Slow Reactions

Chemical companies must transform in a low-carbon world

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Executive summary

Chemicals can and need to become emissions free

It is technically feasible to fully decarbonise the production of chemicals by 2050, and it is becoming increasingly economically viable.

The costs of delaying the transition are rising. As the costs from the European Union Emission Trading System are forecast to quadruple by 2030[1] for the chemical industry, it faces significant risks if it does not become emissions free by the middle of the century.

However, there is a positive outlook in terms of end-market demand. Producing emissions-free chemicals has only a very marginal effect on the price of the end products. For example, producing plastic bottles with emissions-free chemicals would only be expected to increase the price of those bottles by 1 percent[2]. The transition also offers up a host of new opportunities for the sector, such as in ammonia for shipping.

The technologies for decarbonisation exist. Through green hydrogen and electrification, chemical companies can produce emissions-free chemicals, thereby avoiding the risks and harnessing the opportunities arising from the transition. As renewables and green hydrogen will come to undercut the cost of their fossil counterparts by 2030[3], the transition is becoming increasingly economically viable.

But the transition requires action beyond just chemical production. Fertilisers and plastics are key end products of the chemical industry, so chemical companies must also target their Scope 3 emissions as part of their decarbonisation strategies.

The industry has high emissions but has taken little action

Over 95 percent of manufactured products rely on chemicals[4]. Consequently, the sector is responsible for over 5.8 percent of global greenhouse gas (GHG) emissions[5]. As part of the European Union's aim of carbon neutrality, the European chemical sector has committed to net zero emissions by 2050[6].

Yet credible transition plans in the sector remain scarce, with only two out of the 21 Stoxx Europe 600 Chemicals companies having a Science Based Targets initiative (SBTi)-approved 1.5C target[7]. This report focuses on the seven primary chemicals responsible for over two-thirds of the sector's energy use[8]. Moving their production to zero emissions is the first port of call for the industry to take action on their commitment, and for investors to have 1.5C-aligned portfolios.

The chemicals are: ammonia, methanol, ethylene, propylene, benzene, toluene and xylene. We know these chemicals as "petrochemicals".

Their emissions stem from using fossil fuels in roughly equal parts (50/50) as[9]:

- "Feedstock", where fossil fuels are an input into the chemical reactions, with emissions resulting from these reactions. Emissions are also embodied in the end product (such as a plastic bottle or fertiliser). These end product (Scope 3) emissions are released further down the value chain, when a bottle is burned for example.
- Energy consumption, where fossil fuels are used to produce heat, steam and power for compression, cooling and other processes. Emissions are caused as fossil fuels are burned for energy needs.

Getting to net zero requires decarbonising energy use and chemical inputs

The chemical industry needs to transition away from fossil fuels for both energy and feedstock needs. There are existing technologies and processes that allow for this transition. All of the potential pathways to decarbonise share the need to:

- electrify energy processes using only renewable energy
- replace fossil feedstock with green hydrogen or green methanol.

For ammonia and methanol production, producers must replace fossil fuel feedstock with green hydrogen and electrify their processes to use only renewable energy. For aromatics (benzene, toluene, and xylene) and olefins (ethylene, propylene), fossil fuel feedstock needs to be replaced with "green" methanol (produced via green hydrogen and electrification) which then undergoes methanol-to-olefin or methanol-to-aromatics processes.

The CO_2 required for the chemical structure of methanol, aromatics and olefins must have been captured elsewhere for these primary chemicals to be truly carbon neutral.

Scope 3 emissions cannot be ignored either

Changing production processes to become emissions free does not fully eliminate the GHG footprint of the chemical industry because of its significant Scope 3 emissions (see "A complex sector — what is the scope of this report?" for more on these emissions).

In the case of ammonia, fertilisers embody significant amounts of GHG emissions (~40 percent)[10] which are set free when it is used. This needs to be mitigated through changes in farming practices and adjustments to the design of the fertiliser end product. Ultimately, we need to reduce overall fertiliser usage.

In the case of the other chemicals, they are the key inputs for plastic production. To reduce emissions and pollution from plastics, we need a closed-loop recycling system that ensures continuous circularity of plastic. Re-using and mechanical recycling need to be at the forefront, but the chemical industry can also play a role in “chemical recycling”, which refers to the use of existing plastic as feedstock for new plastic.

Chemical companies need to mitigate the significant Scope 3 emissions from fertilisers and plastics. The industry can also act as an enabler to decarbonise the wider economy. For example, emissions-free ammonia can be used as a green fuel in industries such as shipping and aviation.

False solutions distract the industry from clear emissions-neutral pathways

The current solutions outlined by industry actors fail to hit the mark.

Blue hydrogen (using natural gas with carbon capture) is advocated for but has been shown to be higher in emissions and costs than green hydrogen. Upstream natural gas emissions are ignored, as are studies such as that by Bloomberg New Energy Finance showing that green hydrogen will be cheaper than blue hydrogen by 2030[11]. To avoid locking in emissions, infrastructure and costs, the chemical industry needs to orientate itself towards green hydrogen.

The continued use of fossil fuel feedstocks with carbon capture and storage (CCS) suffers the same drawbacks: higher emissions and higher costs, compared to the green hydrogen and renewable electrification route. There is a risk the chemical industry could lock in assets with higher emissions and expose itself to stranded assets.

Biomass is limited as a solution for decarbonisation. Biomass can have worse climate impacts than coal at combustion, faces significant land constraints and represents a high opportunity cost where a low carbon-intensity crop is used to cover soil instead of high carbon-intensity forests[12]. It is unlikely to be a sustainable source for chemical production processes.

Green hydrogen and electrification with renewable energy represent a truly emission-neutral decarbonisation pathway. With the technical and economic potential of renewable energy far exceeding any known fossil fuel reserves — and exceeding estimated energy demand in 2050 by over 100 times[13] — it is likely to be the most economical pathway too. Increasing carbon prices are only supporting that equation.

Real industry challenges

The chemical industry is likely to need support to decarbonise. It will need abundant and cheap renewable energy, an international level playing field, significant investments and changes to the way end products are used.

The chemical industry, policy makers and the investment community all have a role to play in this.

What should investors do?

Investors should engage with the chemical companies in their portfolio on the standards set out in this report to ensure their portfolio is braced for the risks and opportunities arising from the transition.

Recommendations to investors

Below we give guidance to investors on how to engage with chemical companies on achieving net zero emissions by 2050. We also provide a tangible outcome ("Tracking outcome") that investors can use to measure company performance and the success of engagements over time, and to take appropriate action.

Investors can use the following questions and tracking outcomes in their engagements with chemical companies involved in the production of ammonia, methanol, ethylene, propylene, benzene, toluene, and xylene, as well as fertilisers and plastics. They can also be used for companies that buy these primary chemicals to assess their procurement strategy and the demand signal they send. ShareAction has created a shortlist of such companies, which are referenced at the end of this section. The list can also be found in the Annex for easier reference at the end of the report.

Engagement questions

Ammonia and methanol

Does the company have a credible plan to replace fossil fuel feedstocks with emissions-free alternatives such as green hydrogen by 2050 at the latest?

Tracking outcome: The company has a credible plan to replace all feedstock with emissions-free alternatives such as green hydrogen (produced with 100 percent renewable energy). It does not intend to use blue hydrogen as a solution. It does not intend to use biomass as feedstock, or fossil fuels with carbon capture as a mitigation technology.

Does the company have a credible plan to use 100 percent renewable energy for energy needs (steam, heat, compression, cooling etc.) by 2050 at the latest?

Tracking outcome: The company has a credible plan to electrify all new and existing processes and switch to 100 percent renewable energy. Ideally, it cements such a commitment by joining the RE100 initiative[i] or similar initiatives.

Where CO_2 is needed, does the company have a credible plan to ensure this CO_2 is carbon neutral by 2050 at the latest?

Tracking outcome: The company is committed to the procurement of captured CO_2 to ensure the overall neutrality of its use as an input for its chemical products. It discloses the source of CO_2 and how its neutrality is ensured throughout its life cycle.

i https://www.there100.org/

High-value chemicals (HVCs)

Does the company have a credible plan to replace current production processes for high-value chemicals with net zero emission processes, such as methanol-to-olefins (MTO) and methanol-to-aromatics (MTA), by 2050 at the latest?

Tracking outcome: The company has a credible plan to change production for HVCs to processes such as MTO and MTA, using green methanol (produced via green hydrogen and electrification) as feedstock. It does not propose solutions centred on blue hydrogen, biomass or fossil fuels with carbon capture.

Does the company have a credible plan to use 100 percent renewable energy for energy needs (e.g. for the MTO/MTA processes and any other energy consumption), by 2050 at the latest?

Tracking outcome: The company has a credible plan to electrify all new and existing processes and switch to 100 percent renewable energy. Ideally, it cements such a commitment by joining the RE100 initiative[ii] or similar initiatives.

ii https://www.there100.org/

End products and Scope 3

Does the company have a credible strategy to mitigate all its Scope 3 emissions by 2050 at the latest?

Tracking outcome: The company discloses all sources of Scope 3 emissions and has a credible strategy to mitigate each source. For fertilisers and plastic, please see some more detailed questions below.

Where the company is involved in the value chain for fertilisers (e.g. producing primary chemicals such as ammonia, or being a direct fertiliser producer), does the company have credible plans to mitigate emissions at all stages of the product's life cycle by 2050 at the latest?

Tracking outcome: The company ensures the production of chemicals needed for fertilisers is emissions free and switches its portfolio to fertilisers with inhibitors (see fertiliser section of this report for more information). The company has a credible strategy to mitigate emissions for fertilisers by working with stakeholders to improve fertiliser application.

Where the company is involved in the value chain for plastics (e.g. producing primary chemicals such as methanol and HVCs, or being a direct plastic producer), does the company have credible plans to mitigate emissions at all stages of the product's life cycle by 2050 at the latest?

Tracking outcome: The company has a plan for all new production of plastics, including relevant primary chemicals, to be emission free (e.g. as per the processes outlined in this report for methanol and HVCs). The company also engages with stakeholders to ensure a circular value chain for its products with a focus on re-use and recycling. If re-use and mechanical recycling options have been exhausted, the company is looking into developing emissions-free chemical recycling options (chemical recycling should not supersede other recycling investments). The company is not involved in bio-plastics.

Supporting recommendations

Does the company use an internal carbon price to assess existing and future projects?

Tracking outcome: The company uses a regional carbon price that is aligned with the scientific recommendations for the IPCC 1.5C limited-to-no overshoot scenarios. The company uses the carbon price to assess existing and future projects. The company makes outputs from the analysis publicly available alongside a description of assumptions.

Investors are further encouraged to ask questions aligned with the CA100+ benchmark[xiii].

iii https://www.climateaction100.org/wp-content/uploads/2021/03/Climate-Action-100-Benchmark-Indicators-FINAL-3.12.pdf

Potential target companies

This research applies to **all chemical companies involved in the production or procurement of the chemicals outlined in this report and their end products**. This includes indices of chemical companies (e.g. the Stoxx Europe 600 Chemicals index).

ShareAction has created a shortlist of European targets based on their market capitalization and footprint in the chemicals and end products covered in this report.

Table 1: List of European chemical company targets

Company name	Country	Ammonia	Methanol	Light olefins	BTX	Plastics/ polymers	Fertiliser
BASF SE	Germany		x	x	x	x	
Covestro AG	Germany			x	x	x	
Croda International plc	UK					x	x
EMS Chemie Holdings AG	Switzerland			x	x	x	
Evonik Industries AG	Germany			x	x	x	
Koninklijke DSM N.V.	Netherlands					x	
L'Air Liquide S.A.	France	x	x	x	x		
Lanxess AG	Germany	x		x	x	x	
LyondellBasell	Netherlands		x	x	x	x	
Givaudan SA	Switzerland				x		
Solvay SA	Belgium	x	x	x	x	x	x
Yara International ASA	Norway	x					x
Symrise AG	Germany		x	x	x		

Introduction

Why is decarbonising chemicals important?

The sector has high emissions, but the EU has committed to net zero by 2050

We could not live in a world without chemicals. They are part of everyday products in and outside our homes[14], with over 95 percent of manufactured products relying on them[15]. It is therefore unsurprising that the chemical and petrochemical sector is responsible for over 5.8 percent of global GHG emissions[16].

To limit global warming to 1.5C, global GHG emissions need to reach net zero by 2050[17]. The European Union has committed to a 55 percent decrease in emissions by 2030 and net zero emissions by 2050 in response[18].

The European chemical industry is responsible for about 16.7 percent of global chemical sales[19], and therefore has a key role to play in decarbonising the sector as a whole. As part of the European Union's commitment to carbon neutrality, the European chemical sector has also committed to net zero by 2050[20].

There is little corporate action, putting investors at risk

Credible transition plans in the sector remain scarce, with only two out of the 21 Stoxx Europe 600 Chemical companies having an SBTi approved 1.5C target[21].

As the EU is taking steps to reach net zero by 2050, chemical companies might be caught unprepared. As will investors with chemical holdings.

The costs from the European Union Emission Trading System are forecast to quadruple by 2030[22] for the chemical industry. This would come with a bill of 1.5 billion euros in 2021 alone.

This can be avoided. The technologies for decarbonisation exist.

Through green hydrogen and electrification, chemical companies can produce emissions-free chemicals. And as renewables and green hydrogen will come to undercut the cost of their fossil counterparts by 2030[23], the transition is becoming increasingly economically viable.

There are also opportunities that can be harnessed. For example, CO_2-free ammonia offers a possible solution to the shipping and aviation industries as they look to replace fossil fuels in a zero-emissions world.

What can investors do?

Engaging with chemical companies today can help industry and investment portfolios prepare for the transition.

This report sets out how the chemical industry can reach zero emissions by the middle of the century. The engagement guidance, coupled with the information in this report, is designed to support investors in their conversations with companies to reach this goal.

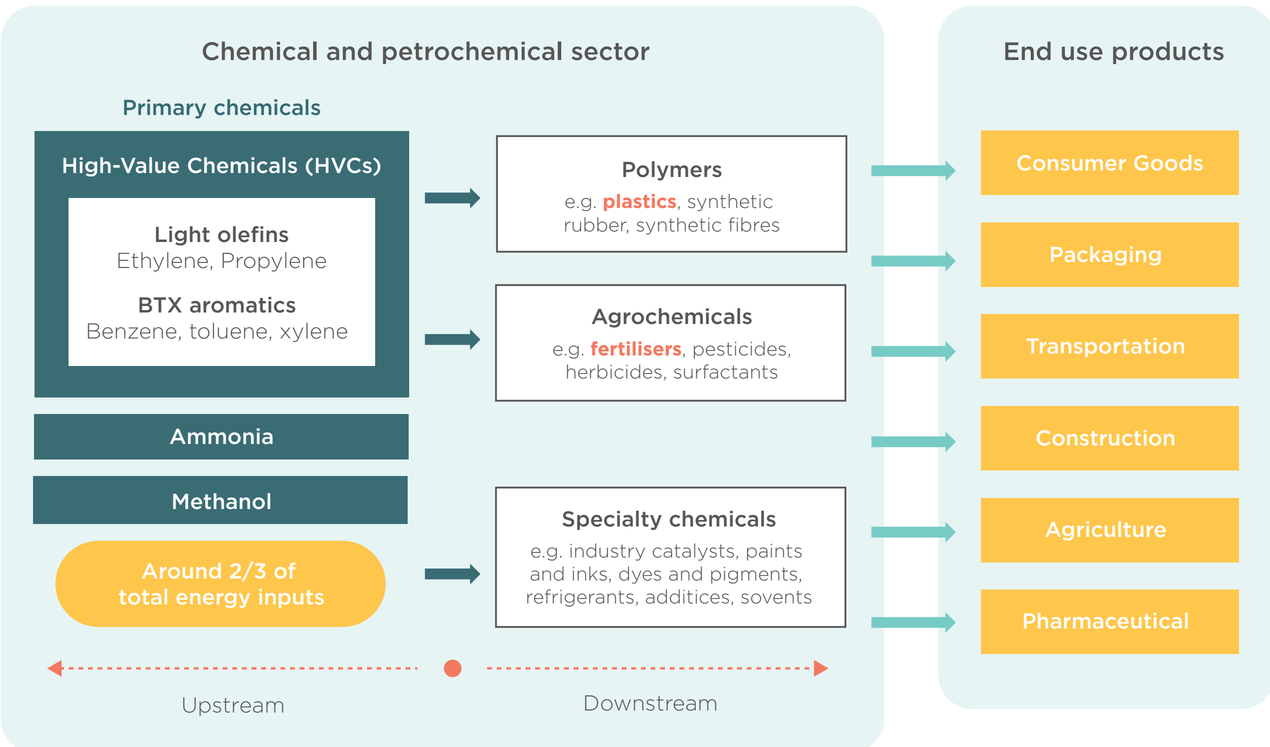
A complex sector — what is the scope of this report?

Understanding the decarbonisation pathway of the sector is made harder by its complexity. There are hundreds of different chemical processes that are needed to manufacture thousands of different products[24].

For the sake of this report, we will focus on the seven primary chemicals responsible for over two-thirds of the sector's energy use, as well as two of their key end products; namely plastics and fertilisers[25]. This means that while the chemical sector encompasses a wider range of chemicals, we focus only on petrochemicals in this report.

Petrochemicals can be defined as chemicals that are derived from petroleum — in other words, oil and gas[26]. They are depicted in Figure 1 below.

Figure 1: Seven focus chemicals and two focus end products (in bold)



Source: IEA, 2018

Where do emissions come from?

Despite being the largest industrial consumer of oil and gas, the chemical industry's direct CO2 emissions are lower than those of other industrial sectors, such as steel. This is because the petrochemical sector consumes fossil fuels both to generate energy in the manufacturing process, but also as "feedstock"[27].

Definition[28]: Energy consumption and feedstock

Energy consumption: As in many other industries, such as the steel and cement industries, fossil fuels are often used to produce energy and heat for the process of transforming input materials to output materials. They are used for steam and heat creation, or as power to run compression, cooling and other processes. They can be burned on site or purchased as energy from utility companies, depending on the relevant part of the process.

Feedstock: About half of the chemical sector's oil and gas demand is for feedstock[29]. Feedstock is when fossil fuels enter the chemical process not to produce heat or energy, but as a component of the chemical produced. As an analogy, timber could be burnt to produce energy or heat (akin to energy consumption), but it could also be used as a construction material for buildings (akin to feedstock). Emissions are released from fossil fuel feedstock both during the chemical reaction and as Scope 3 emissions (see below).

Figure 2: Energy needs and emissions proxy for petrochemicals

Source: ShareAction, 2021

Breaking emissions down by scopes helps explain how feedstock and energy consumption are linked to the chemical industry's carbon footprint.

Scope 1 – direct emissions from owned or controlled resources:

In the chemical sector, Scope 1 emissions come from the combustion of fossil fuels on site for energy and heat used in production processes ("energy consumption")[30] and the emissions released from fossil feedstock during the chemical reactions.

Scope 2 – indirect emissions from purchased electricity and heat:

As with most other industries, Scope 2 emissions in the chemical sectors come from the energy purchased to run their production facilities ("energy consumption"). As the sector decarbonises, many processes will need to be electrified (e.g. through heat pumps or electric furnaces that require electricity instead of direct fossil fuel combustion as with traditional furnaces), meaning that Scope 2 emissions will likely rise as Scope 1 emissions fall[31].

Scope 3 – indirect emissions further up or down the value chain:

The chemical industry is in a special position when it comes to Scope 3 emissions. This is down to two main reasons:

A) Fossil fuel feedstock[32] which enters the physical makeup of the end products of the chemical industry, such as plastics and synthetic fibre.

In this case, the carbon is embodied in the product. Plastic and chemical waste often ends up being incinerated instead of being sent to landfill (which also poses its own environmental problems, such as plastic pollution), at which stage the CO_2 embodied in these products as feedstock is released.

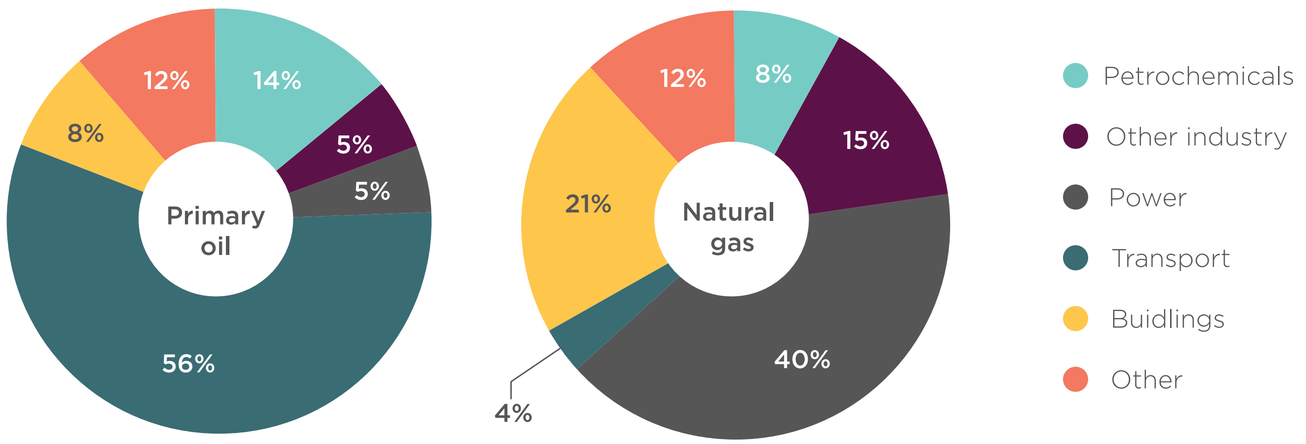
Using natural gas as chemical feedstock also releases Scope 3 emissions further up the value chain because of methane leaks, for example in gas pipes.

B) Nitrogen fertilisers which are a key end product for the chemical industry.

As described in more detail in the "Ammonia" section of this report, the production of nitrogen-based fertilisers involves both CO_2 and nitrogen oxide (a powerful greenhouse gas), which are released when applied to the field by farmers.

This combined demand for oil and gas — as both feedstock and for energy consumption — makes the petrochemical industry the second largest driver of oil demand and the fourth largest driver of gas demand globally (Figure 3)[33]. For the chemical industry, a transition to net zero emissions means a transition away from oil and gas.

Figure 3: Chemicals as a driver of oil and gas demand



Note: Petrochemicals includes process energy and feedstock

Source: IEA, 2018

Why does changing the production of these seven chemicals get us to net zero by 2050?

By making the production process of these chemicals emission free, we can target the vast majority of emissions from the sector. Due to the heterogeneity of the sector, exact emission data is hard to get, but we know that these seven chemicals are responsible for about 66 percent of the sector's energy demand. This translates into emissions across Scopes 1 to 3.

We can eliminate Scope 1 and 2 emissions entirely by changing the production of these chemicals, ensuring no emissions are released from feedstock during chemical reactions, or from energy consumption for heat, steam, compression and other processes.

As we eliminate fossil fuel feedstocks, emissions further up and down the value chain are reduced to zero, eliminating Scope 3 emissions. Further up, emissions from fossil fuels — such as methane leaks in the natural gas value chain — are eliminated. Further down, emissions from plastics and other end products — such as synthetic fibres, paints, adhesives, beauty products and similar — are eliminated as the replacement feedstock is emission neutral. In other words, there are no emissions embodied in the product that can be released during use.

The exception to this are nitrogen fertilisers, which contain nitrogen oxide as part of their chemical makeup. There are further steps needed down the value chain to mitigate those emissions, irrespective of the emissions-neutral production of ammonia.

However, just because we can produce emissions-neutral petrochemicals does not mean it is always the best solution. Where plastic forms a key end product of a petrochemical, re-use and recycling are less resource intensive than the creation of new plastics and have other environmental benefits. Decarbonisation pathways for petrochemicals must work in conjunction with circularity considerations.

Decarbonisation pathways

Quick read: Summary of all chemicals

The full decarbonisation of the production processes for the chemicals covered in this report is technologically feasible and becoming increasingly economically viable. This summary provides a quick read of the findings from the technical sections of this report. Unlike the extended sections, it does not outline and compare current and zero-emissions production processes or the sources of emissions (including Scope 3).

1. Ammonia and 2. Methanol

For ammonia and methanol, the basic approach is to replace fossil fuel feedstocks with "green" hydrogen produced by 100 percent renewable energy, making the feedstock emissions free. For energy consumption, the electrification of processes with renewable energy replaces the need for fossil fuel energy.

This combination of green hydrogen and electrification is the basic recipe for emission-free production.

In addition, methanol production requires CO_2 to provide the carbon atom in methanol's chemical structure. This can be captured elsewhere and then inserted into the production process to keep it overall carbon neutral. In this way, the chemical industry can even become a net importer of CO_2.

3. HVCs (ethylene, propylene, benzene, toluene, xylene)

The process for high-value chemicals (HVCs) requires an additional, intermediate step to become emissions free.

To move away from fossil fuel feedstock, green methanol (produced via green hydrogen and electrification, as above) is needed. This green methanol is then converted to the desired HVC through existing processes called methanol-to-olefins (MTO) and methanol-to-aromatics (MTA).

4. Decarbonising Scope 3

Changing chemical production processes to become emissions free does not fully eliminate the GHG footprint of the chemical industry. This is because of its significant value chain emissions for end products such as fertilisers and plastics.

In the case of ammonia, the use of fertilisers sets free significant GHG emissions (~40 percent of total emissions)[34], which need to be mitigated through changes in farming practices and adjustments to the design of the fertiliser end product. Ultimately, we need to reduce overall fertiliser usage.

Emissions-free ammonia can also be used as a green fuel in industries such as shipping and aviation, allowing the chemical industry to enable the decarbonisation of other industries.

The other chemicals covered are key inputs for plastic production. To reduce emissions and pollution from plastics, we need a closed-loop recycling system that ensures continuous circularity of plastic. Re-use and mechanical recycling need to be at the forefront, but the chemical industry can also play a role in "chemical recycling". Chemical recycling refers to the usage of existing plastic as feedstock for new plastic.

If the chemical industry takes all the steps outlined above, it can achieve emissions-free chemical production. It can also enable actors along its value chain and across other industries to decarbonise. The industry faces both opportunities from taking these steps and risks from ignoring or delaying them.

Ammonia

The current production processes for ammonia are a large source of CO_2. However, emissions-free alternatives are already technically feasible and available. A description of both processes — the current process and the emissions-neutral alternative — can be seen below.

Ammonia is the chemical with the second largest tonnage in the world[35]. It plays a big role in agriculture, with over 80 percent of all ammonia produced being used as some form of nitrogen fertiliser[36].

It should be noted that as ammonia is primarily used to produce fertilisers, further GHG emissions — both CO_2 and nitrogen oxide — are emitted at later stages of the value chain. Therefore, this report will go beyond the decarbonisation of the ammonia production process to encompass Scope 3 emissions in the section called "Reducing emissions from fertilisers".

Ammonia: Current production process[37,38]

The current production processes for ammonia (NH3) as a primary chemical release significant amounts of CO_2 (Figure 4)[39]. This CO_2 stems from two sources: fossil fuels as feedstock, and fossil fuels used for energy consumption. In Europe, ammonia plants mainly use natural gas as feedstock, however this does differ across the globe, with China heavily relying on coal, for example[40].

Step 1

In the first step of the ammonia production process, natural gas (as feedstock) is split into hydrogen and CO_2 with the help of steam (fossil fuels used for energy consumption), before undergoing further steps. This also results in the separation of nitrogen from the air as a side effect.

At this stage, CO_2 is released in a direct stream, with emissions from feedstock estimated to be around 1.33 t/tNH3. The CO_2 in this instance can be seen as a by-product of the hydrogen reformation from natural gas, with the hydrogen being required as a chemical building block for ammonia and the CO_2 as "waste" from the process.

Step 2

In the second step, the hydrogen reacts with nitrogen on an iron catalyst at a pressure of 150–350 bar and temperature of 350–550°C, and forms ammonia.

Sources of emissions

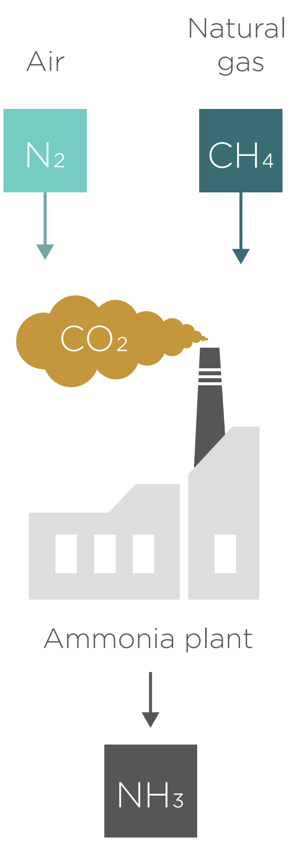
From the steps above, the sources of CO_2 from current ammonia production processes can be summarised as:

1. Energy consumption emissions
    - CO_2 from the fossil fuels used to produce heat for steam to split the natural gas
    - CO_2 from the fossil fuels used for energy to create the heat and pressure necessary for ammonia synthesis under Step 2 (and other steps not described in detail)

2. Feedstock emissions
    - CO_2 from using natural gas (or outside Europe, often coal) as a feedstock for the chemical reaction, where the CO_2 stream is a waste by-product of the process
    - Ammonia is also a building block for fertilisers, which leads to further CO_2 and N_2O (nitrogen oxide, a powerful greenhouse gas) emissions in Scope 3, as described in "Annex II: Reducing emissions from fertilisers"

CO_2 emissions for the whole process are estimated to be 1.82 t/tNH3, including the 1.33 t/tNH3 from the feedstock.

Figure 4[41]: Current ammonia production process



Source: fertilizers europe, 2020

Ammonia: Emissions-neutral production process[42]

New production methods and technologies can reduce emissions (with the exception of Scope 3 emissions) to zero. The main requirements (Figure 5) are the provision and usage of green hydrogen instead of natural gas as feedstock.

Definition[43]: Green hydrogen

Green hydrogen refers to hydrogen produced from 100 percent renewable energy.

Step 1

In the low-carbon production process, the steam and other reforming steps of natural gas to hydrogen can be omitted. As no CO_2 is needed for ammonia, the natural gas to hydrogen reformation can simply be replaced by the direct supply of green hydrogen to the process. This completely circumvents the CO_2 stream that would otherwise be emitted by the splitting of natural gas to hydrogen and CO_2 in the current process.

Therefore, CO_2 is saved as the feedstock is now green hydrogen, and as the production of steam to split natural gas can be omitted.

However, due to the lack of the other reformation steps (which in the current process result in a clear stream of nitrogen), an air separation unit is now required to separate nitrogen from the air. This is technically feasible for new and existing plants but must be run off 100 percent renewable energy to be emissions free.

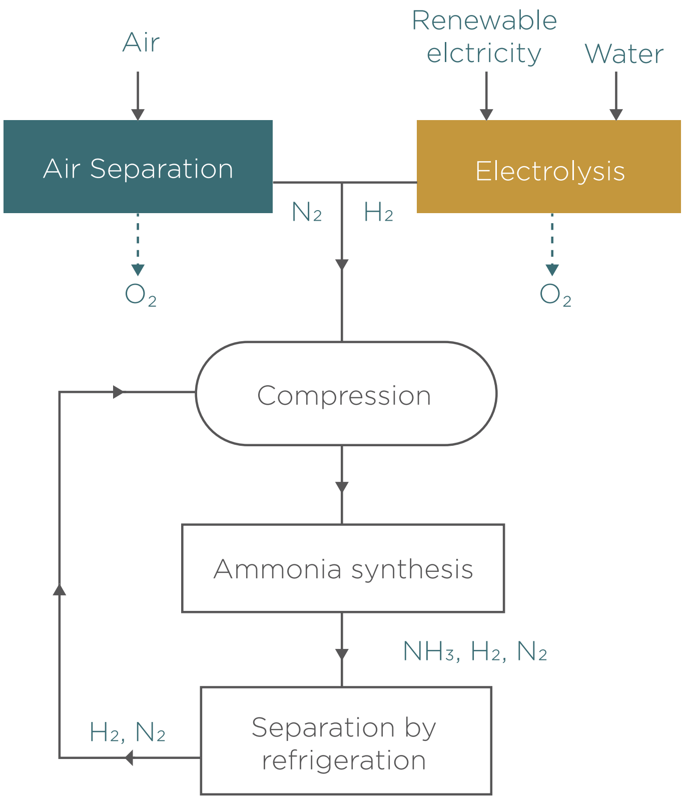
Step 2

In the second step, the nitrogen and hydrogen (from green hydrogen) need to be compressed and refrigerated for separation, which results in the required ammonia output.

Consequently, a compressor is needed both to compress nitrogen and hydrogen to the required 100-250 bar and for refrigeration. For this process to be carbon neutral, the energy required for the compressor needs to be zero carbon through the use of 100 percent renewable energy.

The production of ammonia in this way is seen as technically feasible and the integration of new or alternative production steps fairly straight forward according to DECHEMA[iv], an expert network of chemical engineering.

Figure 5: A low carbon ammonia production process[44]



Source: DECHEMA, 2017

iv https://dechema.de/en/

Mitigated emissions

From the steps above, the sources of emission mitigation compared to the current ammonia production processes can be summarised as:

1. Energy consumption emissions
    - There is no requirement for steam generation to split natural gas into CO_2 and hydrogen, eliminating energy consumption emissions at this stage completely
    - There is no requirement for high heat as there in with existing production methods, eliminating energy consumption emissions at this stage completely
    - New and existing processes — such as air separation, compression and refrigeration — can and need to be electrified and run off 100 percent renewable energy to be emissions free,

2. Feedstock emissions
    - The CO_2 "waste" from using natural gas as feedstock to create hydrogen for the chemical reaction is eliminated as CO_2-free green hydrogen is used directly

Non-Mitigated emissions

Making ammonia production emissions free is a critical first step to decarbonising the chemical industry. But the chemical is responsible for vast emissions of nitrogen oxide further downstream, with 40 percent of emissions being caused when fertilisers are applied to the field[45]. This nitrogen oxide cannot be mitigated in the production process. Annex II "Reducing emissions from fertilisers" at the end of the report describes this in more detail.

Methanol

Methanol is one of the highest volume chemicals in Europe[46]. It is mainly used to make other chemicals, such as formaldehyde (~40 percent of usage), which forms the basis of a variety of plastics, paints and textiles[47].

The largest use of methanol is in the plastics industry, but it goes beyond that. Methanol production is closely linked to plastics, meaning a discussion of its value chain decarbonisation cannot ignore the problem around plastic circularity. The section "Emissions reduction through plastic recycling" will dive deeper into this issue.

As with ammonia, the decarbonisation of methanol is heavily reliant on green hydrogen and the electrification of energy consumption.

Methanol: Current production process[48]

Step 1

As opposed to ammonia, methanol does require CO_2 or carbon monoxide (CO) as part of its chemical makeup. Hence, in the first steps of production, both hydrogen and CO/CO_2 are needed as inputs into the process.

In the conventional production process, as with ammonia, natural gas (or other fossil fuels, primarily outside Europe) is reformed to hydrogen and CO_2 with the help of steam. The CO_2 released in the reformation of natural gas to hydrogen is re-used for the methanol synthesis later. However, the chemical requires less CO_2 than is released at this stage, resulting in a stream of surplus CO_2.
At the end of this stage, a feed gas — which substitutes a mixture of hydrogen, CO_2 and CO — will be needed for the methanol synthesis under Step 2.

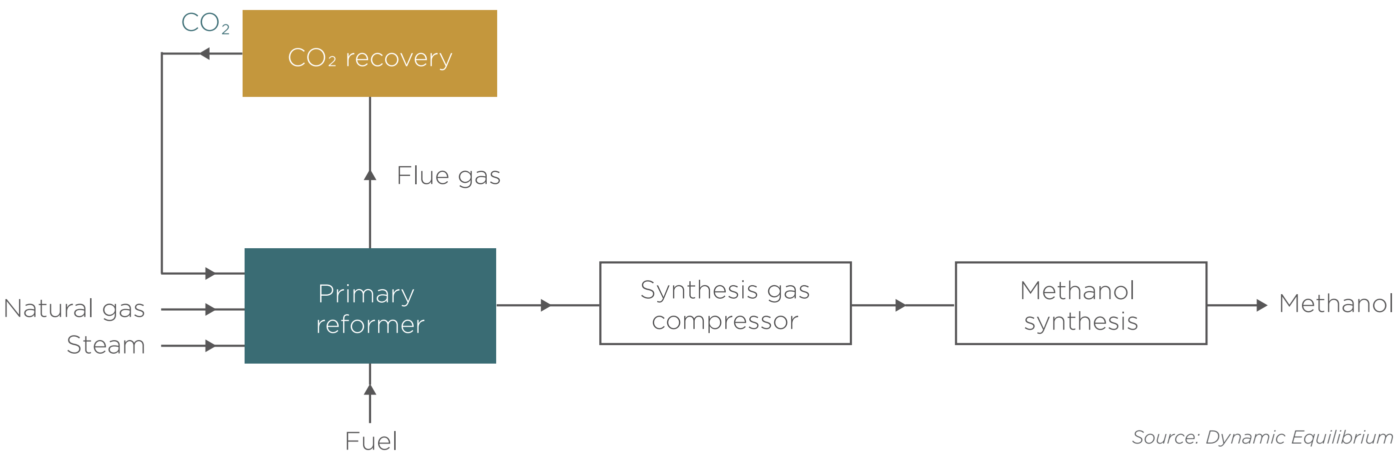
Step 2

There are a multitude of reactors and processes for the synthesis of methanol from the feed gas that results from Step 1, but they all tend to have the following attributes in common.

The feed gas is compressed and fed into a methanol converter. However, during the methanol synthesis in the converter, only about 5 percent of the feed gas is converted to methanol at each pass, resulting in a loop system to re-use "leftover" feed gas from the previous pass.

The basic process described above is also depicted in Figure 6[49] below.

Figure 6: Methanol production



Source: Dynamic Equilibrium

Sources of emissions

From the steps above, the sources of emissions from current methanol production processes can be summarised as:

1. Energy consumption emissions
    - CO_2 from the fossil fuels used to produce heat for steam to split the natural gas
    - CO_2 from other non-renewable energy used in the processes under step 2 (the processes vary between manufacturers, but all use energy to run them)

2. Feedstock emissions
    - Surplus CO_2 from the conversion of natural gas to hydrogen and CO_2 for the feed gas (as not all of it is used during the chemical reaction)
    - The release of some more of the feed gas mix, also containing methane, due to inefficiencies[50]
    - Scope 3 emissions: the CO_2 bound in methanol, resulting from its fossil fuel inputs, is released later down in its value chain, for example when plastics are burned (see "Annex II: Emissions reduction through plastic recycling")

Methanol: Emissions-neutral production process[51]

The key sources of emissions during the current methanol production process can be mitigated with similar solutions to those available for ammonia production.

Step 1

Green hydrogen can replace the natural gas feedstock and steam reforming process, as with ammonia.

However, by replacing natural gas with green hydrogen, methanol is missing a source of the carbon in its structure, previously synthesised from the feed gas. Hence, CO_2 needs to be added to the process. For this to be carbon neutral, the CO_2 must have been captured elsewhere, and needs to be neutral on a life-cycle basis. This way, the production of methanol can become a net importer of CO_2 in a carbon neutral future.

Step 2

Current production processes vary, as will solutions. The general approach will be the same, though.

Where existing processes use fossil fuels directly (e.g. by burning it to create heat) they need to move to electrified alternatives (e.g. a heat pump). All new and existing processes already using electrified energy need to move to 100 percent renewable energy (produced on-site or purchased through the company's energy provider).

The viability of this decarbonisation pathway has already been proven in projects such as Iceland's "George Olah Renewable Methanol Plant".

Mitigated emissions

From the steps above, the sources of emission mitigation compared to the current ammonia production processes can be summarised as:

1. Energy consumption emissions
   - There is no requirement for steam generation to split natural gas into CO_2 and hydrogen, eliminating energy consumption emissions at this stage completely
   - There are no emissions from energy consumption in other processes as new and existing processes can and need to be electrified and run off 100 percent renewable energy

2. Feedstock emissions
   - Green hydrogen eliminates natural gas as a feedstock and the related CO_2 and other emissions
   - The CO_2 that is used for methanol production has been captured elsewhere and no additional emissions are created; the low-emission process becomes an importer of CO_2 rather than an emitter

Scope 3

If methanol is produced in the emissions-neutral way set out above, its Scope 3 emissions are eliminated. For example, if a piece of plastic or synthetic fibre made in this way was burned, there would be no fossil fuel feedstock in it to release emissions. With the new feedstock, the CO_2 released would stem from captured CO_2, creating no additional emissions. This discussion obviously emits any emission sources in intermediate production steps from methanol to plastic.

So, is emissions-neutral production the solution for everything?

No, unfortunately not. Most methanol (and high-value chemicals, as per the next section) is used to produce plastics. This production — even in an emissions-neutral way — requires a lot of resources, such as production facilities and large amounts of renewable energy.

More production also creates more plastic waste, which in turn creates more environmental pollution and health hazards.

We can reduce emissions today by re-using and recycling plastics, while methanol production transitions. We can save resources and reduce pollution by continuing to prioritise the circularity of existing plastics over the production of new plastic — both today and in 2050.

Consequently, plastic circularity should form part of any methanol producer's transition strategy. Annex II of this report, "Emissions reduction through plastic recycling", delves into the issues around Scope 3 emissions and circularity in more detail.

Ethylene, propylene and BTX

This section of the report covers five chemicals that share a common production process. Together, these chemicals are called "high-value chemicals" or HVCs. Ethylene and propylene are also known as "olefins", while BTX chemicals (benzene, toluene and xylene) are also known as "aromatics". They are primarily produced through a process called "steam cracking", which is highly energy intensive, consuming approximately 40 percent of the total energy used in the petrochemical sector[52].

The production of these chemicals follows a similar pattern and can be interlinked[53], with aromatics being by-products of the production of olefins (Figure 7) under some production paths.

Over 85 percent of the production of light olefins (ethylene and propylene) is used for polymers, a basic building block for all types of plastics, including packaging[54]. Hence, these types of chemicals are closely linked to plastics, meaning a discussion of their value chain decarbonisation cannot ignore the problem around circularity. The section "Emission reduction through plastic recycling" will dive deeper into this issue.

Figure 7: Breakdown of HVC

High-Value Chemicals (HVCs)

Light olefins
Ethylene, Propylene

BTX aromatics
Benzene, toluene, xylene

Source: IEA, 2018

Aromatics get their name from their specific smell and shared characteristics. Like ethylene and propylene, they are used in the production of plastics, but they are also key components of other consumer products such as paints, pharmaceuticals and solvents[55].

HVCs: Current production process

There are several ways of producing HVCs. For ethylene and propylene, the most common process is steam cracking[56]. For aromatics, around 72 percent currently come from a reforming process coupled with oil and gas refining, while 24 percent come from steam cracking[57].

HVC production linked to the refining of oil and gas is unlikely to be viable in a 1.5C-aligned world, where the extraction of fossil fuels decreases towards zero.

The alternative low-carbon route is an adaptation of the current steam cracking process, which is what this report will focus on.

Step 1

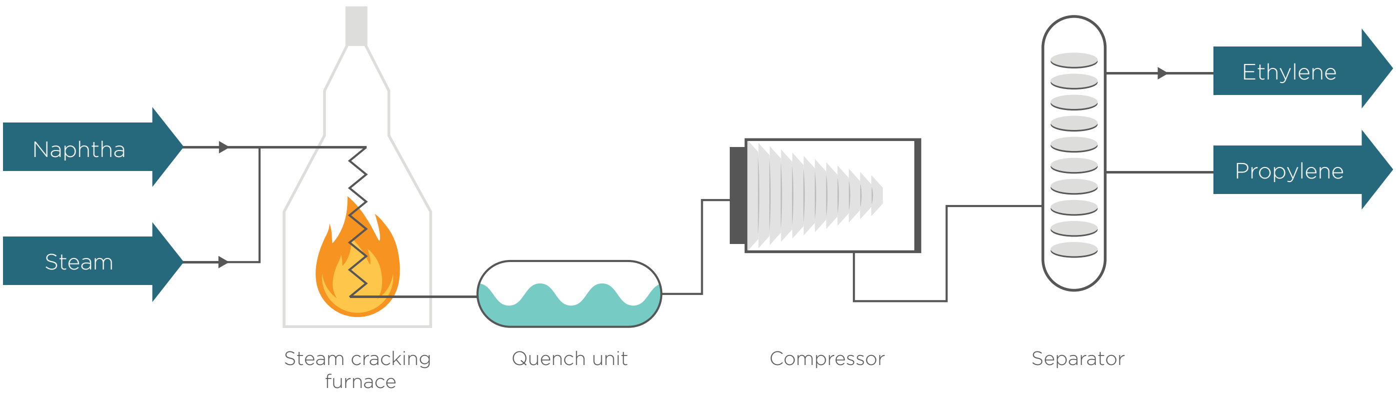
For steam cracking, a feedstock is vaporised with the use of super-heated steam, with temperatures reaching up to 1100C[58]. The feedstock is predominantly naphtha (~68 percent in Europe[59]) or natural gas liquids. Naphtha is a by-product of the refinery process for transport fuels such as diesel and kerosene[60]. It usually has a negative margin for oil and gas companies, and its production is highly dependent on the economics of the refinery's main products[61]. It is reasonably likely that the production of naphtha would be phased out in a world where the demand for oil and gas as transport fuels falls.

This process is called steam "cracking" because the heated steam cracks the bonds of the feedstock hydrocarbons to create the required chemicals. At this stage there is a release of greenhouse gases, including methane, which are re-used as an energy input to the steam generation[62].

Step 2

The cracked gas is then cooled and undergoes other processes, such as compression (see Figure 8). By varying the feedstock (e.g. naphtha or alternatives such as liquified natural gas) and the exact processes used, ethylene, propylene and/or BTX chemicals are produced in different ratios and output levels.

Figure 8[63]: Sample depiction of a naphtha steam cracker



Source: YOKOGAWA, 2004

Sources of emissions

From the steps above, the sources of emissions from current HVC production processes can be summarised as:

1. Energy consumption
   - CO_2 from the fossil fuels (e.g. naptha) used to produce extreme heat and steam to crack the feedstock
   - Some of the gas mix produced for the chemical production contains methane and heavy oils, which are re-used for the steam generation
   - CO_2 from other non-renewable energy usage in the process, e.g. for compression

2. Feedstock
   - CO_2 and other greenhouse gas emissions (e.g. methane) from any inefficiencies or purging of the cracked gas within the production process
   - Scope 3 emissions: the CO_2 bound in HVCs, resulting from its fossil fuel inputs, is released later down the value chain, for example when plastics are burned (see "Emissions reduction through plastic recycling" in Annex II of this report)

HVCs: Emissions-neutral production process

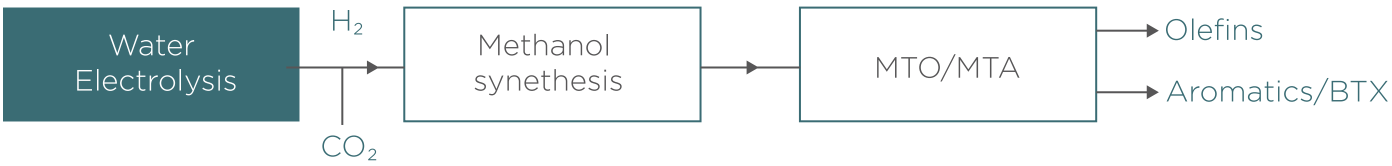
There are existing production process for emissions-neutral HVCs. It relies on emissions-neutral methanol (produced as per the previous section) as feedstock and a specific set of production methods.

These production methods vary but are grouped as methanol-to-olefins (MTO) and methanol-to-aromatics (MTA). They all use emissions-neutral methanol, produced with green hydrogen and renewable energy (Figure 9)[64].

The green methanol is also used in further steps to produce the desired output chemicals. These further steps are part of the MTO and MTA processes, which turn the “green” methanol to olefins and aromatics, and are already licensed and commercially available[65]. The choice of process and catalyst used in the process determines the output mix of ethylene, propylene and the BTX chemicals[66].

Calculations by DECHEMA show that these processes require about 2.8 tonnes of methanol for a tonne of ethylene and propylene, and 4.3 tonnes for a tonne of BTX chemicals. As green methanol is not used for HVC production at scale today, this will probably significantly increase the demand for low-emission methanol[67].

Figure 9: Low-carbon olefins and aromatics through methanol



Source: DECHEMA, 2017

Mitigated emissions

From the steps above, the sources of emission mitigation compared to the current HVC production processes can be summarised as:

1. Energy consumption emissions
   - There is no requirement for the steam cracking process, eliminating its high energy needs and CO_2 and other GHG emissions
   - There are no emissions from energy consumption in other processes if the MTO and MTA steps are electrified using 100 percent renewable energy

2. Feedstock emissions
   - Green methanol eliminates naphtha and other fossil fuel-based feedstocks and their related emissions
   - The CO_2 that is used for the production of methanol has been captured elsewhere and no additional emissions are created

Scope 3

If HVCs are produced in the emission neutral way set out above, their Scope 3 emissions are eliminated. For example, if a piece of plastic or synthetic fibre made in this way was burned, there would be no fossil fuel feedstock in it to release emissions. The CO_2 from the green methanol feedstock, if released, would stem from captured CO_2, creating no additional emissions. This discussion obviously emits any emission sources in intermediate production steps from HVC to plastic.

So, is emissions-neutral production the solution for everything?

No, unfortunately not. This is for the same reasons as for methanol.

Annex II of this report, “Emission reduction through plastic recycling”, delves into the issues around Scope 3 emissions and circularity in more detail.

Myth busters

The pathways outlined in this report allow for the chemical industry's emissions to come down to zero if employed by 2050 by relying on green hydrogen and electrification.

Readers might also have come across arguments for alternative solutions, such as:

- blue hydrogen
- biomass
- carbon capture and storage

The following myth busters unpack why we view these alternatives as "false" solutions. If employed in the transition, they would fail to reduce the chemical industry's emissions to zero. They are also likely to be higher in cost.

Myth buster: Hydrogen — why only green, and no blue, hydrogen?

There are different types of hydrogen, of which only one, green hydrogen, is truly sustainable. However, many actors push for the inclusion of blue hydrogen as a bridge solution.

Investors might come across pathways, or even company disclosures, claiming that using blue hydrogen is a feasible decarbonisation strategy for the chemical sector. Many refer to the fact that hydrogen demand for feedstock will be high, with Agora estimating that the production of the chemicals covered in this report will require 148 TWh of hydrogen feedstock per year. Some argue it will not be possible, or economically viable, to meet all of this demand through green hydrogen produced from renewable energy. The next section, "Myth buster: can we have enough renewable energy?", will debunk that argument in more detail.

What types of hydrogen exist?

Grey hydrogen refers to hydrogen produced using natural gas as an input. The most common process for producing grey hydrogen is the steam reforming process, as outlined in the "current processes" sections earlier in this report. Black and brown hydrogen stem from similar processes, but use coal and lignite as inputs respectively.

Today, 99 percent of hydrogen production globally uses gas and coal inputs for production. There is no room in a 1.5C-aligned world for using hydrogen from fossil fuels as feedstock for chemical production due to high emissions, and eventually cost.

Blue hydrogen refers to hydrogen produced using natural gas as an input, but as opposed to grey hydrogen, the carbon emitted during the production process is captured or otherwise mitigated. The two methods most frequently mentioned would be steam reforming with carbon capture and storage (CCS), or methane pyrolysis. In methane pyrolysis, a high-heat chemical process is used to split natural gas into hydrogen and solid carbon (instead of CO_2 gas, as in steam reforming)[68], omitting the CCS process.

Green hydrogen refers to hydrogen "produced by electrolysis, a process that uses an electrical current to split water into hydrogen and oxygen, using power generated from renewables." It should also be noted that "[t]his label is sometimes misleadingly applied to hydrogen derived from grid electricity, which will only be as 'renewable' as the grid itself is". This report classifies "green hydrogen" as hydrogen produced from 100 percent renewable energy.

Why is blue hydrogen not the solution?

There are several direct climate and economic drawbacks to using blue hydrogen, which highlight the importance of green hydrogen for the chemical sector, namely:

- Carbon-capture and storage technologies are expensive, do not exist at scale yet, aren't 100 percent efficient at capturing carbon and still require renewable energy to run them in the first place ("Myth buster: do we need carbon capture in the production of chemicals?" gives more insight into this).
- During the extraction and transportation of natural gas (used as an input for blue hydrogen) methane leaks, which causes significant emissions upstream that in some cases makes natural gas even more polluting than coal[69]. **This means even if carbon capture became 100 percent efficient, blue hydrogen would still never be truly emissions free.** Unfortunately, not even the IEA accounts for these emissions reliably.
- Setting up blue hydrogen infrastructure would lock in fossil fuel use in the longer term, and increase overall emissions compared to pursuing green hydrogen to start with.
- Blue hydrogen will be less cost-effective than green hydrogen as soon as 2030[70]. When also taking into consideration the emissions points above, this suggests that blue hydrogen should not even be used as an interim solution over green hydrogen from an economic perspective.

For these reasons, green hydrogen and related investments should be at the forefront of any chemical company's decarbonisation strategy.

Source and further reading: CarbonBrief, 2020, "In-depth Q&A: Does the world need hydrogen to solve climate change?"[v]; Agora, 2021, "No-regret hydrogen"[vi]

v https://www.carbonbrief.org/in-depth-qa-does-the-world-need-hydrogen-to-solve-climate-change

vi https://www.agora-energiewende.de/en/publications/no-regret-hydrogen

Myth buster: Can we have enough renewable energy?

Using green hydrogen and electricity to run chemical production processes requires large quantities of cheap renewable energy if these processes are to be emissions free.

Many people question the feasibility of this, proposing blue hydrogen, biomass and carbon capture as a solution instead.

However, the world has the technical and economic potential to meet its energy demands a hundred times over with renewable energy by 2050. In fact, renewable energy sources are several times more abundant than any tapped or untapped fossil fuel reserves, according to recent research by the Carbon Tracker Initiative (CTI).

According to their research, "Global energy consumption in 2019 was 65 petawatt hours (PWh). However, with current technology the world has the potential to capture more than 5,800 PWh annually from solar PV alone — as much power in a single year as could be generated by burning all known fossil fuel reserves. In addition, onshore and offshore wind could capture nearly 900 PWh a year."

Renewables are already more economical than fossil fuels in the case of around 60 percent of solar and 15 percent of wind power generation. By 2030, all solar energy will be economical, and at current growth rates, renewables will have pushed oil and gas out of our energy systems by 2035.

In short, we have the potential for renewable energy generation far beyond what fossil fuels could ever supply — and far beyond what we will ever need — and it is going to be better for our planet and our pockets.

Other common myths questioning the feasibility of 100 percent renewable energy are related to land use, storage and intermittency.

In fact, renewables would only take up about 0.3 percent of available landmass, even less than fossil fuel infrastructure currently does. Land constraints are not a limitation; we might even be able to free up land through the shift to clean energy.

When it comes to questions around storage and intermittency, there are many solutions. But most importantly, the numbers from CTI to establish the world's renewable potential already use the levels of energy generation in the lowest month of the year. This means the estimates of our renewable energy potential above are already incredibly prudent. Even with this degree of prudence, renewable energy is super-abundant.

Source and further reading: Carbon Tracker, 2021, "The Sky's the Limit"[vii]

vii https://carbontracker.org/solar-and-wind-can-meet-world-energy-demand-100-times-over-renewables/

Myth buster: Biomass — why is it not the solution?

Some pathways recommend the use of biomass to decarbonise the chemical industry. This relies on the assumption that biomass is carbon neutral and abundant.

However, these assumptions do not hold true entirely.

There is a physical limit on the land available to produce biomass for feedstock or energy, as biomass directly competes with agricultural needs for land. In fact, it is unlikely that we can produce enough biomass sustainably for sectors such as the chemical industry. In comparison, a solar panel needs only one twentieth of the land a biomass crop would need to produce the same amount of energy.

Further, the climate impacts of biomass can be worse than coal, due to it being less efficient in combustion and releasing other global warming side-effects such as heat and water vapour.

Classifying biomass as carbon neutral is also a question of time — it can take decades for the CO_2 release to be re-absorbed by new plant growth (e.g. when using wood as a source for biomass). As we are already facing increasing risks of overshooting the carbon budget, this time we do not have.

This view also makes the assumption that the sources of the biomass are managed in a sustainable way, which is not always the case. In fact, preventing a major cause of climate change, namely deforestation, should be on top of the climate agenda instead.

Investors will be familiar with the concept of "opportunity cost", which refers to the potential benefits that are lost by not choosing the best available investment option. If we were to use "sustainable" crops in lieu of forests, this also represents an opportunity cost in terms of carbon emissions, as a low carbon intensity crop is used to cover soil instead of high carbon intensity forests.

Even using biomass with carbon capture is not a solution. This process would require 25 to 55 percent more energy (and therefore even more land) than without it, and it is very costly.

All in all, biomass represents a heavy opportunity cost compared to using renewable energy and green hydrogen for the chemical industry, and is limited by land use requirements.

Investors should be wary of sustainable biomass claims.

Source and further reading: Mark Z. Jacobson, 2020, "100% Clean, Renewable Energy and Storage for Everything"[viii]; ShareAction, 2019, "The Biomass Blind Spot"[ix]

viii https://www.cambridge.org/highereducation/books/100-clean-renewable-energy-and-storage-for-everything/26E962411A4A4E-1402479C5AEE680B08#overview

ix https://shareaction.org/wp-content/uploads/2019/01/InvestorReport-Biomass.pdf

Myth buster: Why don't we need carbon capture in the production of chemicals?

Some pathways suggest using carbon capture along with fossil fuel feedstock and energy generation. As with blue hydrogen, the continued use of oil and gas with carbon capture and storage (CCS), would not eliminate the upstream emissions of fossil fuels. CCS is very unlikely to ever be able to capture and successfully store 100 percent of the carbon emissions of the processes it aims to tackle.

Further, CCS technologies require substantial amounts of energy, which would still require new renewable energy capacity to be considered truly carbon neutral. They also need large upfront investments, which may only pay out over time and at the right carbon price; experts argue that with the falling prices of renewable energy, the cost of CCS is never going to be justified.

This makes them an expensive, higher risk and inefficient solution compared to directly using renewable energy.

Using CCS to decarbonise chemical production presents an opportunity cost over green hydrogen and renewable energy. It is more costly, less efficient and does not eliminate all emissions compared to the emissions-free chemical production processes set out in this report.

Source and further reading: Mark Z. Jacobson, 2020, "100% Clean, Renewable Energy and Storage for Everything"[10]

x https://www.cambridge.org/highereducation/books/100-clean-renewable-energy-and-storage-for-everything/26E962411A4A4E1402479C5AEE680B08#overview

Industry challenges

The chemical industry faces several challenges in following the roadmap set out in this report. Some of these challenges are not, or are only partly, within the control of chemical producers. This highlights the importance of an integrated and holistic approach to the sector.

1. Access to abundant and cheap renewable energy

The chemical industry will need access to abundant and cheap renewable energy to electrify its processes and use green hydrogen as a feedstock. However, grids around the world are not run by 100 percent renewable energy yet. At the same time, the cost of renewable energy, such as solar, continues to fall[71].

While transitioning the grid lies somewhat outside the control of chemical companies, they do have some power over ensuring the supply of green energy for their own needs. Companies can take an active approach to building or purchasing their own renewable energy. For example, Power Purchase Agreements (PPA) would mean that a company is in a direct procurement contract that is adding designated renewable capacity to the grid:

"In a direct procurement contract, an agreement is signed between a buyer (the company procuring the electricity) and a renewable electricity generator. The contract ensures the procurement of electricity generated by a specific renewable project with renewable attributes[72]."

Companies can influence renewable energy supply for their own needs, and by sending a demand signal, can also help speed up the general grid transition.

2. Competitiveness and carbon pricing

Making green hydrogen and electrification cost-competitive compared to current production processes is subject to two levers: the fall in costs of renewable energy (more information in "Myth buster — can we have enough renewable energy?") and correctly pricing fossil fuels and their cost to society through carbon pricing.

Both levers are currently being activated, though the latter is subject to the political agenda.

The European chemical industry accounts for 8 percent of the emissions covered by the Emissions Trading System (ETS). As the ETS is being adjusted to reflect the ambition of reducing emissions at the EU level, it is estimated that the European chemical industry will face a bill of 1.5 billion euros in 2021, which could double by 2030[73]. This will make current fossil fuel-based production processes less economically attractive than low-carbon alternatives. An extension of the ETS to cover further emissions, such as those related to feedstock both up and downstream, would enhance this effect.

While the social cost of emissions is being priced in at the European Union level, this could pose a competitive disadvantage to the industry compared to peers operating outside the ETS. The EU is considering steps to level the playing field in other heavy industries, such as steel and cement, through a carbon border adjustment mechanism[74].

The chemical industry will likely need similar support if it is to remain competitive with players abroad.

3. Investment needs and demand for emissions-free chemicals

Retrofitting existing production processes and investing in new emissions free ones will require substantial amounts of investment.

Most importantly, it will require an end market for emissions-free chemicals. Thankfully, producing emissions-free chemicals has only a very marginal effect on the price of its end products. For example, the price of plastic bottles is only expected to increase by 1 percent[75]. The transition also offers up a host of new opportunities for the industry, such as in ammonia for shipping.

This gives some insight into the dynamics of investments and pay-offs for the chemical industry. However, more analysis is needed to establish what support might still be required for the sector to transition.

For example, ensuring demand for emissions-free chemicals (even if just at a slightly higher cost) will go a long way to justifying the industry's investment needs. Further support from governments can also help reduce the risk of projects[76] and ensure a successful transition.

4. Emissions beyond production

As outlined earlier, a large proportion of the chemicals discussed in this report are used to produce plastics and fertilisers, which have significant Scope 3 emissions. However, chemical companies themselves have limited influence over these emissions.

A change in agricultural practices, in the case of fertilisers, and a more circular economy, in the case of plastics, are needed. Much of this goes beyond a chemical company's control. However, chemical companies can — and should — be using their influence to engage with governments, customers and other stakeholders to accelerate these changes.

Annex I: Recommendations to investors

Below we give guidance to investors on how to engage with chemical companies on achieving net zero emissions by 2050. We also provide a tangible outcome ("Tracking outcome") that investors can use to measure company performance and the success of engagements over time, and to take appropriate action.

Investors can use the following questions and tracking outcomes in their engagements with chemical companies involved in the production of ammonia, methanol, ethylene, propylene, benzene, toluene, and xylene, as well as fertilisers and plastics. They can also be used for companies that buy these primary chemicals to assess their procurement strategy and the demand signal they send. ShareAction has created a shortlist of such companies, which are referenced at the end of this section.

Engagement questions

Ammonia and methanol

Does the company have a credible plan to replace fossil fuel feedstocks with emissions-free alternatives such as green hydrogen by 2050 at the latest?

Tracking outcome: The company has a credible plan to replace all feedstock with emissions-free alternatives such as green hydrogen (produced with 100 percent renewable energy). It does not intend to use blue hydrogen as a solution. It does not intend to use biomass as feedstock, or fossil fuels with carbon capture as a mitigation technology.

Does the company have a credible plan to use 100 percent renewable energy for energy needs (steam, heat, compression, cooling etc.) by 2050 at the latest?

Tracking outcome: The company has a credible plan to electrify all new and existing processes and switch to 100 percent renewable energy. Ideally, it cements such a commitment by joining the RE100 initiative[xi] or similar initiatives.

Where CO_2 is needed, does the company have a credible plan to ensure this CO_2 is carbon neutral by 2050 at the latest?

Tracking outcome: The company is committed to the procurement of captured CO_2 to ensure the overall neutrality of its use as an input for its chemical products. It discloses the source of CO_2 and how its neutrality is ensured throughout its life cycle.

xi https://www.there100.org/

High-value chemicals (HVCs)

Does the company have a credible plan to replace current production processes for high-value chemicals with net zero emission processes, such as methanol-to-olefins (MTO) and methanol-to-aromatics (MTA), by 2050 at the latest?

Tracking outcome: The company has a credible plan to change production for HVCs to processes such as MTO and MTA, using green methanol (produced via green hydrogen and electrification) as feedstock. It does not propose solutions centred on blue hydrogen, biomass or fossil fuels with carbon capture.

Does the company have a credible plan to use 100 percent renewable energy for energy needs (e.g. for the MTO/MTA processes and any other energy consumption), by 2050 at the latest?

Tracking outcome: The company has a credible plan to electrify all new and existing processes and switch to 100 percent renewable energy. Ideally, it cements such a commitment by joining the RE100 initiative[xii] or similar initiatives.

xii https://www.there100.org/

End products and Scope 3

Does the company have a credible strategy to mitigate all its Scope 3 emissions by 2050 at the latest?

Tracking outcome: The company discloses all sources of Scope 3 emissions and has a credible strategy to mitigate each source. For fertilisers and plastic, please see some more detailed questions below.

Where the company is involved in the value chain for fertilisers (e.g. producing primary chemicals such as ammonia, or being a direct fertiliser producer), does the company have credible plans to mitigate emissions at all stages of the product's life cycle by 2050 at the latest?

Tracking outcome: The company ensures the production of chemicals needed for fertilisers is emissions free and switches its portfolio to fertilisers with inhibitors (see fertiliser section of this report for more information). The company has a credible strategy to mitigate emissions for fertilisers by working with stakeholders to improve fertiliser application.

Where the company is involved in the value chain for plastics (e.g. producing primary chemicals such as methanol and HVCs, or being a direct plastic producer), does the company have credible plans to mitigate emissions at all stages of the product's life cycle by 2050 at the latest?

Tracking outcome: The company has a plan for all new production of plastics, including relevant primary chemicals, to be emission free (e.g. as per the processes outlined in this report for methanol and HVCs). The company also engages with stakeholders to ensure a circular value chain for its products with a focus on re-use and recycling. If re-use and mechanical recycling options have been exhausted, the company is looking into developing emissions-free chemical recycling options (chemical recycling should not supersede other recycling investments). The company is not involved in bio-plastics.

Supporting recommendations

Does the company use an internal carbon price to assess existing and future projects?

Tracking outcome: The company uses a regional carbon price that is aligned with the scientific recommendations for the IPCC 1.5C limited-to-no overshoot scenarios. The company uses the carbon price to assess existing and future projects. The company makes outputs from the analysis publicly available alongside a description of assumptions.

Investors are further encouraged to ask questions aligned with the CA100+ benchmark[xiii].

xiii https://www.climateaction100.org/wp-content/uploads/2021/03/Climate-Action-100-Benchmark-Indicators-FINAL-3.12.pdf

Potential target companies

This research applies to **all chemical companies involved in the production or procurement of the chemicals outlined in this report and their end products.** This includes indices of chemical companies (e.g. the Stoxx Europe 600 Chemicals index).

ShareAction has created a shortlist of European targets based on their market capitalization and footprint in the chemicals and end products covered in this report.

Table 1: List of European chemical company targets

Company name	Country	Ammonia	Methanol	Light olefins	BTX	Plastics/ polymers	Fertiliser
BASF SE	Germany		x	x	x	x	
Covestro AG	Germany			x	x	x	
Croda International plc	UK					x	x
EMS Chemie Holdings AG	Switzerland			x	x	x	
Evonik Industries AG	Germany			x	x	x	
Koninklijke DSM N.V.	Netherlands					x	
L'Air Liquide S.A.	France	x	x	x	x		
Lanxess AG	Germany	x		x	x	x	
LyondellBasell	Netherlands		x	x	x	x	
Givaudan SA	Switzerland				x		
Solvay SA	Belgium	x	x	x	x	x	x
Yara International ASA	Norway	x					x
Symrise AG	Germany		x	x	x		

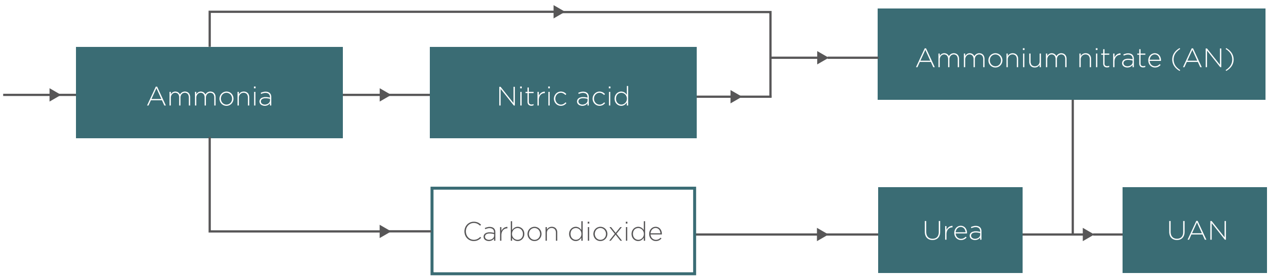
Annex II: Scope 3 emissions

Reducing emissions from fertilisers

Overview: There are more types of fertilisers than just ammonia

Over 80 percent of ammonia is used to produce nitrogen fertilisers, of which there are several types (Figure 10).

Figure 10[77]: Ammonia to nitrogen fertilisers



Source: fertilizers europe

As per the section above, the production of the initial ammonia can technically be fully decarbonised; which is a necessary step for the chemical industry to achieve its alignment with 1.5C pathways.

To further eliminate emissions from the production of nitrogen fertilisers, the production processes of nitric acid and urea also need to be decarbonised. While these substances are beyond the direct scope of this report, it is important to highlight that urea requires CO_2 as part of its chemical makeup, which is released when the fertiliser is used.

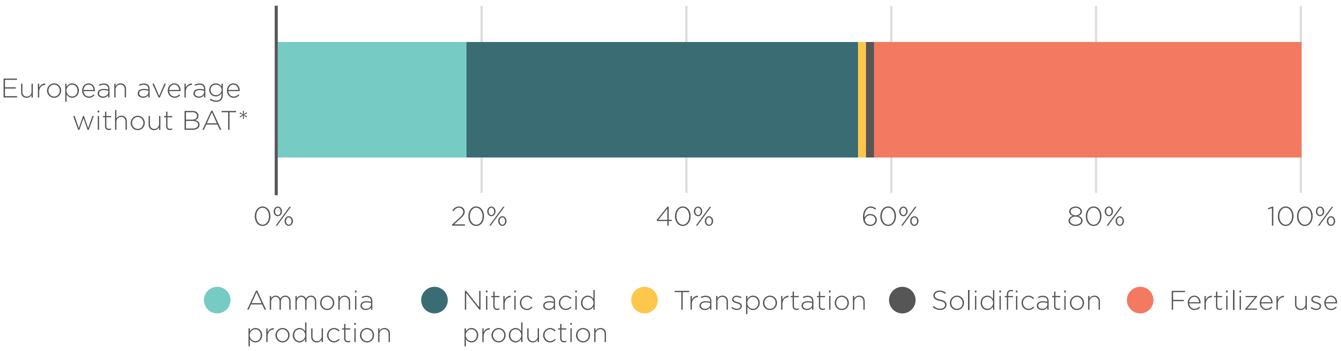
About 40 percent of fertiliser emissions are from use and 60 percent from production

Producing emissions-free ammonia alone will not eliminate its Scope 3 emissions, as ammonia plays a key role in agricultural GHG emissions.

Nitrogen oxide (N2O) has a global heating potential 300 times that of CO_2[78]. Agriculture is the dominant driver of the increase in atmospheric nitrogen oxide, which needs to be curbed to limit global heating to 1.5C[79].

In the nitrogen fertiliser lifecycle, emissions stem from the production and transportation of ammonia and its derivatives (approximately 60 percent of emissions) and from their use, namely when they are applied to the field (approximately 40 percent of emissions)[80].

Figure 11: Lifecycle carbon footprint of nitrogen fertilisers — production and use



Source: Yara

The nitrogen (N2) from the air that is used to produce ammonia is not a greenhouse gas. But the chemicals it forms during use are.

Ammonia (N3H) itself is a gas, and when it is released into the atmosphere it causes a greenhouse effect. It forms into nitrogen oxide and other nitrates once it is applied to the soil. Other nitrogen fertilisers derived from ammonia, such as urea and ammonium nitrate, also form into nitrogen oxide and other nitrates when used. All these forms of nitrogen cause global heating[81]. Using urea on the field releases further CO_2 emissions.

But why do fertilisers cause emissions in the first place?

Plants need nitrogen in the soil to grow. **The emissions problem arises when there is "surplus" or free nitrogen in the soil[82].**

Only about 50 percent of fertiliser applied to fields is used by plants[83]. This leads to significant surplus nitrogen in the soil, which is released into the atmosphere as greenhouse gases. This process is worsened by the fact that fertilisers reduce the number of microbes or bacteria in the soil[84], which under normal circumstances prevent nitrogen surplus. Microbes also produce crucial minerals that plants need. This creates a feedback loop, where a decrease of microbes and other organisms in the soil due to heavy fertiliser use creates the need for more nitrogen and mineral fertilisers.

So how can we reduce emissions from fertilisers beyond the production stage?

Replacing fertiliser-based farming practices:

As described above, even if produced in an emissions-free way, ammonia and its derivatives (urea, ammonium nitrate) release GHG emissions when used as a fertiliser. The only truly effective way to reduce these emissions is to limit the use of fertilisers.

This requires different "nature-positive" and regenerative approaches to agriculture[85].
In fertilizer-free farming, certain plants — known as "nitrogen-fixing plants" — absorb nitrogen (N2) from the air and "fix" it in the soil for bacteria to convert to forms of nitrogen that plants can absorb[86], essentially acting as a natural fertilizer factory, without the surplus.

Less fertiliser and timing of fertiliser application[87]:

Where synthetic fertilisers are used, they can be applied in much lower quantities. Fertiliser over-usage is obvious given that, at present, only half of the fertiliser applied gets absorbed by the plants (see above). Yet farmers have more to fear from a nitrogen shortage, which reduces yields, than an oversupply. They therefore apply too much[88].

A more targeted approach, both in regard to the amount of fertiliser used and its placement, could help reduce emissions without reducing yields. This also includes timing; applying fertiliser when it is most needed by crops increases the likelihood that the nitrogen is taken up by the plants rather than being released into the atmosphere.

Slow-release fertilisers and inhibitors[89]:

Fertilisers can be designed to release more slowly, or we can inhibit their conversion to usable nitrogen for plants. This decreases the risk of there being excess nitrogen in the soil, and consequently reduces emissions.

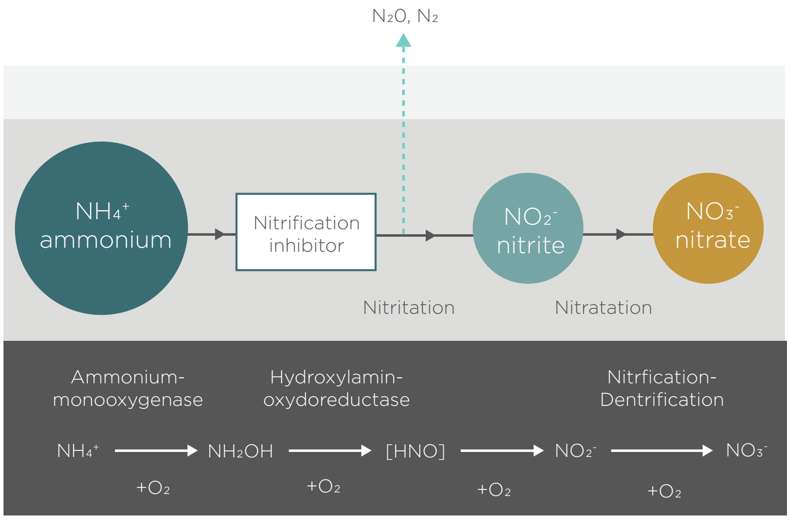
There are two main types of inhibitors: urease inhibitors and nitrification inhibitors.

Urease inhibitors work by preventing the release of gaseous ammonia — which happens when urea is converted to ammonia — for about two weeks (further conversions to nitrate then follow). Through the use of urease inhibitors, ammonia loss through this conversion process can be reduced by up to 80 percent as a greater proportion of the fertiliser is taken up by plants over the delayed time period.

Nitrification inhibitors delay the conversion of ammonia to nitrate and thus allow more of the fertiliser to be taken up by the plants, reducing GHG emissions. How long they delay this process for depends on soil conditions (Figure 12).

Not touching on fertilisers when talking about the decarbonisation of the chemicals industry would be to ignore a massive part of its Scope 3 emissions. However, the debate certainly goes beyond anything that could be covered in a few pages, and the discussion above should not be seen as exhaustive.

Figure 12: Nitrification inhibitors visual



Source: fertilizers europe, 2017

Ammonia: Opportunities in a low-carbon world

Green ammonia could be a lever for decarbonisation beyond the chemical industry. Ammonia produced from green hydrogen and renewable energy shows some promise as a fuel in shipping and aviation — industries that are grappling with alternatives to fossil fuels. It might also be an alternative to hydrogen as a form of energy storage. Due to its higher density, it needs less space to store energy than hydrogen[90].

There are some caveats to these applications though. Ammonia contains nitrogen oxide, which is released when exposed to the air. These emissions need to be mitigated for ammonia to be classified as an emissions-free fuel.

Nonetheless, with the production of green hydrogen and derivatives such as green ammonia, the chemical industry has an opportunity to contribute to the decarbonisation of other hard-to-abate sectors.

This section of the report certainly does not give enough credit to the full scope of this discussion, but it should not be left unmentioned.

Emissions reduction through plastic recycling

What is the link between plastics and chemicals?

Methanol and high-value chemicals are inputs for plastic production. Forty percent of methanol is used to produce formaldehyde, a basis component of plastic[91], and 85 percent of light olefins are used to produce plastics[92].

Under their current production methods, they contain fossil fuels as feedstock. These fossil fuels are released as Scope 3 emissions of chemical companies when the plastic is burned. By changing to emission neutral production methods, these Scope 3 emissions can be avoided.

So why should we still focus on plastic circularity?

1. Absolute emissions can be reduced

Currently existing plastics and those being produced using current methods contain fossil fuels. Re-use and recycling of these plastics means fewer emissions are released at the end of their life (e.g. when burned). This can lower the chemical industry's Scope 3 emissions starting today.

2. Pollution is a critical part of the equation

The issue with plastic goes beyond emissions, with plastic pollution creating increasing harm to our health and ecosystems[93]. Even if the emissions embodied in plastic are not released — for example in cases where the plastic ends up in landfill — this does not make these plastics a feasible solution for our environment. While plastic pollution falls outside the scope of this report, it is a crucial issue for a report on methanol and HVCs.

3. Resource needs can be lowered

As we move to emissions-neutral production of the chemicals used in plastics, we will need a lot of resources. This particularly holds true as the demand for plastic increases, requiring new facilities. At the same time, plastic waste is accumulating. Re-using and recycling that waste is much more resource efficient than producing new plastics.

Can chemical companies form part of the circularity value chain?

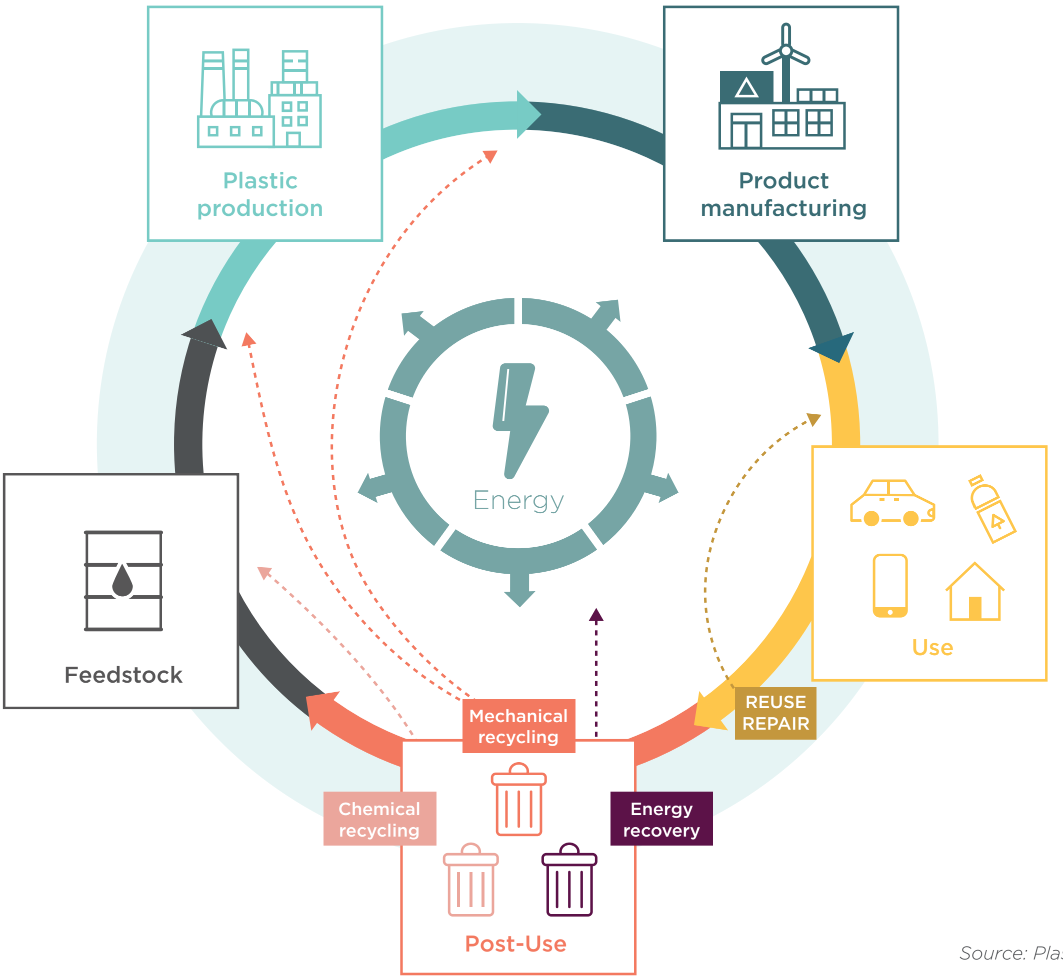
Chemical companies' Scope 3 emissions are affected by the lack of plastic circularity. Managing these emissions means being an active player in the circularity value chain, for example through engagement with relevant stakeholders.

But chemical companies might also be able to offer a solution to the circularity problem.

There are several forms of recycling available at the moment (Figure 13) that each have their own advantages and disadvantages.

Re-use and mechanical recycling must be prioritised at all times, but there will likely be some need for chemical companies to create chemical recycling solutions.

Figure 13[94]: Recycling plastics



Source: PlasticsEurope, 2018

The following list is given in hierarchical order, with the best-available recycling technique first[95]:

1. Product re-use

Increasing the re-usability of plastics has been proven with durable plastic bottles and similar circular approaches can be developed for other use areas. This is by far the most effective and least resource-intensive way of reducing plastic waste. But unfortunately, it is limited in many applications.

2. Mechanical recycling

Mechanical recycling refers to what most people think of when they hear the term "recycling". It is the process of collecting plastic waste and processing it into new pieces of plastic. There are several limitations to this approach.

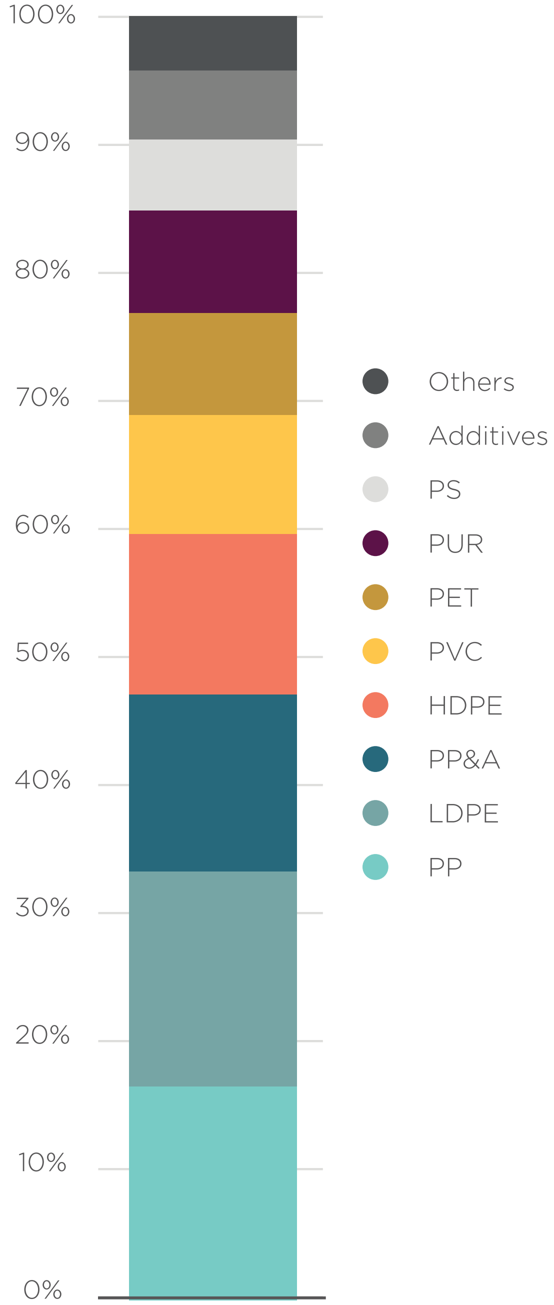
One hurdle is the collection and processing of plastic waste. In the UK, only 2 percent of plastics are recycled within its borders[96].

Another is the purity of that waste. Plastic comes in all forms and shapes, which have their own chemical properties97. The well-known PET or PVC plastics are only two types of plastics out of many (Figure 14).

Mechanical recycling does not change the molecular structure of plastic. As a result, it is difficult to combine different types of plastic[98].

Even if we can separate plastic types for recycling, it often results in lower grades of plastics due to impurities. These can only be used for downgraded applications99. A visual example of this would be the combination of one type of plastic, such as PET bottles, from different coloured products. The mechanically recycled product of these inputs could not be guaranteed to have one consistent, light colour[100]. This is a particular challenge for clear plastics.

Figure 14: Types of plastics



Source: Refficiency, 2020

Together, re-use and mechanical recycling are the most resource effective ways to recycle plastics and the only ways proven at scale as of today; this is why they must be prioritised.

3. Chemical recycling[101]

Chemical recycling refers to the process of either reducing the plastic back down to its original chemical building blocks using chemical solvents, using plastic as a feedstock into the production processes of chemicals that make up plastics (e.g. for methanol or HVCs), or a process called "depolymerisation".

Using solvents or a "depolymerisation" process face some of the same difficulties as mechanical recycling regarding the need for a single stream of plastic waste, and the output of degraded plastic. The other approach, namely using plastics as feedstock, is more relevant to this report's discussion. Plastic, under exposure to extreme heat and steam, can be used in a similar fashion to virgin fossil fuels. This makes intrinsic sense, as fossil fuels are embodied in plastic because they were used as feedstock when the plastic was produced.

Therefore, for the methanol or HVC production process, virgin fossil fuels could be replaced by plastic as a feedstock for the steam reforming or cracking process.

This process, called "gasification" or "pyrolysis", is when the plastic is broken down into its basic components — or, in simplified terms, reverted back to its original feedstock. It can then be re-used as feedstock. The advantage of this method is that it does not face the same limitations that others do around plastic purity.

There are some issues with this, however.

Emissions can be released if the plastic was originally produced with chemicals that used fossil fuels as feedstock

If the original feedstock was fossil fuel-based (as with all plastic currently in circulation) and therefore contains CO_2, the emissions in that fuel might be released into the atmosphere. This depends on the new chemical produced (e.g. ammonia, which does not require CO2, compared to methanol, which does) and the efficiency of the process. Further, if the energy consumption of the process is not powered by 100 percent renewable energy but by burning virgin fossil fuels (or fossil fuel-based plastics), it creates more emissions.

It is resource intensive, even if we use plastic produced with emissions-neutral chemicals (which do not exist yet)

Using pyrolysis on plastics produced from green hydrogen as feedstock should not encounter these issues.

This is because there are no additional emissions in the feedstock (as per the emissions-neutral pathways outlined in this report for methanol and HVCs). Hence, the plastic, having been derived from emissions-neutral feedstock in the first place, is also emissions neutral if re-used as "new" feedstock into the chemical production process.

However, there is no such plastic in circulation today.

We remember from the beginning of this report that emissions stem from feedstock and energy consumption.

This production process requires energy consumption to turn the plastic back into its primary chemical components. For this to be entirely emission free, it must also be electrified with 100 percent renewable energy.

A lot of energy is needed to turn the original chemicals into plastic that can be used, to collect that piece of plastic as waste for feedstock, to turn it back into its original chemical components, and then to turn that chemical into another piece of plastic. It also needs infrastructure in place to collect plastic waste for recycling.

Chemical recycling is thus a more energy-intensive approach than re-use and mechanical recycling, but still needs a similar infrastructure for waste collection. Consequently, it should be used as a last resort when all re-use and mechanical recycling opportunities have been exhausted.

4. Energy recovery

The least efficient use of plastic waste is for energy recovery.

Plastic waste could potentially be burned to produce energy, and the CO_2 from the process captured[102]. This would require expensive carbon capture equipment, and extra energy to run such equipment. It is unlikely to be economical, and is currently not deployed at any scale. It also suffers from the same drawbacks of carbon capture in general (see "Myth buster: Why don't we need carbon capture in the production of chemicals?" for more information).

It is an inefficient way of producing energy[103], and does not reduce the demand for new plastic production either[104]. Further, when plastic is burned it releases toxic pollutants into the air[105]. While burning plastic waste for fuel poses an alternative to plastic pollution, from an emissions perspective it is vastly inferior to the other recycling methods mentioned, which also achieve the ultimate aim of reducing plastic pollution.

Burning plastics for energy recovery, even with carbon capture, should be avoided at all costs.

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ShareAction is a non-profit working to build a global investment sector which is responsible for its impacts on people and planet. We mobilise investors to take action to improve labour standards, tackle the climate crisis, and address pressing global health issues, such as childhood obesity. Over the last 15 years, ShareAction has used its powerful toolkit of research, corporate campaigns, policy advocacy and public mobilisation to drive responsibility into the heart of mainstream investment. We want a future where all finance powers social progress.

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