastics polyethylene and polypropylene respectively), account for over 70% of all chemical production. Current manufacture of olefins occurs by a process known as steam cracking of naphtha, an energy-intensive process that generates large amounts of CO_2 (1.2 – 1.3 tonnes of CO_2 (tCO_2) per tonne of olefin).[2] Their use includes a wide range of intermediate and final products, including polymers, chemical fibres, solvents, synthetic rubber and high-value speciality chemicals. These intermediates are subsequently used by other manufacturing and industrial sectors to produce useable end products (Figure 1).[3]

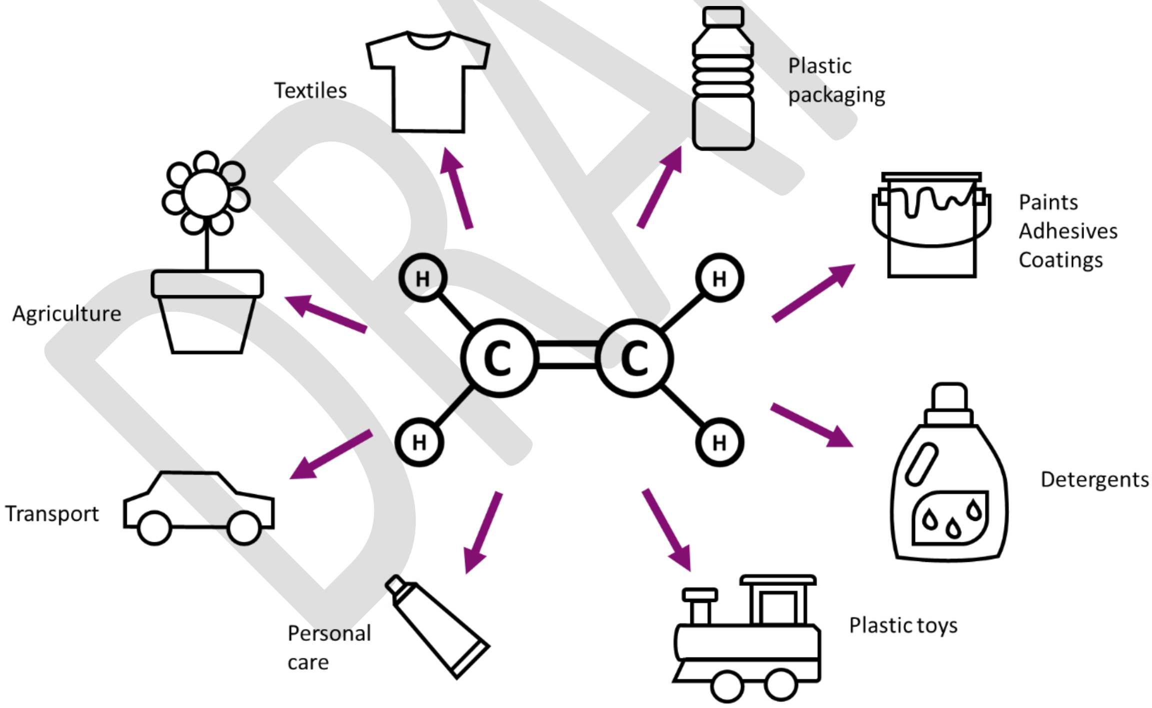


Figure 1: Products produced from ethylene can be found in numerous consumer products across many different sectors.

Demand for high-value chemicals is predicted to grow 50% by 2050, with a forecasted demand of 340 Mt of ethylene alone (Figure 2).[4]

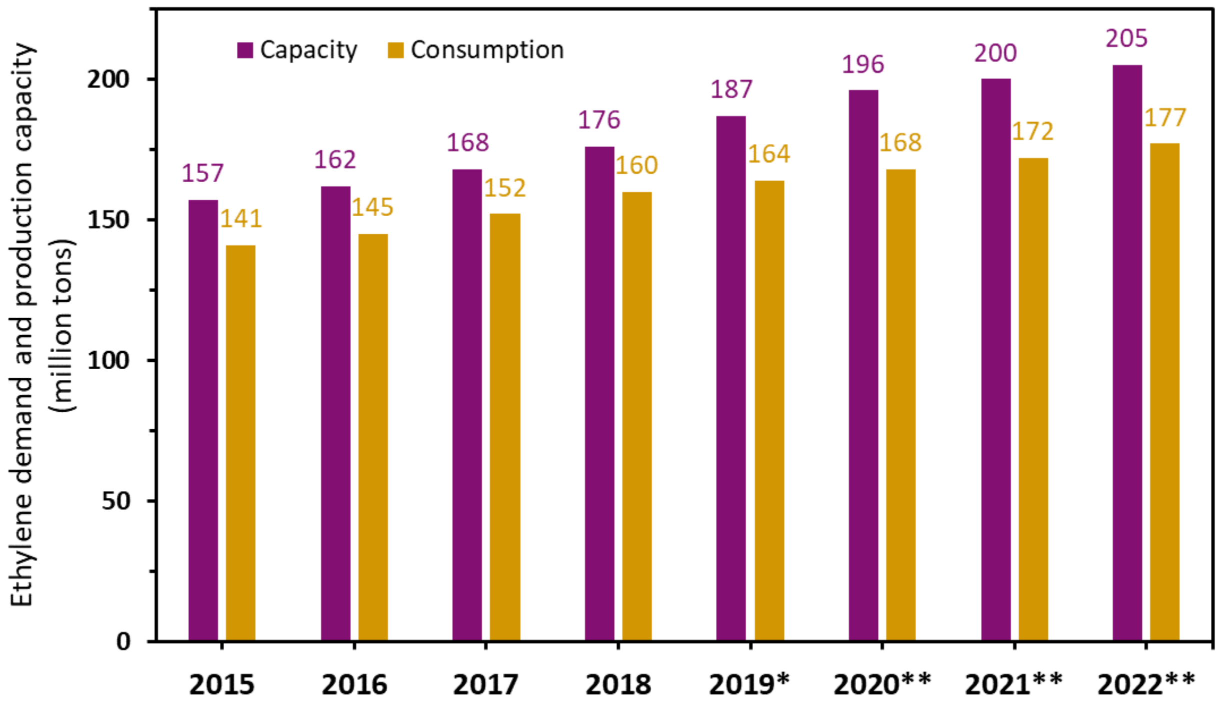


Figure 2: Global ethylene demand and production capacity (in million tons) between 2015 – 2022. The single asterisk (*) refers to estimates and the double asterisks refer to forecasts (**).[5] Statista. (2020). *Ethylene demand and production capacity worldwide from 2015 to 2022 (in million tons)*. *Statista*. Statista Inc. Accessed: September 20, 2024. https://www-statista-com.sheffield.idm.oclc.org/statistics/1246694/ethylene-demand-capacity-forecast-worldwide/

Fossil Carbon

The importance of fossil fuels for our modern society cannot be understated, as evidenced by the vast range of products that can be obtained from fossil fuels (Figure 1). However, the vast majority of extracted fossil fuels are used for fuel purposes across sectors including aviation, maritime and personal and commercial transport. Just 5% is used to make the majority of consumer products available (Figure 3). Many of these products are carbon-based and thus would not exist without these fossil carbon sources.

They have proven an invaluable resource in shaping the world as we know it today. However, the environmental damage caused by extraction and use of fossil fuels now far outweighs their usefulness. We urgently need alternative sources of carbon that will allow us to continue producing many of the products we rely on, but without the consequential environmental damage.[6-8]

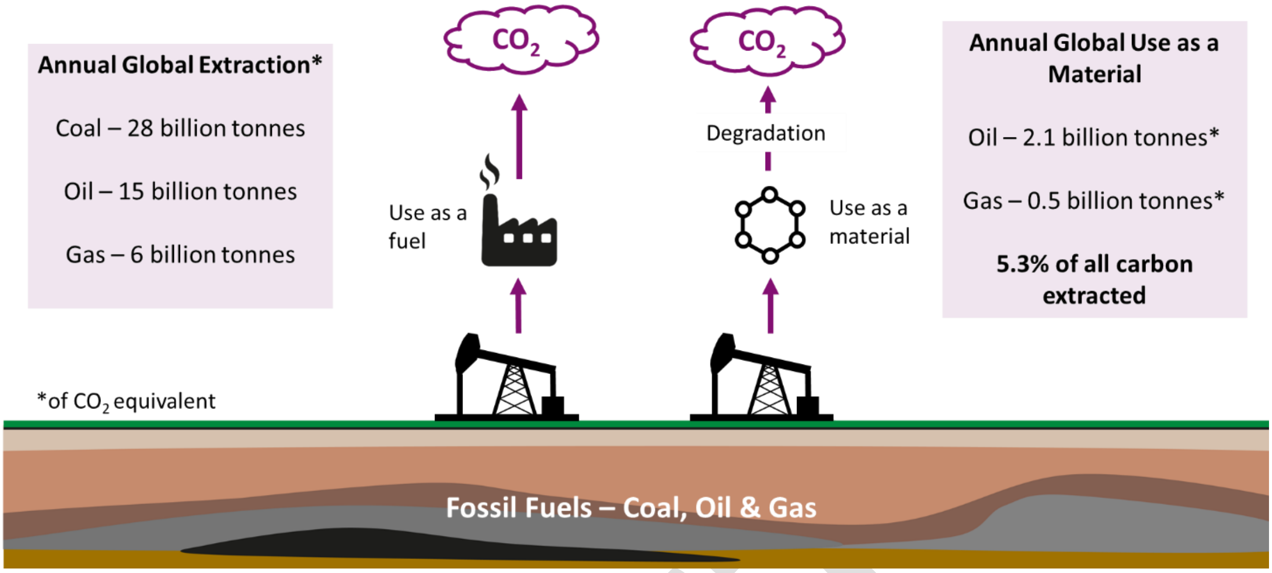


Figure 3: Annual global extraction and material use of fossil fuels (coal, oil and gas) considering use cases of fuel or material/product production (in CO_2 equivalents). Carbon emissions arise from both cases, with embedded carbon emissions in the material pathway released as products degrade. Only 5.3% of all carbon extracted globally per year is used to product products.

The Circular Economy

A Circular Economy (CE) offers a vision where products and materials are designed to be reused, repaired or remanufactured, ensuring resource extraction, waste generation and pollution are kept to a minimum. By focussing on society-wide benefits, it seeks to redefine growth by gradually decoupling economic activity from the consumption of finite resources. All of this is underpinned by a transition to systems and sources of renewable energy. Three key principles are the foundation: 1) better product design to remove waste and pollution; 2) keeping products and materials in use; 3) regenerating natural systems. Current business models are linear and focus on a 'take-make-use-dispose' approach - they are not sustainable in the long-term (Figure 4).

Figure 4: A linear economy of take-make-use-dispose.

Crucially, transitioning to a CE also brings many positive benefits, not only addressing the negative aspects of a linear economy. **It represents a fundamental shift that generates business and economic opportunities, provides environmental and societal benefits and builds long-term resilience** (Figure 5). It is estimated that a CE in Britain could create over half a million jobs by 2030.1 Furthermore, circular models can **reduce production costs and bolster resource security, lessening import dependency and supply chain disruption risks.**

The CE, and Industrial Symbiosis and Resource Efficiency in particular, aims to transform the way we manufacture and consume products. Relying solely on renewable energy solutions to reduce greenhouse gas (GHG) emissions will only address 55% of these emissions. The CE can reduce a significant portion of the remaining 45%.[9] Intense demand for energy and resources can be cut by circulating products and materials, instead of producing new ones.

Figure 5: A circular economy, where extraction of natural resources is minimised and recycling of materials is promoted.

Moving to a circular economy is imperative not only for environmental reasons. It has potential for wide-ranging economic and societal benefits, giving the capacity to grow and thrive, create green jobs, upskill the workforce, increase self-sufficiency by reducing import reliance, improving infrastructure and providing a brighter outlook for future generations.

Chapter 2

Key Findings

Key Findings

A series of three, senior stakeholder discussion workshops were conducted under Chatham House Rules (also in accordance with UK Competition Law) with representatives from academia, industry, financial institutions, NGOs, learned societies and the House of Lords. Discussions centred around the policy opportunities and hurdles facing the transition to a circular chemical economy and solutions for delivery. Of particular focus were the financial and fiscal requirements which would enable a smoother transition.

The following chapter presents the key findings from these workshops.

Technologies

As alluded to in the previous section, **CO_2 is currently viewed and classified as a waste product**, but it is a valuable commodity resource for many industries within the chemical sector and beyond, not merely a contributer to climate change. Uses include cold transport systems and refrigeration, decaffeination and food / feed protection. Instead of 'landfilling' this feedstock, emerging technologies are in development and scale-up phases to enable its use as a chemical feedstock, therefore creating new revenue streams, jobs and growth potential. Policy incentives need to better reflect the utilisation value.

Furthermore, current UK policies place an **over-importance on using biomass for fuel production**. The policy incentives in using biomass for fuel generation without extraction of valuable chemicals first is unsound. Sustainable aviation fuel (SAF) and similar methods are not sustainable in the long-term and there are valuable chemical feedstocks to be extracted before conversion into fuel. The current focus of CCUS and biomass policies needs to be shifted towards prioritising chemical and product production over fuel production.

A repeated theme was the importance of de-risking technologies and building demonstrator units to attract further investment for scale-up and growth. Accessing these resources and facilities for **scaling-up early-stage research and building demonstrator units** is currently extremely difficult, especially within the biotechnology sector. A 'chicken and egg' scenario arises – researchers seek funds from investors to build demonstrator units, yet investors want to see demonstrator units before any funds are released. Timely and focussed government intervention to support this early-stage is needed. A portfolio of demonstrator units would help to boost investor confidence and de-risk these new technologies.

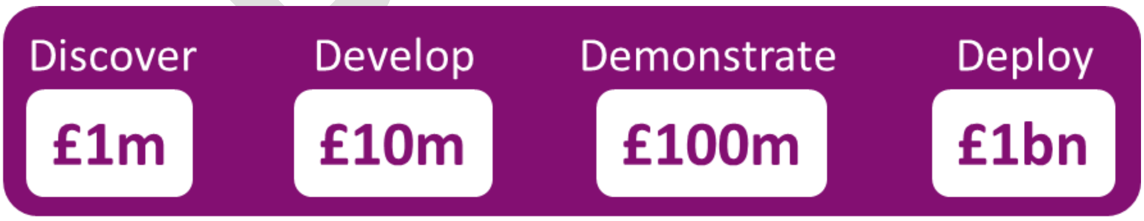
Financial and Fiscal

The UK is not seen as an attractive location for investment, by industry and financiers. **UK-based finance opportunities are severely lacking which poses a significant barrier to developing and scaling innovation, in part due to a high degree of risk aversion.** Increasingly, funding of the scale required is being sought and obtained overseas leading to an outward flow of UK innovations.

UK labour and energy costs are high, which in combination with low productivity in a sector with chemicals essentially embedded in the oil and gas industry is making progress on change slow.

Investment risk remains a significant challenge, particularly with business-as-usual activities having greater stability and return on investment. Policy intervention is urgently needed in this space to assist in de-risking these technologies and more sustainable activities. Dis-incentivising business-as-usual activities with concurrent financial support for new technologies in early-stage commercialisation would be helpful. A hyper-focus on return on investment within short timescales is another challenge. Financiers within the workshops indicated that they follow the policy with regard to their business and investment activities. Therefore, policy intervention is urgently needed to drive the necessary changes in behaviour, understanding and investment decisions.

Limited investor understanding of this sector further adds to the perceived degree of risk and reluctance to provide investment funds. **Sector funding requirements are also far greater** than in other areas, in the billions of GBP, with considerably high seed funding costs and a large gap between the early and pre-commercial stages requiring additional support. Funding in the hundreds of millions is unlikely to be enough so measures to de-risk and support investor funding are necessary. This further compounds the lack of understanding of this sector.



Care must be taken by governments to ensure that fiduciary duty is applied, ensuring that public money is put to best possible use for greatest societal benefit. This will become especially apparent as new technologies emerge, and interventions by government will be needed to financially support and accelerate these technologies onto the market.[7]

Better collaboration between government, industry, academia and financial institutions is sorely needed. Communicating earlier and more frequently will help to remove hurdles to change and make this complex research field more accessible to non-specialists. Furthermore, better collaboration is urgently needed between different government departments as competing priorities and objectives are a barrier to change. The recent appointment of a Circular Economy Minister (Mary Creagh MP) is a positive and welcome step. A priority for the Minister must be the creation of a unified industrial strategy that aligns with government priorities and ambitions and brings this vitally important issue further up the policymaking agenda. A Civil Service Theme Lead would also be beneficial towards this objective.

General

Generally, the importance of the UK chemical sector, and in particular the importance of carbon, was believed by participants to be under-appreciated and / or misunderstood by policymakers and consumers. Therefore, the messaging from the chemical sector needs to be simplified and framed in terms of the economic and societal benefits, not just the technical aspects.

Principally, the utilisation value of carbon needs to be recognised, enabling the switch from consumer to custodian of carbon.[7] Vast swathes of the products in our modern society contain carbon of some form, often derived from fossil fuels. Thus, it is a misnomer to claim to **decarbonise** the chemical sector. To do so would eliminate it and the many products it provides – **we need to *decarbonise* our energy supplies and *defossilise* our carbon sources**. Approximately 93% of a barrel of oil is used for fuel. If and when fossil-based fuels are phased out, there is reduced relative (to current operations) economic incentive to extract the remaining 7% for chemicals manufacture.[3] As such, multiple sources of alternative, non-fossil fuel carbon will be needed, but the exact amounts are unclear. Often market and consumer demands have a strong influence over a particular direction.

There was general agreement that “chemicals” are still viewed in a negative light and are presented in a manner that is too complex for most audiences. The value of new technologies is not best demonstrated from a technical perspective and so further education is needed, to better promote current successes, the positive impact they are having on economic issues and how more investment would be put to best use for further gains. Simpler forward-facing narratives around ‘winning hearts and minds’ are required. This should be evidenced using independent LCAs and focused on how new technologies with circular business models can provide the same or comparable goods with added value.

With respect to policy changes, it was stated that the environment is relatively low on the agenda. The narrative angle should therefore include more understandable figures based on economics and employment as drivers with opportunities to provide or incentivise finance, plus how the policy changes themselves could be financed, for example the route to shifting subsidies. The narrative framing must contend with the scale of the chemical industry with its global reach across sectors. This scale and the time required for transition means long term stability, both political and economic, is required. There was further consensus that this transition should be fast as industry needs to act now to avoid chemicals shortages in the UK in the mid-term. In terms of UK economic drivers there is a real fear that chemicals manufacture will move offshore to more accommodating nations where costs are lower. We have a real opportunity to onshore chemicals manufacture to create a **new** chemicals industry and supply chain.

Consequently, greater efforts are needed to **incentivise Carbon Capture & Utilisation (CCU) over Carbon Capture & Storage (CCS).** The latter is economically unproductive, possibly even detrimental, and likened to 'landfilling'. Considering the activities of installation and pipe networks will require economic activity, the final result is an additional cost without revenue. There must be profitable economic activity created, and this will come with **utilisation,** not storage. These utilised carbon emissions are a potentially valuable single carbon (C-1) feedstock for much of the chemical sector, with great potential for further revenue generation.

There are currently four established options for reducing carbon emissions – electrification, low-carbon hydrogen (H_2), CCU and CCS. Currently only, H_2 and CCS receive significant government funding and there is no lobby to promote CCU as a solution.[10, 11] While the recommendations from the G20 endorsed Mission Innovation report on Accelerating Carbon Dioxide Utilisation and Storage (CCUS)[12] was proposed in 2017, this is now seen as a political mistake as most current policy focusses on CCS of CO_2, not CCU. The "U" has been lost, or used to promote enhanced oil recovery (EOR) with the captured CO_2 being used as a working gas. If carbon capture is to be used as a solution, something needs to be done with the CO_2. Currently, there are no suitable storage options available in the UK and utilisation options are still in infancy and not yet at scale.

Furthermore, EfW plants performing CCS are utilising a significant amount of their produced energy in the process (40% or more can typically be sacrificed). Ideally creating localised circular economies would be beneficial. For example, soft drinks producers purchasing captured CO_2 for carbonation (utilisation). Sustainable aviation fuel (SAF) from captured CO_2 may appear to be "utilisation" but is just a delayed emission utilisation, unless direct air capture (DAC) can be made commercially and environmentally viable to facilitate carbon dioxide reduction (CDR). The latter has become a new policy of the US DOE with the introduction of incentives through the Inflation Reduction Act (IRA).[13] An example of CCU is the *Flue2Chem* project, with further information given in the Case Study example on pg. 27

Waste is generated along the entire supply chain, from extraction to manufacture and ultimately consumer use. The majority is upstream, but there is an **overfocus with current policies on the consumer** (downstream portion) to deal with waste and products at the end of their useable life. Shifting this focus equally along the entire supply chain will enable a greater shared responsibility in reducing waste and increasing supply chain efficiencies. Some current incentives and areas of policy focus are disjointed. A **system that can help to drive efficiencies upstream**, such as a carbon tax or realistic CDR incentives, could trickle benefits throughout the value chain. However, regulatory enablers of efficiencies can be too slow – in turn holding back industrial development or incentivising it to leave the UK. To further the carrot and stick analogy, it is worth reiterating that concomitant 'carrots' need to be put in place towards more environmentally friendly and circular solutions. Otherwise, it can increase costs and thus affect the economic condition and activity of the average consumer (custodian).

While intellectual property (IP) generation is generally strong **the transition to commercialisation and retention of IP is weak**. **The UK is not seen as an attractive investment for scaled infrastructure**, which is compounded by high manufacturing, low productivity and high labour costs. In turn this creates an **outward flow of manufacturing** meaning emissions of embodied carbon are overseas, with embodied carbon of imports not counted. The new Carbon Border Adjustment Mechanism is meant to address this. Reshuffling on public investment to support R&D and smaller scale development could increase the attractiveness of the UK.

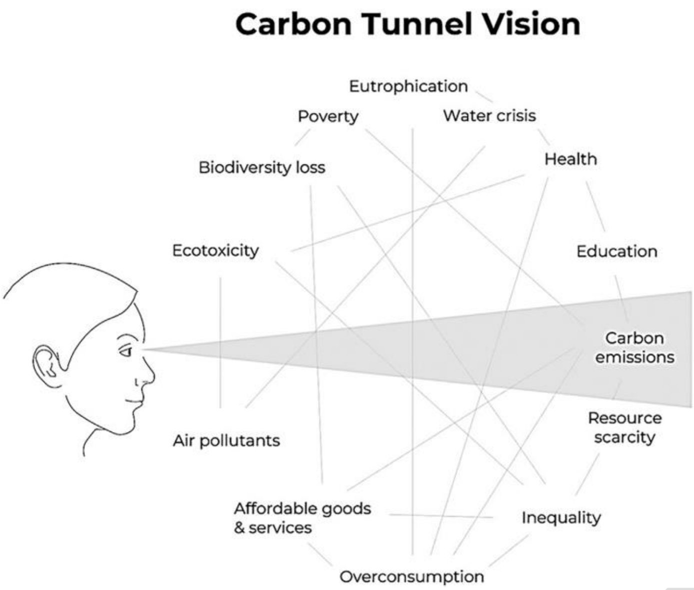
> ***"For these multi-million / billion pound [£] investment areas there are few funding mechanisms. Horizon Europe is one, but that is Europe-centric. Most of the partners and mechanisms are in the EU. We generate IP but the connections are not domestic as large-scale funding and partners are elsewhere. We need to get on board with these massive funding bodies and partnerships. It is futile to go alone."***
>
> *NGO representative*

Something **must** change if the UK is to remain competitive and a leader in science and innovation technologies. This is compounded by the feeling among participants that current policies rely too heavily on the 'stick' and don't offer much in the way of 'carrot' – policies are quick to punish but slow to reward. The US Inflation Reduction Act was repeatedly highlighted as a good example of prioritising environmental protection coupled with economic growth. This landmark bill was signed into law in August 2022, with the aim of reducing the deficit, fighting inflation and reducing carbon emissions. The legislation rewards high-emitting companies that store or utilise emitted GHGs with increased tax credits of $85 per tCO_2 captured for storage and $65 per tCO_2 captured for utilisation. It is hoped that these credits will give greater incentive and convince investors to make greater effort at CCUS. If the UK was to adopt similar legislation, greater tax credits should be given to utilisation over storage.[13]

Overall, a **longer-term outlook is needed to prioritise environment over profit,** facilitated by increasing profit potential and decreasing risk to invest in such areas. A repeated theme from financial representatives was the **need to de-risk** technologies to enable investment funds to be released, compounded by a lack of understanding of much of the technical details of these technologies. An impediment to change is that **understanding of the chemical industry and circular business models are underdeveloped and different across UK administrations**. **Further education** is needed to help investors and policymakers understand this technical space. If the risks are not fully understood, investor confidence will be low.

Demonstrator units were repeatedly mentioned as a key way of de-risking technologies and making them more attractive to private investment. However, accessing funds to scale processes up and develop demonstrator units is often difficult. The investment journey is not the same as for the technology industry – timescales are longer and the money needed is much greater. Costs can very quickly grow for investment and there is a misconception that lower funding amounts are needed. There is considerable uncertainty about making changes, with multiple factors at play – economics, market demands, consumer choices, depreciation costs and the decreasing costs of technology over time. A portfolio of demonstrator units would help to boost investor confidence in novel technologies as viable investment opportunities and therefore assist in de-risking these new technologies. More widely, a national 'database' of demonstrator units and UK industry capabilities could help to guide innovators and entrepreneurs to these resources and foster greater collaboration. Secure database ownership and maintenance would be required to ensure accuracy and relevance.

A hyper-focus on return on investment (ROI) under short timeframes is another significant barrier to change. A longer-term positive impact and ROI, that considers environmental and sustainability impact on an equal or greater footing than profit alone, is necessary to allow for novel and emerging technologies to have a real and lasting positive impact. Yet, technologies must have suitable ROI to be economically viable to succeed.



Finally, **competing priorities and strategies** of government departments are hindering progress. A unified, multi-department approach is needed, with clear, attainable sustainability targets. **The sole focus on Net Zero can hinder broader sustainability achievements and potentially cause a "carbon tunnel vision"** (Figure 6).[6] Thus a more holistic view is required to address overall environmental issues, of which emissions reduction is just one aspect.

Figure 6: Adopting a 'carbon tunnel vision' has potentially negative implications for wider sustainability and environmental issues. CO_2 emissions need to be tackled, but not at the expense of social responsibility, social impact factors, and other sustainability metrics.

Chapter 3

Key Recommendations

Key Recommendations

From the key findings listed in the previous chapter, a series of key policy recommendations can be proposed to enable an accelerated deployment of a circular chemical economy.

Technologies

1. **Support industrial symbiosis clusters.** Industrial Symbiosis is defined as an arrangement between two or more industrial facilities or companies by which waste or by-products of one become feedstocks for another.[14] These could be intra- or inter-sector depending on the requirements. Such initiatives will help to accelerate circular businesses, promote waste reduction and resource efficiency. The issue of waste regulations and permitting as mentioned previously, is a significant hurdle in this instance, and concerted efforts should be undertaken to make Industrial Symbiosis clusters easier to implement and maintain.
2. **Create national, collaborative public sector research institutions operating as a commercial business with industry and academia.** To incentivise partnerships and commercialisation and support early-stage research scale-up, plus the added benefits of employment opportunities and revenue generation. A repeated concern during the workshops was the difficulty in accessing financial and material resources to scale university-level research to commercial readiness, particularly within the biotechnology sector. Shared facilities would help to spread the costs burden and lower the barrier to entry into the market for viable technologies.
3. **Support novel technologies and early-stage research through all TRL levels to de-risk investment opportunities.** Greater access to financial support and resources to assess and minimise risk in building demonstrator units should enable quicker scale-up and growth. The TRL 'Valley of Death' refers to TRLs 4 – 7 where neither the public or private sector prioritises investment.[15] Consequently, many promising technologies end their commercialisation journey here. Support is available for TRLs 1-3 in the early stage and at TRLs 8-9 approaching commercialisation, but more effort is needed to ridge this gap. By not support this middle sector, there is a risk of effectively pushing technologies off a cliff into the 'valley of death'.

   Investments and support need to reorganised into **fewer pots of larger amounts of money** to prioritise investment into the most promising technologies that will have the greatest impact. Attempting to fund everything is not possible and difficult decisions will need to be made.

4. **CCU must be prioritised over CCS.** CCS options are akin to landfilling, an option which must be minimised as far as possible according to the waste hierarchy.[16] Current infrastructure is not only under-developed to enable CCS, but transport and logistical considerations need to be taken into consideration. CCU can be revenue generating and give rise to economic growth and jobs creation. A longer-term vision for CCU must be realised with investment in infrastructure. Where carbon obtained from CCU is to be used as a feedstock (for example in Industrial Symbiosis Clusters), waste regulations and transporting permits will need adapting to suit these requirements.

   Large-scale CO_2 utilisation offers great potential to fundamentally change the chemical sector. It could change not only the way that fossil resources, feedstocks and renewable energy sources are used, but also lead to the creation of new markets, products and value chains.[17]

   Nonetheless, CCU is not a catch-all solution to solving emissions mitigation issues – this is a common misconception. The reduction of emissions should be pursued in the first instance ahead of mitigation of emissions, of which CCU technologies are one of several solutions, in accordance with the waste hierarchy principles. The mitigation potential of carbon capture technologies is estimated to be one order of magnitude smaller than current levels of CO2 emissions.[18]

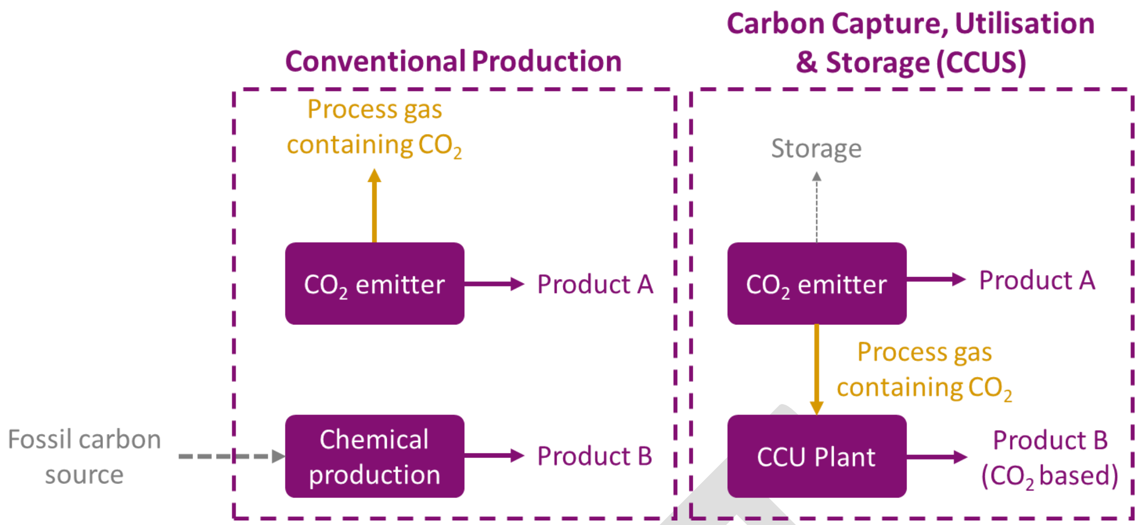
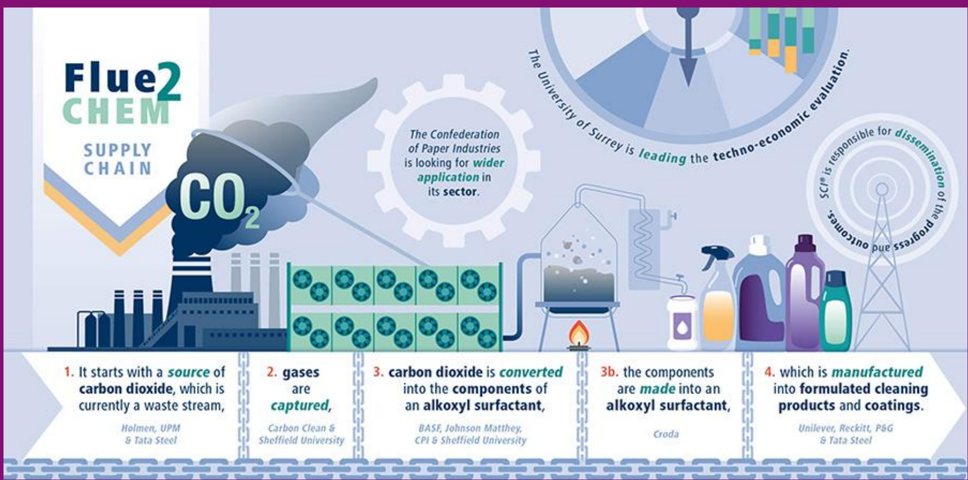


Figure 7: Conventional production (left) of products from fossil carbon sources results in significant CO_2 emissions released to the atmosphere. Employing carbon capture utilisation and storage (CCUS) (right) captures CO_2-containing process gases to replace fossil carbon sources for further product creation.[2]

Case Study: *Flue2Chem*

The *Flue2Chem* Project is a £5.4m, two-year programme spearheaded by Unilever and SCI, with 13 further organisations involved, representing the full supply chain from resource extraction to consumer product. With funding from Innovate UK, via the UK Research and Innovation (UKRI) Transforming Foundation Industries Challenge, the partners aim to take waste gas from foundation industries such as metal, glass, paper and chemicals, and generate an alternative source of carbon for UK consumer products – one not obtained from fossil fuel extraction.



Cardon dioxide is first captured before conversion into a surfactant, the key ingredient in many cleaning products. This surfactant is passed further along the supply chain for formulation into a detergent, ultimately aiming for sale to consumers.

This novel approach clearly demonstrates the importance of involving the entire supply chain in transforming current and established modes of operation. Change is possible, and necessary.

More funding for similar projects, extending beyond the chemical sector, are urgently needed for a complete and sustainable overhaul of our industrial sectors.

Financial and Fiscal

1. **Carbon taxes should be of a sufficient scale to actively disincentivise poor behaviour not simply act as a punitive charge.** Anecdotal evidence was heard of companies accepting carbon taxes as a reasonable cost of business as they were cheaper and easier than altering business practices. Furthermore, the carbon emission efficiencies should be considered with only the actual carbon savings subsidised – see **Box 1**.

Box 1 – Carbon Emission Efficiencies

Carbon emission efficiency refers to the economic benefits of production activities that simultaneously emit carbon, such as carbon capture operations. The fewer carbon emissions generated per unit of production output; the more carbon emission efficient the process is.

In this context, the subsidy incentive for CCU/S activities should not be for the total amount of carbon captured, but rather taking the efficiency of the process into account. For example, if a particular process captures 10 tonnes of CO_2, but 9 tonnes of CO_2 are emitted doing so, then the efficiency is just 1 tonne and, therefore, any subsidy should only apply to this 1 tonne (and not the full 10 tonnes).

Adopting this approach would correct incentives towards driving process efficiencies and carbon capture *with value-added purpose*.

Consider the case of biofuels and recycled carbon-derived fuels. CCU from waste gases requires power displacement when conducting an LCA, which could be 'dirty' and also have limited indirect emissions (accounted for), while biofuels indirect emissions are not accounted for (under the EU Renewable Energy Directive[19]) but could be significant. Therefore, producing goods in locations with 'dirty' grids is unattractive. As the grid gets 'cleaner', the LCA improves (providing argument for a stage gated threshold, if necessary) but consequently, there is no incentive to move away from burning gas for power, despite the availability of carbon-free power.

There is a further implication regarding the setting of thresholds for GHG emissions savings. For CCU, this would be less stringent with fewer indirect emissions, while for biofuels it would be higher. As a result, there is real risk of continuing with fossil-derived power and CCU recycled carbon fuels as obligations would be lower for emissions savings.

2. **Greater appreciation of the value of the chemical industry** from an economic and political perspective. The figures given in the introduction help in some way to convey the value of the chemical industry from an economic perspective. Nonetheless, the valley from a societal perspective is enormous yet often under-appreciated. Chemicals have received a bad reputation, fuelled partly by media coverage of the harmful and sometimes toxic effects of chemicals. To put simply – everything is made from chemicals.
3. **Oil and gas tax relief refocussed towards re-skilling and training.** Disincentivising current business as usual approaches whilst concurrently promoting more sustainable practices will be required. By engaging a phased transition of oil and gas tax relief incentives towards green sector jobs and training, minimal job losses and continued growth are possible - see **Box 2.** Nevertheless, this is contingent on the new, circular

chemical industry sector being established and 'taking over' the market - in part this will be fulfilled by longer term ROI and the green skills that are trained.

Box 2 – Reallocation of Incentives Through Tax Relief for Oil and Gas

The UK oil and gas sector employs over 200,000 people[4] and incentives through tax relief have been a part of ensuring continued job retention and economic growth. Opponents of phasing out oil and gas extraction often cite job losses as a reason not to do so. A phased reallocation of such incentives will help to address this concern by ensuring minimal job losses through re-skilling and re-training. Many current oil and gas sector employees possess the necessary skills and expertise to transition to green sector jobs with the correct retraining and education.

By way of an example, assuming an annual tax relief of £11 billion:

- Year 1: £10 billion to oil and gas; £1 billion to green sector/retraining
- Year 2: £9 billion to oil and gas; £2 billion to green sector/retraining
    - Continuing until no oil and gas subsidies are present:
- Year 11: £11 billion to green sector/retraining

4. **Additional support for investment opportunities.** Investment funding guarantees should be offered more frequently and include a requirement of independent investment review to de-risk and boost investor confidence. Public equity, private funds and wider debt and equity instruments are needed to develop and scale CE interventions and technologies.[9] As highlighted previously, investor risk-aversion is compounded by a lack of understanding of the technologies and broader sector requirements. An independent body, capable of bridging the knowledge gap between finance, science and technology, was suggested as a means of boosting confidence.
5. **A stronger and clearer carbon credit framework** will help to incentivise further emissions reductions and the CE transition. The current framework is weak, unclear and insufficient to incentivise the net-zero transition. It was highlighted as an example that solar industry growth is greatest when oil prices surge. Energy decarbonisation and

subsidisation of sustainable renewable sources of carbon should be incentivised more strongly to create revenue generation opportunities in greener sectors, with a progressive tax on fossil carbon as a disincentive to business as usual. Carbon offsetting is permitted greenwashing and should not be encouraged. Furthermore, voluntary uptake is slow and insufficient, necessitating policies that enable and enforce mandatory implementation.

General

1. **Recognise the value of typical waste products, such as carbon dioxide.** Current 'waste' streams contain valuable resources and feedstocks for many chemical industries, helping to reduce environmental damage and boost economic growth. Using feedstocks classified as waste streams is complicated by permitting regulations surround transport and disposal options. Collaboration between government departments would help to address this.
2. **Adopt a unified industrial strategy for a CE transition.** Government departments need to develop a robust, unified, cross-cutting intra-departmental strategy, with industry collaboration, that looks to the longer-term future. The objectives and boundary conditions should be determined within this strategy with enough flexibility to allow industry and academia to innovate towards the goals themselves.
3. **Refocus the current biomass strategy on value extraction before fuel generation.** Valuable commodities and chemical compounds should be extracted first before any remainder is turned into biofuel, thus generating new revenue streams and jobs. We need alternative sources of carbon that are not derived from fossil fuels with biomass presenting one of several potentials.
4. **Implement a standardised Life Cycle Assessment (LCA) framework** to assist in determining the degree of risk for investment, but current approaches do not fully consider the whole system and related boundaries. Too often, LCAs are manipulated to give a desired outcome or full boundary conditions or environmental impacts are not considered. It is important not to adopt a carbon tunnel vision and neglect other metrics of sustainability.[6] Standardised frameworks and guidelines would enable better comparisons between technologies and selection of the most environmentally beneficial option.
5. **Embrace longer-term thinking to achieve positive impact.** Sustainable initiatives typically require longer investment and return periods to have measurable impact. A hyper-focus on short-term, high return technologies is unsustainable and hindering progress.

Chapter 4

Conclusions and Policy Priorities

Conclusions

Moving to a circular economy is imperative not only for environmental reasons. It has potential for wide-ranging economic and societal benefits, giving the UK the capacity to grow and thrive, create green jobs, upskill the workforce, increase self-sufficiency by reducing import reliance, improve infrastructure and provide a brighter outlook for future generations.

By engaging with senior stakeholders from academia, industry, NGOs and government, we have identified the key challenges and opportunities in transitioning the UK chemical sector towards a circular economy. These challenges and opportunities are wide-ranging but can be classified into general, technology and financial. Additionally, these recommendations have shaped a number of key recommendations across the same themes and culminated in three policy priorities for this new chapter of government:

1 A unified, long-term, forward-looking industrial strategy for the chemical sector

2 Leverage more public and private finance to rapidly scale-up university research to commercial readiness

3 Short-term fiscal support for an accelerated deployment followed by transitional oil and gas tax relief incentives towards green sector jobs and training

The scale of this challenge is vast, but surmountable with dedicated perseverance and collaborative efforts towards a common goal.

Glossary

CCS	Carbon Capture & Storage
CCU	Carbon Capture & Utilisation
CCUS	Carbon Capture, Utilisation & Storage
CO_2	Carbon Dioxide
GHG	Greenhouse gas
H_2	Hydrogen
IP	Intellectual Property
ROI	Return on Investment
SAF	Sustainable Aviation Fuel
tCO_2	Tonnes of CO2

Carbon Border Adjustment Mechanism (CBAM): A policy that aims to ensure that carbon-intensive imported goods are subject to a carbon price that is similar to that of equivalent domestic production.

Carbon Dioxide Reduction (CDR): Technologies and processes that reduce atmospheric levels of carbon dioxide. Also refers to chemical processes that transform carbon dioxide into other chemicals, such as carbon monoxide and methane.

Circular Economy (CE): A system in which resources are kept circulating for as long as possible, through efficient material use, reuse and recycling loops. It is an alternative to the linear economy in which materials are made, used and disposed.

CO_2 equivalent: A metric used to compare the global warming potential (GWP) of different greenhouse gases.

Demonstrator units: Small pre-commercial units that show proof of concept at suitable scale.

Direct Air Capture (DAC): Technologies that extract carbon dioxide directly from the atmosphere, as opposed to point source capture.

Downstream: For petroleum refining, refers to processes that produce finished products for consumers.

Enhanced Oil Recovery (EOR): The practice of extracting oil from a well that has already undergone primary and secondary extraction processes. Carbon dioxide can be injected into oil wells, increasing the pressure and increasing extracted oil.

Ethylene: A colourless gas consisting of 2 carbon atoms and 4 hydrogen atoms with global production exceeding that of any other hydrocarbon.

Hydrocarbon: A chemical compound consisting solely of carbon and hydrogen atoms.

Industrial Symbiosis: A practice where companies and industrial facilities, both within or across sectors, exchange waste and by-products to create mutual benefit.

Indirect Emissions: Emissions resulting from organisational activities but actually emitted from sources owned by other entities.

Investment Funding Guarantees: Provides assurance to stakeholders (investors, lenders, and project owners) that all obligations related to an investment will be fulfilled. They serve as instruments to secure funding, protect the project against potential losses in the event of non-performance.

Life Cycle Assessment (LCA): A process of evaluating the effects that a product has on the environment over the entire period of its life thereby increasing resource-use efficiency and decreasing liabilities.

Naphtha: A general term applied to petroleum products distilled from crude oil at temperatures less than 240 °C.

Olefins: Unsaturated hydrocarbons consisting of at least one carbon-carbon double bond.

Point Source Capture: Technologies that extract carbon dioxide from single, highly carbon-emitting sources such as flue stacks.

Propylene: A colourless gas with a slight petroleum odour, consisting of 3 carbon atoms and 6 hydrogen atoms. Also known as propene, a common use is in the formation of the plastic polypropylene (PP).

Steam Cracking: The primary method of producing ethylene and propylene from petroleum sources. A hydrocarbon feed is heated to around 850 °C in the presence of steam.

Upstream: For petroleum refining, refers to exploration, drilling and extraction activities.

Scan to learn more

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