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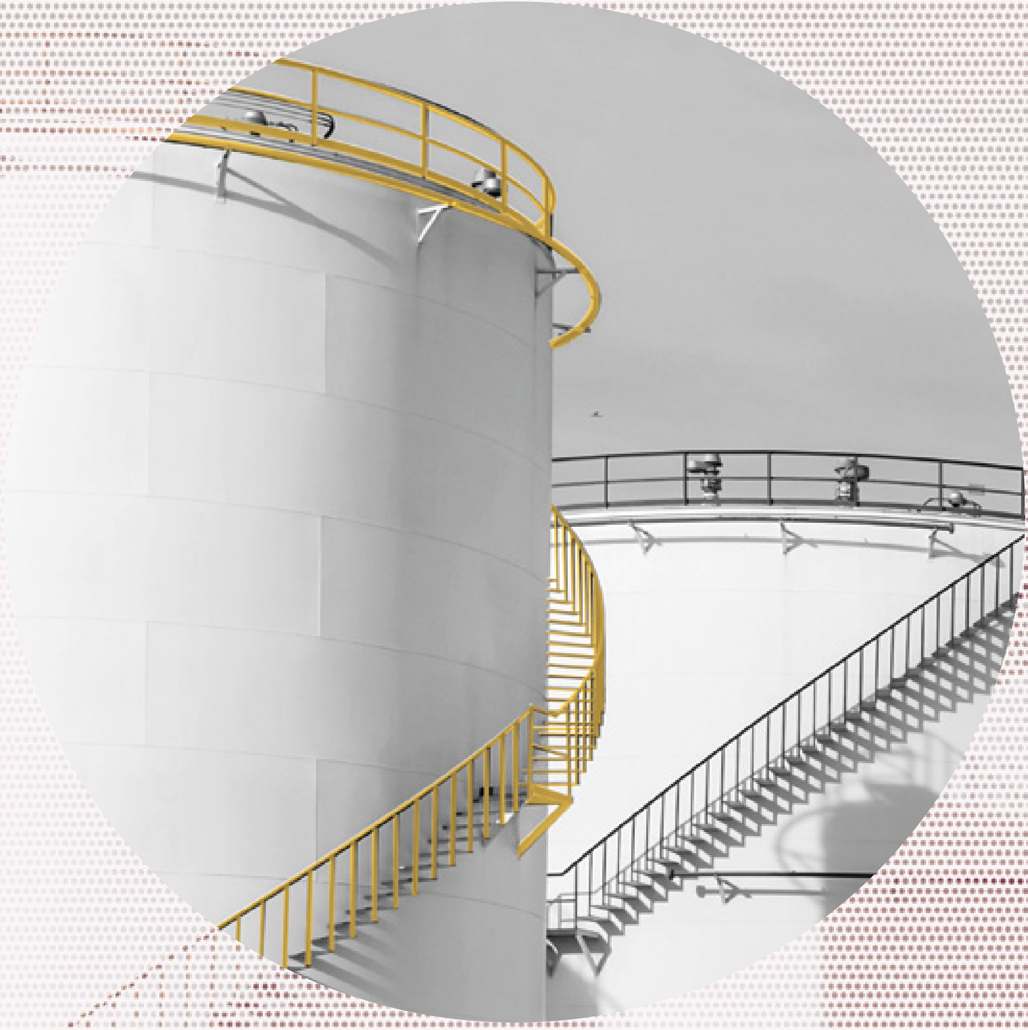
AGENCY FOR
ECOLOGICAL
TRANSITION

SECTORAL TRANSITION PLAN FOR THE FRENCH CHLORINE AND ETHYLENE INDUSTRIES



EXPERTISES

CHLORINE AND ETHYLENE

Summary report

MARCH
2025

With the
contribution of the
European Union
LIFE programme

Finance
ClimAct

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Cross-cutting editorial

Sylvain WASERMAN
Chairman and Chief Executive Officer of ADEME

The chlorine and ethylene industries are part of a colossal value chain, making them important cogs in the machine that is France's manufacturing sector. Vital to the production of plastics and many chemicals and pharmaceuticals, they contribute greatly to French innovation and the country's trade balance. The chemical industry has made great strides in emissions reductions since the 1990s, yet these two sectors are today still responsible for 8.5% of France's total industrial emissions. While they run on different types of energy and generate different kinds of emissions (steam and gas for chlorine, naphtha and fossil resources for ethylene), both will need to decarbonise if the country is to achieve its climate targets by 2050.

In collaboration with France Chimie and industrial stakeholders in both sectors, ADEME has built comprehensive models and produced a full analysis, with three highly instructive transition scenarios. Each of these scenarios is very different, but all three apply to both the chlorine and ethylene industries, highlighting the range of technological, economic, and societal challenges they face on the road to decarbonisation. Against a backdrop of high energy prices and fierce international competition, decarbonisation can be seen as an opportunity to rebuild competitiveness and forge greener credentials for an industry currently reliant on fossil resources.

The trio of scenarios shows that the challenge can be approached in a variety of ways, and a combination of technologies and solutions will no doubt be required if decarbonisation targets are to be met. That includes upgrades to production facilities, some of which may be mature and already well embedded, while others may require more drastic changes to existing processes. In addition, the significant infrastructures needed to produce, transport and store electricity, hydrogen, and CO_2 will require closer cooperation between government and industry. At the same time, the industries will need to adjust to the changing regulatory context and in particular the French law combating waste and promoting the circular economy. Known informally as the "AGEC" law, it will impact the single-use packaging market and encourage recycling, enabling for the sector to diversify and introduce greater circularity. Finally, it will be vital for the French chlorine and ethylene industries to remain competitive in the face of global competition.

This study of the chlorine-ethylene industry is the last in a series looking at France's nine most energy-intensive sectors, and marks a crucial step towards the future of industry transition plans in France and Europe. Building on this work, forward-looking studies and additional inter-sector analyses will be carried out covering the whole of France, while standards and methodologies will be published. These combined efforts will continue to connect up industry and business-level transition plans with national and European planning in the coming years.

We would like to extend our warmest thanks to all those who contributed to this work, particularly professionals in the chlorine and ethylene sectors, and France Chimie.

Magali Smets
Managing Director of France Chimie

Base Chemicals companies operating steam crackers and chlor-alkali electrolysis are an asset for France: they provide the building blocks of a vast range of products that are essential to the economy, both for everyday products and in high-tech sectors, including energy transition technologies. The Covid-19 crisis and geopolitical tensions are a reminder that they are critical to the sovereignty of France and the European Union.

However, their continued existence on French or European soil is now being called into question by strong competitive pressure from countries with abundant energy resources, which are subsidising their production more and more, and often meeting less strict environmental standards.

It is against this backdrop that the Base Chemicals industry must successfully achieve its transformation to significantly reduce its greenhouse gas emissions and thus contribute to achieving carbon neutrality by 2050. In order to anticipate the changes that need to be made, a number of planning exercises have been carried out, leading to the signing of ecological transition contracts by the 50 sites that emit the most greenhouse, and the publication of decarbonisation roadmaps by the sector federations.

ADEME's chlorine/ethylene ecological transition plan takes a different and complementary approach by imagining contrasting scenarios, testing different market trends, in particular the evolution of electricity, gas and CO_2 prices, ansd estimating their impact on decarbonisation strategies. It has enabled companies to re-examine the mix of solutions to be implemented and to identify the assumptions whose level of uncertainty needs to be reduced. This plan converges with the work of the sites and federations on the essential conditions for a competitive energy transition: a competitive supply of low-carbon electricity, appropriate public support, trade defence mechanisms, infrastructure for transporting electricity, CO_2 and hydrogen, and a favourable framework for recycling polymers. It shows that there is a way to boost the competitiveness of a sector in France that is essential to building a resilient, low-carbon economy in Europe.

We welcome this detailed modelling and scripting by ADEME, with the support of the companies involved in this Sectoral Transition Plan. It sheds valuable light on how to choose the path towards a more sustainable and competitive industry.

Project background

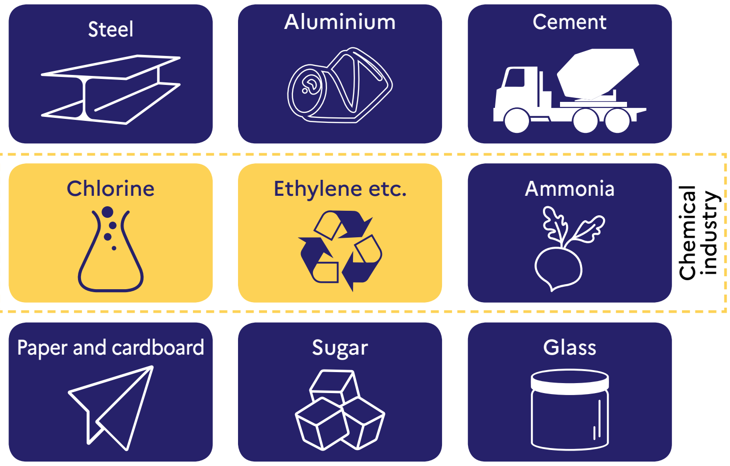
From the National Low-Carbon Strategy to the Sectoral Transition Plan

The current National Low-Carbon Strategy (SNBC) sets out the path France intends to take to achieve carbon neutrality by 2050, a commitment it made following the 21st Conference of the Parties (COP 21) convened under the United Nations Framework Convention on Climate Change (UNFCCC). For manufacturing industry, this objective translates into an 81% reduction[1] in greenhouse gas emissions (GHG) compared to 2015. While a number of guidelines have been put forward (e.g. giving priority to low-carbon energies, improving energy efficiency, developing breakthrough technologies, etc.), there have so far been no details on timeframes and the way they will apply to different sectors. Yet the challenges of decarbonising industry vary greatly from one sector to another. Moreover, industry needs medium-term visibility to make investments: industrial plant has a lifespan of several decades, so the effects of today's investments will continue until 2050. For the government, the aim is to put forward effective policies in support of the decisions needed to achieve national emissions reductions targets.

By drawing up these Sectoral Transition Plans (STPs) in consultation with the key stakeholders in the sectors concerned, ADEME aims to provide visibility for both manufacturers and investors, as well as the government. The project is therefore a continuation of the work carried out for the SNBC, breaking down heavy industry into nine sectors (Figure 1) in order to tailor decarbonisation solutions for each one.

Part of a European LIFE programme[2] called Finance CliMAct[3], the aim of these transition plans is to explore different decarbonisation scenarios in order to identify the transformations in industrial sectors required for a carbon-neutral society. This project takes a 360° view, looking not only at the technological aspects but also at markets, funding, costs and jobs. Ultimately, this work should lead to the formulation of proposals for "public-private" actions to accelerate transition in these key sectors.

Figure 1.
The nine industries with STPs.



This document summarises the main results of the Sectoral Transition Plan for the ethylene and chlorine sectors.

STP method

Phase I : Survey of the industry. This phase entails mapping the market (consumption, imports-exports, production) and building a model representing the energy consumption, GHG emissions and production costs of French industry in 2015.

Phase II : Projections. Each scenario is based on (i) the projection of a transition environment, (ii) the formulation of assumptions about market trends and the implementation of decarbonisation technologies, (iii) modelling and (iv) analysis of the results.

Phase III : Development of action plans. The method, tools and assumptions used are described in greater detail in the full report.

In a dedicated guide, ADEME sets out the method used to construct the various STPs, step by step, illustrated by feedback on STPs carried out by ADEME.

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[1] Ministry of Energy Transition, 2020, National Low-Carbon Strategy.

[2] The LIFE programme is a European funding programme for the environment and climate action created in 1992. The 2014-2020 period had a budget of EUR 3.4 billion.

[3] Website: finance-climact.fr

Project

Finance ClimAct

With the contribution of the European Union LIFE program

30
people working full time on the project

18
million euro budget

5
years

Project objectives

Regulation & supervision

French and EU plans on sustainable finance

CTH

Observatory

Stress-tests

Households

Facilitating retail investors' investment decisions based on environmental objectives.

The project supports our understanding of retail investors' expectations regarding sustainability and their ability to act upon them (Investors Preferences) and puts in place a clear and credible information to identify sustainable financial products (Labels).

Preference

Financial institutions

Taking climate change into account in financial sector management and supervision.

The project equips financial institutions and their supervisors to integrate climate into risk management while promoting long termism (PACTA and Climate Stress-Tests) and to encourage transparency regarding the contribution of institutions to the mitigation of climate change and their resilience to its consequences (Climate Transparency Hub and Sustainable Finance Observatory).

PACTA

Greenfin

European Ecolabel

ACT

PACTE Industrie

Industry

Favour investment in energy efficiency and the low-carbon economy, in line with the National Low Carbon Strategy and the European Green Pact.

The project aims to train and equip companies and their financiers to develop low-carbon strategies (ACT) and enable the implementation of energy efficiency and low-carbon projects in the most emissive industrial sectors (INVEEST and Sectoral Transition Plans).

Sectoral Transition Plans

Projet partners

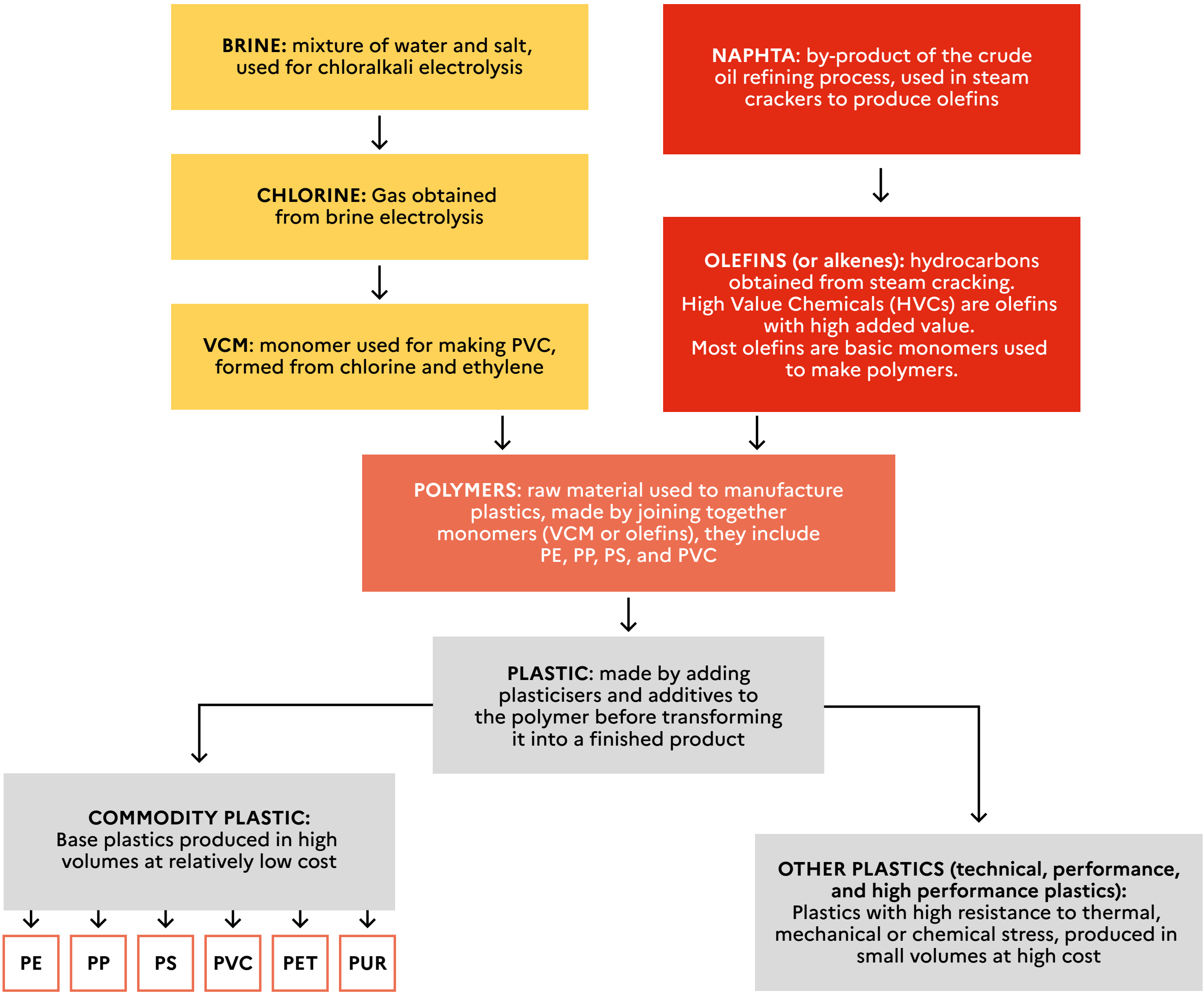
ACPR, AMF, Banque de France, Finance for Tomorrow, GreenFlex, Institute for Climate Economics, Ministry of Ecological Transition, 2° Investing Initiative, Institut de la Finance Durable, RMI (Rocky Mountain Institute)

Scoping for the combined study of Chlorine and Ethylene (olefin) production

At first glance, the chlorine and ethylene sectors might appear quite different, in terms of both the production processes they used and the products they make. The first deals with mineral chemistry, and uses electricity to turn salt into chlorine, while the second involves organic chemistry, specifically "cracking" hydrocarbons to produce molecules for the petrochemical industry. **But both sectors come together further down the value chain, contributing to the manufacture of polymers used to make plastics.** Most of the olefins produced by steam cracking (ethylene, propylene, etc.) are subsequently used to produce plastic materials for a variety of purposes. Similarly, over half of the chlorine produced in France is used in combination with ethylene to make vinyl chloride monomer (or VCM), which is in turn used to manufacture polyvinyl chloride, more commonly known by the acronym PVC. As a result, these two sectors share a part of their value chain - plastics. It is for this reason that they are dealt with jointly in this report.

Figure 2 below shows the different chemicals and compounds considered in this report:

Figure 2. Simplified diagram showing the relationships between the different chemicals considered and modelled in the chlorine and ethylene STP.



In addition to the basic inputs and outputs of the processes, the report looks at two specific categories of products:

- **High Value Chemicals (HVCs):** Of the olefins, HVCs are the main marketable products derived from steam cracking, and include ethylene, propylene, butadiene, acetylene, benzene, and hydrogen. Not only are HVCs the main yardstick used by petrochemical manufacturers to measure their production, but they are also used as a reference in the EU-ETS[4] benchmark for steam crackers[5]. This category is mainly used to construct technological models for steam crackers.
- **Commodity plastics:** manufactured in high volumes at relatively low cost, this category includes the world's six most common plastics:

- High and low-density polyethylene (PE)
- Polypropylene (PP)
- Polystyrene (PS)
- Polyvinyl chloride (PVC)
- Polyethylene terephthalate (PET)
- Polyurethane (PUR)

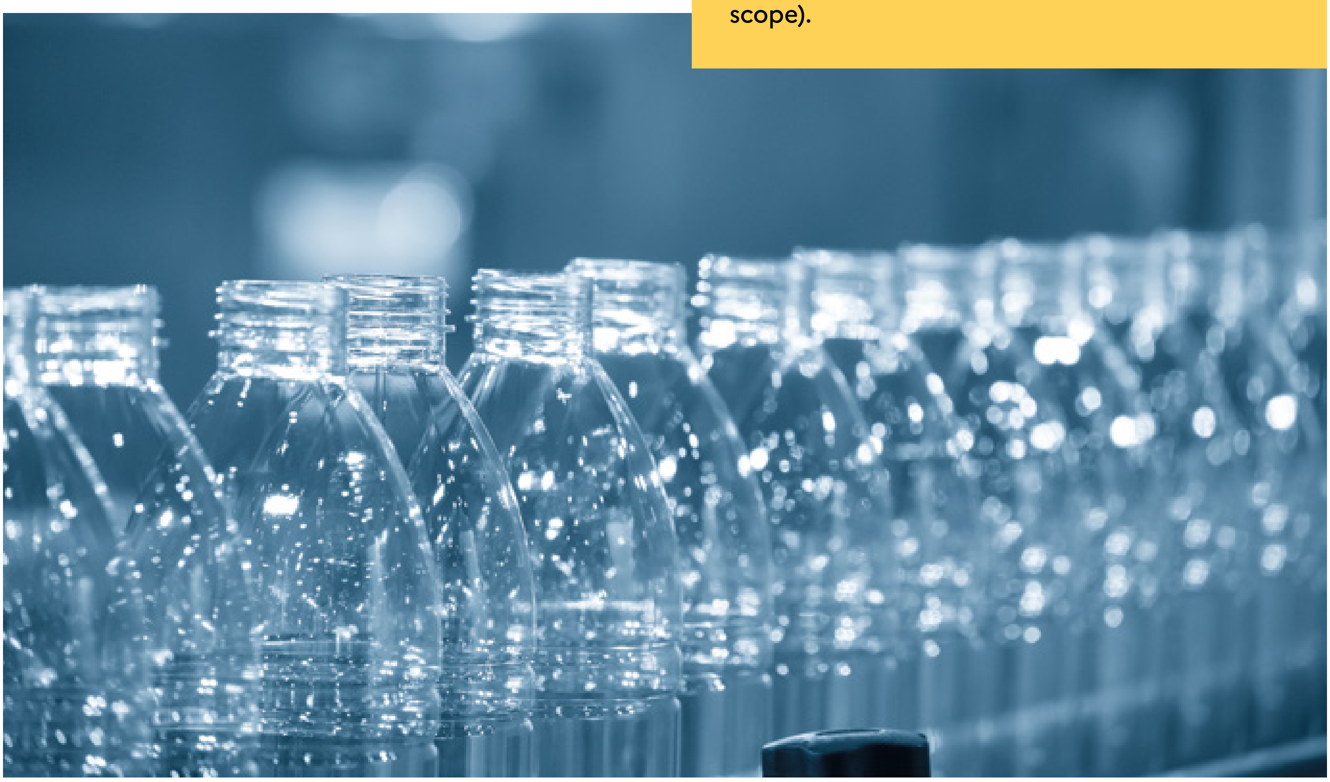
Of these six commodity plastics, technological models were only built for PE, PP, PS, and PVC in the Sectoral Transition Plan.

The scope of the models was limited, owing to the complex nature of both the technologies concerned and the sector's value chain. Detailed models were only developed for a selection of products. These do, however, represent the majority of the French sector's industrial output (approximately 60% for polymers, and over 90% for HVCs).

Specific industries, such as those linked to organic, inorganic, and fine chemicals, or other types of plastics are included in the market models.

Why is PET included in the "market models" only, rather than in technology models?

Polyethylene terephthalate (PET) is one of the best-known commodity polymers. It is among the most popular virgin polymers in France, with some 410 kt[6] tonnes used in 2019. Unlike other commodity plastics, all PET used in the country is imported, France's last production facility having closed in 2009. For this reason, PET has been excluded from the technological models developed (i.e. direct scope) for this study. However, the PET market (imports and exports) and the recycled polyethylene terephthalate (rPET) market (manufacture, imports, exports, recycling) are both included in the market models (indirect scope).



➜ Empty PET bottles on a conveyor belt © Pixel B/Shutterstock

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[4] EU ETS: European Union Emissions Trading System

[5] Guidance Document No. 9 on the harmonised free allocation methodology for the EU-ETS, 2019

[6] https://presse.ademe.fr/wp-content/uploads/2024/03/Bilan-national-du-recyclage-2012-2021.pdf

The main limitations of the exercise

All the results presented are based on an ambitious exercise to model decarbonisation trajectories for the ethylene and chlorine industries going forward to 2050, using an innovative methodology that nonetheless has certain limitations, particularly in terms of scope and access to data. Readers should take this into account when looking at this document, especially in terms of the conclusions that they may draw from it. In particular, it is important to consider the following:

• A common emissions reduction target for different industrial sectors:

The SNBC's[7] 81% reduction target for the manufacturing industry was applied to the chlorine and ethylene sub-sector as an input constraint for the scenario-building exercise. This has the advantage of defining a common framework for all the sectors covered by a Sectoral Transition Plan. However, this assumption closes the door to a more flexible allocation of emissions reduction targets between industrial sectors for which abatement potentials and associated decarbonisation efforts may be different. An analysis of all sectors could eventually contribute to defining more appropriate targets.

• A limited objective that does not take into account all the criteria for the ecological transition:

The current National Low-Carbon Strategy's (SNBC 2) target for the manufacturing industry focuses on direct GHG emissions (category 1) and therefore does not take into account emissions from power generation (category 2) or indirect emissions upstream and downstream of the value chain (categories 3, 4, 5 and 6). Owing to the specific features of the chlorine sector, which is energy-intensive and demands large volumes of imported steam, category 2 is nonetheless treated separately in the chlorine-VCM-PVC value chain. This is not the case for the production of olefins and other polymers. Similarly, the target does not take into account carbon footprint variations resulting from increases or reductions in olefin, chlorine, and polymer imports. Finally, this single-criterion target does not take account of impact transfers to other types of pollution (air, water, resources, and human health).

• A broad-brush view of an ethylene and chlorine sector heavily dependent on external factors:

The aim of this exercise is to provide an overview of the factors affecting GHG emissions from the manufacture of olefins, chlorine, and polymers. It was therefore necessary to make assumptions about parameters outside of the sector, such as demographics and changing social attitudes to the use of plastics. To enable comparisons, energy and CO_2 price trajectories were set in the same way in all the scenarios, with an accompanying economic analysis at the end of the report. An analysis of the way these factors impact the competitiveness of the ethylene and chlorine industries is, however, a different exercise, and requires an in-depth study looking at how ethylene, chlorine, and polymer supply chains are likely to be organised in the future.

• This sectoral approach could be further enhanced by other factors determined by other economic actors:

Since the olefin and chlorine industries are a node in a complex economy that interacts with upstream and downstream entities (themselves evolving), an exhaustive, systemic approach to decarbonising the sector would require adopting a vision that goes well beyond the scope of this sector, and therefore numerous assumptions about other nodes in the system. This is the goal of ADEME's broader outlook project, entitled "Transition(s) 2050"[8], published at the end of 2021.

• Furthermore, as in any foresight exercise, the range of assumptions and combinations of assumptions is infinite, and each scenario could be "challenged" further:

While they are not predictions, these scenarios are essentially the product of internal work done by ADEME that has been put to industry stakeholders for their feedback. They reflect possible situations that are technically plausible, and more or less desirable. The aim is to help industry stakeholders take ownership of the exercise, each within the realm of their own prerogatives and with the same requirement for transparent assumptions and scenarios, while acknowledging the limitations of this exercise.

Incidentally, the full report that accompanies this summary provides additional information on the context of the scenarios and the way in which the transition could occur in terms of jobs or potential industrial strategies. The aim is to broaden the scope of reflection in relation to the various results of the summary. These elements of analysis, which can be described as academic, are based on extensive bibliographical research and sources of public information, as well as interviews with industry stakeholders, and are intended to be as objective as possible, given the cross-referencing of all these sources by the authors.

[7] The current revision of the National Low-Carbon Strategy (3rd edition) will potentially result in the definition of new sectoral objectives.

[8] For more information, visit the dedicated website: https://transitions2050.ademe.fr/

The chlorine and ethylene[9] industries: some statistics[10]

CHLORINE

6 operators with 9 chlorine and VCM production sites

1 Mt of chlorine and 900,000 t of VCM manufactured annually

1 Mt of CO_2eq
or 1% of French manufacturing industry and 5% of chemical industry emissions

3 TWh of electricity used
for chlorine electrolysis, and 2.5 TWh of imported steam

50%
of chlorine produced used to manufacture PVC, the rest used by the chemical industry

3,930 direct jobs and 3,960 indirect jobs in 2020

POLYMERS

6 sites dedicated to polymerisation of PVC and 10 polymerisation units (for PE, PP, PS)
83% of which are on or near a steam cracking site

2.1 Mt of PE, PP, and PS imported

700,000 t of PVC exported
with 85% going to Europe and 1.8 Mt of PE, PP, and PS exports

100 %
of French PET is imported (last PET production site closed in 2009)

1.15 Mt of PVC
produced and 3.7 Mt of PE, PP, PS produced annually

More than 60% of PVC is used by the construction industry

ETHYLENE

5 operators with 6 olefin production sites

4.5 Mt of naphtha used annually on average to produce olefins

5.8 Mt of HVC
produced annually on average (ethylene, propylene, butadiene, BTX), or 13% of European olefin output

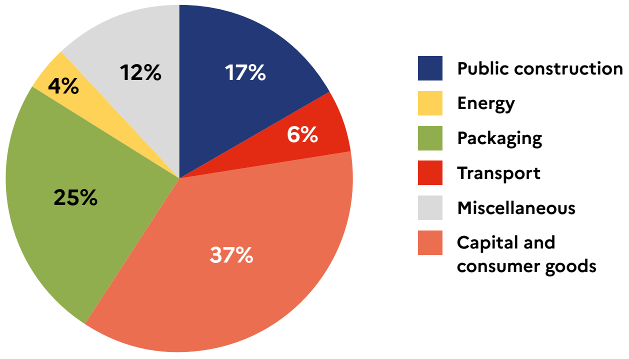
5.3 Mt of CO_2eq
or 7.5% of French manufacturing industry and 25.4% of chemical industry emissions

10 %
of HVCs imported for use, equivalent to 0.45 Mt, almost half of which is propylene

10 %
of HVCs produced for export, equivalent to 0.58 Mt, almost two-thirds of which is ethylene and propylene

3,300 direct jobs and 1,860 indirect jobs in 2020

PLASTICS



End use of plastics (components and products) by sector in 2015

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[9] The polymers considered by the Ethylene STP are commodity plastics such as PE, PP, and PS / [10] Mean 2015 – 2019

Summary for decision-makers

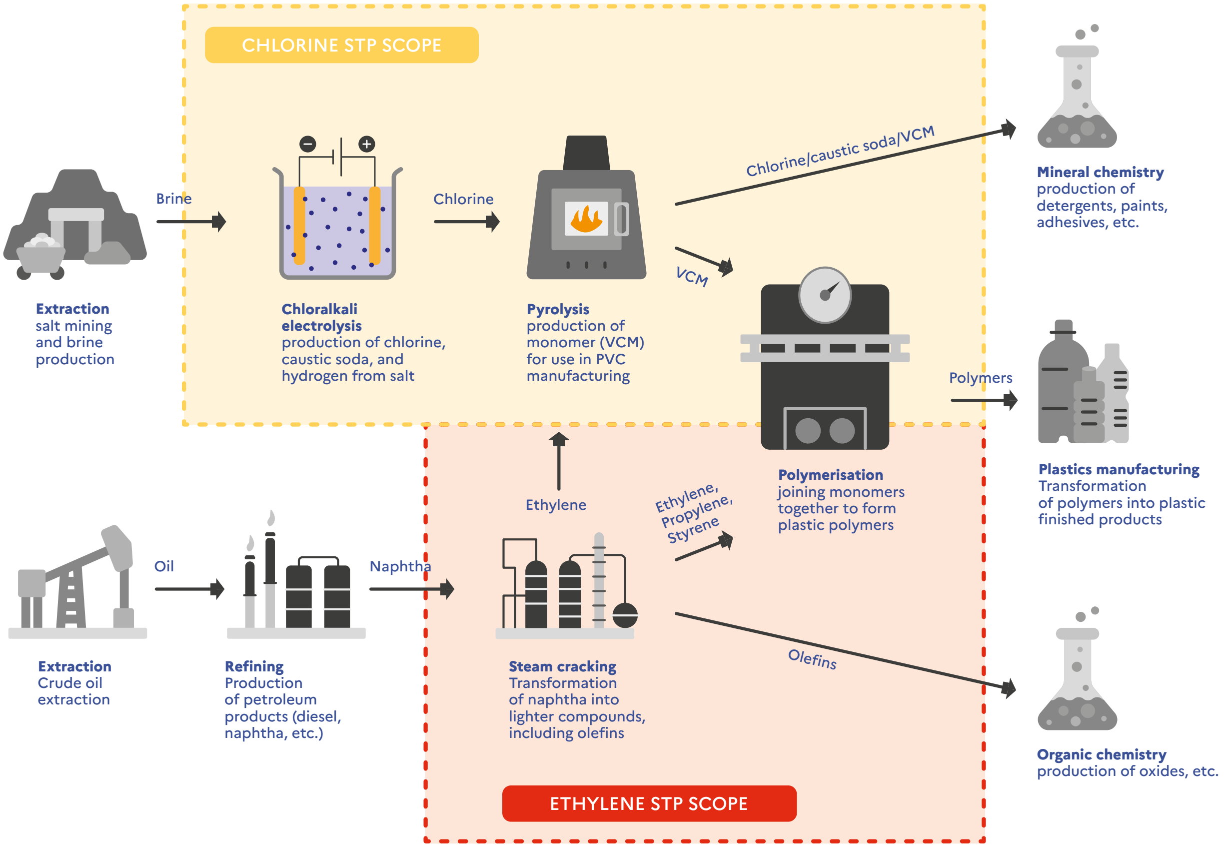
Chlorine and olefins: crucial for the plastics and chemical industries.

The chlorine and olefin sectors respectively account for around 0.5% and 7.5% of French industrial GHG emissions. Meanwhile, the chlorine industry demands 4 TWh/year of electricity, and the ethylene industry uses 26 TWh/year of co-produced fossil energy inputs (not including electricity), making them two of the most energy-intensive sectors. Both are central to the base chemicals sector, and are crucial for France's plastics and fine and speciality chemicals industries, the second largest in Europe behind Germany in 2019.

More than 4.5 Mt of polymers manufactured in France every year come from olefins and chlorine produced by French steam crackers and electrolysers respectively, along with 4.9 Mt of chemicals ranging from cosmetics to detergents and oxides. As in many capital-intensive industries, there are a limited number of operators, most of them international groups capable of financing the chemical platforms needed. The olefins sector is made up of five major players (TotalEnergies, Ineos, ExxonMobil, LyondellBasell, and Eni) operating steam crackers based on integrated chemicals platforms capable of producing between 250 kt/year and 740 kt/year of olefins and aromatics, along with PE, PP, and PS polymerisation lines. The chlorine sector, meanwhile, is split into two categories with different target markets. Two of the largest companies, Kem One and Inovyn, specialise in PVC and together account for more than 80% of chlorine and PVC production capacity. The rest is shared between five operators with more modest production capacities, mostly focused on speciality chemicals. Geographically, most ethylene facilities are to be found in industrial port complexes, whereas chlorine facilities are based near hydro-electric power plants. This is due to the history and specific features of the two sectors, with ethylene requiring access to large quantities of raw material imported close to refineries, while the more energy-intensive chlorine sector was initially established in areas with easy access to large amounts of electricity.

The interactions between the main manufacturing processes analysed in the chlorine and ethylene STP are shown in Figure 3 below.

Figure 3. Main production processes and products studied in the Chlorine and Ethylene STPs.



At the top of this chain, the main raw materials used are naphtha and LPG (liquefied petroleum gas) derived from refined crude oil for the ethylene sector, and brine (a mixture of salt and water) for the chlorine sector. Naphtha is used in the steam cracking process to produce olefins (ethylene, propylene, butadiene, etc.), while brine is subjected to electrolysis to produce chlorine and sodium hydroxide (caustic soda). Olefins can be used in organic chemistry to manufacture PP, PE, PS, or to make ethylene glycol and in the chemical or cement industries. Chlorine can be used in the inorganic chemicals industry or mixed with ethylene to make VCM, which is then polymerised to produce PVC. Once the polymerisation process is complete, the resulting plastics can be customised with additives and plasticisers before being turned into finished products.

Most of the commodity plastics made in France are exported (2.7 Mt in 2015, or 59% of total output), with 85% of exports going to EU countries. While these figures have tended to fluctuate from year to year, falling slightly since 2015, they underline the importance of the European market for French industry. A similar trend can be seen for imports. Although plastic is now omnipresent, the sectors in which it is ultimately used in France depend largely on the type of polymer concerned: packaging for PE, construction for PVC and PS, capital and consumer goods[11] and the automotive industry for PP. In France in 2015, 37% of all plastics were used by the capital and consumer goods sector, 25% by the packaging sector, 17% for construction, 6% for transportation, 4% for energy, and 12% for other sectors.

➜ Transparent HDPE pellets © Stanislau Valynkin/Shutterstock

The future of plastics hinges on multiple factors:

• International trade and the competitiveness of the polymer sector

While France remains Europe's leading manufacturer of polymers (alongside Germany), the market has been heavily impacted by the war in Ukraine and the resulting higher energy and oil prices. Faced with rising prices, French plastics firms are increasingly turning to cheaper imported polymers (mainly from the US and China), and clients further down the value chain are even directly importing finished plastic products. At the same time, the Chinese domestic market has cooled in recent years, leading Chinese polymer manufacturers to look to new markets overseas, including in Europe. As globalisation has accelerated, the European polymer market – historically dominated by EU countries – has found itself competing against foreign actors, further complicating the playing field for a French industry already struggling to remain competitive.

• The rise of plastic recycling

In the decades to come, the growth of plastic recycling – and therefore the quantity and quality of recycled feedstock available on the market – could reduce the need for virgin raw materials, and in turn demand for petrochemicals and chlorine. Although recycling has been developing steadily over the last 15 years, the overall proportion of recycled material in products remains low, at an estimated 15% in France[12]. This means there is considerable scope for progress. In addition to improvements in waste collection, many plastics are currently difficult to recycle using mechanical means[13] (the most commonly used technology), while the relatively low price of virgin plastics compared with recycled plastics offers little incentive to invest. Despite this, the development of new chemical recycling techniques[14], new regulations, and new waste collection schemes like ERP (Extended Producer Responsibility)[15] could accelerate the growth of recycling in the years ahead.

- **Pro-circular economy regulatory developments**

The AGEC law[16] combating waste and promoting the circular economy is targeting the sale of single-use plastics with a panel of measures by 2050, including plans to phase out the use of single-use plastic packaging by 2040. At the same time, the EU's Packaging and Packaging Waste Regulation[17] aims to introduce similar measures (albeit slightly less ambitious) to those set out in the AGEC law in terms of reducing single-use plastics[18] while promoting recyclability and circularity rates. As a result, the entire European market – the main outlet for French polymers – will have to contend with falling demand for packaging-grade plastics. Given that packaging represents around 25% of the market for olefins, and single-use packaging accounts for most of that figure, these laws will have a game-changing impact on demand for PE and PET, the main plastics used for packaging.

- **Alternative olefin production methods and carbon content-related changes**

More and more industrial players, whether equipment manufacturers or suppliers of solutions (e.g. Axens, Honeywell), or operators (e.g. Braskem, Syclus, Sumitomo Chemicals) are offering low-carbon and/or bio-based propylene and ethylene made using processes such as Methanol To Olefins (MTO)[19] or Bioethanol To Olefins (BTO)[20]. While the quantities produced are currently negligible compared with petroleum-based olefins, a combination of different mechanisms (regulatory changes, rising demand for low-carbon products, etc.) could lead to these processes being used more widely, ultimately competing with the French incumbent producers. Incidentally, while there are not yet any European regulations on the re-use of captured (in particular biogenic) CO_2 in plastics or chemicals as a substitute for fossil carbon, captured CO_2 combined with H_2 could be used to manufacture polymers that can then be turned into plastic products[21]. If the technical and regulatory obstacles can be overcome (e.g. energy penalty, carbon content calculation, etc.), Carbon Capture and Utilisation (CCU) would open up new and potentially strategically important markets in the next few decades. However, CCU is no substitute for root-and-branch, sector-wide decarbonisation.

Taken together, these developments would imply a raft of changes in the plastics industry, whether in terms of demand in certain markets (most notably packaging) or industrial firms' production methods and positioning.

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[11] Consumer goods are products purchased by households for personal use and consumption, such as food and clothing, while capital goods are tangible assets used by businesses to produce other goods and services, like machinery and tools.

[12] The percentage of recycled materials used in new products varies depending on the sector and type of plastic concerned (https://presse.ademe.fr/wp-content/uploads/2024/03/Bilan-national-du-recyclage-2012-2021.pdf).

[13] Mechanical recycling, which currently accounts for 99% of all plastic recycling in France, involves shredding or milling plastic waste, then heating it to make new products.

[14] Chemical recycling involves converting polymeric waste back into monomers or making new feedstock by altering the chemical structure of plastics by cracking, gasification, or depolymerisation. Although it does not change the polymer's chemical structure, dissolution is also classed as a form of chemical recycling, whereas mechanical recycling does not use chemical reactions or solvents to purify the material.

[15] Extended Producer Responsibility is inspired by the "polluter pays" principle. Under the EPR scheme, economic operators (manufacturers, distributors, importers) are responsible for the entire life cycle of the products they market, from design to end of life.

[16] Law No. 2020-105 of 10 February 2020 on anti-waste efforts and the circular economy, known informally as the AGEC law.

[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0677

[18] Single-use plastic products (SUPs) are used once, or for a short period of time, before being thrown away.

[19] Process of synthesising olefins from methanol.

[20] Process of synthesising olefins from bioethanol.

[21] CO_2 storage in plastic products should primarily concern long-life products.

[22] CCU (Carbon Capture and Utilisation) involves capturing CO_2 for use as a direct feedstock or for synthesising fuels, chemicals, or materials.

Three scenarios to illustrate the challenges of decarbonising these sectors

The three decarbonisation scenarios suggested for the chlorine and ethylene sectors in these STPs were deliberately chosen to reflect contrasting situations, intended to highlight different technological and market trajectories.

The main assumptions on which they are based are shown in Table 1 and the associated parameters described below.

- The **"Petrochemicals and globalisation"** scenario assumes a highly competitive and globalised economy for the plastics industry, with European industrial producers losing ground to their international rivals, causing France's trade balance to deteriorate. Under this scenario, decarbonisation is achieved mainly through Carbon Capture & Storage[23] (CCS), along with mature energy efficiency measures and low electrification.

- The **"Electricity and European protectionism"** assumes that a mechanism will be introduced to regulate plastics imports from non-EU countries. By focusing on the European market, the main source and destination for French polymer imports and exports, French industry can win back market share with the help of substantial State aid, under a policy designed to modernise energy and logistical infrastructures while also supporting RDI[24]. There are two main decarbonisation drivers here: first, a well-developed power grid capable of allowing mass process electrification, whether for steam crackers or the chlorine industry; and second, strong support for the rollout of innovative technologies, such as selective membranes or MTO in the ethylene sector.

- The **"Bio-based and local specialisation"** scenario assumes that all European countries – including France – will adopt a more local outlook, prioritising their domestic industries and markets. This results in a decline in trade affecting both imports and exports. Combined with the introduction of circular economy measures and the rapid development of mechanical recycling, demand for virgin polymers contracts and manufacturers look to stay competitive by specialising in products with high added value, particularly bio-based products. The decline in output in turn causes emissions to fall sharply, while investments improve the energy efficiency of steam crackers and electrolysed hydrogen is used as a substitute for fossil-based feedstocks.

Table1. Main market and technology assumptions modeled for the three scenarios.

	Petrochemicals and globalisation	Electricity and European protectionism	Bio-based and local specialisation
Polymer demand	↘	↘	↘
Polymer trade balance	↘	↗	→
Polymer recycling type and increase/decrease in circularity rate	Pyrolysis ↗	Mechanical and chemical ↗	Mechanical ↗↗
Polymer production	↘↘	→	↘↘
Main technological choices	CCS	Electrification	Energy efficiency and use of bio-based materials

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[23] Carbon Capture & Storage: a technology that entails capturing CO_2 from industrial processes and fumes and then storing it permanently underground.

[24] RDI: Research, Development and Innovation.

All of the scenarios either meet or exceed the SNBC 2 target set for industry of reducing category 1 emissions by 81% between 2015 and 2050, including for category 2 emissions in the chlorine sector, as shown in Table 2.

In terms of learnings, the "Petrochemicals and globalisation" scenario illustrates the risk that French polymer manufacturers and naphtha-based steam crackers could lose market share to China and the US in a context of high energy costs, and the impacts of widespread CCS adoption on the sector's energy use.

Conversely, the "Electricity and European protectionism" shows the importance of Europe as the main market for French polymers, and the impact on production levels of maintaining exports. Mass electrification opens up the possibility of energy savings, which in turn limits production cost increases, but requires heavy investment in plant resulting in an additional 10.5 TWh of electricity consumption by 2050.

Finally, the "Bio-based and local specialisation" scenario assumes that people will adopt more resource-efficient lifestyles, with manufacturers needing to anticipate the resulting decline in production in order to preserve business and jobs in the sector. There are also considerations to do with biomass that can be used by biorefineries or Bioethanol To Olefins (BTO) units, and the high CapEx[25] costs of modernising the steam cracker fleet.

Table 2. Main technical and economic outcomes of the three scenarios vs. benchmark year 2015.

	Petrochemicals and globalisation	Electricity and European protectionism	Bio-based and local specialisation
Direct ethylene sector emissions vs. 2015	-82 %	-81 %	-81 %
Direct and indirect chlorine sector emissions vs. 2015	-90 %	-92 %	-94 %
Ethylene electricity consumption	+3 TWh	+10.5 TWh	+3.3 TWh
HVC production vs. 2015	-35 %	-14 %	-42 %
Chlorine production vs. 2015	-32 %	-3 %	-47 %
Investments	€4 billion	€6.1 billion	€7.3 billion
HVC production costs	x2.2	x1.9	x2.7
Chlorine production costs	x1.22	x1.13	x1.25

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[25] CapEx: Capital Expenditure

Key learnings

Infrastructure planning: a challenge for the adoption of decarbonisation technologies

The introduction of decarbonisation technologies generally goes hand in hand with the need for appropriate infrastructure. This includes new decarbonised power generation facilities and distribution networks in the "Electricity and European protectionism" scenario, CO_2 transportation and storage infrastructures for CCS in the "Petrochemicals and globalisation" scenario, and hydrogen and renewable energy production in the "Bio-based and local specialisation" scenario. Given the timescales (up to 10 years for an electricity connection) and quantities involved (up to 10 TWh/year of additional electricity consumption), government and industry need to work together to pave the way for the infrastructure needed for decarbonisation. Access to competitively priced electricity is also key to the ability of French industry to withstand the challenge of foreign rivals. Specific decisions will need to be taken depending on exactly where sites are located, since solutions deployed for a whole industrial platform may be different from those suited to standalone sites. Finally, decisions will also be needed on the future supplies of incoming materials and energy, particularly for naphtha given the uncertain outlook of fossil energies and refineries in France, combined with the rise of alternative olefin production methods.

Possible actions:
Conjugate decarbonisation and competitiveness with national infrastructures.

1. Provide support for industrial decarbonisation projects in the form of CapEx and OpEx subsidies

2. Anticipate new infrastructure requirements both locally and nationally

3. Support research and innovation in breakthrough decarbonisation technologies, alternative olefin production techniques, and biorefineries

Plastic recycling: a pressing need for the environment, business, and sovereignty

While this study does not specifically address the environmental impacts of recycling, Life Cycle Analyses (LCAs) of the plastics industry agree that recycling – especially of the mechanical variety – has a smaller footprint than the production of virgin feedstocks. Any future increase in the collection, sorting, and recycling of plastic waste in France in the future will therefore mean three things: reduced demand for virgin raw materials in the polymer industry, higher circularity rates for recycled raw materials among plastics manufacturers, and the need to maintain sovereignty by limiting the reliance on imported naphtha. While polymer manufacturers can stay in business thanks to chemical recycling via depolymerisation or pyrolysis/gasification, this will mean researching and developing new, more technically and economically efficient recycling methods. Industrial specifications will also need to be updated, to improve collection and separation (eco-design) and facilitate the use of recycled raw materials in products. The way plastic waste is managed in France generally will also need to be improved, to guarantee a certain level of sovereignty.

Possible actions:
Expedite recycling and the circular economy whilst anticipating their impacts.

4. Develop recycling and anticipate its impact on the existing industrial fleet (competition between virgin and recycled raw materials)

5. Promote the use of recycled raw materials throughout the value chain and leverage recycled plastic content as a selling point to open up new markets

6. Establish and sustain effective waste management in the interests of sovereignty

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[26] For the first phase, the CBAM covers products in six pilot sectors (iron and steel, aluminium, cement, fertilisers, hydrogen, and electricity).

Constantly changing markets and challenges to be overcome

The international market is the main outlet for French-made polymers, and the European Union is by far the biggest partner for imports and exports. In recent years, however, international competition has intensified for a variety of reasons. High energy prices in Europe, coupled with rising imports from China and the US, have had a not inconsiderable impact on French polymer exports. There is an important need to provide European businesses with a fair commercial framework that emphasises the benefits of low-carbon production. The Carbon Border Adjustment Mechanism (CBAM) due to be introduced soon in six pilot sectors[26] should provide some pointers as to the effect this kind of carbon content regulation will have on Europe's ability to compete. However, a similar mechanism for the plastics sector will need to be adjusted to include the entire plastics value chain and avoid simply shifting imports from polymers to finished products, which would penalise both plastics manufacturers and polymer-makers alike. At the same time, if French firms are able to position themselves strongly in high added value sectors, such as speciality or bio-based plastics, they could win back market share while securing jobs in the industry.

Possible actions: Ensure fair competition to prioritise low-carbon products and safeguard jobs.

7. Leverage public sector purchasing power by introducing carbon content criteria into polymer procurement

8. Look at how to adapt the CBAM to the specific features of the plastics value chain

FOCUS ON CHLORINE

Category 2 emissions, key to sustainability and competitiveness.

While the Sectoral Transition Plans are focused on category 1 emissions (from processes or direct combustion), the chlorine sector is a major consumer of electricity and steam, both of which are associated with category 2 emissions. Most of the emissions generated by the production of chlorine and PVC are category 2, and as such are included in this study. Not only do these emissions have an environmental impact in the form of 1M tonnes of associated CO_2, but they are also important factors for the competitiveness of industry. In the chlorine sector, for example, the decarbonisation methods employed to lower these emissions are technologies designed to reduce the amount of energy used, whether in the form of electricity or steam. With energy prices likely to rise between 2024 and 2050, it is all the more crucial to improve efficiency in order to limit growth in production costs. Most of these technologies are mature and can be deployed at industrial scale within a relatively short timeframe. In addition to cutting emissions, this will also lighten the load on the power system, while helping to decarbonise the network gas mix by reducing the need to produce steam.

FOCUS ON ETHYLENE

RDI and infrastructure development needed for breakthrough technologies.

Unlike the chlorine sector where decarbonisation can be achieved largely via mature, quick-to-deploy methods, root-and-branch decarbonisation of the ethylene sector will rely more on breakthrough technologies. Some of these technologies (e.g. electric steam crackers, selective membranes) are in their infancy, while others (e.g. CCS) may require lengthy leadtimes to deploy or may be unsuited to certain locations. It is therefore important not just to support research and innovation efforts, but to help scale pilot projects for industry-wide application to the existing fleet of steam crackers, thereby moving from an energy mix dominated by fossil fuels to one based around low carbon technology and renewables. The degree to which these technologies are able to penetrate the industry is also likely to be influenced by strong exogenous factors. First, they require dedicated infrastructure to be planned, built, or redeveloped: electricity, H_2, and as a last resort, CO_2. Second, the development of biorefineries is a major challenge in terms of the potential supply of bio-based feedstocks (bionaphtha, bioLPG, etc.) for steam crackers. Finally, new HVC and polymer production methods based on alternative processes like MTO and BTO raise a number of other issues in terms of access to CO_2, H_2, and electricity. Whether or not these methods can actually be adopted in coming decades will depend greatly on the ability to obtain and transport these energy inputs, high production costs, and potential difficulties sourcing bio-based products.

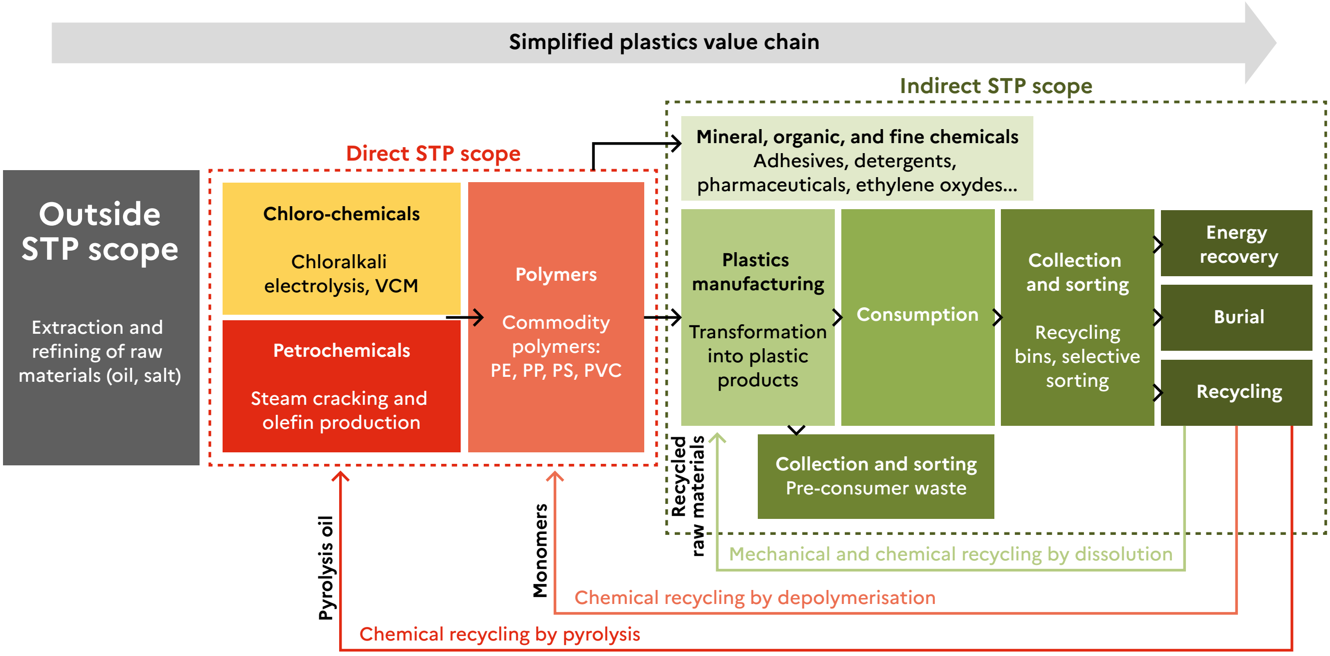
1. Challenges for decarbonising the ethylene and chlorine industries

1.1. A highly uncertain market outlook

1.1.1. Sectors heavily dependent on changes in the way plastic is used

Figure 4 below is a simple illustration of the plastics value chain, showing which elements are included in the technological models (direct scope) and market models (indirect scope).

Figure 4. Simplified plastics value chain and scope of the chlorine and ethylene STPs.



Plastics have a multitude of different applications, depending on the polymers concerned. Some consumer sectors may be buoyed by the transition, for example the automotive sector may grow with the move to electric vehicles, while the construction sector could benefit from energy efficiency renovations. The picture is different for the industrial and household packaging sector, however, which could potentially be severely affected by the adoption of new regulations, such as Act No. 2020-105 of 10 February 2020 combating waste and promoting the circular economy[27] (the AGEC law), the ban on single-use plastic packaging due to come into force in 2040, or the EU's Packaging and Packaging Waste Regulation[28] (PPWR). The use of household and industrial packaging, which represents 1.2 million tonnes of plastics every year[29], mainly PE, PP, and PET, may decline significantly as a result of these measures. The ban on single-use plastic packaging may have a huge impact on demand for polymers, and in turn the production of olefins used to make them. In addition, the growth of recycling will provide plastics manufacturers with a considerably broader supply of recycled raw materials, while plastic products may be more frequently re-used, extending their useful lifespan.

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[27] https://www.legifrance.gouv.fr/loda/id/JORFTEXT000041553759

[28] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0677

[29] Volumes of plastic waste suitable for chemical and physical recycling in France, ADEME, 2022.

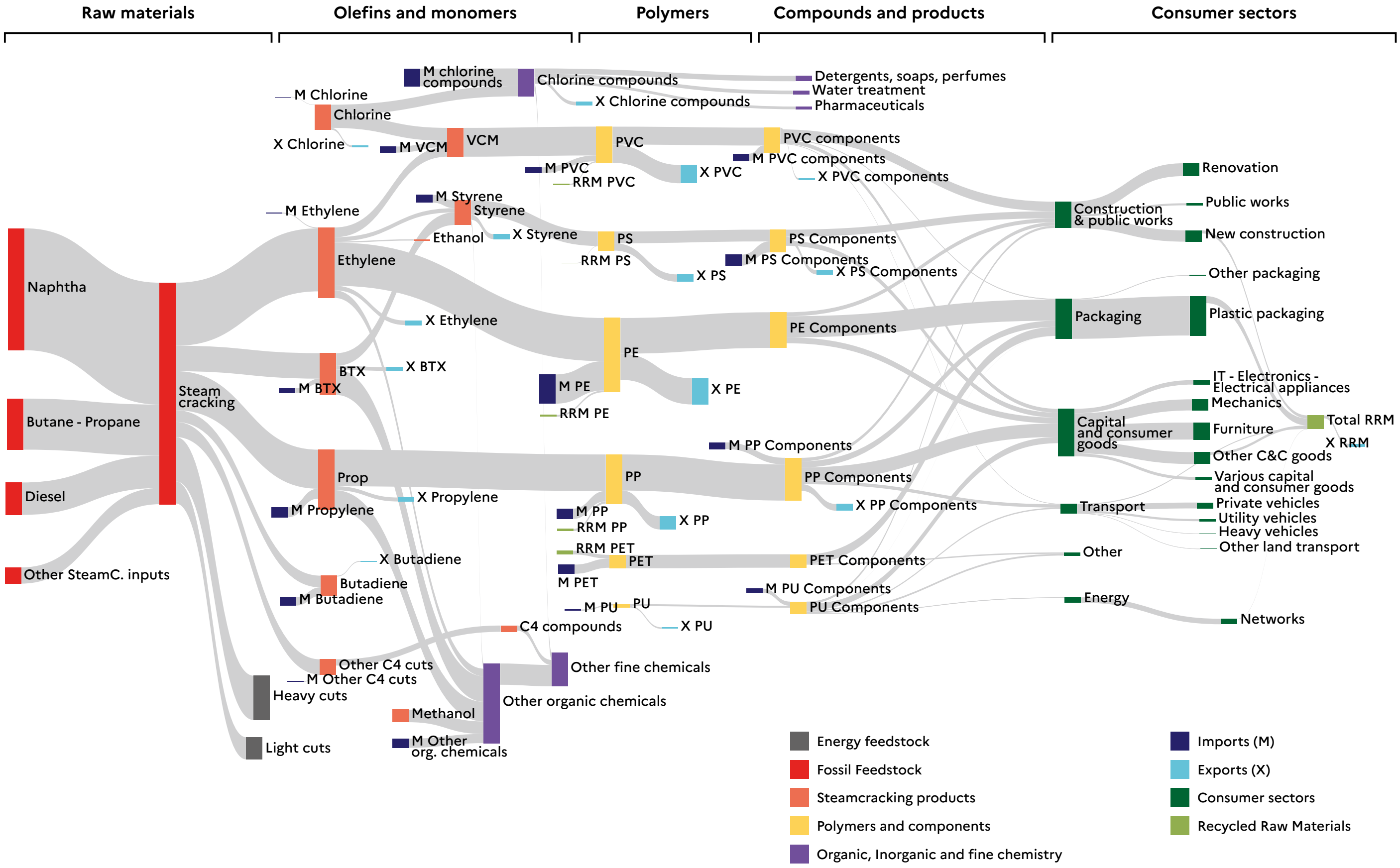
Incidentally, despite being used in France mainly to manufacture commodity plastics, chlorine and olefins are still essential components in many other chemicals. These include polyurethane (PU), solvents, pharmaceuticals, and certain fine chemicals:

For chlorine: Although France devotes a larger proportion of chlorine to PVC production than the rest of Europe, nearly 50% of overall production was for fine chemicals in 2015. Much of this chlorine is used to make disinfectants, particularly bleach, and water treatment products. Isocyanates are used in combination with polyols to produce polyurethane, an insulating plastic material, or can be used to make paints and adhesives. The rest are used in cosmetics (chloromethane), pharmaceuticals (dichloromethane), epoxy resins (epichlorohydrin), solvents, and other fine chemical applications.

As regards olefins and steam cracker outputs, a very high proportion of French olefins (over 65%) is used to manufacture polymers. The remainder is used to produce ethylene oxides, which are in turn used to produce Mono-, Di-, Tri- and PolyEthylene Glycol (MEG, DEG, TEG, and PEG), ethoxylates, ethanolamines or polyols for various sectors in the chemical, cement and petroleum industries.

While these applications do not account for the majority of the volumes of chlorine or olefins used, they nevertheless represent high value-added products, which is not the case for polymers. The Sankey[30] diagram in Figure 5 shows the different sectors using olefins and chlorine, as well as the associated import and export flows.

Figure 5. Sankey diagram for chlorine and ethylene in France, 2015. Flows in tonnes (ADEME estimate based on figures from Eurostat, NegaWatt, and UN Comtrade).



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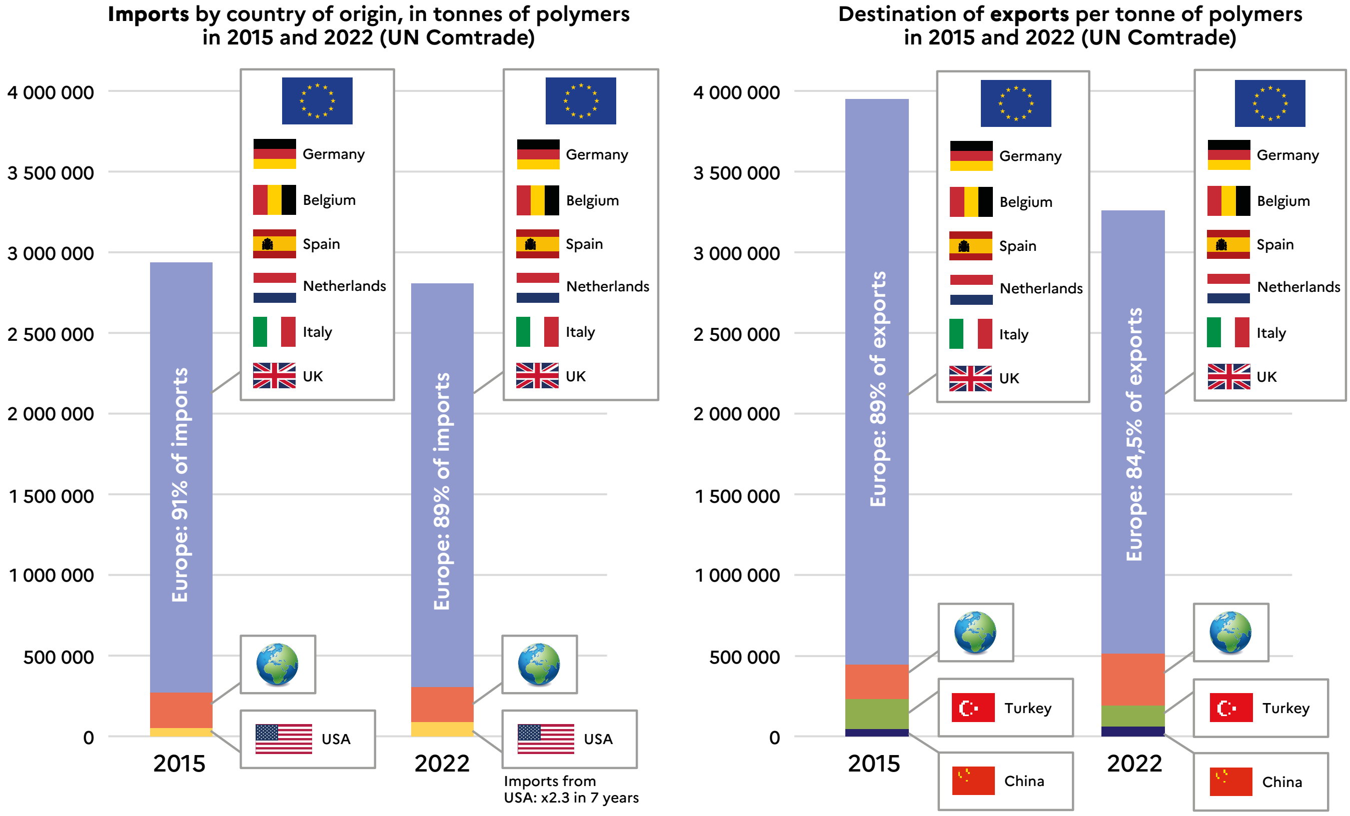
[30] It was not possible to establish exact links between the recycled raw materials produced and the different consumer sectors. This explains the absence of a "recycling loop" from consumer sectors to polymers.

1.1.2. Sectors heavily dependent on international trade

In 2014, France was a net exporter of virgin polymers PVC, PE, PS, and PP. Although around 15% of PVC exports are to non-EU countries (Tunisia, Algeria, etc.), the vast majority of French import and export trade is with Europe[31]. While France is a major European polymer exporter, a status it owes to the rapid expansion of its chemicals industry between the 1950s and 2000s, it faces strong international competition, particularly from certain Asian countries and the United States. There had already been differences in the prices of energy and raw materials (naphtha, ethane, petroleum gas, etc.) between different regions of the world since 2015, with countries such as China and the US having access to cheap coal, gas, and oil. These disparities were then exacerbated by the 2022-2023 energy crisis. Major European producers like France and Germany are therefore having to contend with low-cost imports of plastics and plastic products from overseas, in a context where China – which has an industrial overcapacity – is looking to maximise exports in response to shrinking domestic demand. While the European Union has introduced anti-dumping policies for certain polymers[32], the outlook for France's plastics export trade balance remains uncertain. The abolition of free allowances under the EU-ETS scheme could also load additional costs onto manufacturers in the sector, whether in the form of CO_2 emissions costs or higher energy bills as energy companies look to pass on their own increased costs. While a Carbon Border Adjustment Mechanism (CBAM) is planned for the petrochemicals sector by 2030, it is difficult to estimate its impact on the industry's competitiveness without knowing exactly how it will be applied. These international and intra-European trade aspects are illustrated in Figure 6, which shows the French trade balance in the polymers PE, PP, PS, and PVC, and the main trading partners for imports and exports.

Figure 6. Geographical distribution of French PE, PP, PS, and PVC imports and exports in 2015 and 2022 (ADEME estimate based on figures from Eurostats and UN Comtrade).



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[31] Source: UN COMTRADE

[32] https://policy.trade.ec.europa.eu/news/commission-protects-eu-industry-pet-plastic-dumping-next-five-years-2024-04-03_en

[33] CCU (Carbon Capture and Utilisation) involves capturing CO_2 for use as a direct feedstock or for synthesising fuels, chemicals, or materials.

[34] ADEME, 2023 Electrocarburants en 2050, Quels besoins en électricité et CO_2, https://librairie.ademe.fr/ged/8346/Electro-carburants-en-2050-rapport.pdf

1.1.3. A multitude of possible future scenarios for energy and materials feedstocks currently sourced from refineries

The global energy transition is expected to usher in a raft of changes in the use of fossil energies, and petroleum-based products in particular, such as the decision to phase out ICE vehicles in Europe by 2035, or the widespread use of biofuels. Yet petroleum remains the principal source of the naphtha used in French steam crackers to produce olefins for polymer manufacturing. The move to electric vehicles, planned for 2035 with a likely ban on the sale of ICE (Internal Combustion Engine) vehicles in Europe, could have a major impact on French refineries that produce naphtha in addition to fuels. While some process changes may actually improve yields from this type of hydrocarbon cut, French steam crackers will probably be forced to use a mixture of domestically-produced naphtha, imported naphtha, and other imported feedstocks, combined with the use of alternative feedstocks. These alternatives could come from three main sources:

- **pyrolysis of plastic waste**, which generates pyrolysis oil that can be used as a substitute for naphtha;
- the **use of electrochemical processes** to produce e-fuels, such as e-naphtha, a by-product of e-kerosene production;
- the **use of biomass** to produce bionaphtha from the biokerosene production process.

These alternative feedstocks are both an opportunity and a risk for French petrochemical firms. They may reduce the carbon footprint of petrochemical feedstocks via CCU[33] for e-naphtha or bio-based raw materials for bionaphtha, the combustion of which emits larger amounts of biogenic CO_2. However, it is unclear exactly how much of these materials industry will have access to in the future, as their availability is dependent on various factors, such as the development of biofuels and e-fuels in the aviation industry, the expansion of biorefineries, or exogenous factors including energy prices or changes in the regulatory landscape. Another factor to consider is that producing these materials will require more electricity or biomass[34], thus posing the risk of France becoming dependent on imports if its own refineries close. The use of pyrolysis oil, meanwhile, is not in itself enough to decarbonise steam cracker production, as the process and emissions generated remain unchanged. It may, however, be an advantageous way to use plastic waste that cannot be recycled mechanically, depolymerised, or dissolved.

Besides their availability, another crucial factor to consider with these alternative feedstocks is their price and impact on production costs. Owing to the way they are produced, bio-based or electro-based feedstocks will necessarily be more expensive than conventional naphtha. The higher cost will be passed on in the price of the finished product, potentially in the form of a premium recognising their low-carbon origin. These risk factors add to the general uncertainty surrounding the ability of the French industry's ability to compete in a world where non-European competitors have access to cheap ethane and naphtha.


➜ Petrochemical tanks © SritanaN/Shutterstock

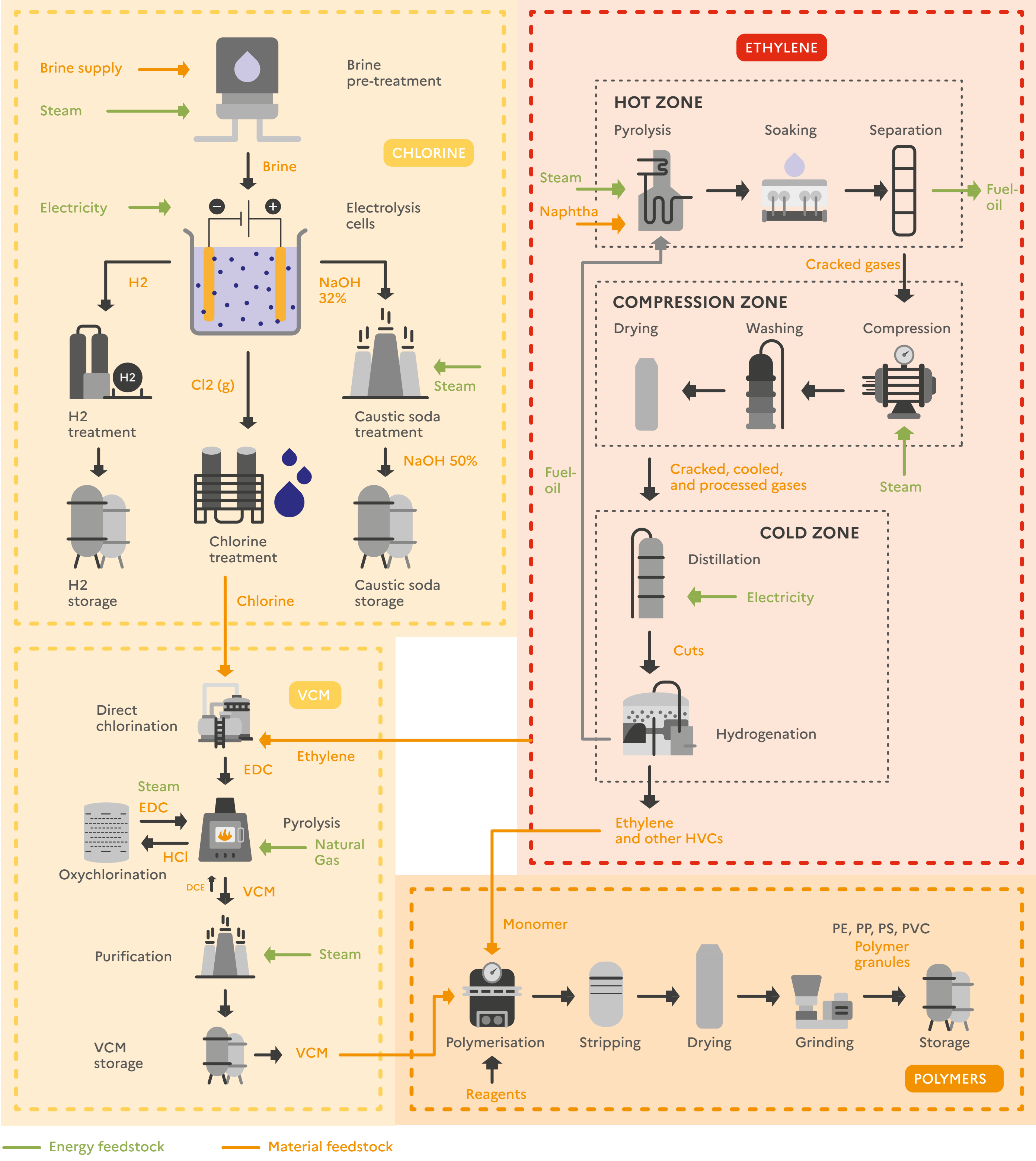
Aside from the costs of sourcing raw materials, the all-important question is: what will energy prices look like in 2050? The future of the chlorine sector, a highly energy-intensive industry where electricity accounts for more than 50% of production costs, is intrinsically linked to electricity prices. As processes are increasingly electrified, access to cheap, low-carbon electricity will be crucial if manufacturers are to remain competitive, especially if international rivals develop renewables to a significant degree.

To conclude, the outlook for French polymer production is highly uncertain, and will be dictated by developments in its historic and future markets, and the international trade landscape. Although chlorine, olefin, and polymer manufacturers face reduced forward visibility, there are a range of possibilities open to them and they must innovate to overcome the technological challenges of decarbonisation while securing France's industrial sovereignty.

1.2. Chlorine and ethylene: two very different technologies, one shared value chain

Figure 7 below shows the production processes included in the scope of the technological model, distinguished according to the main products, namely chlorine, VCM, ethylene (and HVC) and polymers (PE, PP, PS, and PVC).

Figure 7. Diagram showing chlorine, VCM, ethylene, and polymer production processes.



1.2.1. Chlorine production: energy- and steam-intensive

In France, chlorine is most commonly manufactured by salt water (brine) electrolysis, otherwise known as the chlor-alkali process, using a membrane electrolyser[35]. This involves separating the chlorine from the sodium by running an electric current between an anode and a cathode. The process is mainly powered by electricity, and it takes around 3 MWh of electricity to produce one tonne of chlorine. It also uses steam. The products are chlorine (Cl2), NaOH (caustic soda), and H_2 (hydrogen). The production process is illustrated in figure 7[36].

Once the chlorine has been obtained, it can be used in tandem with ethylene to manufacture Vinyl Chloride Monomer (VCM), which can then be polymerised to make PVC. The process of making VCM involves three main stages[37]: direct chlorination, pyrolysis, and oxy-chlorination. The VCM produced can then be packaged and shipped to polymerisation sites where it is used to manufacture PVC.

STP and category 2 emissions: the specific case of chlorine

Since the Sectoral Transition Plans are focused on achieving the targeted 81% cut in category 1 emissions set by SNBC 2, category 2 emissions were disregarded in the studies looking at other sectors. Owing to the large quantities of imported electricity and steam it uses, however, the chlorine sector generates mostly category 2 emissions, and these are difficult to overlook. Accordingly, they are taken into account in this report and treated separately from category 1 emissions, while specific decarbonisation measures are suggested for each category of emissions in each scenario.

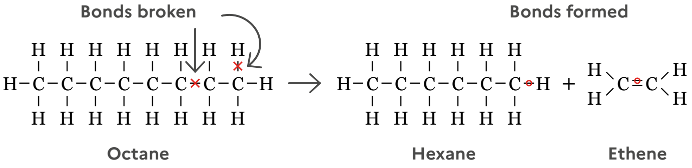
1.2.2. Energy-intensive naphtha-based steam cracking

The steam cracking process involves using steam to pyrolyse C-C (carbon-carbon) or C-H (carbon-hydrogen) bonds from hydrocarbon molecules (e.g. naphtha) into smaller molecules, olefins and aromatics (Figure 8). **With that in mind, the rest of this report will focus specifically on certain high added value olefins: High Value Chemicals (HVC), namely ethylene, propylene, butadiene, and benzene[38].**

In France and Europe, the most common steam cracking process uses mostly naphtha, a liquid by-product of oil refining. The steam cracker, in which the process takes place, consists of three main spaces, each of which plays a complementary role:

- The hot zone, where the mixture of steam and hydrocarbon feedstock is pyrolysed at around 850°C, then separated into a heavy fraction (fuel oil) and a light fraction (cracked gas);
- The compression zone, where the hot cracked gases are compressed to around 35 bar before being washed, dehydrated and dried;
- The cold zone, where the hydrocarbon cuts are distilled and hydrogenated to obtain ethylene and other olefins. In addition, a gaseous fuel gas (98% CH_4 and approximately 2% H_2), produced as a by-product of the steam cracking reaction, is redirected to the steam cracking furnaces[39]. Olefin production is a complex, optimised, and highly integrated energy-intensive process, which is unusual in that it draws energy (fuel oil and fuel gas) from its own material feedstocks.

Figure 8. Simplified representation of the process of steamcracking to form ethylene.



Unlike other processes in the chemicals sector, such as steam reforming for the production of ammonia which uses large volumes of natural gas, steam cracking in existing industrial facilities is not especially dependent on natural gas, which accounts for just 5% of the energy used.

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[35] Other electrolysis techniques, such as those using mercury (banned in Europe since 2015) or diaphragm cells, are not covered here. The membrane technique is seen as the best available, and accounted for 85% of French installed production capacity in 2021. It is this process that will be looked at in more detail in this part of the report.

[36] Best Available Techniques (BAT) Reference Document for the Production of Chlor-alkali, 2014.

[37] https://aida.ineris.fr/sites/aida/files/documents-bref/JRC109279_Lvoc_bref2017.pdf

[38] As per the EU ETS based on "Guidance Document No. 9 on the harmonised free allocation methodology for the EU-ETS post 2020 Sector-specific guidance", Final version issued on 15 February 2019 and updated on 29 July 2019.

[39] ENSPM Formation Industrie IFP Training "Pétrochimie des oléfines et des aromatiques – Mise en œuvre du vapocraquage" 2005.

Ethane steam cracking: a solution unsuited to this modelling exercise

Steam cracking can also be carried out using a different feedstock: ethane. Unlike naphtha, which is used in liquid form, ethane is a gas. It mainly comes from fossil sources: gas reservoirs, oil wells, mineral deposits[40]. Ethane is obtained from a variety of extraction and refining processes, including natural gas, crude oil, or coal processing. This may explain why ethane steam cracking is a well-established process in coal, natural gas and oil-producing countries such as the United States and the United Arab Emirates.

As with naphtha, ethane steam cracking is carried out in a three-zone steam cracker. However, the use of a different hydrocarbon feedstock affects:

- the temperature at which the process is carried out (higher than for naphtha steam cracking);
- the amount of energy used (32% less than with naphtha steam cracking);
- the resulting CO_2 emissions (21t CO_2 / GWh less than for naphtha);
- the infrastructures needed (generally more modest);
- products and yields (2.6 times more ethylene produced than with naphtha steam cracking, but ten times less propylene, four times less butadiene, and five times fewer aromatics).

All of these features tend to make ethane steam cracking the more competitive option in terms of material yields, emissions, and production costs. However, the process is less competitive when it comes to producing olefins other than ethylene. Regardless, ethane remains a fossil raw material and some of the methods used to extract and produce it generate significant levels of pollution, or even breach French regulations, as with fracking[41] for example. Essentially for these reasons, ethane steam cracking will not be included in the Ethylene Sectoral Transition Plan.

1.2.3. The polymerisation stage: from monomer to polymer

Olefins and VCM are needed to manufacture plastics. But these products, referred to as monomers, must first undergo a process known as polymerisation. This involves bonding the monomer molecules together to form polymers. Adjuvants with plasticising effects are then added, before the polymers can be transformed into plastic products (Figure 9[42]). While the polymerisation process can vary slightly depending on the type of polymer being made (PP, PE, PS, or PVC)[43, 44], it generally entails the same sub-processes, with a polymerisation reaction usually followed by a purification and drying stage, before the polymers are ground down into pellets of the desired size. Polymerisation plants run mainly on electricity and steam, and consequently generate mostly category 2 emissions. Unlike those generated by chlorine production, however, these emissions are not included in our models.

Figure 9. Simplified representation of the process of polymerising.

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[40] https://reptox.cnesst.gouv.qc.ca/Pages/fichecomplete.aspx?no_produit=3483#:~:text=Il%20est%20principalement%20obtenu%20%C3%A0,gaz%20liqu%C3%A9fi%C3%A9%20(liquide%20r%C3%A9frig%C3%A9r%C3%A9).

[41] Act No. 2011-853 of 13 July 2011 aimed at prohibiting the exploration and exploitation of liquid or gaseous hydrocarbon mines by hydraulic fracturing and repealing exclusive exploration licences granted for projects using this technique.

[42] https://www.savoirsetpouvoirs.com/file/5ea3293d878f0

[43] https://aida.ineris.fr/sites/aida/files/documents-bref/pol_bref_1006_VF_0.pdf

[44] https://www.techniques-ingenieur.fr/base-documentaire/materiaux-th11/matieres-thermoplastiques-monographies-42147210/poly-chlorure-de-vinyle-ou-pvc-am3325/

[45] CO_2 savings calculated on the basis of emission factors for different energy sources from the ADEME Empreinte database: https://base-empreinte.ademe.fr/

1.3. Leveraging technology to decarbonise: different sectors, different degrees of transformation

The HVC (ethylene) and chlorine manufacturing sectors differ in terms of their process, energy mixes, and the types of emissions they generate. Yet both share the same basic decarbonisation building blocks. The foundation in each case is a range of mature, well integrated decarbonisation technologies capable of making processes more efficient. Then, a panel of breakthrough solutions driving radical change at production while paving the way for the drastic emissions reductions needed to meet the SNBC targets.

1.3.1. A handful of mature, generally accepted technologies for partial decarbonisation

The mature technological solutions currently available to decarbonise HVC and chlorine production in fact offer only limited scope for reducing the carbon footprint of the industrial facilities that make these products. While some of these solutions may appear to generate only weak emissions reductions, they nonetheless have the advantage of lowering the need for energy, which would drive improved competitiveness while keeping investment costs modest. These solutions can be deployed at sites without fundamentally altering the process, making their adoption easier. They mainly serve to lower category 2 emissions (imported steam and electricity), and to a lesser extent category 1 emissions, by allowing the use of fossil fuels (e.g. natural gas in the chlorine sector) to be reduced or even abandoned altogether.

Mature chlorine and VCM decarbonisation solutions: energy efficiency and fossil fuel substitutes (Table 3).

The most mature solutions for reducing the carbon footprint of chlorine and VCM production mainly involve improving energy efficiency (improving electrolyser performance, lowering steam consumption) and changing the energy mix (from steam to electricity via Mechanical Vapour Recompression (MVR), move to a low-carbon mix for steam boilers). These measures can serve to reduce industry's reliance on external energy supplies. Altogether, these solutions combined could reduce energy use by up to 2 MWh/$t_{Cl2/VCM}$, for a saving of 0.7 tCO_2/$t_{Cl2/VCM}$ (category 2 included).

Table 3. Summary table showing mature decarbonisation solutions for the chlorine sector.

Mature decarbonisation solutions for chlorine and VCM production	Objective	Method	Energy savings (kWh/$t_{product}$)	CO_2 savings (tCO_2/$t_{product}$)[45]	Emissions category	TRL
Electrolyser improvement	Reduce power consumption of chlor–alkali electrolysers	Roll out zero-gap bipolar membrane water electrolysers	200-500 kWhth/t_{Cl_2}	0.01428	2	9
Steam network energy efficiency (chlorine)	Reduce steam consumption across entire network	Carry out audits, add extra evaporation effects, recover waste heat	200 kWhth/t_{Cl_2}	0.06156	2	9
Steam network energy efficiency (VCM)	Reduce steam consumption across entire network	Carry out audits, add extra evaporation effects, recover waste heat, hot chlorination	300 kWhth/t_{VCM}	0.09234	2	9
Mechanical vapour recompression (MVR)	Use an electric compressor with a high COP to produce steam	Install MVRs to replace evaporation effects at the salt extraction, sodium hydroxide evaporation and EDC purification stages	1 150 kWhth/t_{Cl_2} 330 kWhth/t_{VCM} (+250 kWh electric)	0.455544	1/2	9
Change boiler energy mix	Replace gas boilers with low-carbon alternatives	Install biomass or electric boilers to replace gas boilers for steam production	380 kWhgaz/t_{Cl_2} (+380 kWh electric or biomass)	0.07638	1	9

Mature decarbonisation solutions for HVCs: mainly energy efficiency and electrification of rotating machinery (Table 4).

Aside from everyday process optimisation measures to ensure steam cracker reliability and that consumption rates (of energy and raw material) remain optimal, there are two other mature solutions for lowering the carbon footprint of HVC production. The first, energy efficiency, encompasses a number of actions aimed at improving pyrolysis within steam cracking furnaces, ensuring that the steam produced is distributed properly, and improving plant functionality. This last action can be achieved by replacing obsolete steam cracking furnaces (horizontal furnaces, those more than 20 to 25 years old) with more energy efficient models. The second solution, electrification of rotating machinery, entails replacing steam-driven compressors (e.g. cracked gas compressors), pumps (e.g. dosing pump) with electrically-powered devices. The motive force is presently generated by fuels that are themselves by-products of the steam cracking reaction, such as fuel oil. All of these solutions together would allow energy savings of 2.2 MWh/t_{HVC} for a carbon saving of 0.7 t CO_2/t_{HVC}. But these measures alone are insufficient to decarbonise steam crackers fully.

➜ Lyondellbasell steamcracker (Berre, France) © G. Rossignol

Table 4. Summary table showing mature decarbonisation solutions for the ethylene sector.

Mature decarbonisation solutions for HVC production	Objective	Method	Energy savings (kWh/$t_{product}$)	CO_2 savings (tCO_2/$t_{product}$)	Emissions category	TRL
Combination of energy efficiency measures	Reduce use of fossil fuels, reduce steam leakage, increase furnace operating times	Various methods (e.g. modify heat radiation tubes, improve bleeds and repair steam leaks, optimise compressor controllers, reduction, torches)	766 kWh/t_{HVC}	0.11 t_{CO_2}/t_{HVC}	1	9
Furnace optimisations	Reduce fossil fuel use	Replace obsolete steam cracking furnaces with more efficient models	330 kWh/t_{HVC}	0.07 t_{CO_2}/t_{HVC}	1	9
Mechanical vapour recompression (MVR)	Improve compression and separation operations in the cold zone	Use an electric compressor with a high COP to produce steam	250 kWh/t_{HVC}	0.16 t_{CO_2}/t_{HVC}	1	9
Electrification of rotating machinery	Reduce steam consumption	Replace steam turbines with electric motors	915 kWh/t_{HVC}	0.36 t_{CO_2}/t_{HVC}	1	9

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[46] https://link.springer.com/article/10.1007/s10800-008-9556-9

[47] While ODC is already deployed industrially at a chlorine plant in Tarragona with a high TRL, rolling out the technology on a large scale at French sites would require highly extensive and costly modifications to existing electrolysers and processes. As such, it represents a breakthrough technology for the sector.

1.3.2. Breakthrough technologies requiring more radical process changes but creating new dependencies

While there are mature technological solutions that are already known to the industry, they are nonetheless insufficient to achieve the SNBC target of reducing carbon emissions by 81% by 2050. Accordingly, there is a need for more disruptive technologies that are not already on the market to achieve drastic reductions in category 1 emissions.

Breakthrough technologies for chlorine and VCM: Oxygen Depolarised Cathodes (ODC) and phasing out of natural gas for EDC cracking furnaces (Table 5).

- **ODC technology** is a recent development, and until now has only been deployed on an industrial scale at one site, in Tarragona, Spain. It involves introducing oxygen at the cathode to suppress the formation of hydrogen, thus lowering the voltage required in the electrolysis cells[46]. The process uses up to 30% less electricity than a traditional membrane. However, this lower energy consumption can be offset by the fact that ODC produces no hydrogen, which could otherwise be used as an industrial energy source, while ODC also requires an additional supply of oxygen. Despite high installation costs, it remains an attractive solution to the issue of chlorine plants' energy-intensive operations, and could be economically advantageous if electricity prices were to rise significantly.

➜ Petrochemical plant © industryviews/Shutterstock

- **Converting EDC cracking furnaces: electrification or hydrogen combustion.** EDC is pyrolysed by the combustion of natural gas in a cracking furnace, and is the main source of category 1 emissions in the chlorine-VCM-PVC value chain. While CO_2 emissions can be cut by optimising the process or reducing the gas' emission factor, the main alternative is still to substitute the fossil gas with low-carbon energy sources, namely electrification or hydrogen combustion.

Table 5. Summary table showing breakthrough decarbonisation solutions for the chlorine sector.

Breakthrough decarbonisation solutions for chlorine-VCM production	Objective	Method	Energy savings (kWh/$t_{product}$)	CO_2 savings ($tCO_2/t_{product}$)	Emissions category	TRL
Electric pyrolysis furnace	Substitute fossil fuel combustion with electricity	Replace burners with electric combustion technology	1 000 kWhth/t_{VCM} (+1 000 kWh electric)	0.2 tco_2/t_{VCM}	1	< 7
Pyrolysis furnace incorporating 50%-100% H_2 combustion	Substitute fossil fuel combustion with low-carbon or renewable hydrogen	Incorporate hydrogen into the fuel mix	500-1 000 kWhth/t_{VCM} (+500-1 000 kWh hydrogen)	0.1-0,2 tco_2/t_{VCM}	1	7-9
Oxygen Depolarised Cathode[47]	Modify the electrolysis reaction to suppress hydrogen formation and reduce electricity consumption	Use a special cathode with oxygen injection	850 kWh/t_{Cl_2}	0.03468 CO_2/t_{Cl_2}	2	8-9

Breakthrough technologies for HVC production: Steam cracking furnace electrification, pre- and post-production CCS (Table 6).

Most of the breakthrough technologies capable of significantly reducing the carbon footprint of HVC production concern the hot zone, which generates between 70 and 80% of a steam cracker's overall emissions.

Table 6. Summary table showing breakthrough decarbonisation solutions for the ethylene sector.

Breakthrough decarbonisation solutions for HVC production	Objective	Method	Energy savings (kWh/$t_{product}$)	CO_2 savings ($tCO_2/t_{product}$)	Emissions category	TRL
Electric steam cracking furnace	Substitute fossil fuel combustion with electricity	Replace burners with electric combustion technology	2021 kWh/t_{HVC}	1.8 t CO_2/t_{HVC}	1	< 7
Steam cracking furnace incorporating 50% H_2 combustion	Reduce fossil fuel use	Incorporate 50% hydrogen into the fuel mix	670 kWh/t_{HVC}	0.235 t CO_2/t_{HVC}	1	7-9
Pre-combustion CCS	Capture carbon and produce hydrogen	Use steam reforming for unburned gas fuels – Separate CO_2 (for capture at steam reformer unit outlets and storage) and H_2 (for re-use)	1 000 kWh/t_{HVC}	0.157 t CO_2/t_{HVC}	1	6-9
Post-combustion CCS	Capture carbon emitted by fossil fuel combustion	Capture and store carbon at steam cracking furnace outlets	–	0.130 t CO_2/t_{HVC}	1	7–9
Selective membranes	Improve energy performance of separation operations	Replace fractionating columns with membranes made from polymers or inorganic materials	715 kWh/t_{HVC}	0.13 CO_2/t_{HVC}	2	6-7

➜ Indoor tank in a petrochemical planta © hramovnick/Shutterstock

Electrification of steam cracking furnaces

One of these solutions – electrifying steam cracking furnaces – is attracting attention from industrial producers, since it promises to reduce CO_2 emissions by up to 90% compared with conventional steam cracking, a saving of around 1.8 tCO_2/t_{HVC}. The technology involves replacing existing burners with electrical heating solutions in the steam cracking furnace. The use of electricity eliminates the need to burn fuel gas. In addition, if the electricity comes from low-carbon sources, the CO_2 emissions reductions can be maximised.

Regardless of where the electricity comes from, however, the additional energy input needed is very significant indeed at over 5 000 $kWhe/t_{HVC}$. This requires not just a substantial step-up in the site's power supply, but network infrastructures compatible with existing petrochemical sites. Electrification also results in unconsumed surplus fuel gas, for which industrial firms will need to find an alternative outlet while minimising the extent to which the resulting emissions are simply passed on to another sector or a different operation within the same value chain.

Hydrogen combustion

Burning hydrogen in place of conventional fuel gas is another breakthrough technological solution being looked at closely by the industry. The higher the hydrogen content of fuel gas, the lower the resulting CO_2 emissions. For example, using 50% hydrogen fuel translates to carbon emissions of 0.235 tCO_2/t_{HVC}. Hydrogen can be sourced in two ways: either imported (preferably low-carbon or renewable, to limit its carbon footprint), or as a by-product from the steam cracker, where it is contained in fuel gases[48]. In this latter case, hydrogen is obtained by reforming the fuel gas in an SMR (steam methane reforming) unit positioned close to the steam cracker.

This technology, which is currently being studied and developed in the petrochemicals sector with a higher level of maturity (TRL of 7 to 9) than the electric steam cracker, will require burners compatible with the use of fuels with high hydrogen content. Denitrification units may be considered, to deal with the resulting increase in NOx emissions.

Carbon capture and storage (CCS)

At the pre-combustion stage, CCS is a supplementary breakthrough solution that can be combined with hydrogen combustion, but only in cases where the hydrogen is sourced from fuel gas. After the steam reforming phase, when the hydrogen is carried to the burners, the resulting CO_2 is captured as it exits the reforming unit. Post-combustion CCS is used as a last resort for residual CO_2 emissions that have not been reduced by other decarbonisation measures. It entails capturing fumes containing CO_2 as they exit the steam cracking furnace chimneys. The rest of the process is the same, whichever type of CCS is used. The CO_2 is prepared, transported, and stored in a dedicated facility.

The capture, transportation, and storage operations themselves generate additional energy consumption of 295 $kWhe/tCO_2$ throughout the CCS chain. It is worth noting that the most mature capture technology currently involves using chemical absorbents like amine solvents (e.g. monoethanoloamine). Scaled for a low CO_2 content in steam cracker fumes (approx. 7% to 12%), it accounts for 42% of the total energy penalty.

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[48] The proportion can be higher if the feedstock mix contains so-called "light" hydrocarbons (ethane, butane, propane).

1.3.3. Recycling and feedstocks: using alternative feedstocks and processes to decarbonise olefin production

Other methods can be employed at every stage of the value chain to produce lower-carbon feedstocks and achieve structural emissions reductions. The first concerns the techniques used to recycle plastics, which are used as a recycled raw material at various points in the value chain (see Figure 10 below).

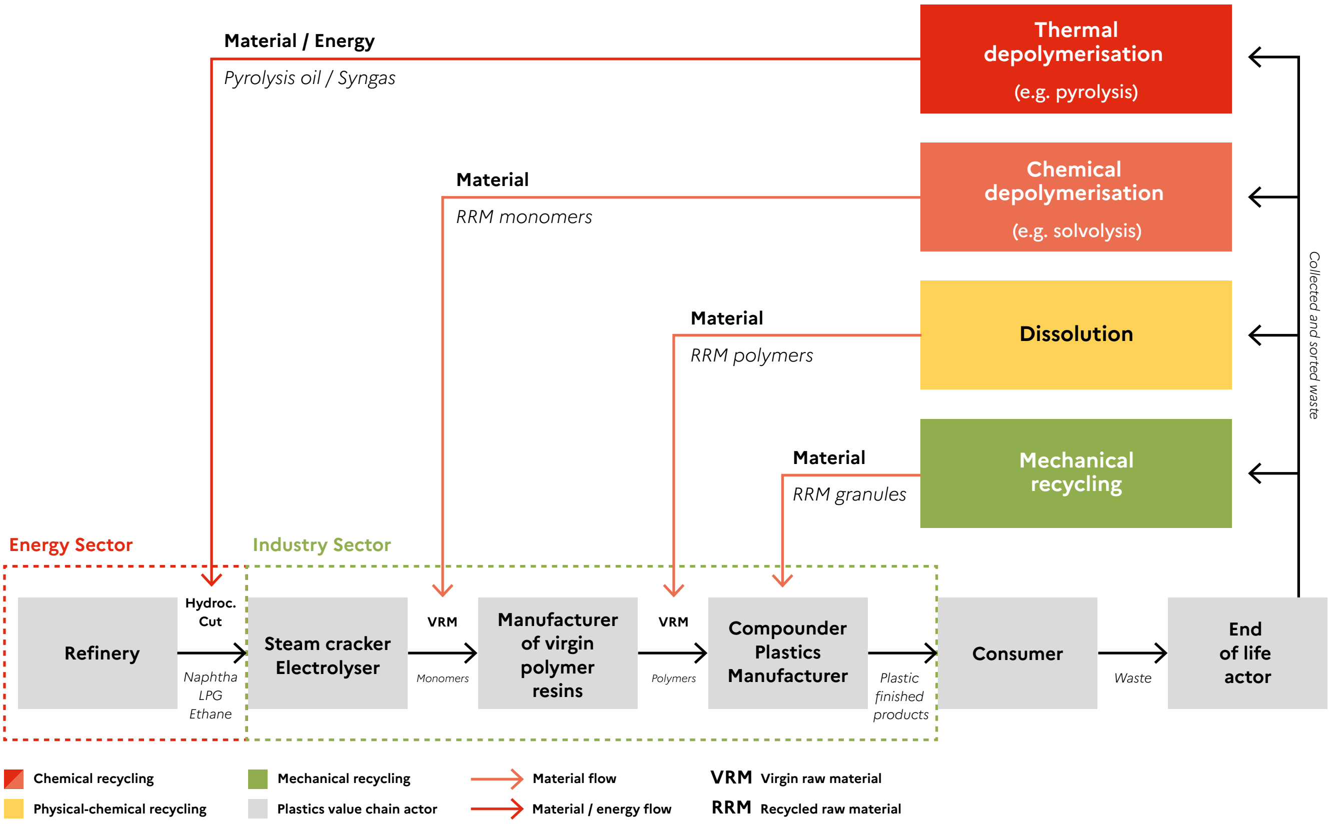
Mechanical recycling involves collecting, sorting, washing, and milling plastic waste, which is then melted down into recycled pellets. Regeneration is the process of producing the recycled raw material. While this technique is currently the most mature and industrially developed, it is nonetheless limited to certain specific plastics and requires plastic waste to be sorted carefully with an upstream purity rate. It also weakens the structure of the polymer with each additional recycling cycle, and does not necessarily eliminate polymer additives and pollutants.

To mitigate the risks inherent to mechanical recycling and process waste that cannot be dealt with by this method, other recycling technologies offer interesting alternative solutions:

- Physical recycling by dissolution provides polymers free of additives or admixtures;
- Chemical recycling by chemical depolymerisation (e.g. solvolysis) produces monomers;
- Chemical recycling by thermal depolymerisation (e.g. pyrolysis)[49] produces either syngas or pyrolysis oil which can be used as a raw material in place of naphtha. This recycling technique uses large amounts of energy and generates significant GHG emissions, and is therefore seen as a way of limiting fossil resource extraction rather than a decarbonisation vector.

For this reason, chemical recycling by pyrolysis is excluded from the Ethylene STP.

Figure 10. Allocation of recycling products between stakeholders in the value chain.



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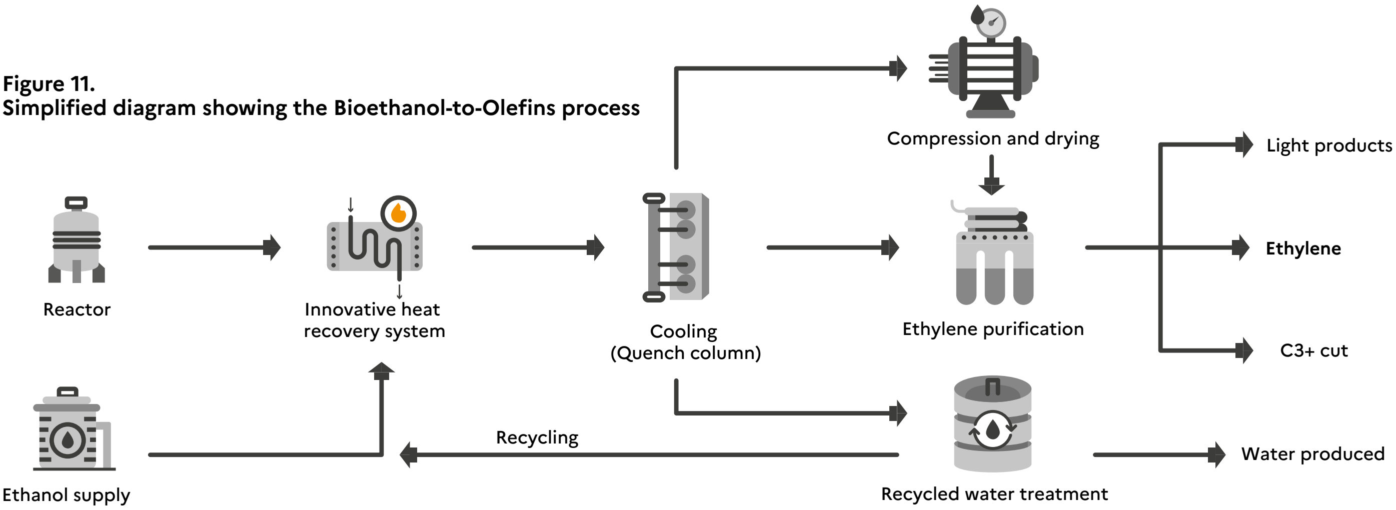
[49] Also known as recycling by thermolysis or conversion.

[50] https://www.braskem.com.br/usa/news-detail/braskem-expands-its-biopolymer-production-by-30-following-an-investment-of-us-87-million

[51] https://www.syclus.nl/

Figure 11.
Simplified diagram showing the Bioethanol-to-Olefins process



In addition to recycling techniques that provide recycled material throughout the plastics value chain, there are two alternative methods of producing olefins that eliminate the need for steam cracking while using low-carbon or bio-based feedstocks:

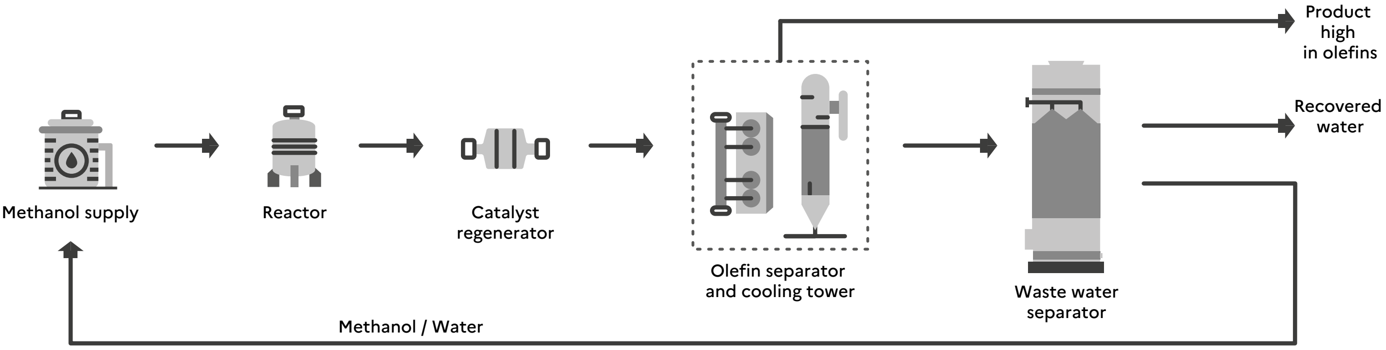
- **Bioethanol To Olefins (BTO):** the BTO process shown in Figure 11 uses bioethanol from biomass (beetroot, cereals, wood, residues) to make bioethylene by dehydration. The bioethylene can then be used by polymerisers to manufacture bio-based plastics, avoiding the fossil emissions normally generated by steam crackers. This technique is already used at scale by the Brazilian company Braskem[50], but is increasingly being trialled in Europe, in many cases based on technology developed by chemicals firm Axens[51]. While this method has the advantage of fixing biogenic carbon in plastic products, it may be in competition with food industry applications. Unless second generation wood-based bioethanol is developed widely, the potential of this technology could be limited.

- **Methanol To Olefins (MTO): the MTO process shown in Figure 12** is an electrochemical technique that converts methanol into a variety of olefins. If it uses electro-sourced methanol (produced from captured biogenic CO_2 and electrolytic H_2) or renewable methanol (from gasification or reformed biomass), it has the potential to provide the plastics sector with a new source of low-carbon feedstocks. However, this technology is currently in the development stage, and comes with high costs (in terms of both CapEx and OpEx). It also requires very large amounts of electricity and biogenic CO_2.

The STP scenarios: snapshots of a market in transition

As we have seen, there are multiple factors – both technological and commercial – liable to impact the value chain of these two sectors in the coming decades. There will be changes not just to conventional production facilities (steam crackers and electrolysers), but also in terms of recycling infrastructures and alternative production methods, with knock-on effects on feedstock and energy sourcing. Meanwhile, the traditional plastics market will be operating in an increasingly challenging environment, with tougher international competition and changes to consumption (regulations on packaging, inclusion of recycled raw materials, and lower-carbon products). The scenarios presented in the next section of this report aim to illustrate all of these effects.

Figure 12. Simplified diagram showing the Methanol-to-Olefins process.



2. Three contrasting scenarios to simulate the challenges of decarbonisation

2.1. Main transition assumptions for 2050 in the three scenarios

Each of the three scenarios simulates a different set of circumstances, seeking to show what the sector could look like in years to come. They are all very different. This is a deliberate choice, designed to clearly distinguish the differences resulting from technological or societal decisions, and how those decisions might shape the sector's future. While it is likely that the future reality will actually be a combination of all three scenarios, the lessons we can learn from them today will nonetheless be useful for addressing the challenges that lie ahead. They also illustrate how the 81% emissions reduction target set by SNBC 2 could be achieved in a variety of ways by pulling two levers simultaneously, namely production levels and technological advances. In short, the aim of these three scenarios, which should be used for information and comparisons rather than taken individually, is to answer the following question: "What needs to be done to decarbonise the industry by 2050? ".

Table 7 shows the main qualitative assumptions made regarding the key uncertainty factors for transition of the ethylene and chlorine sectors. The quantitative figures for these assumptions are presented in the full report.

➜ Ethanol production plant © Chawranphoto/Shutterstock

Table 7. Key socio-economic and technological uncertainty factors for transition of the olefin and chlorine industry and qualitative assumptions for each scenario.

		Petrochemicals and globalisation	Electricity and European protectionism	Bio-based and local specialisation
Limitation of single-use plastics		**French** The AGEC law applies in France, but the only European measure is the PPWR	**European** The PPWR sets its targets higher while aligning with the AGEC law, which applies across Europe	**Global**[52] Beyond the AGEC law in France and the PPWR in Europe, a global treaty on plastic pollution is accepted
Sobriety actions and circular economy		**Low** Weak support for the adoption of circular economy and sobriety policies	**Medium** Circularity rates increase with more recycled raw materials used, particularly those derived from chemical recycling by chemical depolymerisation	**High** Consumer sobriety actions and strong support for recycling and sustainable design policies
Preferred plastic recycling method		**Pyrolysis** Most plastic waste rejected by sorting centres is used to make pyrolysis oil for steam crackers	**Depolymerisation** Chemical recycling by chemical depolymerisation develops alongside chemical recycling by pyrolysis and mechanical recycling	**Mechanical and physical by dissolution** Priority is given to mechanical recycling and recycling by dissolution, with chemical recycling reserved for harder-to-process waste
Extent of globalisation		**High** **Global demand rises.** High levels of imports and exports between countries, with no tariffs or customs barriers to trade, strong competition	**Medium** **Global demand rises.** Trade remains strong between European countries, but is limited with the rest of the world by protectionist measures	**Low** **Global demand remains stable.** European and international trade falls back to focus on domestic industries
Production level		**Significant decline** Falling exports combined with rising imports causes production to decline sharply	**Moderate decline** European market protectionism against imports from the rest of the world allows the continent to maintain production close to 2015 levels	**Significant decline** Lower imports are not enough to compensate for falling exports combined with shrinking domestic demand, causing production to decline sharply
Feedstocks		**Traditional petroleum based** Naphtha remains the main feedstock, with the addition of pyrolysis oil	**Low-carbon** Low-carbon e-naphtha and e-methanol cover a limited part of feedstock requirements	**Bio-based** Bionaphtha and bioethanol cover a limited part of feedstock requirements
Technology	Ethylene	**CCS and partial electrification** CCS is the main technology deployed in the ethylene sectors, with lower investment in upgrading production facilities	**Total electrification and MTO** Steam crackers (rotating machinery and steam cracking furnaces) are electrified on a massive scale, MVR and MTO technology is deployed	**Energy efficiency, H_2 combustion, partial electrification, and BTO** Steam cracking furnaces are upgraded, hydrogen is used widely as a substitute for fuel gas, and BTO technology is adopted
	Chlorine	**Energy mix changes and energy efficiency** Partial use of mechanical vapour recompression, hydrogen combustion, and biomass	**Chlorine: Total electrification and ODC** Pyrolysis furnaces are fully electrified, MVR is used widely, and CDO is deployed partially	**Chlorine: Energy efficiency and hydrogen** MVR, high-temperature chlorination, hydrogen combustion, and electric boilers all deployed on a moderate scale

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[52] A new global treaty on plastic pollutions may be applied differently from one country to the next, but will limit overall production of single-use plastics internationally

2.2. Results: SNBC targets achieved in all scenarios, with varying trajectories for production levels and CapEx

2.2.1. "Petrochemicals and globalisation" scenario: CCS the main decarbonisation solution in a competitive globalised market

Foreign polymer imports driven by international competition.

This scenario represents a continuation of current trends in terms of polymer demand and international trend. Despite the rise in global demand for plastics assumed in this scenario, French industry loses market share to strong international competition, particularly from Asia and the United States. This causes exports to fall over the period 2025-2030, bringing production of most polymers back down to 2015 levels. This trend becomes more acute over the period 2030-2050, with the polymer sector shrinking slightly, with an unavoidable knock-on impact on the production of olefins, chlorine, and VCM. While the non-polymer chemicals sectors (chlorochemicals, ethylene and propylene oxides) do not suffer the same decline, they are unable to maintain overall HVC and chlorine production at pre-2020 levels. Although demand remains steady until 2030 in some consumer sectors such as construction and the automotive industry, limiting the decline, this trend subsequently wanes, leading to falling production.

Table 8. Polymer demand in 2030 and 2050.

Demand	Petrochemicals and globalisation	
	2030 vs. 2015	2050 vs. 2015
PVC	-11 %	-32 %
PE	-22 %	-62 %
PP	-12 %	-41 %
PS	5 %	-6 %

These results vary slightly depending on the polymer concerned. For example, polyethylene (PE, very widely used for packaging) is heavily affected by the AGEC law's restrictions on single-use plastics. Conversely, new builds in the construction sector and the need to install insulation drive higher demand for PVC and PS by 2030, with production of those plastics remaining similar to 2020 levels, falling only modestly by 2030 but more markedly by 2050. Projected demand for and production of fine chemicals is based on conservative assumptions. Assumed variations in demand for each polymer and production of the main products in the value chain are shown in Table 8 and Table 9.

Table 9. Production of HVCs, polymers, chlorine, VCM, and PVC in 2030 and 2050.

		Petrochemicals and globalisation		
		Production		Capacities
		2030 vs. 2015	2050 vs. 2015	2050 vs. 2015
High Value Chemicals (HVCs)		-9 %	-30 %	-25 %
Polymers	**PE**	-29 %	-67 %	-20 %
	PP	-12 %	-48 %	
	PS	-2 %	-33 %	
Chlorine		-6 %	-32 %	-20 %
Vinyl Chloride Monomer (VCM)		-6 %	-40 %	-33 %
PVC		-3 %	-35 %	-17 %

Fierce international competition in the European market eats into French polymer exports with production declining significantly. In this scenario, that trend is assumed to result in production capacity being reduced by 25% for HVCs, 20% for chlorine, 33% for VCM, and 17% for PVC, and by 20% for the polymers PE, PP, and PS by 2050.

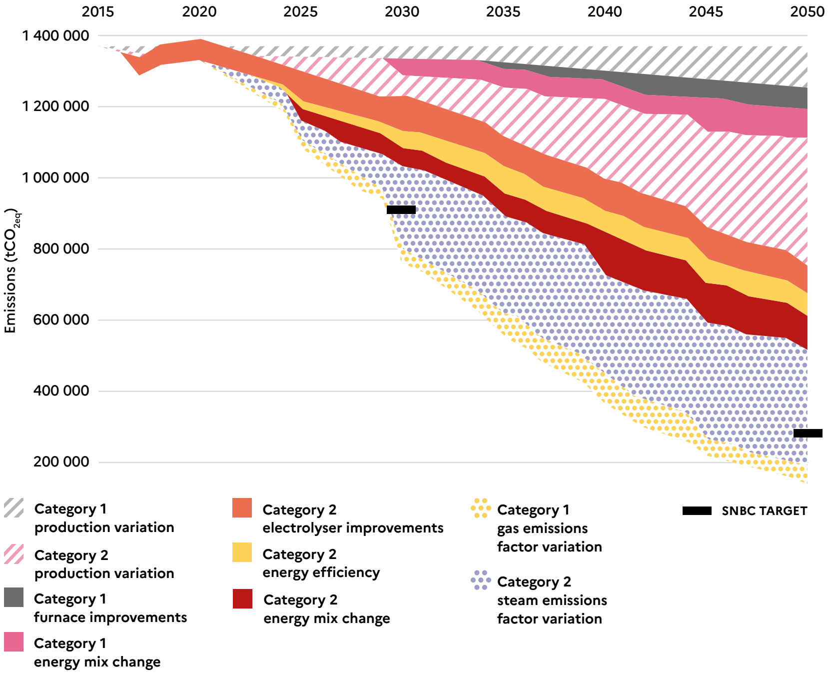
Continued demand for petroleum-based feedstocks offset by the use of CCS to achieve the 81% emissions reduction target.

This scenario mostly assumes that current production methods will continue to be used, in both the ethylene and chlorine sectors.

Chlorine sector

Chlorine sites mostly implement relatively mature measures designed to improve electrolysers and energy efficiency, and alter the energy mix via the use of MVR, biomass boilers, and hydrogen for EDC cracking. This has the effect of reducing category 1 emissions by 96% for chlorine, and by 85% for both categories 1 and 2 (taking into account the change in the emission factor of gas and steam). While decarbonisation measures do allow significant emissions reductions, it is worth keeping in mind that a substantial portion of the CO_2e savings are thanks to decreased production and changes to gas and steam emission factors (Figure 13).

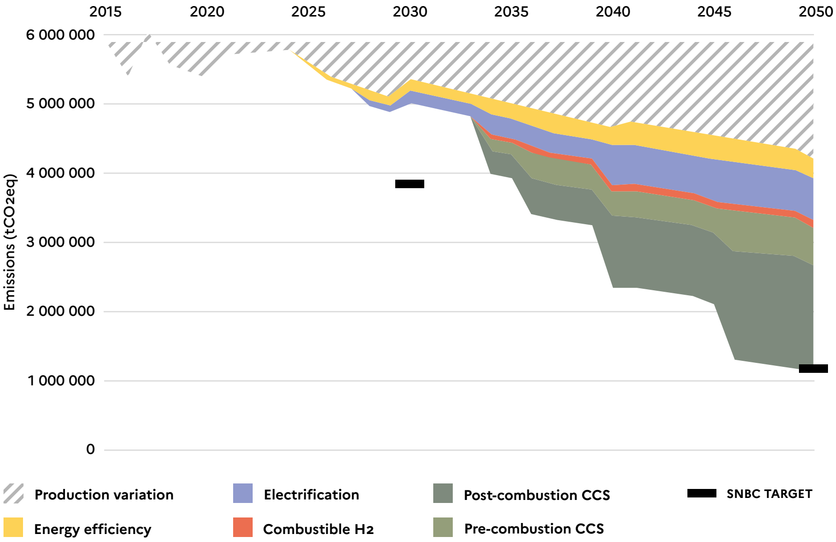
Figure 13. "Petrochemicals and globalisation" scenario, GHG emissions from the French chlorine, VCM, and PVC industry.



Ethylene sector

Since firms in the petrochemical industry have neither the need nor the opportunity to plough heavy investment into upgrading their production facilities, owing to the economic climate, they continue to operate their steam crackers in the conventional way. Feedstocks are partly replaced by oil obtained from pyrolysis of plastic waste, which makes up 7% of the feedstock mix. Despite mechanical recycling developing in France, little nationwide effort is made to drive innovation in plastic waste collection, sorting, and recycling (whether mechanical or chemical). Industry stakeholders seize on the large volumes of hard-to-recycle waste for chemical recycling by pyrolysis, producing oil that can then be used in their steam crackers. While measures are introduced to improve energy efficiency and electrify rotating machinery, CCS remains the main solution. Implemented at the pre- and post-combustion stage, this technology reduces emissions from the olefins sector by 45% by 2050 (Figure 14).

Figure 14. "Petrochemicals and globalisation" scenario, GHG emissions from French ethylene industry (HVC and PE, PP and PS polymer).



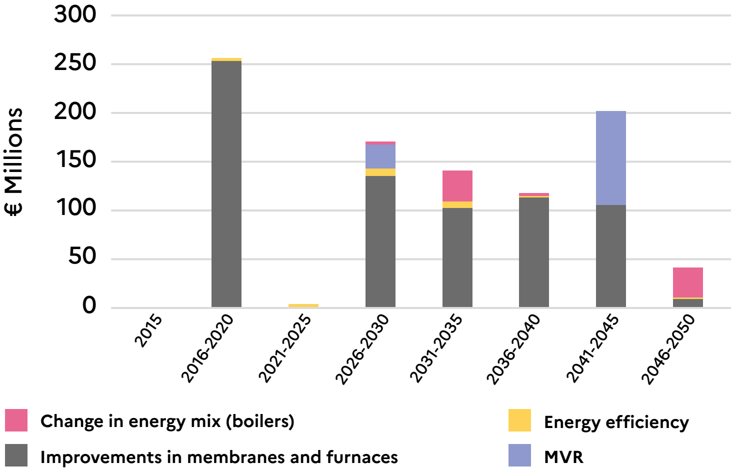
CapEx requirements are contained by continuing to use the same processes.

The various decarbonisation measures in the "Petrochemicals and globalisation" scenario would require an estimated 0.9 billion euros in CapEx for the chlorine-VCM-PVC sector, and 3.08 billion euros for the olefins-PE-PP-PS polymers sector. Most of these investments are in consensual, mature measures that require no radical changes to processes themselves. The investment timelines for these two sectors can be seen in figures below.

Chlorine sector

The CapEx figure for the chlorine-VCM-PVC sector represents the cost of deploying mature, mobilisable technologies across all sites, with the relevant amounts spread evenly over the timeframe considered. The investments mostly involve upgrading electrolysers, by moving to bipolar electrolysers and zero gap membranes. The cost is estimated at close to 730 million euros. Around 250 million euros of that sum was already invested between 2015 and 2020 to convert diaphragm cell electrolysers to membrane cells. The remainder of the costs are split between installing MVR units (around 120 million euros), replacing gas boilers with electric and biomass units (around 50 million euros), and incremental energy efficiency measures (Figure 15).

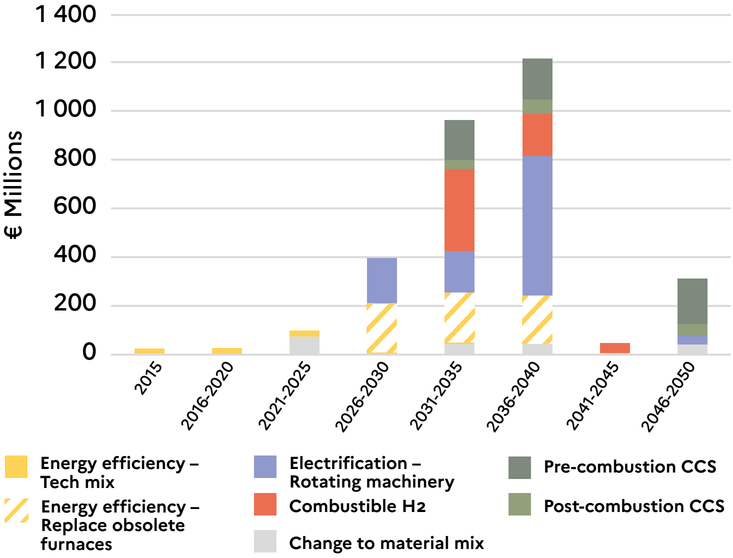
Figure 15. "Petrochemicals and globalisation" scenario, investment timeline in five-year increments for French chlorine, VCM, and PVC industry.



Ethylene sector

As regards the olefins and PE-PP-PS polymers sector, investment is concentrated over the period 2030-2040 with over 2 billion euros. Of that total, 750 million is spent on electrification, 500 million on partially converting steam crackers to hydrogen, and 420 million on installing carbon capture bricks on steam reforming units and crackers. While the costs of CCS may appear relatively limited, they do not include the costs of creating the external infrastructure needed, or indeed the facilities needed to transport and store captured CO_2, which will depend greatly on each site's geographical location and the local industrial fabric. The figure also includes energy optimisation measures and changes to the feedstock mix (Figure 16).

Figure 16. "Petrochemicals and globalisation" scenario, investment timeline in five-year increments for French ethylene industry (HVC and PE, PP and PS polymer).



The "Petrochemicals and globalisation" scenario extrapolates current trends based on the traditional single-energy source business model inherited from the western industrial economies of the 20th century: a growing global plastics market, increasingly global trade, and a reliance on petroleum-based energy and feedstocks. While this trajectory serves to limit the CapEx needed for decarbonisation, it comes at a cost: loss of market share and a sharp decline in output, despite rising global demand.

2.2.2. Scenario: "Electricity and European protectionism": decarbonisation via mass electrification but high CapEx costs

Lower-carbon production sustains intra-European trade.

In the "Electricity and European protectionism" scenario, demand for plastics stagnates in Europe, despite rising in the rest of the world. In France, the markets for different polymers develop in contrasting directions, with the construction industry driving higher demand for PVC and PS in 2030, a trend that levels out in 2050 with subsequent falling demand for all polymers except PS (Table 10).

Table 10. "Electricity and European protectionism" scenario, polymer demand in 2030 and 2050.

Demand	Electricity and European protectionism	
	2030 vs. 2015	2050 vs. 2015
PVC	3 %	-37 %
PE	-25 %	-62 %
PP	15 %	14 %
PS	-11 %	-39 %

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Unlike in the previous scenario, however, this falling demand does not directly translate to lower production. Thanks to the introduction of European controls on polymer and plastics imports, combined with major investment in modernising energy infrastructure (electricity, hydrogen, etc.), European manufacturers are able to hold onto market share and maintain levels of exports within the EU. The majority of French exports are to other European countries, and this is reflected in lower imports of all polymers, with higher exports in 2050. In tandem with relatively strong growth in chemical recycling by depolymerisation in this scenario, allowing polymerisation units to keep operating at the same levels, production levels of the various polymers decline by 1% in the case of PVC, and an average of 15% for PE, PP, and PS. As a correlation of this, levels of HVC and chlorine production decrease slightly, while VCM production falls more markedly under the impact of competition from exports from Belgium and Germany (Table 11).

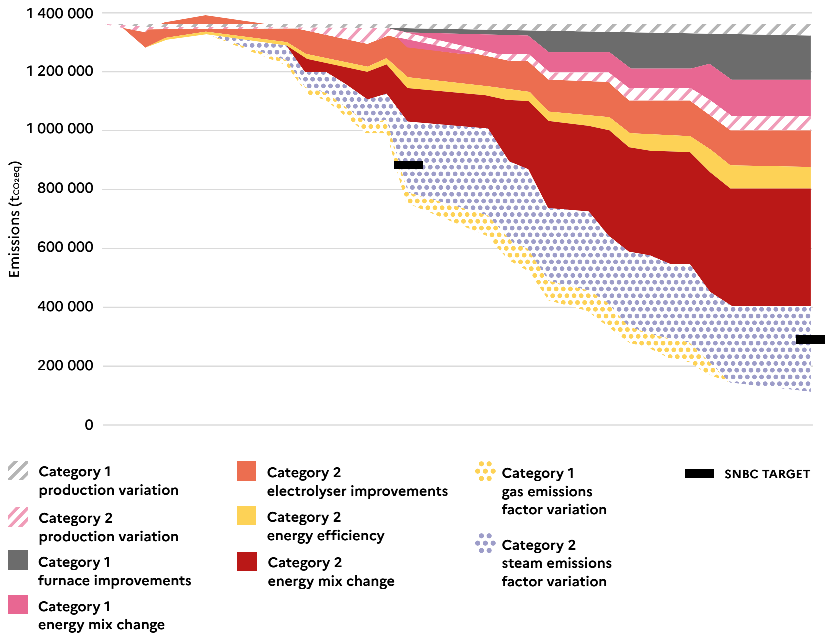
Table 11. Production of HVCs, polymers, chlorine, VCM, and PVC in 2030 and 2050.

		Electricity and European protectionism		
		Production		Capacities
		2030 vs. 2015	2050 vs. 2015	2050 vs. 2015
High Value Chemicals (HVCs)		-6 %	-9 %	-14 %
Polymers	**PE**	-12 %	-20 %	-6 %
	PP	-5 %	-17 %	
	PS	5 %	4 %	
Chlorine		2 %	-3 %	0 %
Vinyl Chloride Monomer (VCM)		-8 %	-18 %	0 %
PVC		6 %	-1 %	0 %

Heavy investment in decarbonisation via electrification and diversification of production methods.

In this scenario, emissions are reduced by the adoption of several breakthrough technologies and mass-scale electrification of industrial processes.

Figure 17. "Electricity and European protectionism" scenario, GHG emissions from the French chlorine, VCM, and PVC industry.



Chlorine sector

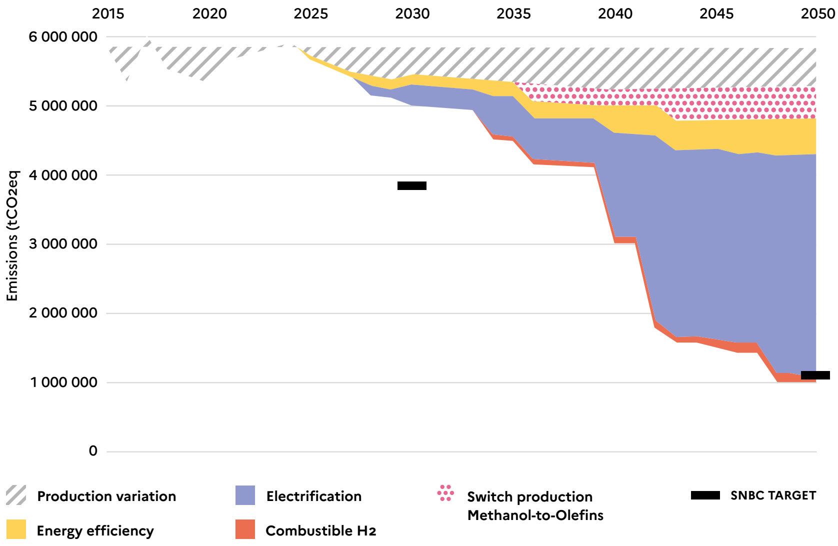
The chlorine-PVC sector is able to completely eliminate its category 1 emissions by adopting all-electric EDC pyrolysis furnaces and replacing gas-fired boilers with biomass and electric units. At the same time, MVR systems are installed en masse at the salt extraction, sodium hydroxide and EDC evaporation stages of the process, allowing substantial steam savings. ODC technology is deployed on electrolysers on a large scale between 2035 and 2045, considerably reducing the amount of electricity needed for chlorine production. Altogether, specific consumption per tonne of PVC falls by 29% by 2050, and category 1 and 2 emissions are cut by 92%. (Figure 17).

Ethylene sector

In the ethylene sector, the main savings come from partial electrification, initially focused on rotating machinery, and then later extending to steam cracking furnaces from 2040 onwards. Accordingly, steam crackers are assumed to be fully electrified. This almost entirely eliminates emissions from the combustion of fuel gas, a by-product of naphtha steam cracking, cutting overall emissions by 54% by 2050. In addition to the electrification of steam cracking furnaces, steam cracker output is partly replaced by 684 kt of production capacity using the MTO (Methanol To Olefins) process. This low-carbon production method using boilers powered by biomass and electricity replaces 663 kt/year of ethylene previously produced by steam crackers, thereby saving 443 kt of CO_2e annually. Finally, energy efficiency measures and the use of a small proportion of hydrogen for combustion provide savings of 521 and 130 kt of CO_2e per year, reducing the overall carbon footprint from 5.8 Mt to 1 Mt of CO_2e/year between 2015 and 2050 (Figure 18).

In this scenario, several different breakthrough solutions are assumed to be adopted in the ethylene sector electrification of steam cracking furnaces and the MTO process. While this significantly decarbonises the industrial processes employed, an additional 19 TWh of electricity is needed to run steam crackers and the MTO process in particular, including 8.5 TWh/year for methanol production. Before these technologies can be deployed at scale, an R&D process is required and the power grid will need to be upgraded locally at the sites concerned.

Figure 18. "Electricity and European protectionism" scenario, GHG emissions from the French ethylene industry (HVC and PE, PP and PS polymer).



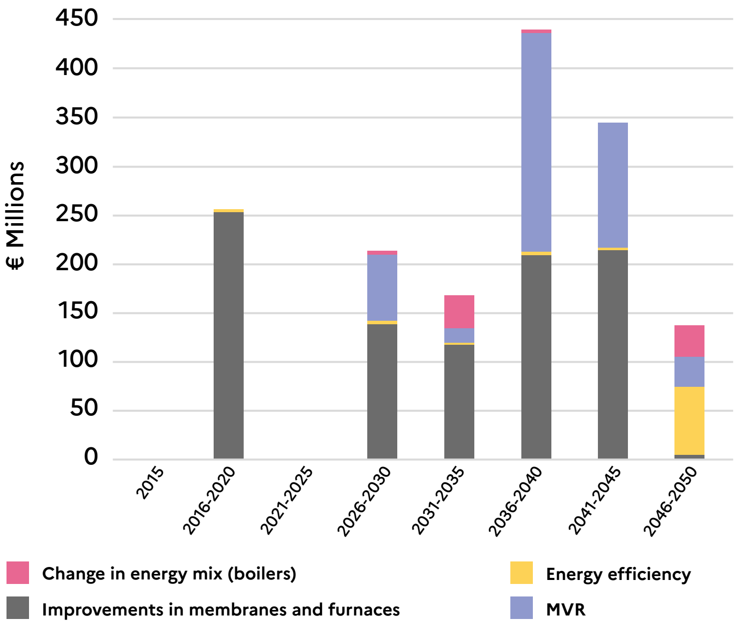
High investment costs concentrated between 2035 and 2050.

Estimated CapEx costs under the "Electricity and European protectionism" scenario are 1.5 billion euros for the chlorine sector, and 4.6 billion euros for the ethylene sector.

Chlorine sector

Most of the 940 million euros of investment in the chlorine sector is concentrated on improvements to electrolysers and furnaces, with 316 million spent on deploying ODC technology and 53 million on electrifying pyrolysis furnaces. A total of 470 million euros is spent on installing MVR systems, with 77 million and 68 million devoted to energy efficiency and installing low-carbon boilers respectively (Figure 19).

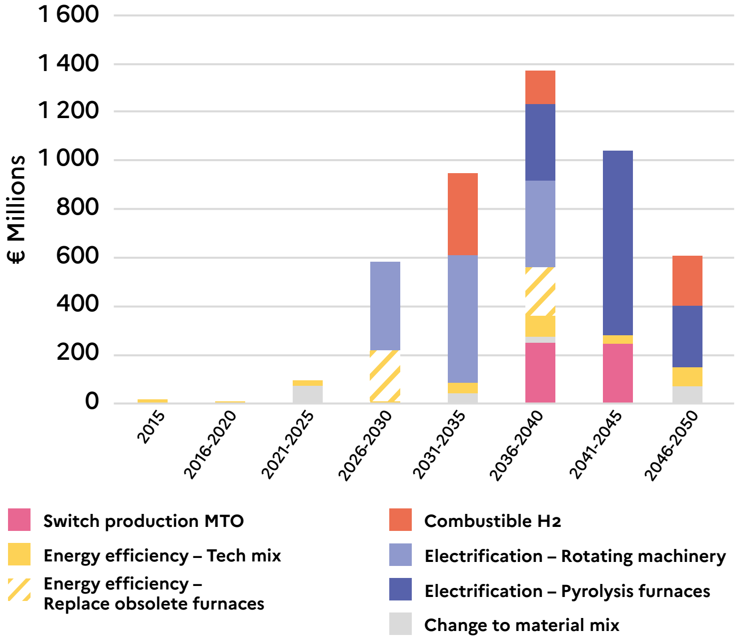
Figure 19. "Electricity and European protectionism" scenario, investment timeline in five-year increments for French chlorine, VCM, and PVC industry.



Ethylene sector

Most of the investments made in the ethylene sector are concentrated on process electrification, with 1.2 billion euros spent on electrifying rotating machinery, and a further 1.3 billion euros on electrifying pyrolysis furnaces. Some 400 million euros go towards optimising furnaces, and 670 million euros to adapting them to run on 50% H_2. Finally, 497 million euros are needed to install MTO-based ethylene production units. These investments only concern ethylene production facilities, and do not include upstream infrastructure such as power grid upgrades or the methanol production sites needed to supply feedstock for the MTO process (Figure 20).

Figure 20. "Electricity and European protectionism" scenario, investment timeline in five-year increments for the French ethylene industry (HVC and PE, PP and PS polymer).



Under the "Electricity and European protectionism" scenario, France successfully maintains its levels of output in the chlorine and petrochemicals industries. However, two things are essential to make this possible: first, massive investment in innovative technologies, to modernise and drastically reduce the carbon footprint of production facilities and ensure they remain competitive; and second, EU-wide cooperation to put European industry on a fair playing field with the rest of the world, combined with sufficiently low electricity prices.

2.2.3. "Bio-based and local specialisation": bio-based feedstocks as the difference-maker for more local production

Social and regulatory developments bring down demand.

In the "Bio-based and local specialisation" scenario, polymer demand and production both decline, particularly in France and Europe. There are several reasons for this. First, ambitious policies are adopted to limit the use of plastics, especially single-use plastics: in France, with the AGEC law; in the EU, which adopts a regulatory framework directly based on the AGEC law in the form of the PPWR; and globally, with the adoption of the Treaty on Plastic Pollution. This in turn drives improvements in collection, sorting, and recycling systems, while plastics exports to developing countries are halted. In addition, circularity rates improve with more recycled materials incorporated into manufactured products, and numerous countries introduce partial bans on single-use plastics. At the same time, social trends in France popularise concepts such as "sobriety" or voluntary energy saving measures, and re-use. Products have longer useful lives thanks to efforts to improve repairability, along with re-use and the use of second-hand products. Demand for plastic falls even more sharply with the use of alternative packaging materials, such as paper, cardboard, and glass. For example, demand for PE polymers falls by up to 79% in 2050 (Table 12).

Table 12. "Bio-based and local specialisation" scenario, polymer demand in 2030 and 2050.

Application	Bio-based and local specialisation	
	2030 vs. 2015	2050 vs. 2015
PVC	-31 %	-69 %
PE	-32 %	-79 %
PP	-4 %	-34 %
PS	-24 %	-69 %

The very sharp decline in demand in this scenario is reflected in a "local retrenchment" in Europe, with trade down strongly and both imports and exports falling at once. Total imports into France decline by 50% on average for the polymers concerned, while exports fall by 25%. Meanwhile, production of PS, PP, and PE polymers drops by 57%, and PVC by 59%. Similarly, production of feedstocks – chlorine, VCM, and olefins – declines by between 42% and 61% (Table 13).

Table 13. Production of HVCs, polymers, chlorine, VCM, and PVC in 2030 and 2050.

		Bio-based and local specialisation		
		Production		Capacities
		2030 vs. 2015	2050 vs. 2015	2050 vs. 2015
High Value Chemicals (HVCs)		-12 %	-35 %	-32 %
Polymers	**PE**	-23 %	-57 %	-29 %
	PP	-22 %	-59 %	
	PS	-20 %	-51 %	
Chlorine		-21 %	-47 %	-29 %
Vinyl Chloride Monomer (VCM)		-27 %	-61 %	-33 %
PVC		-25 %	-59 %	-34 %

The scale of these declining figures serves to illustrate the risk that a loss of intra-European trade poses for France, whose production is mainly destined for the export markets. While some degree of production can be maintained thanks to lower imports, this scenario assumes that production capacity will be reduced by 32% every year for HVCs, 29% for chlorine, 33% for VCM, and 34% for PVC, and by 29% for the polymers PP, PE, and PS by 2050.

➜ PVC window profile © Mindscape studio/Shutterstock

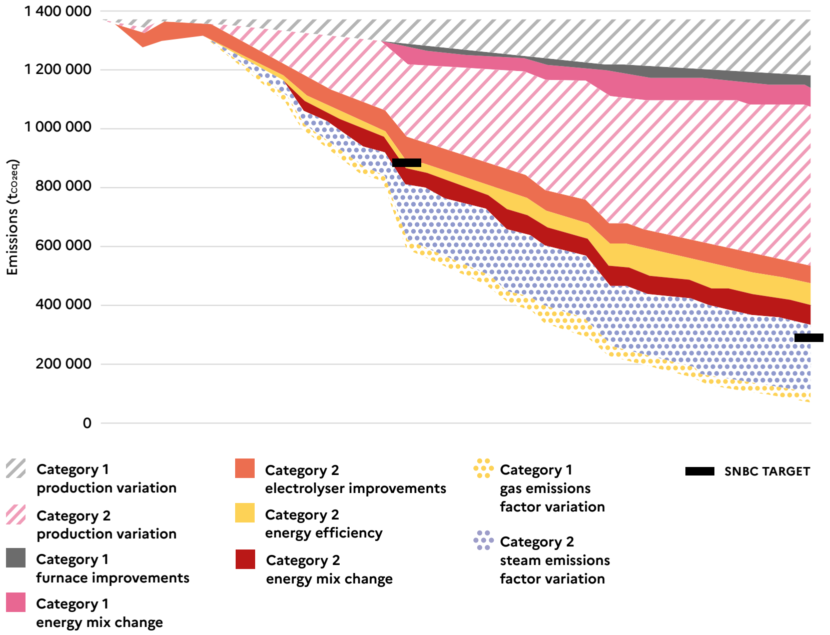
Emissions reductions driven by lower production output and greater use of bio-based materials.

The SNBC target is met through a combination of lower production, an adjusted energy mix, and energy efficiency measures.

Chlorine sector

In the "Bio-based and local specialisation" scenario, emissions reductions in the chlorine sector are largely due to lower production. They represent 715 kt of CO2e per year for the chlorine sector, i.e. 57% of the total. Changes to the emission factors for steam and gas are the next source of reductions, cutting category 1 and 2 emissions by 30 kt and 230 kt of CO2e respectively. The adoption of mature decarbonisation technologies also contributes, albeit to a lesser extent, with improvements to electrolysers, energy efficiency measures, MVR, and electric boilers together generating emissions savings equivalent to 100 kt of CO2e for category 1 emissions, and 195 kt of CO2e for category 2 (Figure 21).

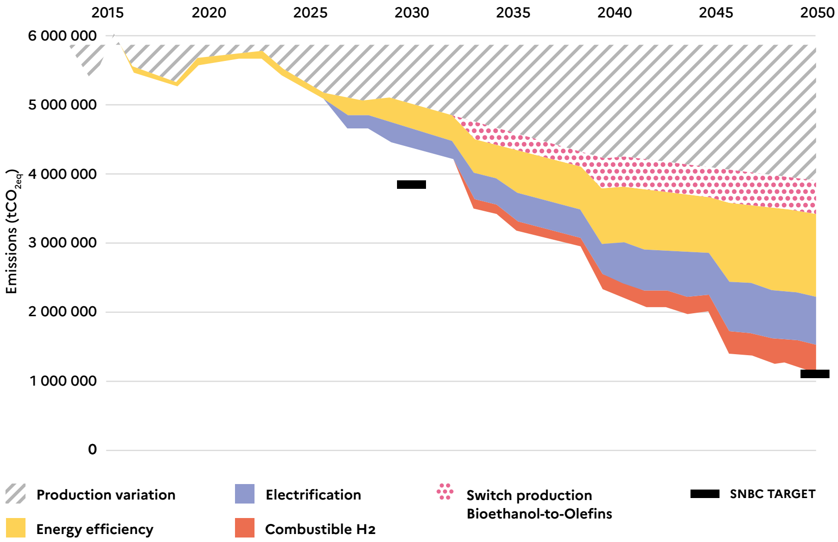
Figure 21. "Bio-based and local specialisation" scenario, GHG emissions from the French chlorine, VCM, and PVC industry.



Ethylene sector

In the ethylene sector, emissions are reduced by 4.7 Mt of CO2e by 2050, some 81% of the overall reduction. Lower production accounts for 40% of that reduction. Decarbonisation technologies provide savings of a further 2.7 Mt of CO2e in total, with energy efficiency measures contributing a reduction of 1.2 Mt CO2e, along with a figure of 700 kt for electrification, and 370 kt for hydrogen combustion. Finally, some steam cracker production is replaced by low-carbon HVC production using the BTO process. The 405 kt of BTO capacity installed by 2050 deliver emissions savings of 469 kt of CO2e, equal to 8% of the overall total (Figure 22).

Figure 22. "Bio-based and local specialisation" scenario, GHG emissions from the French ethylene industry (HVC and PE, PP and PS polymer).



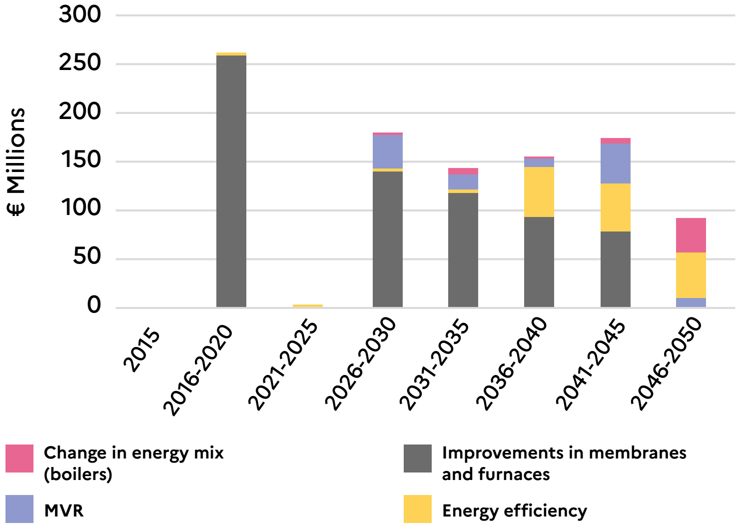
Investments spread across several technological solutions.

Total investments in the "Bio-based and local specialisation" scenario are 0.99 billion euros for the chlorine-PVC sector, and 6.2 billion euros for the ethylene sector, with amounts spread fairly evenly between the various decarbonisation solutions.

Chlorine sector

In the chlorine sector, aside from the 250 million euros already invested between 2015 and 2020, some 440 million euros is spent on improving electrolysers and converting pyrolysis furnaces to hydrogen. VMR is deployed less widely than in the previous scenario and therefore requires more limited investment, totalling 135 million euros and spread over the period 2025-2050. On the other hand, the deployment of high-temperature chlorination at VCM production sites entails higher energy efficiency CapEx costs than in the other scenarios, at 155 million euros (Figure 23).

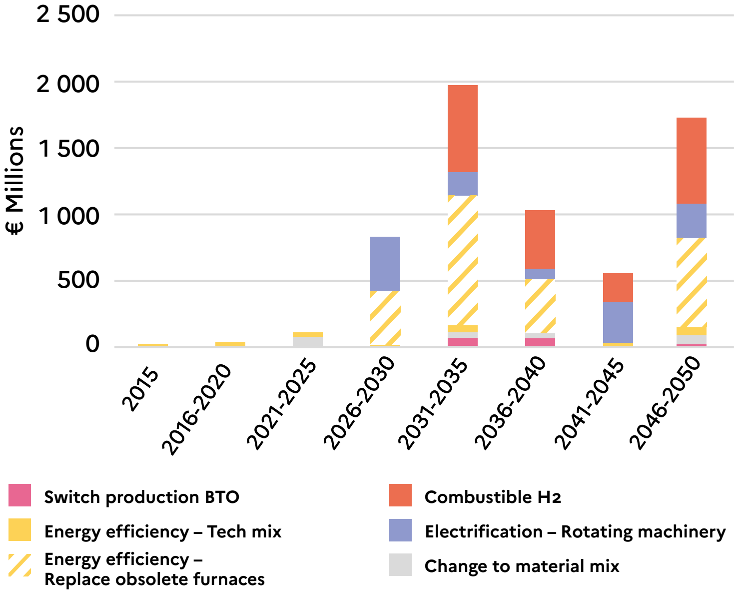
Figure 23. "Bio-based and local specialisation" scenario, investment timeline in five-year increments for the chlorine and PVC sector.



Ethylene sector

In the ethylene sector, the cost of replacing steam cracking furnaces represents the chief expense, totalling 2.4 billion euros. On top of that figure, partially converting facilities to run on hydrogen represents total additional capital costs of 1.9 billion euros between 2030 and 2050. Finally, partial electrification of steam crackers (with only rotating machinery electrified) requires a total investment of 1.2 billion euros. In addition to these measures, opening 405 kt of BTO production capacities by 2050 is assumed to cost a further 134 million euros.

Figure 24. "Bio-based and local specialisation" scenario, investment timeline in five-year increments for the French ethylene sector (HVC and PE, PP and PS polymer).



In the "Bio-based and local specialisation" scenario, trade declines, resulting in lower industrial output in the chlorine and ethylene sectors. While this lower production accounts for much of the reduction in emissions, significant investment is still needed to modernise those sites that remain open. The use of new, bio-based feedstocks does, however, present an opportunity for industrial players to develop bio-based chemicals business, potentially opening up new markets and increasing the added value of the products manufactured.

2.3. Comparative analysis: three contrasting scenarios highlighting the need to anticipate developments in the plastics industry

- **Production levels:** national demand for polymers declines in all three scenarios. However, these falls in demand can affect end production differently depending on two main factors: international trade, through imports and exports, and the type of recycling adopted, which determines where in the value chain the recycled material is reincorporated. For example, the "Petrochemicals and globalisation" scenario has the benefit of rising global demand, but poor competitiveness leads to lower exports, which in turn causes polymer production to contract sharply. Meanwhile, the "Electricity and European protectionism" scenario gets a European mechanism designed to restrict international imports, which serves to maintain levels of exports to Europe - the main market for French manufacturers. The decline in production is much less acute as a result. Finally, the "Bio-based and local specialisation" scenario assumes that exports will fall substantially, but that this trend will be partly offset by a similarly appreciable decline in imports. However, mechanical recycling in this scenario develops on a greater scale, supplying recycled raw materials directly to plastics manufacturers further down the value chain and further squeezing demand, with polymer production falling by 58%. (Figure 25). Regardless of the scenario, all of these reductions are passed on in almost linear fashion to the rest of the upstream value chain, with similar trends observed for olefins, chlorine, and VCM, all of which are much more sensitive to French demand than international trade. Depending on the scenario considered, the resulting lower production also leads to capacity closures in France. (Figure 26).

Figure 25. Comparison of polymer production trends between 2015 and 2050 by scenario.

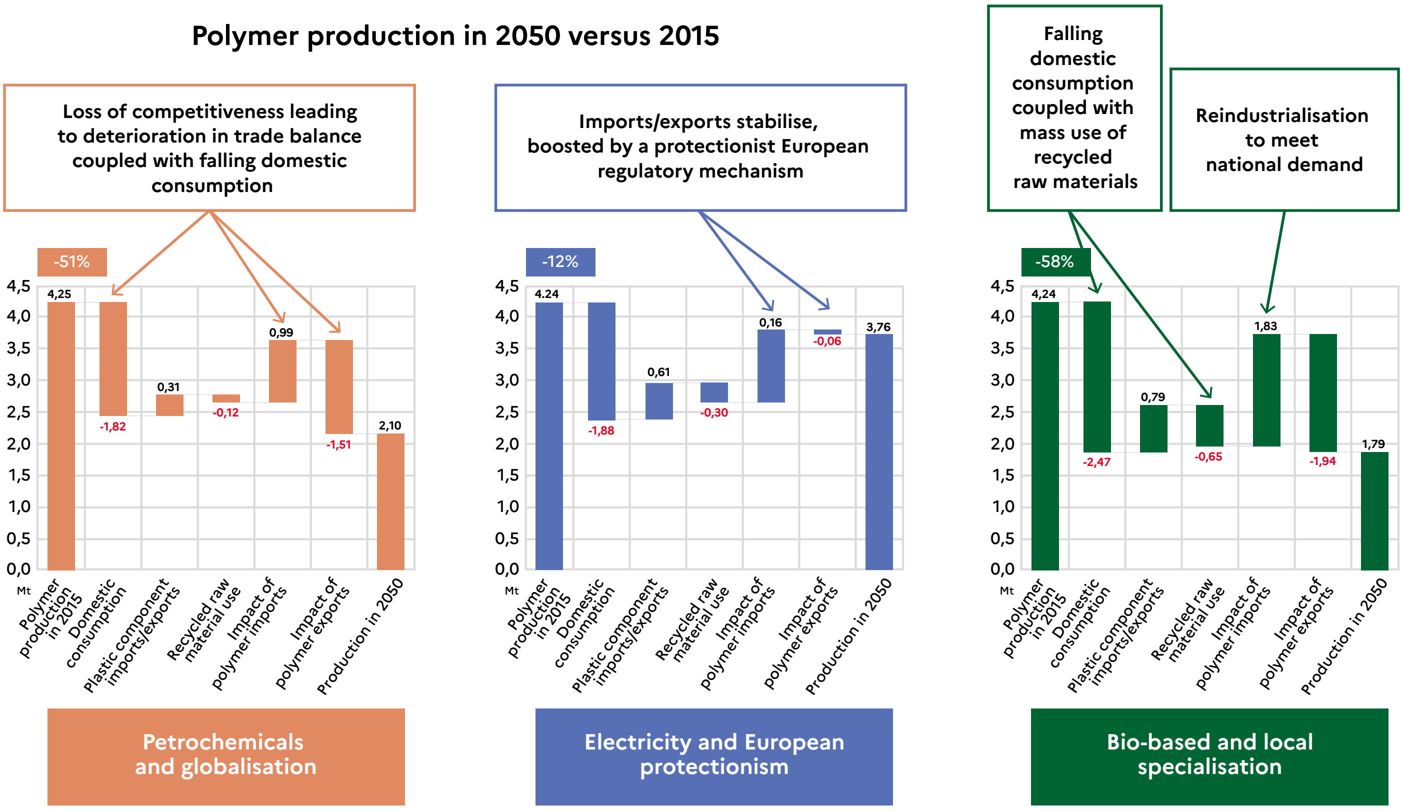
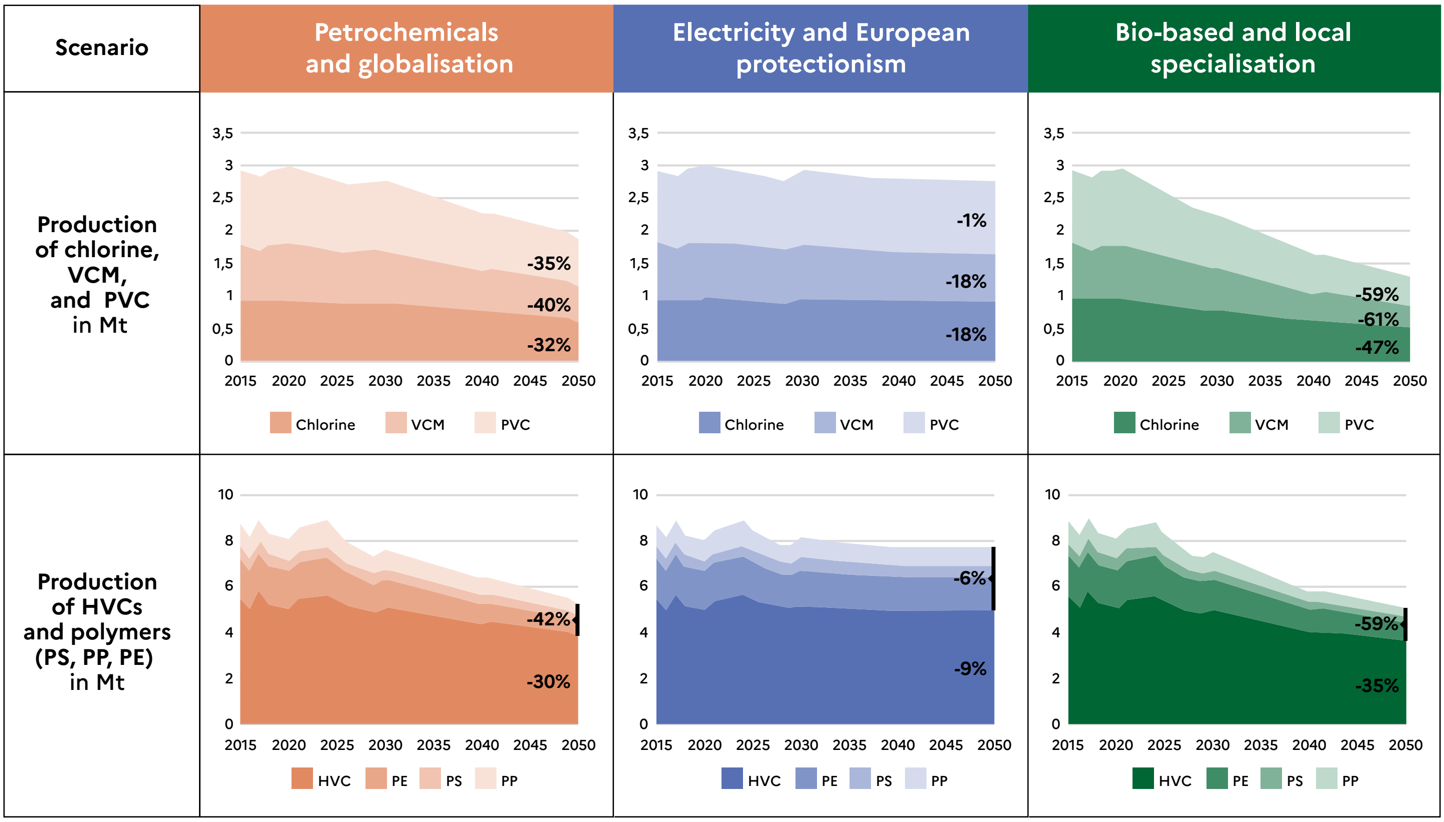


Figure 26. Comparison of production trends in the chlorine sector (chlorine, VCM, PVC) and ethylene sector (HVCs, PE, PP, PS) between 2015 and 2050 by scenario.



Emissions levels: All three of the scenarios studied in this report achieve the target of cutting category 1 emissions by 81% from 2015 levels, while the target for category 2 emissions in the chlorine STP is also met. In the case of chlorine, category 1 emissions are reduced by phasing out fossil fuels in favour of electrification (of furnaces and boilers) and the combustion of biomass and hydrogen, supplemented by a reduction in production. Category 2 emissions, on the other hand, are mainly reduced through the use of MVR and the reduction in the steam emission factor made possible by the use of biogas. For ethylene, the use of CCS, the electrification of furnaces and production cutbacks are the three main factors responsible for the drop in emissions. If production output decreases significantly, less disruptive solutions can be employed, such as energy efficiency measures, partial electrification, hydrogen combustion, or even CCS. If production continues at its current levels, more extensive electrification will be needed, requiring substantial investment.

Energy mix: energy consumption falls in all three scenarios, driven partly by lower production output, particularly in the "Petrochemicals and globalisation" and "Bio-based and local specialisation" scenarios, and partly by lower specific consumption as a result of energy efficiency measures, as in the "Electricity and European protectionism" scenario. On the other hand, the energy mix develops very strongly from one scenario to the next, with mass-scale electrification in the "Electrification and European protectionism" scenario, whereas the other two scenarios see fossil gas consumption falls thanks to energy efficiency measures, the use of alternative energy sources, and partial electrification.

- **Infrastructure requirements vary according to territorial characteristics:** while the choice of technologies deployed may vary from one site to another, the solutions that offer the biggest carbon-cutting possibilities are generally exclusive and dependent on local infrastructure. In the ethylene sector, for example, the choice is between CCS or steam cracker electrification, and between BTO, MTO, or traditional olefin production processes, while in the chlorine sector, manufacturers can use either ODC or conventional membranes. These decisions need to be made right now, to minimise the risk of stranded assets and start making plans for the necessary infrastructure immediately. These choices will also dictate industrial firms' potential future business models, and the markets they are ultimately able to operate in. Moves to lower the carbon footprint of each site also need to fit into the local transition matrix. Depending on the profile of industrial zones and/or ports, the deployment of shared H_2, CO_2 and electricity infrastructure may be envisaged, but it must be planned collectively to ensure that it is correctly sized. A good understanding of the associated issues and challenges for industrial zones is key to optimising local decarbonisation drives, along with proper support for the creation of local synergies.

- **Investment key to opening up new markets:** The task of decarbonising these two highly capital-intensive sectors comes with very significant costs, mostly incurred between 2035 and 2050. While carbon capture and storage does serve to substantially reduce the investment needed, it does not allow the production of so-called "low-carbon" polymers like those that can be obtained via electrification or the use of bio-based feedstocks. In addition, an appreciable proportion of the CapEx and OpEx costs may come from the deployment of alternative olefin production technologies (MTO, BTO), which have the advantage of diversifying the supplies of feedstocks on which the sector depends, in a future where petroleum-based resources are set to become scarcer. Since these breakthrough technologies are currently still in the development stage, it is important to anticipate the future direction that will ultimately be taken, so that investment can be allocated with minimum risk. Investments in certain decarbonisation technologies may also offer an opportunity for industrial players to be more competitive, by improving their energy and feedstock efficiency. The extent of the savings made will depend greatly on future developments in energy and carbon allowance prices.

➜ Bales of plastic bottles waste © JDzacovsky/Shutterstock

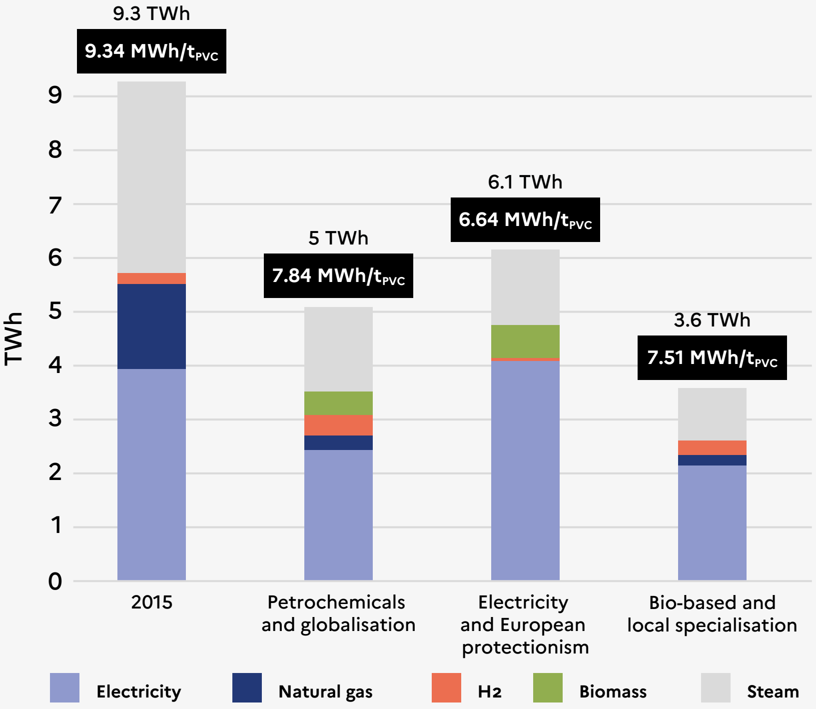
Energy mixes moving away from fossil fuels.

Chlorine

Specific consumption reduced in all three scenarios.

The decarbonisation solutions adopted in the chlorine-VCM-PVC sectors also allow improvements in energy efficiency. Specific consumption is reduced, mainly thanks to the use of MVR requiring smaller quantities of steam. In terms of the energy mix, the use of natural gas declines in favour of electrification and combustion of biomass and hydrogen. The "Electricity and European protectionism" scenario assumes that the share of electricity in the energy mix will rise markedly, but that this will only be partially offset by improvements to electrolysers and the use of ODC. Total energy consumption falls in all three scenarios (by between 33% and 60%) due to the combined effect of energy efficiency measures and lower production (Figure 27).

Figure 27. Comparison of total and specific energy used to manufacture one tonne of PVC in each scenario for each energy carrier.



Ethylene

Significantly lower specific consumption, except in the "Petrochemicals and globalisation" scenario.

Overall energy consumption can be seen to fall in all three scenarios, although both specific consumption reductions and the energy mix vary appreciably in each. In the "Petrochemicals and globalisation" scenario, specific consumption in 2050 is virtually identical to 2015. This reflects the fact that fossil fuels continue to be the main source of energy in this scenario, meaning that CCS measures have no meaningful impact on the carbon footprint of steam crackers. The "Electricity and European protectionism" shows the biggest drop in global consumption, of 43% compared with 2015 levels. This is the scenario in which the energy mix moves away from fossil fuels most markedly, while yields still improve as a result of steam cracker furnaces going electric. Nonetheless, the massive use of electricity (+10.5 TWh) not only leads to a new form of energy dependency, but also requires infrastructures to be upgraded and/or built. New infrastructures are also essential in the "Bio-based and local specialisation", where the main fuel energy source for steam cracking furnaces is hydrogen, with rotating machinery being converted to run on electric power (Figure 28).

Figure 28. Comparison of total and specific energy used to manufacture one tonne of HVC in each scenario.

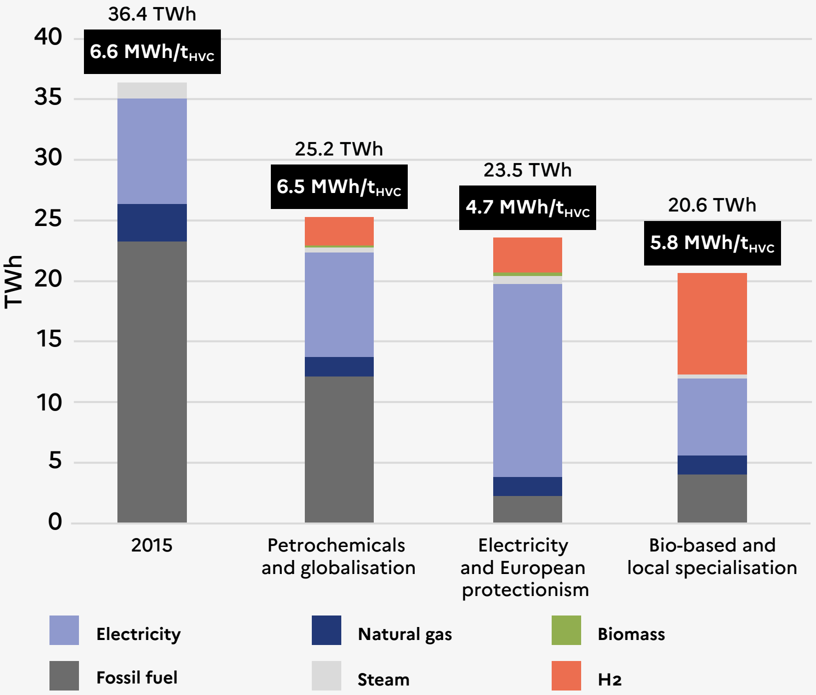


Table 14. Summary of the main results for the three scenarios in the chlorine and PVC sector.

Scenario	Petrochemicals and globalisation	Electricity and European protectionism	Bio-based and local specialisation
Chlorine production	-32 %	-3 %	-47 %
VCM production	-40 %	-18 %	-61 %
PVC production	-35 %	-1 %	-59 %
Chlorine/VCM/PVC production capacity	-20 % / -33 % / -17 %	0 % / 0 % / 0 %	-29 % / -33 % / -34 %
Production variations driven by regulations and plant investments			
Energy consumption	-46 %	-34 %	-62 %
Specific energy	-16 %	-29 %	-20 %
Energy consumption determined both by production levels and more energy efficient production.			
Category 1 CO_2e emissions	-96 %	-100 %	-99 %
1+2 CO_2e emissions	-85 %	-92 %	-94 %
Category 1 emissions abatable by reducing use of natural gas. Category 2 emissions dependent on production, level, but abatable via the deployment of new technologies such as MVR and electrolyser improvement.			
CAPEX	€905 m	€1,523 m	€989 m
Final CapEx largely dictated by deployment of two technologies: MVR and next generation electrolysers.			

Table 15. Summary of the main results for the 3 scenarios in the ethylene sector (HVC and PE, PP, PS polymers).

Scenario	Petrochemicals and globalisation	Electricity and European protectionism	Bio-based and local specialisation
HVC production	-35 %	-14 %	-42 %
Polymer production	-41 %	-6 %	-58 %
HVC / polymer production capacity	-25 % / -20 %	-12 % / -10 %	-32 % / -29 %
Production variations driven by regulations, plant investment, and investments in alternative production processes.			
Fossil fuel consumption	-52 %	-90 %	-86 %
Electricity consumption	+ 3 000 GWh/year	+ 10 500 GWh/year	+ 3 300 GWh/year
Energy consumption determined by production levels, electrification, energy efficiency, and hydrogen-based steam cracking furnaces.			
Category 1 CO_2e emissions	-82 %	-81 %	-81 %
Reduced category 1 emissions largely due to CCS, electrification, and various energy efficiency measures (replacing furnaces with more efficient models, MVR, selective membrane technology).			
CAPEX	€3.1 bn	€4.6 bn incl. €0.5 bn for MTO deployment	€6.3 bn incl. €0.5 bn for BTO deployment
Production cost €/t_{HVC}	€1,538/t_{HVC}	€1,363/t_{HVC}	€1,884/t_{HVC}
Production cost €/t_{poly}	€1,685/t_{poly}	€1,521/t_{poly}	€1,931/t_{poly}
Final CapEx varies depending on extent of electrification, CCS, alternative processes (BTO and MTO), and production plant.			

Whether or not the 81% emissions reduction target can be met will depend on a complex range of factors including developments in both market conditions and technology, in sectors where opportunities to invest in production plant are limited by the lifespan of facilities and the associated costs. Nonetheless, the future of both sectors will hinge on these investments, so it is important to consider how they could affect industrial firms' profits and ability to compete. The next section will therefore look at the socio-economic factors associated with each scenario via a cost analysis, to ensure that industrial firms are armed with the information they need to guide their decisions.

3. Socio-economic analysis

While significant investment is needed to reduce the carbon footprint of these industries, that investment equally represents an opportunity to boost competitiveness by simultaneously cutting energy and carbon costs. The next section looks at how production costs are impacted in each scenario.

3.1. Production costs heavily dependent on raw materials and energy prices

As for many sectors in the chemical industry, the production costs of ethylene, chlorine, and polymers are strongly correlated with energy prices. The example of 2022, when surging electricity and gas prices caused production costs to soar, serves to emphasise the sector's reliance on low-cost energy. This is, in fact, one of the key factors in the European chemical industry's loss of market share to Asian and American rivals, who enjoy access to cheap and plentiful fossil fuels, as highlighted in the chemical industry's own decarbonisation roadmap[53]. Olefin manufacturers are a slightly different case, since they use naphtha as both a feedstock and an energy source via the fuel by-products derived from the process (fuel gas, fuel oil). Finally, fluctuations in CO_2 prices and changes to the way free allowances are allocated (due to end in 2034) could push up costs even higher for industrial producers if they do not commit to a decarbonisation strategy.

To better address these risks, various trajectories were used to simulate future developments in the prices of energy carriers (gas, electricity, steam, H_2), naphtha, and CO_2 transportation and storage, in order to determine how they would impact the cost structure in each scenario (Table 16). These trajectories were built on the basis of different reports[54] and are qualified as "low", "baseline", and "high". The gas and steam prices assumed here also include rises resulting from shifting much of the network mix from fossil gas to biogas. For the sake of comparison, the chosen trajectories are the same for all three scenarios. However, it is entirely reasonable to assume that different transition contexts could see prices behave differently. Table 16 shows the different trajectories for each energy carrier considered, with the exception of CO_2 and H_2 for which there is only one price trajectory.

➜ Industrial boiler for steam production © engineer story/Shutterstock

Table 16. Main price trajectories (low - baseline - high) used to estimate future production costs in the ethylene and chlorine sectors.

		2015	2030	2050	Source
Gas (€/MWh) HHV	Low	32	45	60	ADEME based on FE2050 low (RTE)
	Baseline	32	47	82	ADEME based on FE2050 high (RTE)
	High	32	50	100	ADEME based on ThreeMe S2 (ADEME)
Electricity (€/MWhe)	Low	47	51	49	ADEME based on FE2050 low (RTE)
	Baseline	47	52	55	ADEME based on FE2050 high (RTE)
	High	47	54	62	ADEME based on ThreeMe S2 (ADEME)
Steam (€MWh)	Low	25	36	47	ADEME based on FE2050 low (RTE)
	Baseline	25	37	65	ADEME based on FE2050 high (RTE)
	High	25	39	79	ADEME based on ThreeMe S2 (ADEME)
Electrolytic H_2 (€/kgH_2)		5	4,4	4	ADEME
Naphtha (€/t)	Low	418	242	166	ADEME based on INSEE Statistiques Oct 2023 and AIE oil NZE
	Baseline	418	566	656	ADEME based on INSEE Statistiques Oct 2023 and AIE oil STEPS
	High	418	944	1 107	ADEME based on INSEE Statistiques Oct 2023 and EIA High Price
CO_2 (€/tCO_2)[55]		7,7	112	250	IEA (NZE - WEO2022) point of arrival in 2050
CO_2 transported and stored (€/tCO_2)		–	55	55	ADEME

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[53] https://new.societechimiquedefrance.fr/wp-content/uploads/2024/06/Plan-de-Transition-Chimie-France-CNC-2024-1.pdf

[54] "Futurs énergétiques" by RTE, "Transition 2050" by ADEME

[55] Prices shown for 2015 and 2030 do not include the " effect of free allowances", but the models take into account the fact that some CO_2 emissions are not priced with the existence of this scheme, which is gradually phased out between 2026 and 2034.

3.2. Production costs highly energy-dependent for chlorine and HVCs

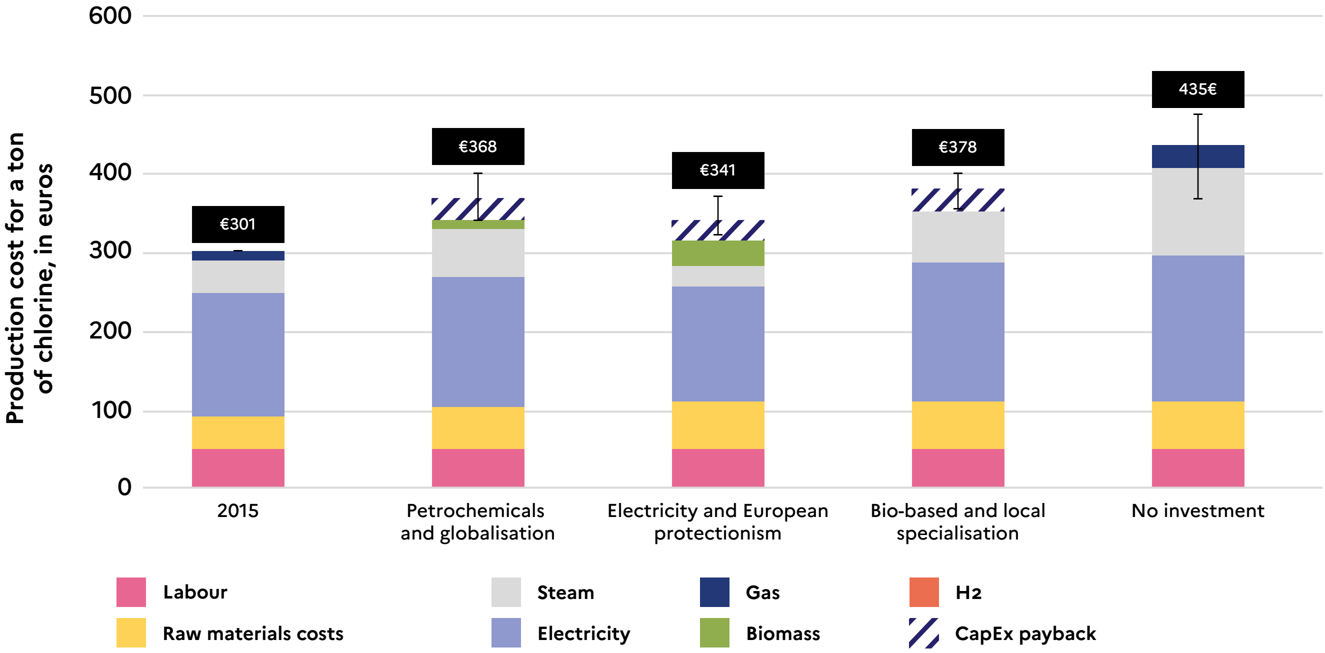
Chlorine production costs are largely dependent on energy prices, but the effect is mitigated by energy efficiency savings.

In the chlorine sector, production costs behave in a relatively similar way regardless of scenario and price trajectory up to 2030, with differences in the extent to which various technologies are deployed not yet having any crucial impact. On average, costs rise by 20%.

By 2050, production costs evolve differently between the scenarios, rising by 22%, 13%, and 25% on the baseline trajectory for the chlorine sector in the "Petrochemicals and globalisation", "Electricity and European protectionism", and "Bio-based and local specialisation" scenarios respectively. In all three scenarios, CapEx costs are less than the additional costs incurred if no investments are made, in which case production costs rise by 44%. This sharper increase is essentially due to the rise in the price of gas and steam, and to a lesser extent CO_2 (Figure 29).

While production costs rise in all scenarios, it is important to note how activating various decarbonisation technologies can help to mitigate the added costs. For example, in the "Electricity and European protectionism" scenario, where investments in energy efficiency and electrification are the highest, the cost of energy required to produce one tonne of chlorine falls by 15% despite the rise in energy prices. Contrast this with the other two scenarios in which there is a greater external reliance on steam and hydrogen, and where production costs rise by an average of 14%. Raw materials costs, mainly for the purchase of salt, also rise slightly to adapt to the membrane process and are similar regardless of the scenario.

Figure 29. Projected specific production cost of chlorine in 2050 under the three scenarios and in one "Zero investment" scenario with the baseline price trajectory and min-max low and high trajectories.



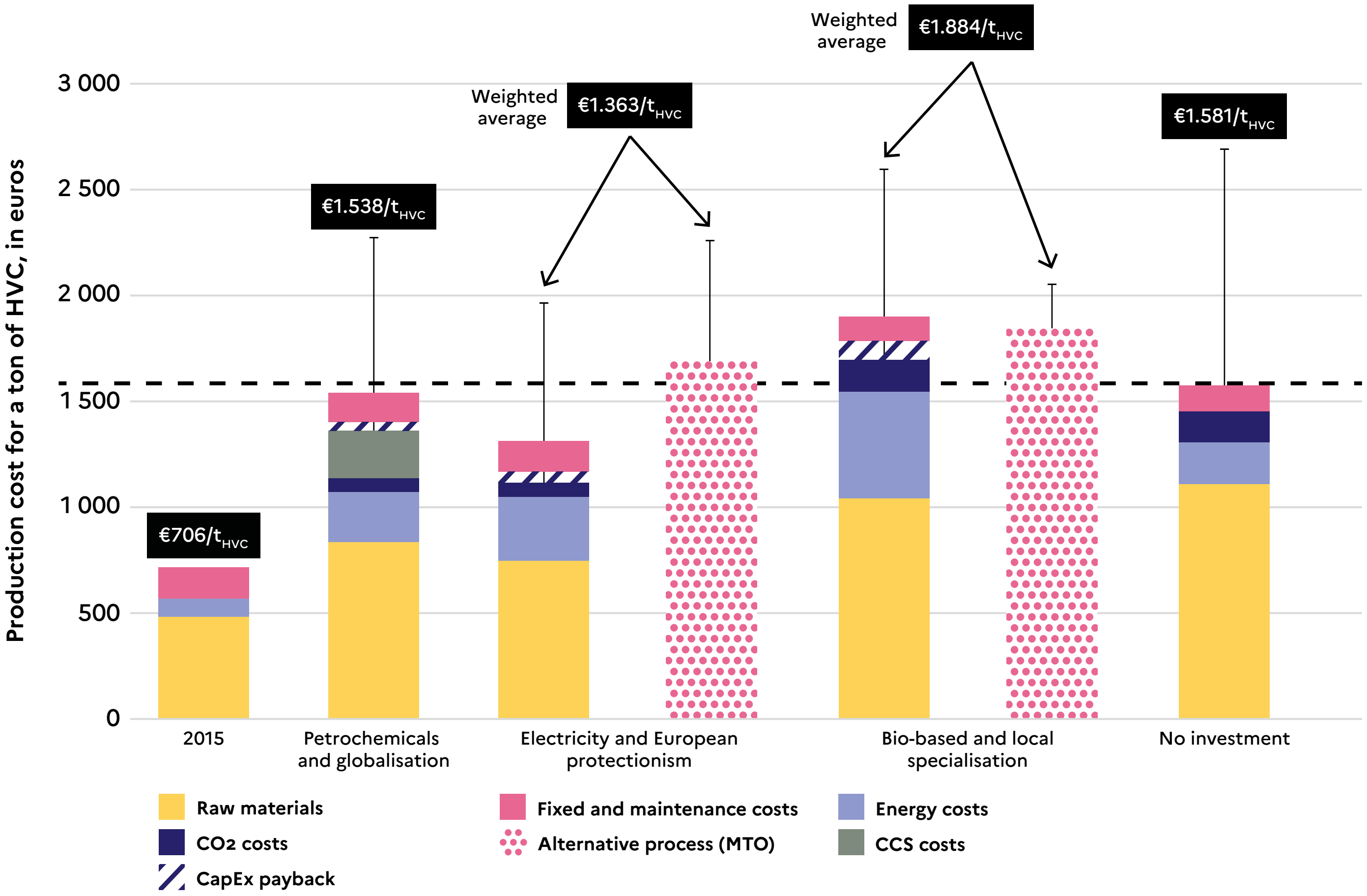
HVC production costs double, mainly due to higher raw materials costs.

In 2015, the costs of raw materials (e.g. naphtha) represented 68% of the total cost of producing a tonne of HVC. However, the costs of imported energy (e.g. natural gas, electricity) only accounted for 11%. This low figure is partly due to the fact that steam crackers are somewhat self-sufficient, being capable of using their raw material to generate their own energy. Also, the majority of petrochemical platforms with steam crackers and polymerisation units are integrated. This means they share energy infrastructure and utilities, reducing their reliance on imported energy. In the case of steam crackers specifically, maintenance costs and overheads (21% of production cost) reflect the need for those units to be constantly optimised and regulated, and not only during planned turnarounds[56].

In 2050, raw materials represent a higher share of the cost of producing a tonne of HVCs regardless of the scenario, due to the high price not only of naphtha but also of alternative feedstocks (pyrolysis oil, e-naphtha, bio-naphtha) (Figure 30). Even if the market for alternative feedstocks expands significantly in response to the growth of sustainable fuels and a greener chemical industry in the coming years, they currently remain marginal in steam cracker feedstock mixes. The transition in the ethylene sector will hinge on whether these feedstocks can be obtained at prices low enough to allow industrial producers to turn a profit.

Nonetheless, raw materials only represent 55% of production costs in 2050, down from 68% in 2015. Energy costs rise markedly as fuel gas is replaced by imported energy. It is worth nothing that in the "Electricity and European protectionism" scenario, massive electrification (of rotating machinery and steam crackers) and improved energy yields see energy rise to account for 23% of production costs, double its previous share.

Figure 30. Projected specific production cost of HVCs in 2050 under the three scenarios and in one "Zero investment" scenario with the baseline price trajectory and min-max low and high trajectories.



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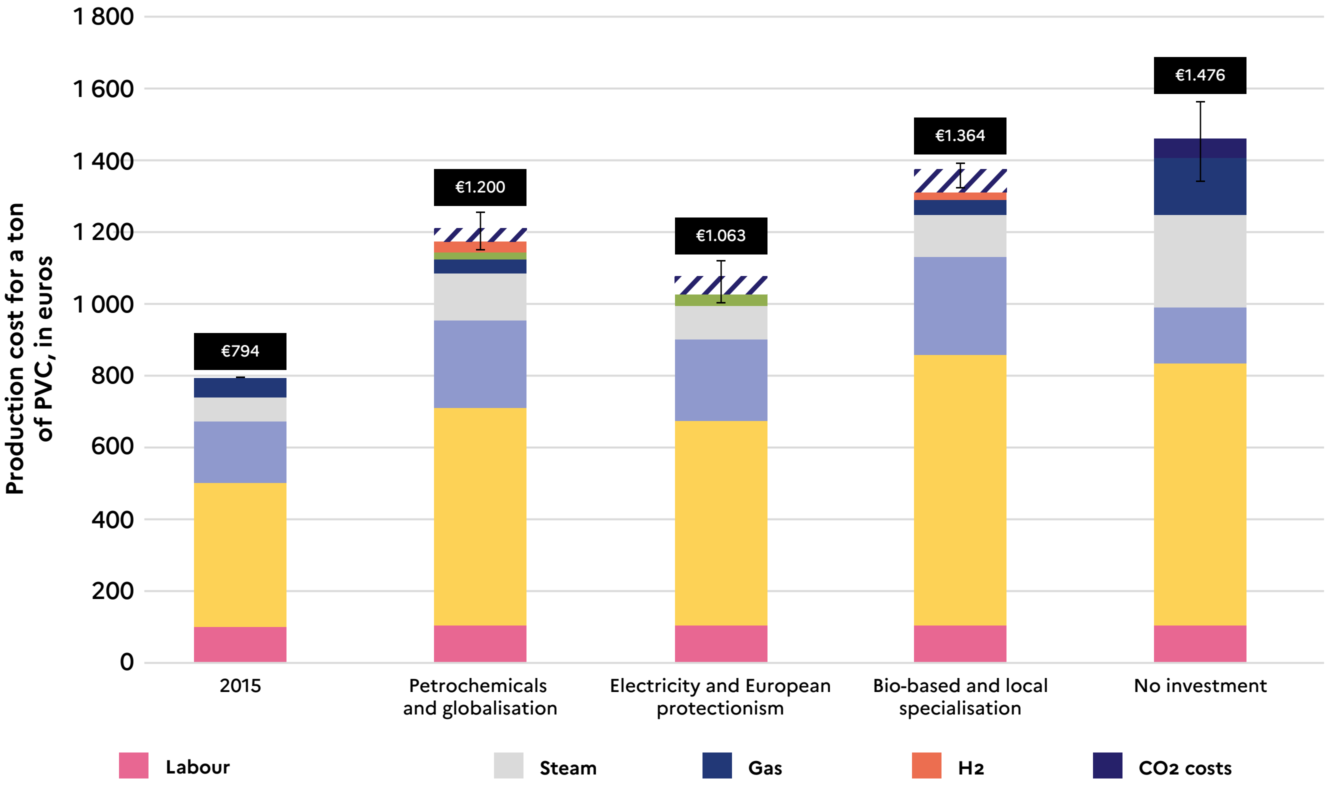
[56] Mandatory shutdown for inspection and maintenance every seven years.

3.3. Polymer production costs (PVC, PE, PP, and PS) heavily dependent on outputs from steam crackers and electrolysers

PVC production cost: ethylene price a major factor in the rise in costs.

In 2050, differences appear with rises of 51%, 34%, and 72% for PVC in the "Petrochemicals and globalisation", "Electricity and European protectionism", and Bio-based and local specialisation" scenarios respectively (Figure 31). In all scenarios, the cost structure of PVC is far more dependent on the prices of raw materials (chlorine and ethylene) than directly on energy price variations. PVC is affected by the impacts of both its its upstream sectors – chlorine and ethylene – which are in turn subject to sharp energy price rises, but it is the ethylene price that has the biggest impact. While raw materials costs remain stable as a proportion of overall cost at 59%, 58%, or 63% in the three scenarios, "Petrochemicals and globalisation", "Electricity and European protectionism", and "Bio-based and local specialisation" (compared with 57% in 2015), they are responsible for 64%, 61%, and 72% of the rise in that overall cost. The cost differences between the scenarios are essentially due to variations in the price of ethylene in each one. This illustrates the extent to which PVC manufacturers are dependent on the price of ethylene[57], and therefore on the decisions made by petrochemical firms. In terms of downstream processes, i.e. at polymerisation units, energy efficiency measures serve to mitigate the energy cost impact, with energy falling from 30% of the overall cost in 2015 to 29%, 28%, and 25% in 2050. Conversely, the "Zero investment" scenario sees energy increase as a proportion of the total cost, rising to 39%.

Figure 31. Projected specific production cost of PVC in 2050 under the three scenarios and in one "Zero investment" scenario with the baseline price trajectory and min-max low and high trajectories.



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[57] The ethylene prices used here are obtained from production cost models in the ethylene sector for the different scenarios.

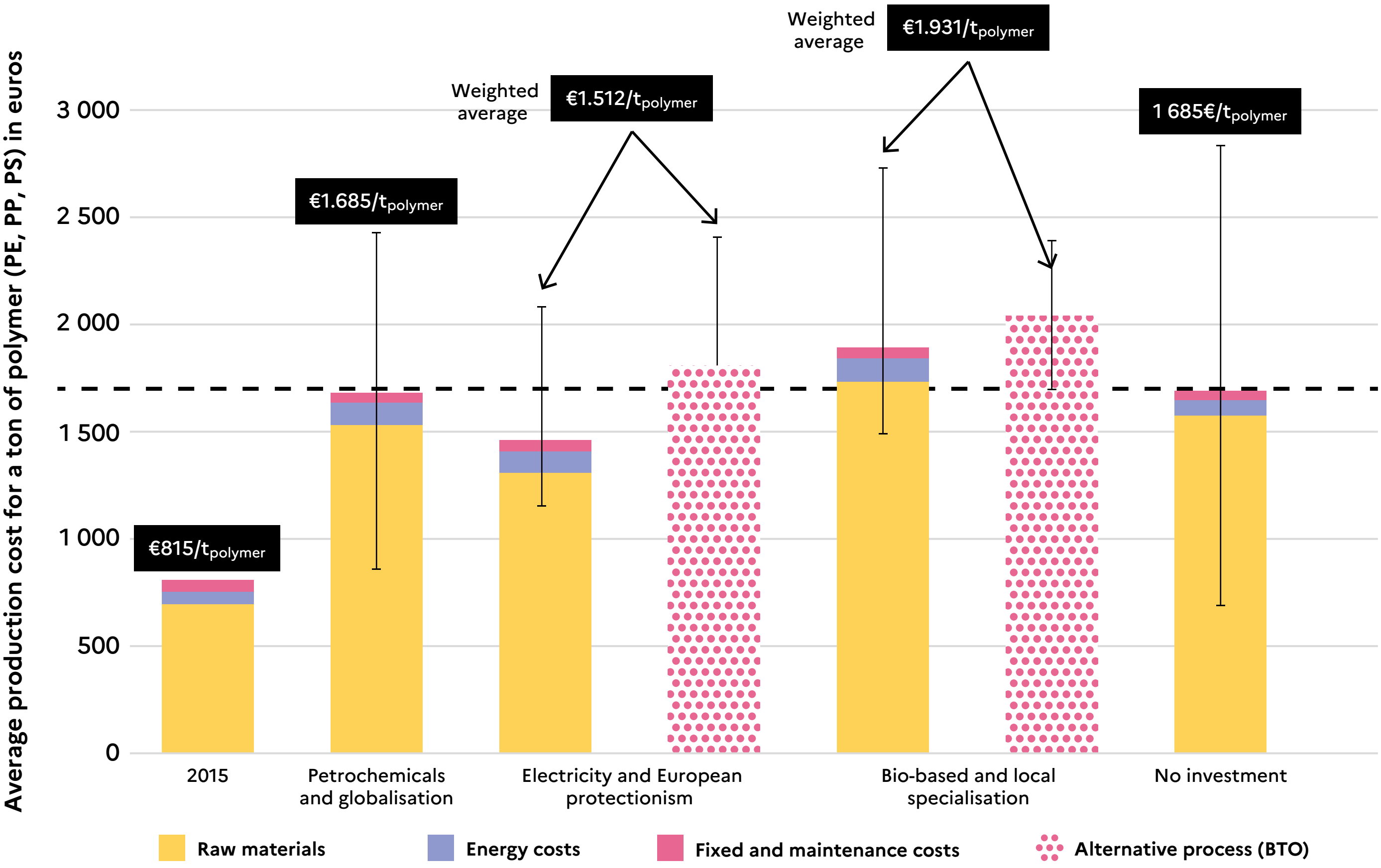
PE, PP, and PS polymer production costs heavily impacted by the price of ethylene and other HVCs (propylene, styrene, etc.) produced downstream from the steam cracker.

Unlike PVC, the process of manufacturing polymers PE, PP, and PS requires a range of HVCs other than ethylene, such as propylene and other monomers like styrene obtained from a chemical reaction between ethylene and benzene. In addition, proportionally, it takes one tonne of product from a steam cracker (e.g. propylene) to manufacture one tonne of polymer (e.g. polypropylene) in a polymerisation unit. This one-to-one ratio illustrates why raw materials represent such a high proportion of the overall production cost. In 2015, HVCs represented 87% of the cost of producing polymers. This ratio remains relatively steady in all of the scenarios, at between 87% and 92% in 2050. As such, it remains the biggest cost item.

Overall, polymerisation uses around 25 times less energy than steam cracking. This is reflected in the cost of energy (including imported energy carriers such as steam) as a proportion of the total cost, which stabilises at close to just 7% of the cost of PE, PP, and PS production between 2015 and 2050.

These polymer cost structure trends mirror those seen with HVCs in all of the scenarios (Figure 30). This may be due to the fact that polymerisation is one of the next stages in the value chain after steam cracking, and as such is entirely dependent on HVC prices due to a cascade effect.

Figure 32. Projected specific production cost of PE, PP, and PS in 2050 under the three scenarios and in one "Zero investment" scenario with the baseline price trajectory and min-max low and high trajectories.



While price rises are to be expected, the impact of higher costs on the competitiveness of French industry can only be judged in terms of the competitors. It is unlikely that non-EU energy prices will rise to European levels by 2050, but the CBAM mechanism introduced in the "Electricity and european protectionism" scenario restricts competition to Europe. This means that French firms – thanks to the specific consumption savings made possible – will be able to maintain their EU exports and therefore their levels of output. Conversely, in the "Petrochemicals and globalisation" and "Bio-based and local specialisation" scenarios, this increase in production costs exacerbates the existing loss of competitiveness, leading to lower exports and loss of market share.

3.4. Ex ante abatement cost: a criterion for choosing between breakthrough decarbonisation technologies

Ex ante abatement costs are used to compare specific technologies. They give an objective picture of which technologies allow the biggest CO_2 savings at the lowest cost, making them a useful decision-making aid. The conditions chosen for calculating the ex ante cost (deployment date, payback period, energy prices) can be adjusted to carry out sensitivity analyses.

For chlorine, abatement costs are heavily dependent on energy prices due to the predominance of energy efficiency measures

The graph in figure 33 shows ex ante abatement costs for the different decarbonisation technologies addressed in the chlorine STP, based on energy prices in 2015 (in blue) and 2022 (in red), over a 20 year period. The abatement potential, in tonnes of CO_2e, is shown for each technology (in green for category 1, yellow for category 2). The differences between the two series indicate that the price of energy plays a major role in the abatement costs for the chlorine sector: these are mostly negative for the 2022 series (when energy prices were very high) and mostly positive for the 2015 series (when energy prices were low). This is due to the fact that most of the decarbonisation technologies available for the chlorine-PVC sector allow energy savings. The CO_2 price, on the other hand, has less of an impact, since many of these technologies serve to reduce the use of imported electricity or steam, which fall under category 2 emissions. Some technologies, such as electrification of pyrolysis furnaces or the use of hydrogen as a substitute for natural gas, entail significant changes to the energy mix, and as such will be particularly sensitive to the respective prices of those energy carriers. The full report will contain sensitivity analyses looking at this issue in more detail.

The technologies with high abatement potential (e.g. furnace electrification, H_2 combustion, and MVR) have the highest abatement costs. Conversely, technologies such as new membranes that allow electricity savings come with low abatement costs (especially if electricity prices are high), but very low abatement potential, as France has a low-carbon electricity mix. Most of the technological solutions considered here have low or even negative abatement costs. This means that decarbonising the industry has a dual advantage, allowing both lower emissions and OpEx savings.

High abatement costs for ethylene due to the adoption of relatively immature (and therefore expensive) technologies, but high abatement potential.

Inversely, an analysis of the ex-ante abatement costs of the decarbonisation technologies adopted in the ethylene STP shows a different or even opposite trend, as can be seen in the graph in figure 34. Since the decarbonisation technologies suggested mostly entail altering the energy mix (replacing fuel gas with electricity or hydrogen) or the material mix (replacing fossil-based naphtha with e- or bio-naphtha), high prices in 2022 translate to higher abatement costs than in 2015. One of the limitations of this analysis is that it does not include variations in the naphtha price between 2015 and 2022, which could affect the results shown. Nor does it take account of the potential gains to be made from reselling stocks of fuel gas and fuel oil once they have been replaced by hydrogen or electrified steam cracking furnaces. Finally, owing to the high abatement potential of certain technologies in terms of category 1 emissions, the CO_2 price may have a greater influence on their final abatement cost. These CO_2-related costs remain negligible as a component of the price of the finished product when compared with other industries such as cement, and as a proportion of the CapEx required. In all cases, regardless of the price benchmark used, the highly capital-intensive nature of measures to decarbonise the sector and the costly technologies needed suggest that abatement costs will be mostly positive for the sector. This issue will be explored in greater detail in the full report, with an analysis looking at how sensitive abatement costs are to electricity and H_2 prices for electric steam cracking furnaces, H_2 combustion steam cracking furnaces and CCS.

Figure 33. 20 year ex ante abatement costs of decarbonisation technologies in the chlorine STP, calculated on the basis of energy prices in 2015 (blue) and 2022 (red).

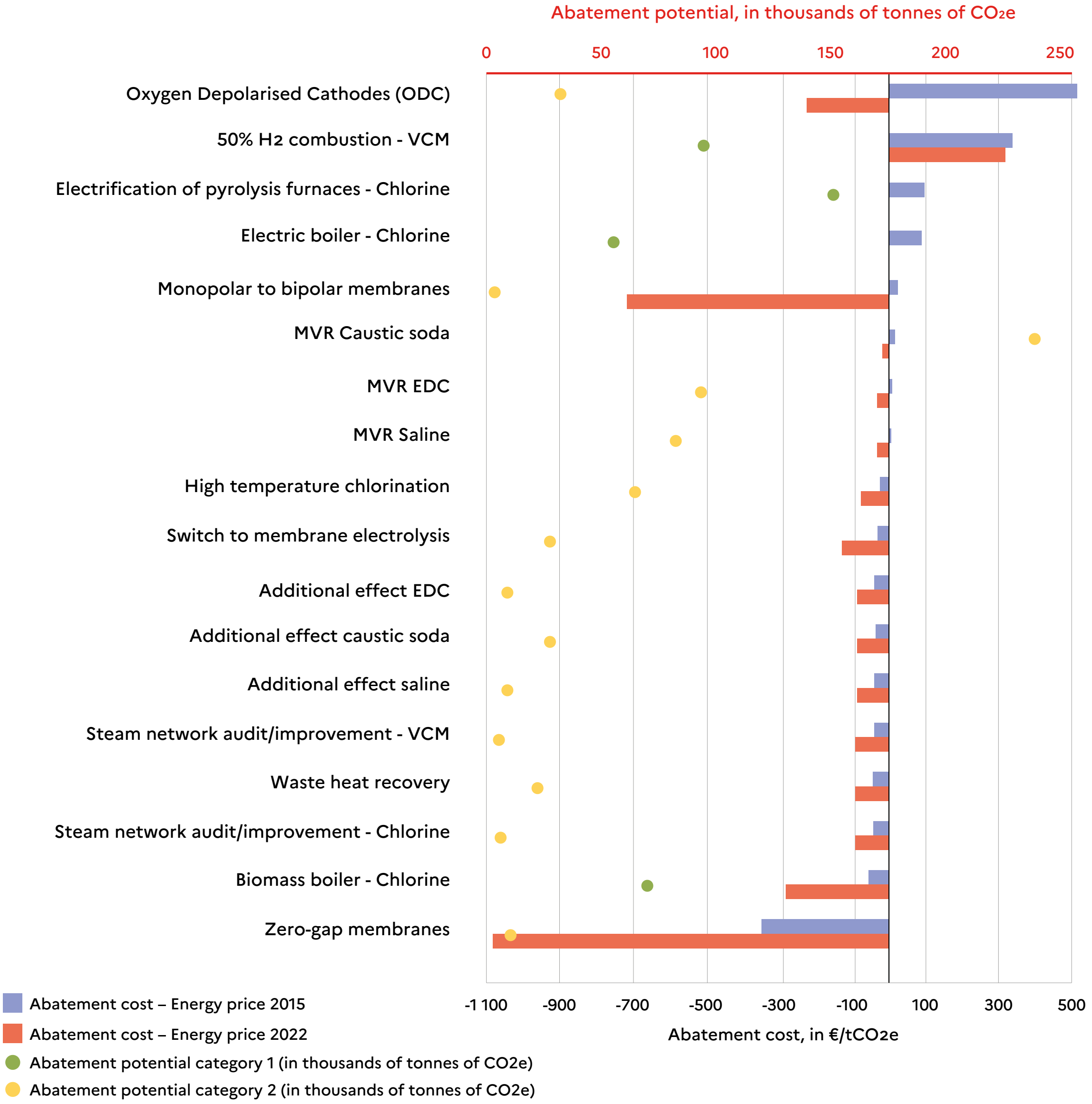
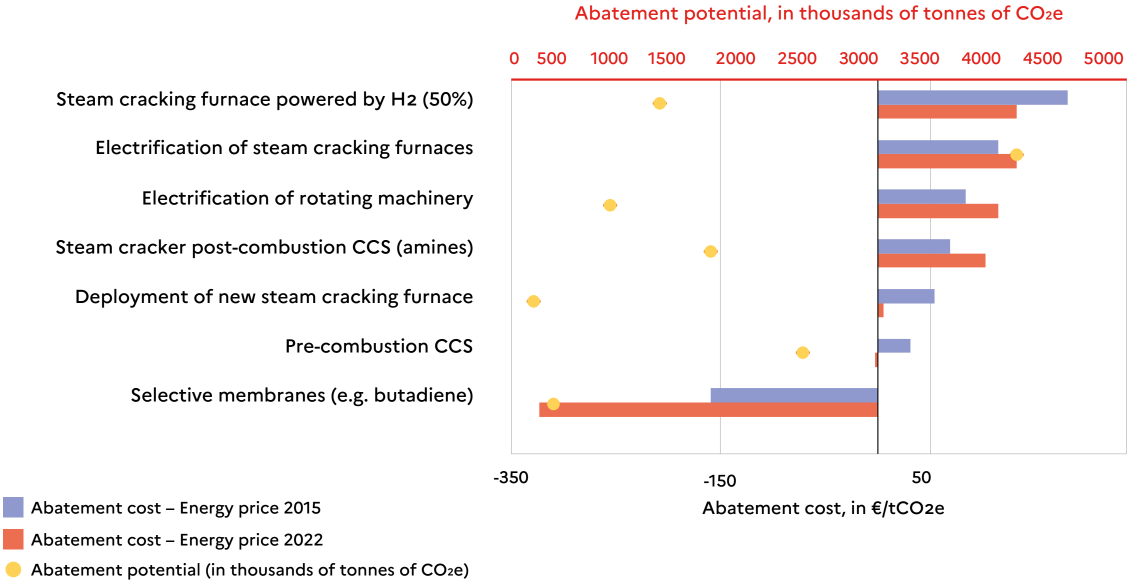


Figure 34. Ex ante abatement costs of decarbonisation technologies in the ethylene STP, calculated on the basis of energy prices in 2015 (blue) and 2022 (red).



3.5. Jobs ●

Initial thoughts on workforce requirements in 2050

The impact of each scenario on workforce numbers is based essentially on two factors: the level and type of production for direct jobs, and energy and materials consumption for indirect jobs further up the value chain. Between 2010 and 2020, numbers of direct jobs (according to the ACOSS-URSAFF database) and upstream indirect jobs (based on energy and feedstock requirements) remained fairly stable in the ethylene/polymer sector, with around 3,300 for the former and 1,900 for the latter between 2011 and 2020. In the chlorine/PVC sector, the number of direct jobs fell by approximately 4,600 in 2011 to around 3,900 in 2020. One reason for this may be the modernisation of production sites, moving from mercury-based electrolysers to membrane technology. Finally, the sector accounted for 3,900 upstream indirect jobs between 2011 and 2020.

Employment models in 2050 reflect contrasting trends in each of the three scenarios, in terms not just of job numbers but also skills in both of the sectors considered. For example, the **"Petrochemicals and globalisation"** scenario sees direct job numbers fall by 30% and 35% for ethylene and chlorine respectively, as production levels decline. Upstream indirect jobs are estimated to vary slightly, rising by 6% in the ethylene sector and falling by 5% in the chlorine sector, maintained by higher electricity and hydrogen consumption, both locally produced energy carriers. In the **"Electrification and European protectionism"** scenario, sustained levels of production ensure that direct job numbers remain stable in both sectors. Upstream indirect job numbers rise sharply by 130% and 25% for ethylene and chlorine respectively, owing to the high levels of electricity consumption. One of the key issues associated with the electrification of industrial processes is therefore the number of indirect energy-related jobs, which could rise in the future. This is especially true in the case of ethylene, where electricity generated in France replaces imported naphtha, which creates fewer upstream indirect jobs. Meanwhile, a significant proportion of the indirect jobs sustained by the chlorine sector is associated with raw materials extraction (salt and brine), which in turn is directly affected by the volumes of chlorine produced. Finally, the **"Bio-based and local specialisation"** scenario sees direct jobs halve as a result of lower production, while upstream indirect job numbers are similarly cut in half in the chlorine sector, although they increase by 15% for the ethylene sector due to its higher electricity and hydrogen consumption.

➜ Site pétrochimique en bord de mer © dongfang/Shutterstock

These estimates are mainly based on projected production output and energy consumption, and should therefore be treated with caution. This is because lower production levels may be partly explained by the rise of recycling, which could generate large numbers of jobs in a neighbouring sector. Finally, the chemical industry remains a heavily integrated sector with high levels of interdependence between firms, particularly on chemical platforms. It is therefore important to note that developments in the production capacities of chlorine and petrochemical sites may have major implications that go well beyond the ethylene and chlorine sectors. Incidentally, the impact of the technologies (BTO, MTO, ODC) could not be assessed owing to their relatively low level of maturity. But besides the need to be able to gauge their effect on jobs, it is also important to consider the new skills that must be developed in order to deploy and operate these technologies optimally. Training – both initial and continuous – will be required and should be anticipated, especially in a sector like the chemical industry where there is currently a shortage of candidates for many positions.

Further down the value chain, **there were over 3,050 firms operating in the French plastics manufacturing sector in 2022, employing nearly 130,000 people.** Plastics manufacturing activity is not entirely correlated with business in the ethylene and chlorine sectors (both of which can be replaced by imports), but rather with downstream demand for plastic products. However, most plastics manufacturers are small businesses and rely heavily on intra-European trade (both imports and exports), and this raises concerns about the ability of firms in this industry to withstand strongly fluctuating market conditions and uncertainties in Europe. Developments in French plastics manufacturing are therefore dependent not only on those in the French polymer sector, but also more generally on the state of the European plastics market and future competition from around the world.

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Acronyms and abbreviations

AC - Abatement cost
ADEME - French Agency for Ecological Transition
AGEC - French anti-waste law for a circular economy (Loi "Anti-Gaspillage pour une Economie Circulaire")
BNR - French National Recycling Report ("Bilan National du Recyclage")
BTP - Construction and civil engineering ("Bâtiments et Travaux Publics")
CAPEX - Capital expenditure
CBAM - Carbon Border Adjustment Mechanism
CCS - Carbon Capture and Storage
CH_4 - Methane
CO - Carbon monoxide
CO_2 (e) - Carbon dioxide (equivalent)
COP - Conference of the Parties / Coefficient of Performance
EEE - Electrical and Electronic Equipment
EPR - Extended Producer Responsibility
EU - European Union
EU-ETS - EU Emissions Trading System
EUR - Euro (€)
FTE - Full Time Equivalents
GHG - Greenhouse Gas
GPA - Gas Purchase Agreement
GW - Gigawatt: 10^9 watts
H_2 - Dihydrogen
H_2O - Water
HVC - High Value Chemicals
ICP - Industrial and Commercial Packaging
LCA - Life Cycle Analysis
LHV / HHV - Lower / Higher Heating Value
Mt - Million tonnes (t): 10^9 kilograms (kg)
MW - Megawatt: 10^6 watts
MWh - Megawatt-hour: 10^6 watt-hours (Wh)
NOx - Nitrogen oxides
O_2 - Dioxygen
OPEX - Operating expenditure
PVC - Polyvinyl chloride
PPWR - Packaging and Packaging Waste Regulation
RRM - Recycled Raw Material
RFNBO - Renewable Fuels of Non-Biological Origin
RED - EU Renewable Energy Directive
STP - Sectoral Transition Plan
SFEC - French Strategy on Energy and Climate ("Stratégie Française Energie-Climat")
SNBC - French National Low-Carbon Strategy ("Stratégie Nationale Bas Carbone")
TWh - Terawatt-hour: 10^12 watt-hours (Wh)
VCM - Vinyl Chloride Monomer
VRM - Virgin Raw Material
WEEE - Waste Electrical and Electronic Equipment
ZIBAC - ADEME's call for "Low-Carbon Industrial Zone" projects

ADEME AT A GLANCE

At ADEME – the Agency for Ecological Transition – we are firmly committed to fighting climate change and the depletion of resources.

On all fronts, we mobilise citizens, economic actors, and local and regional authorities, giving them the tools they need to move towards a more resource-efficient, low-carbon economy that is fairer and more harmonious.

In every field – energy, circular economy, food, mobility, air quality, climate change adaptation, soil, etc. – we advise, facilitate, and help to fund numerous projects, from the research stage through to sharing solutions.

At every level, we put our expertise and forward-looking capabilities at the service of public policies.

ADEME is a public body under the supervision of the Ministry for an Ecological Transition and Territorial Cohesion, Ministry for the Energy Transition and the Ministry for Higher Education and Research.

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CHLORINE AND ETHYLENE

Summary Report

If France is to achieve carbon neutrality by 2050, its industry will need to decarbonise. To this end, the National Low-Carbon Strategy (SNBC) sets GHG reduction targets for industry of 81% by 2050 compared with 2015 levels. Central to the chemical industry, chlorine and ethylene are the basis for plastics and many chemicals, but are also responsible for 8.5% of France's industrial greenhouse gas emissions. The necessary energy transition in this sector represents a real technological, financial, economic, and regulatory challenge. While the three scenarios set out in these sectoral transition plans all achieve the target of reducing GHGs by 81% from their 2015 levels by 2050, they nonetheless illustrate the difficulties facing these two sectors: high energy prices, international competition, and changing demand. Against competitors with access to cheap energy, moves to decarbonise processes and improve energy efficiency are effective ways to help French production remain competitive. International trade, and in particular exports to Europe, will also be key in an increasingly globalised world. Finally, the development of the circular economy and plastic recycling are an opportunity for firms in this sector to refocus on lower-carbon markets and production, and will go at least some way to addressing sovereignty issues. But these changes will require significant investment, energy planning, and suitable infrastructures.

The Finance ClimAct project contributes to the implementation of France's National Low-Carbon Strategy and European policy on sustainable finance. It aims to develop new tools, methods and knowledge that will enable (1) energy-intensive industries to promote investment in energy efficiency and the low-carbon economy, (2) financial institutions and regulators to integrate climate issues into their decision-making processes and align financial flows with energy-climate objectives, and (3) savers to integrate environmental objectives into their investment decisions.

The consortium coordinated by ADEME also includes the French Ministry for Ecological Transition and Territorial Cohesion, the Autorité des marchés financiers (French Financial Markets Authority), the Autorité de contrôle prudentiel et de résolution (French Prudential Supervision and Resolution Authority), the 2° Investing Initiative, the Institut de l'économie pour le climat (Institute for Climate Economics), the Institut de la Finance Durable (Paris Sustainable Finance Institute) and the Rocky Mountain Institute.

Finance ClimAct is an innovative programme with a total budget of €18 million and €10 million in funding from the European Commission.

Duration: 2019-2024

Finance ClimAct

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