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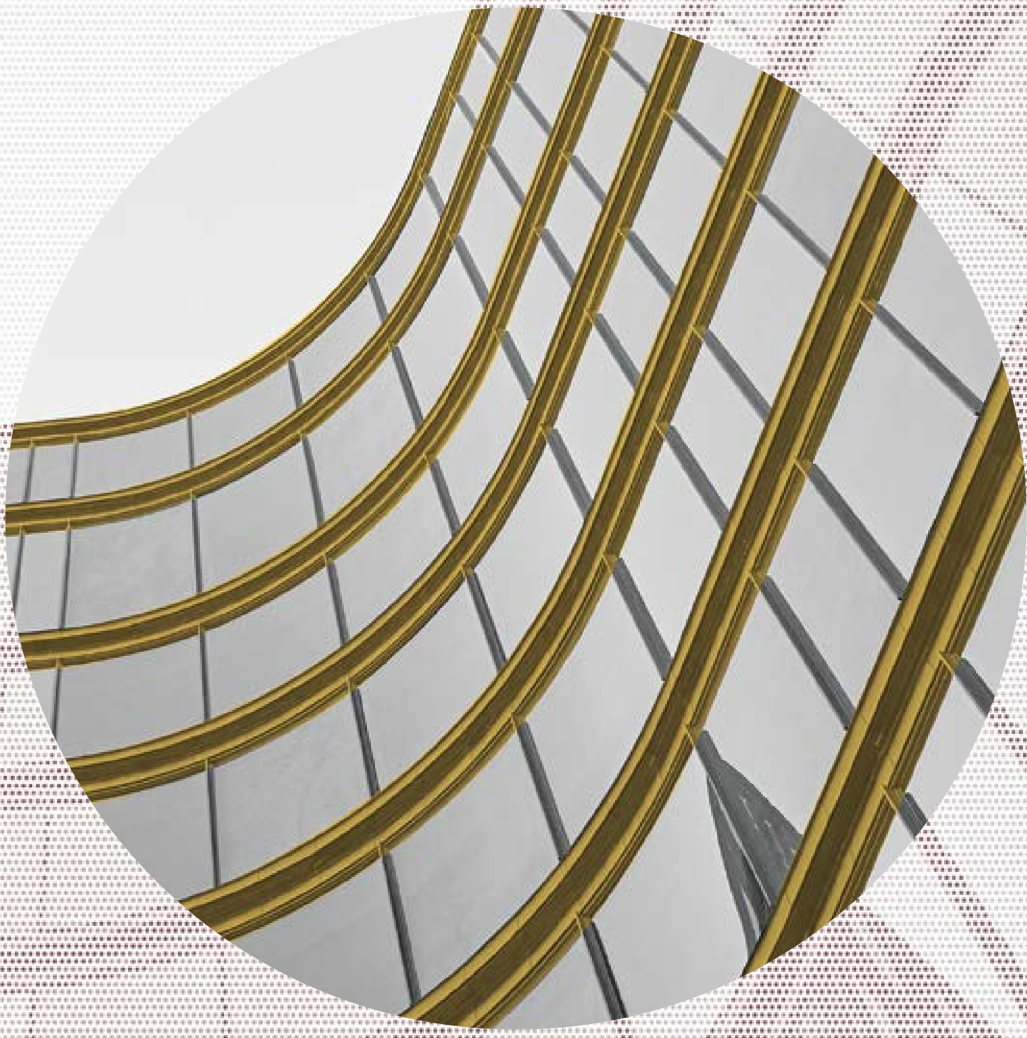
AGENCY FOR ECOLOGICAL TRANSITION

SECTORAL TRANSITION PLAN FOR THE FRENCH GLASS INDUSTRY



EXPERTISES

GLASS
Summary report

NOVEMBER 2024

With the contribution of the European Union LIFE programme

Finance ClimAct

I Care

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Cross-cutting editorial

Sylvain WASERMAN
Chairman and Chief Executive Officer of ADEME

At the heart of our industrial heritage, the French glass industry is a crucial sector for the national economy and the ecological transition.
Accounting for 3% of French industrial greenhouse gas emissions, it is currently facing a number of challenges, at the crossroads of technological innovation, the circular economy and the efficient use of resources.
In this study, ADEME and I CARE have mobilised their expertise and modelling capabilities to offer the glass industry two scenarios, highlighting the various technological, financial and economic transition challenges.
There are some real opportunities for the glass industry. First, a significant reduction in greenhouse gas emissions is possible, through the electrification of its processes, in particular its furnaces, enabling it to quickly transition away from fossil fuel dependency. Second, the reinforcement of the circular economy, with the incorporation of cullet and the eco-design of products, enables a direct gain in competitiveness, thanks to the significant reduction in energy consumption and CO_2 emissions. Lastly, glass, as a central material in the energy renovation of buildings (flat glass, glass wool) and the scaling-up of reusable packaging, is well-positioned for the transition of this sector.
Given this positive outlook, the glass industry has an even greater responsibility to undertake a rapid and ambitious transition of its entire value chain. To this end, ADEME is committed to supporting all actors in the sector in accelerating the necessary changes. This will involve supporting electrification projects, innovative R&D programmes, increasing recycling, integrating specific standards for eco-designed glass products, and developing robust reuse channels. These solutions will not only help to reduce emissions, but also support the transition to a more resilient industry that creates more jobs.
I would like to extend my warmest thanks to everyone involved in this study, in particular the Fédération des Industries du Verre. It is through cooperation and innovation that we will succeed in building a sustainable and competitive glass industry. Together, let us continue to work towards a low-carbon future, where industrial excellence goes hand in hand with ecological responsibility.

Jacques BORDAT
President of the Fédération des Industries du Verre

Glass is present everywhere in our daily lives, and very well-suited to meeting sustainability requirements. The glass industry's transition to a decarbonised world is already underway. Glassmakers are committing to and investing in the decarbonisation of their production.
80% of the industry's emissions are due to fossil fuels (mainly natural gas) used to melt the glass, while the other 20% are emissions related to the decarbonation of raw materials (carbonates).
Our main lever for decarbonisation is to transition away from fossil fuels (natural gas) towards decarbonised energies (low-carbon electricity and biogas). The electrification of furnaces and processes is the key to decarbonising our industry. Depending on the size of furnace and the type of glass produced, this trend will see the emergence of 100% electric furnaces or hybrid electric/gas furnaces, with a majority proportion of electric (80%) and a residual proportion of gas (20%). Highly electrified, hybrid furnaces, which are particularly well suited to large-scale furnaces (for food packaging and flat glass), are at the heart of our decarbonisation strategy. The first hybrid furnace started producing packaging on an industrial scale in Germany in 2023, and a number of investments in hybrid furnaces have been announced for the near future in France. The replacement of furnaces will take place as they are rebuilt, with a lifespan of up to 15 to 20 years for packaging and flat glass furnaces. Visibility is therefore essential if such large investments are to be made.
The glass industry is one of the few gas-intensive industries. Large-scale electrification of furnaces will see it evolve into an electro-intensive industry. Nevertheless, there will still be an incompressible residual need for biogas, particularly for large hybrid furnaces. Decarbonising the gas network is therefore a major lever. France needs to intensively develop biogas production to ensure its energy and industrial sovereignty.
The second decarbonisation lever remains the increased use of recycled glass (cullet). Because glass is 100% recyclable ad infinitum, it fits perfectly into a virtuous circular economy. Already widely deployed for packaging, recycling of glass from the construction industry is gaining momentum with EPR for construction products and materials.
This decarbonisation ambition should enable the manufacture of products to be kept in France that are essential to daily life and to sovereignty. Access to competitive low-carbon energies (low-carbon electricity and biogas), including connection costs, is strategic.

Background

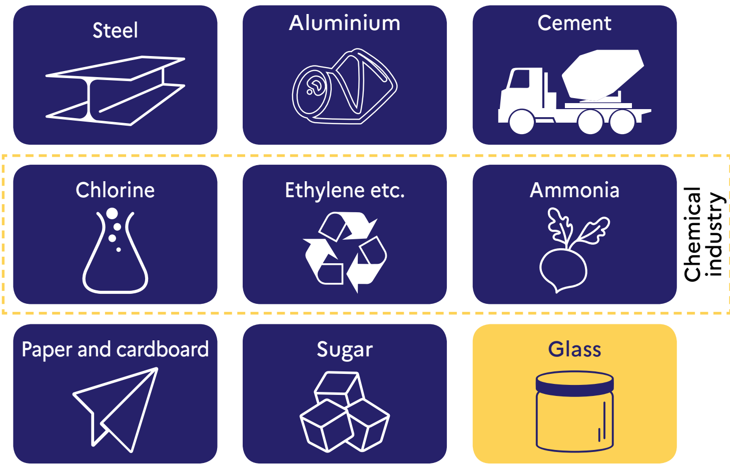
From the National Low-Carbon Strategy to the Sectoral Transition Plan

The current National Low-Carbon Strategy (SNBC2) 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 industry, this trajectory translates into an 81% reduction[1] in greenhouse gas emissions (GHG) compared to 2015. An intermediate target of a 35% reduction in emissions has been set for 2030. While a number of guidelines have been put forward (e.g. providing a framework to encourage management of the demand for energy and materials, giving priority to low-carbon energies and the circular economy, improving energy efficiency, developing breakthrough technologies, etc.), their temporal and sectoral variations have not been detailed. The challenges of decarbonising industry vary greatly from one sector to another. Moreover, manufacturers need medium-term visibility to make investments: industrial equipment has a lifespan of several decades, so the effects of today's investments will continue until 2050. It is in this context that Sectoral Transition Plans are being created.

By drawing up these Sectoral Transition Plans (STPs) in consultation with the key actors in the sectors concerned, ADEME aims to provide visibility for both manufacturers and investors, as well as public authorities. The project is therefore a continuation of the work carried out for the SNBC, breaking down heavy industry into 9 sectors in order to tailor decarbonisation solutions as closely as possible to the industrial issues facing each sector.

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 9 sectors covered by the Sectoral Transition Plans.



This document summarises the main results of the Sectoral Transition Plan for the glass sector.

Box 1

STP method[4]

Phase I: Survey of the industry. This phase consists of 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.

[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

[4] ADEME 2024, Methodological guide to drafting a sectoral transition plan for the decarbonisation of industry.

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

ADEME

Projet partners

ACPR, AMF, Banque de France, Finance for Tomorrow, GreenFlex, Institute for Climate Economics, Ministry of Ecological Transition, 2° Investing Initiative

The main limitations of the exercise

All the results presented are based on an ambitious modelling exercise of decarbonisation trajectories for the glass industry up to 2050, using an innovative methodology that is, however, subject to limitations, particularly in terms of scope and access to data. This is the prism through which the reader should view this document, especially with regard to the conclusions that they may draw from it, in particular by considering the following elements:

• A common emission reduction target for different industrial sectors.

The 81% reduction objective of the SNBC assigned to the manufacturing industry was set for the glass industry sub-sector as an input constraint to the scenario-building exercise. This choice has the advantage of defining a common framework for all the sectors covered by a Sectoral Transition Plan. However, this assumption closes the door on a more flexible approach to emission reduction targets between industrial sectors, which have different abatement potentials and decarbonisation efforts. Aggregating the various STPs could eventually help to define sector-specific objectives.

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

The objective of the current National Low-Carbon Strategy (SNBC2[5]) for the manufacturing industry focuses on direct GHG emissions (category 1) and therefore does not take into account emissions linked to the production of electricity (category 2) or indirect emissions upstream and downstream of the value chain (categories 3, 4, 5 and 6), for example, GHG emissions associated with the extraction and transport of raw materials used in the production of glass, or processes at the end of its life. Similarly, this objective does not address the carbon footprint, i.e. the emissions generated by glass imports. Finally, this single-criteria objective does not take into account the other environmental challenges of the ecological transition (air quality, resources, human health, biodiversity, etc.).

• A broad view of the glass sector, which is therefore heavily dependent on external factors.

The aim of this exercise is to provide a broad, consistent overview of the factors driving the development of GHG emissions in the glass industry. It was therefore necessary to make assumptions about parameters outside of the sector, such as the price of gas, electricity and CO_2. To enable comparison, these price trajectories have been set in the same way in all the scenarios. However, the impact of such factors on the competitiveness of manufacturers is another matter, and would require an in-depth study of the future of the glass industry in Europe.

• This sectoral approach could be further enriched by other factors determined by other economic actors.

Since the glass industry is a node in a complex economy that interacts with upstream and downstream entities, which are 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"[6], published at the end of 2021.

• Furthermore, as with any forecasting exercise, the range of assumptions and combinations of assumptions is infinite, and many variations are obviously possible.

On this basis, without being predictive in nature, the ***"Reuse, Eco-design and Relocation"*** and ***"Large-scale Electrification and other Technological Challenges"*** scenarios have been designed with the participation of actors in the sector. These reflect two technically plausible scenarios, with different degrees of desirability, within which the choices are made by industry and possible public policies. However, they by no means reflect all possible worlds, and other scenarios could be explored to reveal further insights.

Moreover, the full report that accompanies this summary provides additional information on the context of the scenarios and the way in which the transition could impact potential industrial strategies. It also details the assumptions made for each scenario. The aim is to broaden the scope of reflection in relation to the various results of the summary. This analysis is based on extensive bibliographical research and public sources of information, as well as interviews with actors in the sector, and is intended to be as objective as possible, given the cross-referencing of all these sources by the authors.

[5] The current revision of the National Low-Carbon Strategy (3rd edition) will potentially result in the definition of new sectoral objectives. For further information: https://www.ecologie.gouv.fr/strategie-francaise-lenergie-et-climat-lancement-consultation-publique

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

Key figures for the french glass industry (2019)

50

Number of glass production sites

consisting of more than 85 furnaces and with a total capacity of more than 7 Mt/year of molten glass

5.4 Mt

Annual glass production

10 TWh PCI/year

Annual fossil gas consumption[7]

81%

Proportion of fossil fuels

36,000

direct jobs in France in 2018, including the production of hollow glass, flat glass, fibreglass and flat glass processing[8]

2.8 MtCO2e

Direct emissions from glass production[9]

75%

Proportion of direct GHG emissions from fossil fuel combustion

The remaining 25% are "process emissions" linked to the decarbonation of raw materials

57%

of recycled raw materials

proportion of cullet incorporated (internal and external)

25%

Share of energy in production costs[10]

Direct consumption of glass in France

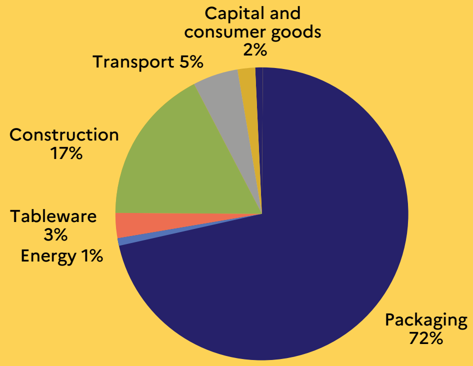


Figure 2.
Source: Analysis and reprocessing of data from the Fédération des Industries du Verre, GlassGlobal, EPR schemes and Customs.

44%

Total direct imports of glass into France[11]

with 87% from the EU28

-0.71 Mt/an

Direct trade balance for glass[12]

8%

Proportion of reusable glass packaging

placed on the market[13]

[7] GEREP / [8] INSEE, France / [9] EU-ETS / [10] ADEME, BREF verrier (Glass Industry Best Available Techniques Reference Document)
[11, 12] Analysis and reprocessing of data from the Fédération des Industries du Verre, GlassGlobal, EPR schemes and Customs
[13] ADEME, EPR schemes Supervision Department. Consumption of reusable packaging / Total packaging consumption, household and professional combined, in tonnes

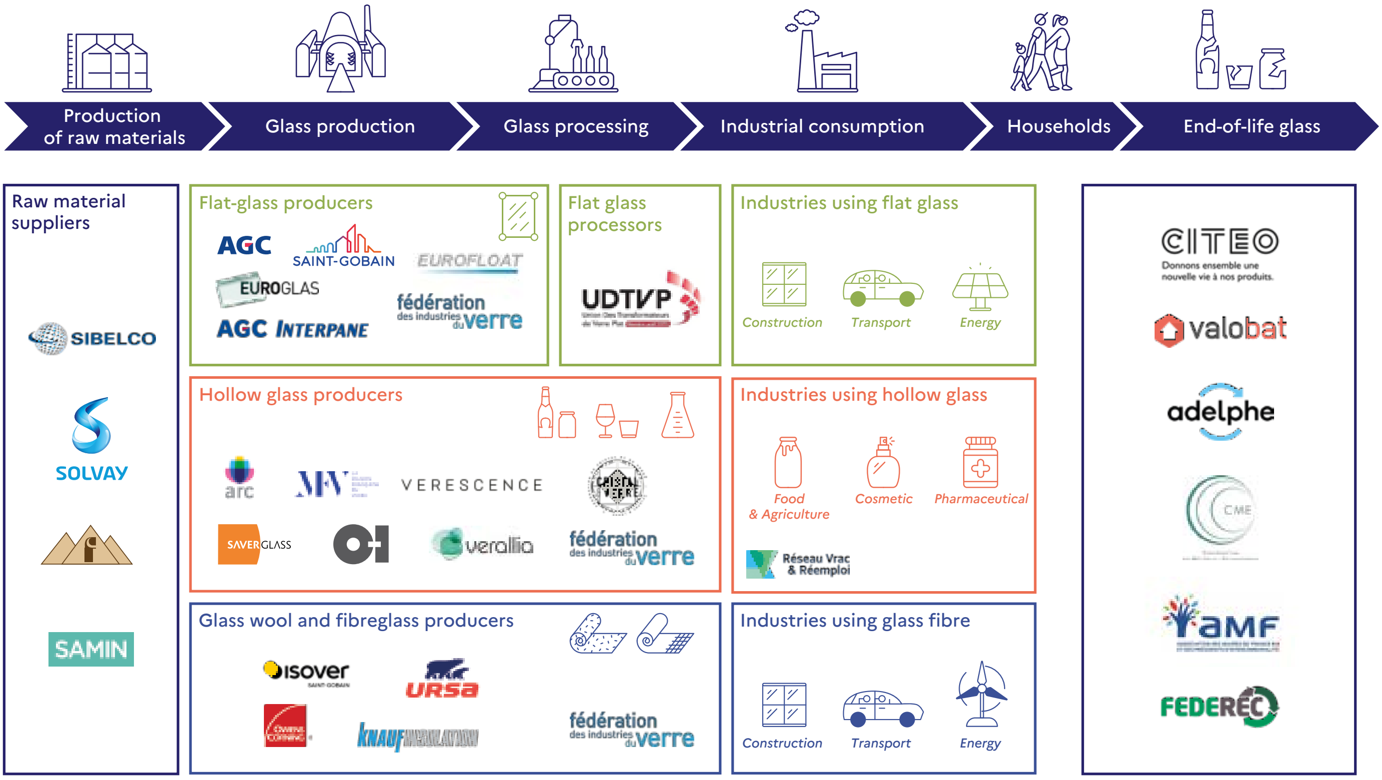
Summary for decision-makers

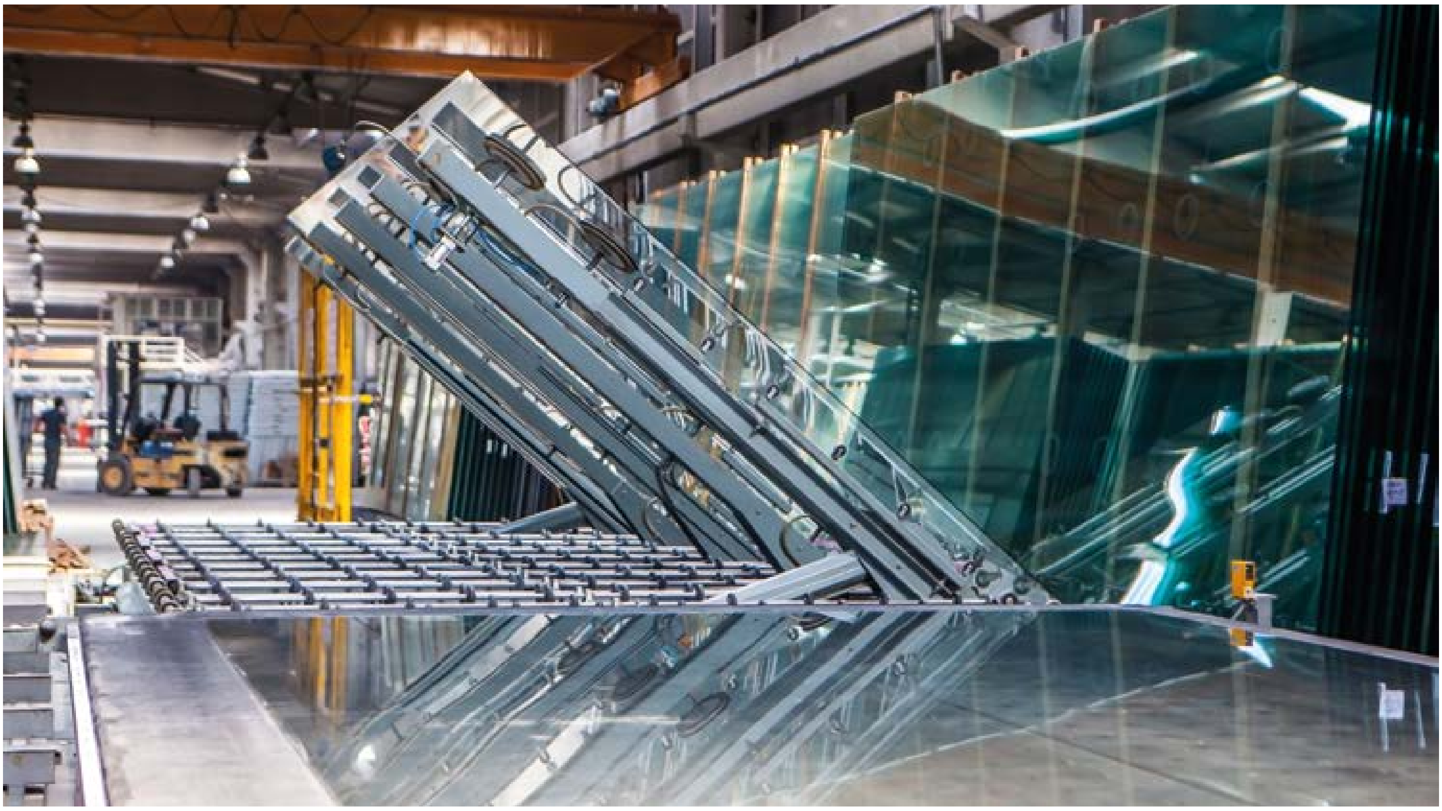
Profile of the glass industry

France produces around 5.4 million tonnes of glass a year (2019), making it Europe's second-largest producer behind Germany. It is divided into three main segments: hollow glass (packaging and tableware), flat glass (construction and transport) and glass wool (thermal insulation for buildings), with respective production of 3.7 Mt, 1.2 Mt and 0.45 Mt in 2019. These segments vary widely in terms of raw material composition, recycled content (cullet) and colour, as well as production and shaping processes. For these three segments, the glass value chain extends from the production of raw materials to the end of the glass's life. This extended value chain accounted for 36,000 direct jobs in France in 2018.

The industry is a major energy consumer, and is particularly gas-intensive (80% of the sector's energy mix): its energy consumption represents 3% of the thermal energy and 2% of the total electrical energy of French industry. In addition to the greenhouse gas (GHG) emissions resulting from the combustion of fossil fuels (natural gas), there are "process emissions", resulting from the decarbonation of raw materials. Direct GHG emissions from this sector amount to 2.8 $MtCO_{2}e$ (2019), i.e. 3% of industry emissions and 0.6% of total French emissions.

Figure 3. Glass production value chain in France.
(The list of actors presented is not exhaustive.)





➜ Machines working with giant glasses © Shutterstock, ilyas yasin uslu

Production prospects determined by transition in the packaging sector, construction and the balance of intra-European trade

Glass is a key material for the packaging (food bottles and jars, cosmetics and pharmaceutical bottles), construction (glazing, insulation), transport (windscreens, side windows) and tableware sectors. The outlook for glass production is therefore highly dependent on developments in these main markets. The ambitious energy renovation of buildings, a central pillar of the energy transition, should lead to an increase in the consumption of glazing and thermal insulation. Furthermore, transformations taking place in the packaging sector are set to radically change demand, with the replacement of single-use plastics, and new markets and consumption patterns (home sales, bulk). However, these upward shifts will only be partially passed on to glass production, due to competition from other materials (plastic packaging, aluminium and paper-cardboard, synthetic and biosourced insulation), eco-design efforts, the development of reusable packaging and the emergence of more frugal lifestyles.

These uncertainties about trends in glass production are compounded by uncertainties about international trade. The widening trade deficit has intensified in recent years, due in particular to the increase in imports of packaging and glass wool from close neighbours (Spain, Portugal and Germany). Competition with glass producers in other regions, notably Eastern Europe and Asia, where production costs may be lower, puts pressure on the French industry to maintain its competitiveness and jobs, while planning its long-term decarbonisation strategy.

Glass manufacturing processes and decarbonisation of processes

Glass manufacturing relies on two types of raw materials:
- Virgin raw materials from mining or industrial processing: silica, fluxes (sodium and potassium carbonate), additives and colourings
- Recycled raw materials or "cullet" (see Box 2) from production scraps (internal cullet), industrial processing waste (pre-consumer external cullet) or recycling channels (post-consumer external cullet). Cullet represents between 10 and 90% of the glassmaking mix (57% on average for the sector as a whole), depending on the product required and the constraints of the manufacturing processes.

These raw materials are mixed in proportions determined by the type of glass to be produced (soda-lime, borosilicate, crystal, etc.).

The first stage involves melting the glass composition in a furnace, whose size (from 20 to 700 tonnes per day) and technology (recuperative, electric, hybrid, etc.) depend on the end product. The furnaces have a lifespan of 5 to 20 years, during which they are never turned off. They represent the most energy-intensive stage of the process, are predominantly powered by fossil fuels (92% of the energy mix) and therefore account for the majority of the industry's GHG emissions (1.7 $MtCO_2e$). Over the last few decades, the use of fuel oil has been replaced by natural gas, and is now largely in the minority.

Once melted, the glass is transferred to shaping tools, which vary greatly depending on the market segment. The resulting glass products are then cooled, treated and packaged for sale.

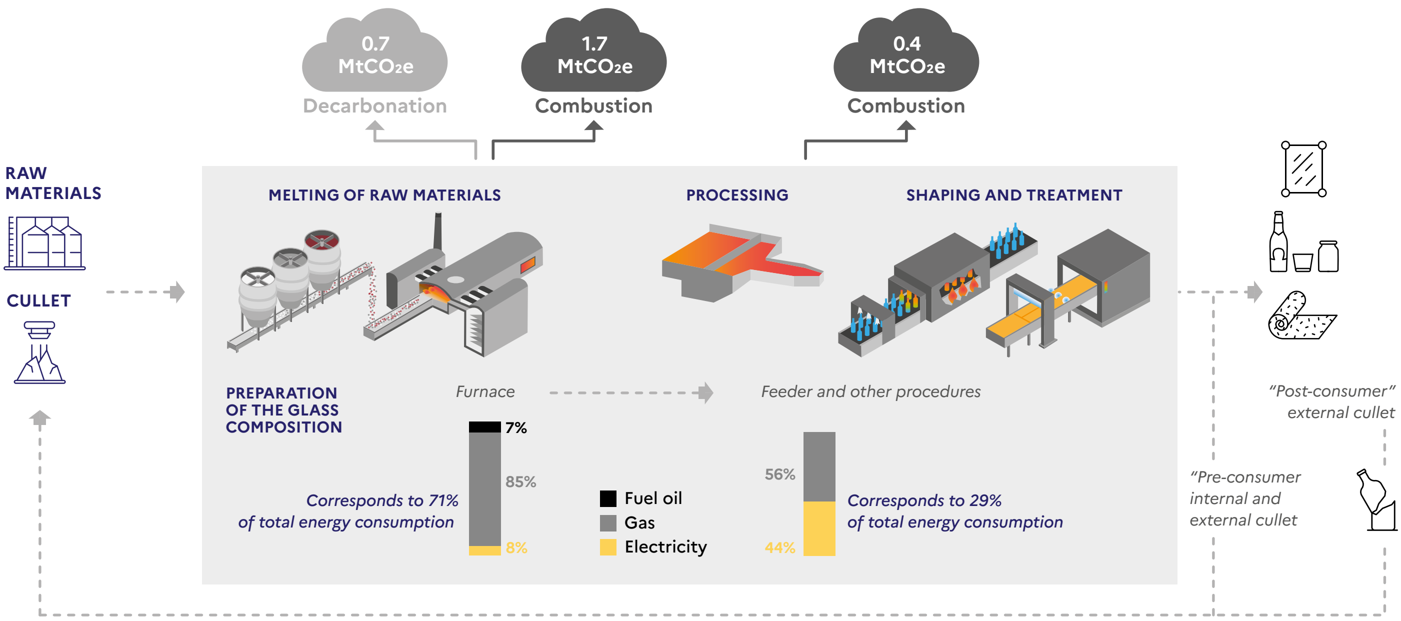
Currently, the decarbonisation of the melting process involves either installing 100% electric furnaces for small-capacity furnaces or hybrid gas-electric furnaces for larger furnaces. Large-scale adoption of these technologies faces technical and economic obstacles such as the availability and maturity of the most ambitious technologies, limits on cullet incorporation, furnace lifetimes and access to competitively priced electricity and "low-carbon" or renewable gas.

Furthermore, the significant proportion of the industry's "process emissions" also requires specific solutions, through the replacement of carbonated raw materials. The use of cullet is common in the industry, but still needs to be optimised for certain segments; this will require an increase in recycling performance in all sectors, as well as sovereignty over this resource to limit exports and ensure a supply in terms of both quantity and quality. The use of alternative non-carbonated raw materials is also envisaged, but these sectors have yet to be developed.

Finally, to limit the consumption of virgin raw materials and energy in the sector, and to meet energy sufficiency targets, the glass industry must turn to more eco-design solutions (reducing product weight, increasing cullet incorporation) and develop reuse channels, particularly in the packaging sector.

The glass industry's transition will therefore be multi-faceted and adapted to each of its segments, their specific technological characteristics and their different markets with multiple transition challenges.

Figure 4. GHG emissions and the challenges of decarbonising the glass industry in France (2019).



Two scenarios to illustrate the technological and economic challenges of an ambitious decarbonisation of the sector

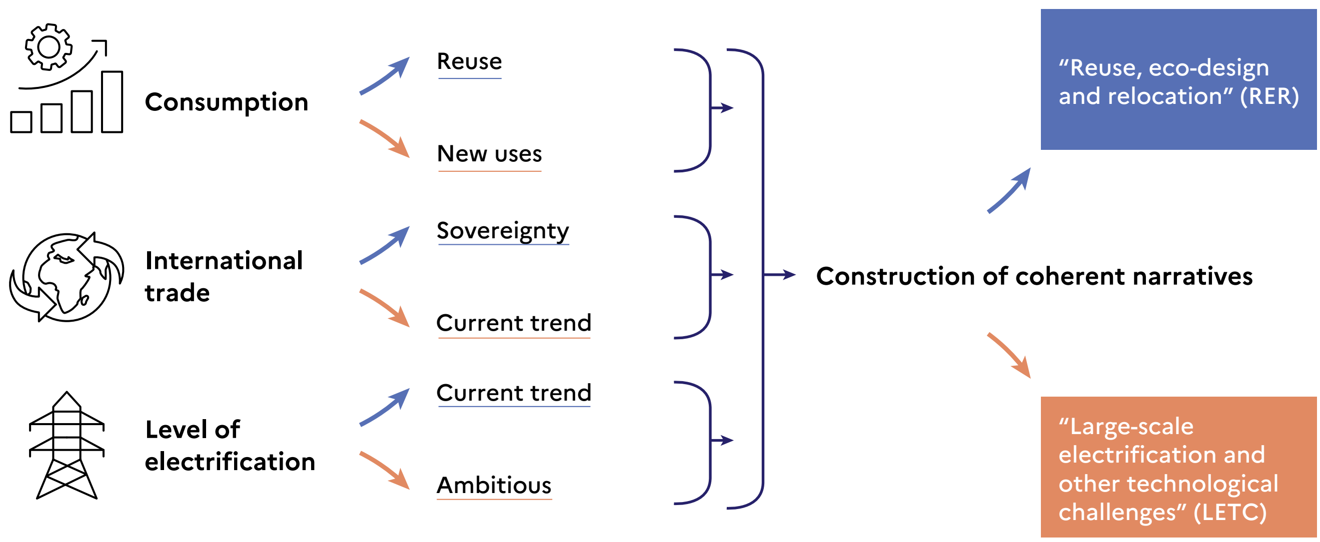
Three structuring factors of uncertainty have been selected as the main points of differentiation between the two decarbonisation scenarios: trends in glass consumption, changes in international trade and the level of technological ambition, particularly regarding the electrification of furnaces and processes. Based on structuring choices regarding the evolution of these three factors, two contrasting transition scenarios have been constructed, serving as a "backdrop" for industrial transitions in the glass sector.

In the ***"Reuse, eco-design and relocation" (RER)*** scenario, France firmly commits to the road of efficient use of resources and sovereignty. On the market side, the reuse of packaging is maximised, complemented by a significant reduction in the weight of non-reusable packaging. The efficient use of resources also applies to the customer sectors: for example, a drastic reduction in new construction is projected in the RER scenario, but this is offset by a massive acceleration in thermal renovation; furthermore, a significant modal shift towards non-motorised and collective mobility and a reduction in the need to transport goods, thanks to short supply chains, are also favoured. Moreover, significant efforts are made to maintain the industry's competitiveness while speeding up its transition, thereby reducing the fall in production through a reduction in imports. In terms of technology, electrification is progressing in line with current trends, with a wide choice of technological solutions. Hybrid melting furnaces are becoming the preferred solution for the glass industry, offering greater flexibility in terms of energy supply, between biomethane and "low-carbon" electricity.

In the ***"Large-scale electrification and other technological challenges" (LETC)*** scenario, France sees significant growth in its glass consumption. Reuse of packaging continues in line with current trends, and the market gradually expands to include new forms of packaging; glass becomes a central element in the transition of this sector, notably through the replacement of single-use plastics. The comprehensive switch to electric vehicles, combined with a massive building renovation and a non-negligible need for new construction, significantly increases the market prospects for flat glass and glass wool. In terms of imports and exports, international trade continues and even intensifies, particularly with neighbouring European countries. On the technological side, this scenario is characterised by a strong prioritisation of the electrification of glass furnaces. This massive direct electrification is complemented by indirect electrification, for example by replacing residual gas with low-carbon hydrogen. Moreover, manufacturers are gradually turning to alternative raw materials that emit less CO_2 during decarbonation. As a result, more technological and innovation challenges are explored in this LETC scenario.

These two contrasting transition scenarios can thus be used to highlight the main transition risks and opportunities for the sector, in more or less favourable technical and economic environments. The purpose of the RER and LETC scenarios is not to make predictions or to demonstrate that only these two alternatives are possible, but to shed light on the conditions required to decarbonise the industry.

Figure 5. Transition factors in the glass industry transition plan and scenarios.



The table below shows the main technical and economic results of the Sectoral Transition Plan for the glass industry in France. In both scenarios, glass production remains constant or increases slightly. In the RER scenario, this stability is attributable to a major relocation effort (lower imports) offset by reuse and eco-design, thereby gradually strengthening the sovereignty and trade balance of the French glass industry. Conversely, in the LETC scenario, the emergence of new uses (reusable glass packaging, materials for energy-efficient renovation of buildings and renewable energies) leads to an increase in glass consumption, resulting in a 20% increase in production, and therefore the opening of new production units.

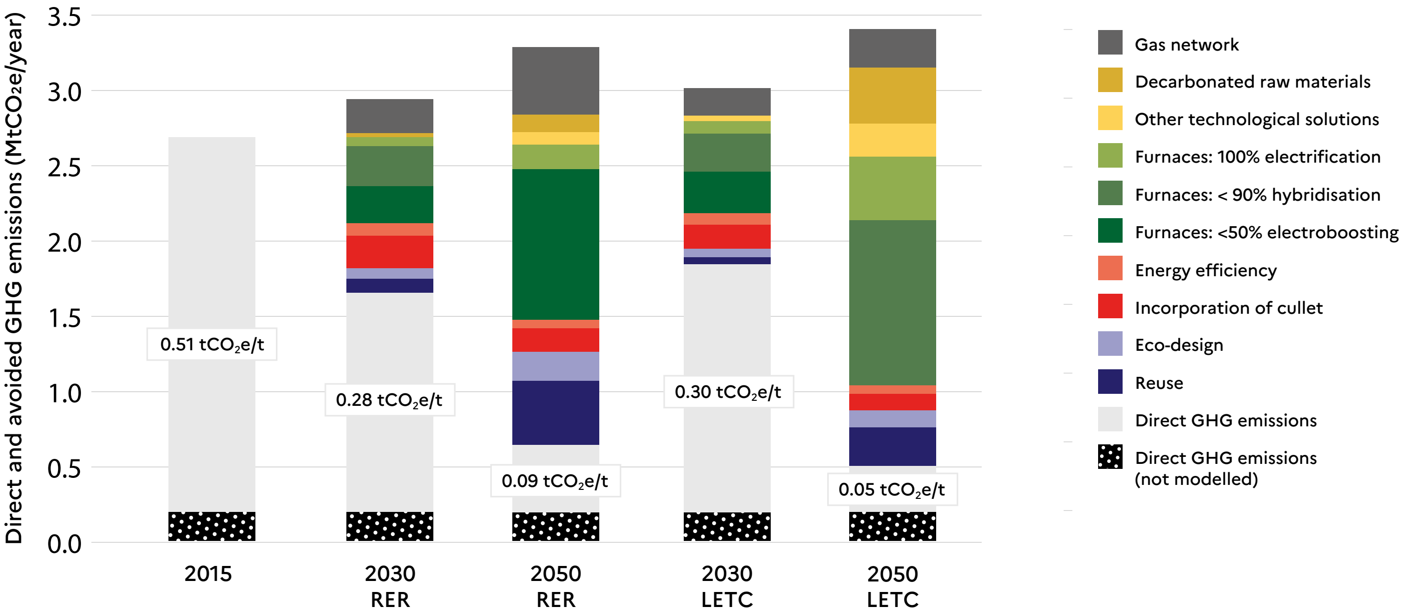
Energy consumption falls in all scenarios, but with significant variations in the energy mix. In the LETC scenario, electrification predominates, with 81% electricity, 16% network gas and 3% "low-carbon" hydrogen; whereas in the RER scenario, the mix is 70% electricity and 30% gas (consisting of network gas but also biogas directly linked to a biogas plant unit). Between 2015 and 2050, demand for electricity is expected to at least double, and even triple in the LETC scenario, which poses challenges in terms of resource availability and potential conflicts of use at local level. Both scenarios reduce the sector's dependence on fossil gas imports, by 68% for the RER scenario by 81% for the LETC scenario.

Ultimately, both these scenarios make it possible to exceed the target of reducing emissions by 81% in 2050 compared with 2015, but require a significant increase in investment (CAPEX), particularly in the LETC scenario, which calls on more expensive technologies (total electrification and hydrogen), and a major relocation effort in the RER scenario. The cost of production increases by a similar amount in both scenarios (about 42%), compared with a cost of inaction of +63% (i.e. with changes in the prices of energy, raw materials and CO_2 and without implementing decarbonisation levers).

Table 1.Summary of the main technical and economic results of the Glass Sectoral Transition Plan.

Change in 2050 vs 2015	Reuse, Eco-design, Relocation	Large-scale electrification and other technological challenges
Direct consumption of glass	+ 12 %	+ 29 %
Glass production	+ 4 %	+ 20 %
Gas consumption	- 68 %	- 81 %
Electricity consumption	+ 160 %	+ 240 %
Decarbonisation	- 82 %	- 88 %
Cumulative investments	+ 2.2 Mds EUR	+ 3.1 Mds EUR

Figure 6. Reduction in direct GHG emissions from the glass industry in France, by lever and by scenario, in 2030 and 2050.
Inset, average specific direct emissions in tonnes of CO_2 equivalent per tonne of glass produced.



Key points

Market changes to anticipate in order to meet the environmental objectives of customer sectors

France's packaging and construction sectors are undergoing profound change as a result of new environmental regulations. For packaging, the French Anti-Waste Act for a Circular Economy requires 10% of packaging to be reused by 2027 and a 20% reduction in single-use plastic packaging by 2025, with total elimination planned by 2040. These objectives should lead to a major reorganisation of the market, with glass packaging playing a greater role as the reusable and recyclable material of choice. For the building sector, regulations such as the gradual ban on the letting of the least efficient housing and the "Tertiary Decree" will require a drastic reduction in energy consumption, and should therefore increase demand for flat glass and glass wool for thermal renovation.

The French glass industry must therefore prepare for these changes and adapt its industrial facilities to transformations in its customer sectors, while remaining flexible to fluctuating demand and competitive in the face of strong intra-European and international competition.

Courses of action

1. Reinforce the glass industry's decarbonisation strategies with an analysis of changes in its markets (construction, transport, packaging). Continue dialogue between industry, citizens and the government to consolidate these strategies within the framework of ecological planning. Make updates and monitoring of the sector's decarbonisation trajectory available to the general public.

2. Support the development of a French and European photovoltaic panel production industry.

Access to competitive decarbonised energy is at the heart of companies' decarbonisation strategies

Decarbonising the glass industry depends on the transition to electrified processes. However, it is hampered by two technical and economic issues: the timetable for electrical connection and uncertainty about the viability of these solutions, in a context of large-scale electrification of industry, the availability of biogas and significant fluctuations in energy prices. Furthermore, industrial innovation is needed for ambitious electrification, particularly for medium and large capacity furnaces (> 150 t/d) for which full electrification is not yet technologically mature, depending on the market segment. To overcome these challenges, the industry must be able to rely on public-private partnerships, financial incentives and price stability for renewable and low-carbon energies.

Courses of action

3. Continue public support for the electrification of furnaces and processes in the glass industry. Include hybrid furnaces in the eligible solutions, pending the development of potentially more ambitious solutions specific to each segment.

4. Develop collaborative research programmes for process electrification, with a focus on high-capacity furnaces. Encourage partnerships between companies, universities and research centres.

5. Provide visibility on the integration of glassmaking sites into the timetable for connection to the electricity grid, including the simplification of administrative procedures. Bring forward contact with network operators and local partners.

Access to cullet and decarbonated raw materials is necessary to reduce process emissions

Recycling glass has major environmental and economic benefits. Glass recycling replaces carbonated fluxes (which cause CO_2 emissions from processes), thereby helping to reduce greenhouse gas emissions in this sector. Moreover, the incorporation of recycled materials reduces the energy consumption of furnaces compared to virgin raw materials, further contributing to the reduction of greenhouse gases and the competitiveness of the industry. Recycling channels for single-use packaging are mature, although their performance could still be improved. However, they need to be deployed to a greater extent in areas where they are not yet widely used: construction, vehicles, capital and consumer goods.

Replacing carbonated fluxes with alternative decarbonated raw materials is still in its infancy and requires major R&D.

Courses of action

6. Increase glass collection, sorting and recycling capacity to meet growing demand for cullet. Subsidise innovative technologies that will improve recycling efficiency and reduce costs.

7. Continue communication campaigns to promote the collection of single-use packaging in order to achieve the collection targets set by the industry (90% by 2030 at the European level).

8. Ensure that EPR schemes (construction products and materials and ELV) are properly implemented to collect flat products and glass wool at the end of their useful lives.

9. Fund R&D projects to replace carbonated raw materials (decarbonated fluxes).

Standards and regulatory support needed for the development of eco-design and reuse

The transition to a circular economy requires regulatory support for the development of eco-design and reuse in the glass industry. For flat glass, the technical characteristics of products are highly standardised and will require major work to develop and promote lighter products with the same performance. For packaging, the ecosystem needed for reuse is still in its infancy and requires regional and national support to develop a complete and efficient reuse value chain (packaging producers, marketers, distributors, collection and washing operators and consumers). The success of these transformations will also depend on consumer acceptance, so it is vital to implement communication and awareness-raising initiatives now to ensure that changes in behaviour are visible and translate into choosing reusable packaging while ensuring a high return rate, with the aim of reducing the environmental impact of packaging over its life cycle.

Courses of action

10. Develop specific standards for lighter flat glass products to guarantee their quality, safety and durability. Harmonise these standards at European level, to make them easier to use. Engage the entire industry in order to bring stakeholders together and facilitate the adoption of these standards, particularly in the building sector.

11. Incorporate eco-design criteria into public tenders, encouraging the use of lighter, low-carbon glass materials.

12. Develop partnerships to create robust, integrated reuse channels across the value chain and throughout France (including the French overseas territories), for the collection, cleaning, reconditioning and redistribution of glass packaging. Set up shared washing centres, and a nationwide network of sorting and aggregation centres. Help companies to improve processes and invest in innovative solutions to facilitate the development of reuse.

13. Launch communication campaigns to raise consumer awareness of the environmental benefits of reuse and eco-design. Promote good practices for returning of glass packaging.

1. The challenges of decarbonising the glass industry

1.1. A heterogeneous sector made up of three segments...

With more than 80 furnaces spread across around 50 sites in France, and annual production of 5.4 Mt/year (2019), the glass industry is highly diversified. Glass production has traditionally been divided into three main types of glass: hollow glass, flat glass and glass wool, all of which serve very distinct markets:

• The **hollow glass** segment, which produces the most glass (70% of glass production in France), includes several product categories, including packaging (91%) and tableware (9%). Bottles and jars make up the majority of production capacity. These containers are used in a variety of sectors, including beverages (wine, water, spirits, beer, sweet drinks, etc.) and dry food (vegetables, sauces, jams, etc.), which account for 83% of hollow glass, compared to 4% for cosmetic bottles and 4% for pharmaceutical bottles. The production of reusable packaging is minimal, at around 1%. Packaging production fell sharply after the 2008 crisis, but has been slowly growing by 1%/year since 2013. France is a European leader, particularly in the production of bottles for beverages (O-I, Verallia, Saverglass) and bottles for cosmetics (Verescence, Stoelzle, Pochet, Zignago) (perfumery and cosmetics), and pharmaceuticals (SGD, and Gerresheimer). French tableware is recognised all over the world, thanks to companies such as ARC International, La Maison Française du Verre (Pyrex©, Duralex©) and La Rochère.

• **Flat glass** is divided into several product categories, such as insulating glass, laminated glass, toughened glass, glass for furniture and coloured glass. It is mainly used in the building sector (78% of production), primarily for thermal renovation, followed by new construction (70/30). Insulating glass dominates this market, used in particular for windows and conservatories. Laminated glass is widely used as safety glass in the building industry, but also in the automotive industry for windscreens. Toughened glass, also a type of safety glass, is manufactured exclusively by specialised processors and used in car side windows and in the construction industry. Flat glass production was at its lowest level after the 2008 crisis, but has made a spectacular recovery since 2015, with growth of around 10%/year. France is a major producer of flat glass in Europe, accounting for around 13% of European production in 2019, provided by AGC, Saint-Gobain, Interpane, Eurofloat and Euroglas. Coloured flat glass production in France is concentrated at Saint Gobain and is mainly used in the automotive industry.

• **Glass wool** includes blown wool and panels. It is mainly used in the building industry for its insulating properties.

Figure 7. Breakdown of glass production capacity by company and by segment in France (2019).
Capacity in millions of tonnes of melted glass per year.
Source: GlassGlobal, Fédération des Industries du Verre, reprocessed by I Care

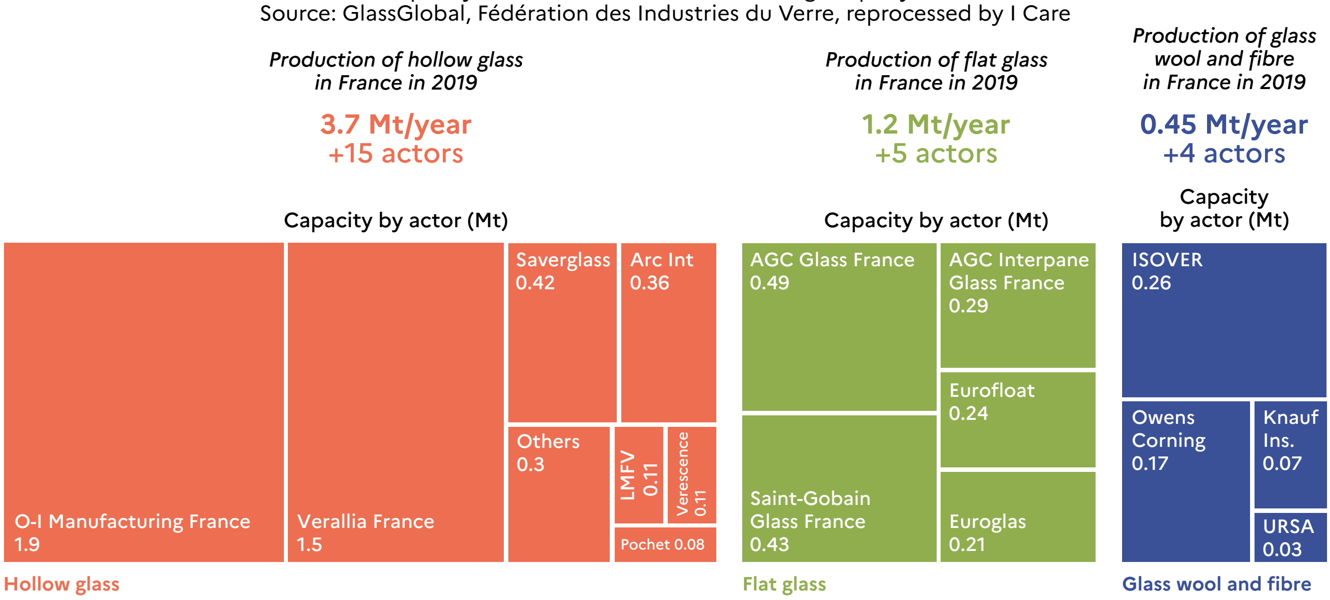
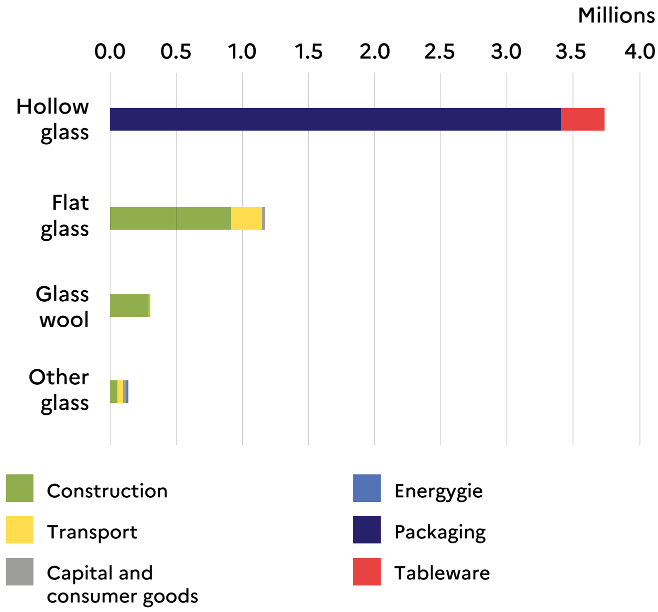


Figure 8. Breakdown of French production by segment and application sector (2019).
Other glass: reinforcement fibre and technical glass.



Other types of glass include a wide range of technical products, such as reinforcement fibre, used in various sectors such as the aerospace and automotive industries, construction, energy, telecommunications, as well as in the manufacture of sports equipment and lighting.

Depending on its application, the composition and even the chemical nature of the glass also varies:

• **Soda-lime glass** takes its name from sodium carbonates, which are the second most important component after silica, and accounts for 90% of the glass tonnage produced[14]. It is the main glass used for packaging, flat glass and glass wool.

• **Borosilicate glass** is used in pharmaceutical packaging, because of its chemical inertness, and in tableware, because of its increased resistance to thermal shock.

• **Special glass** is used for specific markets. Fluosilicate glass has many applications in industry, particularly in the manufacture of semiconductors; its mechanical and thermal properties are also suitable for vitroceramic hobs. Crystal is mainly used in tableware.

Box 2

Cullet

Cullet is broken glass from recycling facilities that is collected, sorted, crushed, cleaned and then added to the mix of raw materials used to make glass. There are three sources of cullet:

• Internal cullet comes from production scraps and products that do not pass quality control at a glass production site, in particular during "batch" changes (variations in composition and colour).

• External "pre-consumer" cullet comes from sources outside the glass production site, but from within the industry, mainly flat glass processing, upstream of the marketing of finished products.

• External "post-consumer" cullet comes from end-of-life glass items, which are classified as waste. They are then collected from building sites or companies, either door-to-door or at voluntary drop-off points.

Cullet is added to the mixture in proportions that depend on the type of glass and the sector. For example, the production of bottles and jars uses an average of 70% cullet, of which 60% is external cullet and 10% internal cullet. This high proportion of recycled raw materials is due both to the maturity of the packaging glass recycling sector, and to reasonable constraints in terms of cullet composition and colour for coloured bottles and jars. However, the cosmetics, pharmaceuticals and tableware sectors impose strict purity criteria on raw materials in order to guarantee the chemical, optical and mechanical properties of the glass, thereby limiting the use of post-consumer cullet. For the same reasons, the flat glass sector only uses post-consumer cullet on a marginal basis, but benefits from an external source of pre-consumer cullet, that comes from offcuts from the flat glass processing industry. In order to increase the collection of quality cullet for the flat glass segment, new recycling channels still need to be set up, in particular around EPR for Construction Products and Materials from the building sector and End-of-Life Vehicles (ELV).

Incorporating cullet into glass furnaces (1) reduces the consumption of raw materials, (2) also has the advantage of using less energy, due to a lower melting temperature, (3) and replaces carbonated raw materials, thereby reducing process emissions.

[14] Soda-lime glass - Association Française des Souffleurs de Verre Scientifiques (les-souffleurs-de-la-science.fr)

1.2. ...which supply distinct markets with uncertain trends.

1.2.1. A wide range of glass imports and exports

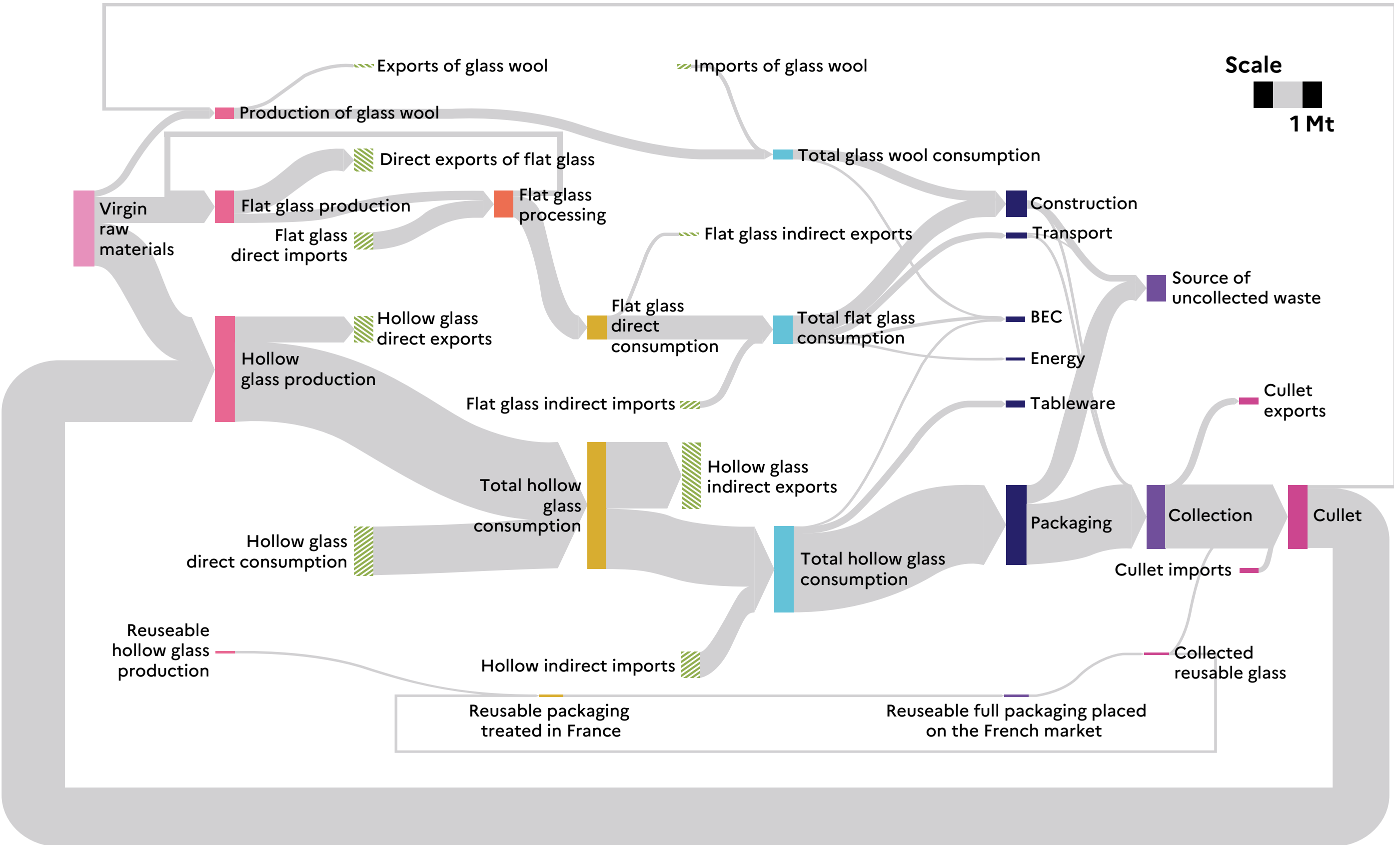
• **Hollow glass:** import-export figures for hollow glass vary considerably depending on the consumer sector. Imports of (empty) packaging have risen significantly over the last 10 years, from 20% to almost 40%, mainly from close neighbours (Spain, Germany, Portugal, Italy) but also from new actors (Bulgaria, Poland); at the same time, exports have also increased from 15% to 20%. As a result, the trade balance for packaging is heavily negative at -1 Mt/year. The opposite is true for indirect packaging, with a trade balance of + 1.5 Mt/year, mainly due to exports of alcoholic beverages but also perfumes, packaged in France in glass containers. The trade balance for tableware is also positive, albeit to a lesser extent, at +159 kt/year, with very high and more internationalised import (56%) and export (77%) rates (35% of exports and 45% of imports outside the EU 28).

• **Flat glass:** direct trade in flat glass (sheets of glass with little or no processing) shows high import (63%) and export (70%) rates, particularly with France's closest neighbours (Germany, Spain and Belgium) and then with the rest of the EU, especially in the context of processing activities. The trade balance has increased in recent years, reaching 200 kt/year in 2019. Indirect trade in flat glass (glass used in joinery, vehicles and capital goods) is less significant, and France's trade balance stands at -100 kt/year, mainly due to imports of glass used in joinery and construction.

• **Glass wool:** the import rate is around 20% (almost exclusively from the EU), with a negligible export rate. The trade balance for this product is around -84 kt/year.

International trade balances are fragile and can change rapidly depending on a number of parameters. The evolution of energy prices, the availability of cullet, the cost of transport (decarbonised) and labour play an important role in the competitiveness of the French industry. The end of free quotas and the forthcoming Carbon Border Adjustment Mechanism (CBAM) are likely to have a moderate impact on this sector, which mainly trades within the EU, with the exception of tableware and technical glass.

Figure 9. Sankey diagram of the glass industry in France (2019)
(flat glass, hollow glass and glass wool).
Direct I-E: trade in glass from the glass industry, with little or no processing such as glass sheets and empty packaging. Indirect I-E: trade in glass from customer sectors: construction (joinery), transport (vehicles), food industry (products packaged in glass containers).



➜ Industrial production of glass containers © Shutterstock, Vera Larina

1.2.2. Trends in demand for glass

Finally, direct consumption of glass is around 6.3 Mt/year (including 0.2 Mt/year of reusable glass), compared with 5.4 Mt/year produced in France, resulting in a negative trade balance of -0.71 Mt/year. However, a significant proportion of this direct consumption is destined for export: total glass consumption in France ultimately amounts to around 5.0 Mt/year, mainly for packaging (63%), construction (23%) and transport (6%).

Hollow glass

Packaging consumption has been growing since 2013 (1.8%/year), driven in part by glass packaging (+2.4%/year). The term "glassification" of packaging has emerged to define this phenomenon in which plastic packaging is being replaced by glass in many sectors such as perfumery and cosmetics. The switch from plastic to glass packaging could continue, leading to an even more pronounced increase in demand for glass. Lastly, new consumer trends such as home delivery of meals, and the development of bulk packaging and reuse, could disrupt the packaging market and therefore glass consumption.

The impact of these developments on demand could be significant, but is still difficult to estimate as it depends on a number of factors, especially changes in regulations and standards. The replacement of plastic packaging is guided in France by the AGEC Act (see above) which provides for the end of single-use plastics by 2040. Furthermore, the act aims to increase the proportion of reused packaging compared with single-use packaging, all materials combined, and sets a new target of 10% of reused packaging placed on the market in France by 2027. Currently, Europe is also adopting the "Packaging and Packaging Waste amending Regulation" (PPWR) , aimed at reducing packaging waste and accelerating the transition to a circular economy model for packaging, in line with the European Green Deal. These regulatory changes will need to be accompanied by changes in consumer habits, in particular to ensure high return rates for reusable packaging.

Flat glass and glass wool

The flat glass segment is closely linked to developments in the construction sector. The flat glass market experienced a decline after the 2008 crisis until 2015, attributed to the decrease in new construction, and has since recovered by 2%/year due to renovation initiatives as part of the energy transition . Demand for flat glass could increase by 3 to 4% annually, mainly as a result of the European Union's ambitious targets, expressed in the European Green deal, which aims to double the annual rate of building renovation.

In France, a strict regulatory framework imposes obligations that encourage renovation work, in particular the Tertiary Eco-Energy Decree (obligation to take action to reduce final energy consumption in the tertiary sector, with a target of reducing energy consumption by 60% by 2050 compared to 2010). Similarly, a number of pieces of French legislation (the Energy Transition for Green Growth Act (LTECV), the Climate and Resilience Act, etc.) set ambitious targets for the energy renovation of housing and introduced a timetable for prohibiting the letting of the least efficient housing. Demand for glass wool, an important material in the thermal insulation of buildings, should also increase in this context.

There are also regulations for new construction such as the RE2020. By setting thresholds for emissions from construction products used and for energy consumption, RE2020 encourages greater thermal insulation of buildings and the use of materials with a reduced environmental impact over their life cycle. On the other hand, the No Net Land Take (NNLT) objective could significantly reduce new construction by 2050, and consequently the demand for flat glass and glass wool associated with this market.

Furthermore, the acceleration of the shift to 100% electric technologies for French vehicles could contribute to a rise in demand for flat glass, although this may be offset by a significant increase in the use of public transport and a reduction in the need to transport goods due to the promotion of short supply chains. Finally, the multi-annual energy programme (PPE) aims to reach between 35 and 44 GW (by 2028) of photovoltaic solar panels, of which flat glass is a constituent, thus contributing to the increase in demand, provided that they are produced in France or by close European neighbours.

[15] Currently being validated by the European Parliament's committee before being put to the vote in plenary session

[16] ADEME (2021), Etude de préfiguration d'une filière a responsabilité élargie des producteurs appliquée aux produits et matériaux du secteur de la construction du bâtiment (Preliminary study of an extended producer responsibility sector for products and materials in the building construction sector)

[17] Xerfi – 2021 – Flat glass manufacturing and processing / [18] Fedeverre interview

[19] These results come from the environmental assessment of deposit-return systems for the reuse of glass packaging in France up to 2025, carried out by the Observatoire du réemploi et de la réutilisation. ADEME has published these results, among eight other studies on deposit-return systems, including one comparing scenarios with and without deposits for the recycling of plastic bottles and cans. incluant celle comparant des scénarios avec et sans consigne pour le recyclage des bouteilles en plastique et des canettes.

1.2.3. Boosting recycling and developing reuse

Recycling

Recycling is an important determinant of the glass value chain, but also a major factor in the decarbonisation of the industry (Box 2). The collection rate for recycling single-use packaging was 77% in 2019, with steady growth of around one percentage point a year. This is an important issue for a sector whose annual supply is estimated at 2.8 million tonnes. This resource, which is critical for glassmakers in their decarbonisation and circular economy strategy, is seeing current demand outstrip available supply. Ambitious policy targets have therefore been set to increase its availability, with a recycling rate of 88% for household packaging by 2029 (EPR for Household Packaging and Graphic Papers).

In contrast, flat glass recycling is still very marginal. The gradual introduction of EPR for Construction Products and Materials for the Building sector, which came into force on 1 January 2023, should help to increase the recycling rate (18% for flat glass by 2027). The total amount of cullet from deconstruction sites is estimated at 200,000 tonnes per year . On the other hand, external pre-consumer cullet from flat glass processing is currently well recovered.

Lastly, the recycling of glass wool, which is also covered by the EPR for Construction Products and Materials for the Building sector, is currently being rolled out, although the amount of material being recycled remains low due to the long life of this material before it is replaced.

Reuse

The proportion of reused glass in packaging consumption remains low (8% of packaging consumption in 2019) and is mainly driven by the professional packaging sector for cafés-hotels-restaurants (CHR). The number of rotations per year is estimated at around 2.5, with a return rate of 70% of the stock per year and a scrap rate of 10% of the stock per year. Ultimately, around half of all reusable packaging needs to be replaced each year, through the production of 45 kt of new reusable packaging.

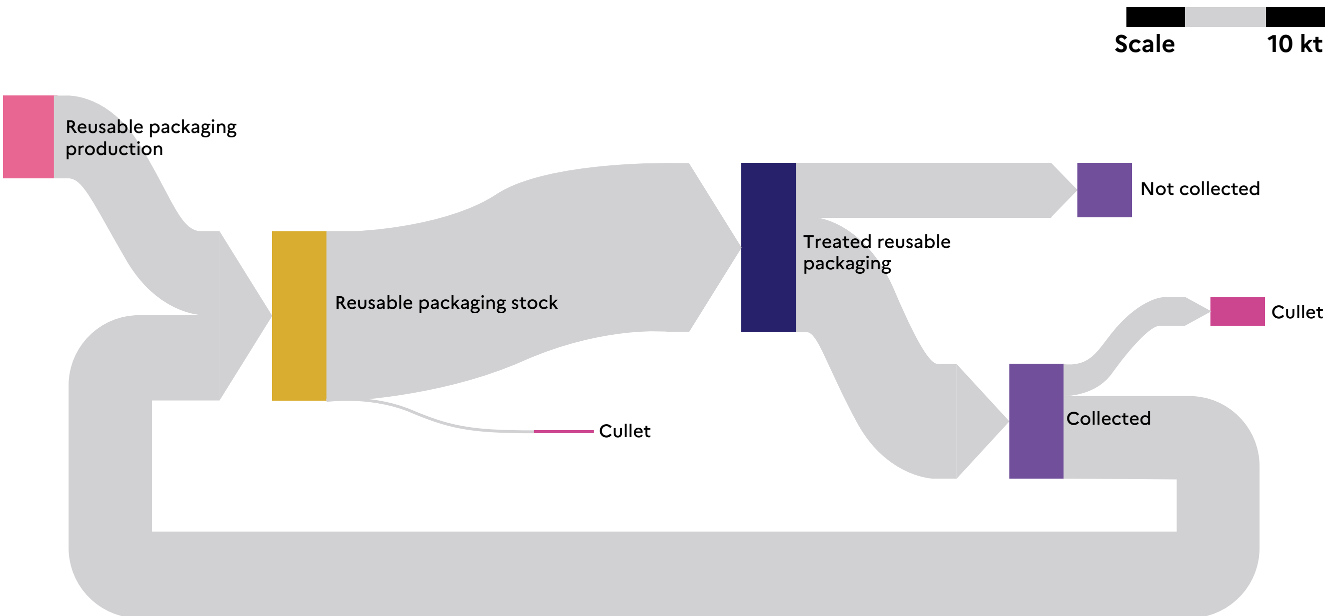
Reuse does, however, involve increasing the weight of packaging in order to make the product more robust and reduce breakage during processing (collection, cleaning, transport, packaging) before it is put back on the market. The combined impact of the packaging reuse rate, average number of rotations, increase in product weight, and the performance of collection and reconditioning channels will therefore influence demand for hollow glass.

Comparative analyses between the use of reusable and single-use glass containers show, however, that reusable containers are superior in terms of their environmental impact. Two main factors explain this advantage:

• First, the very principle of reuse means that the impacts of glass packaging production can be rapidly amortised, particularly in an industrial sector that consumes mostly fossil fuels (see section 1.3).

• Moreover, French agri-food distribution is relatively optimised: the impacts associated with reuse channels would therefore be lower from the second rotation onwards , compared to the consumption of single-use packaging for most of the scenarios studied.

Figure 10. Sankey diagram of re-usable glass packaging in France (2019).
Source: ADEME, 2022, Valorisation des emballages en France ("Packaging recovery in France") - 2020 data (internal file)



1.3. Different production processes...

1.3.1. General glass manufacturing process

1. Preparation of the composition

Glass is mainly produced from silica sand (SiO_2) and internal or external cullet (Box 2). In order to lower the melting temperature of the sand (above 1700°C) to between 1300°C and 1550°C, fluxes are added to the preparation, including sodium carbonate (commonly known as "soda") (Na_2CO_3) and potassium carbonate (K_2CO_3). Other inputs are added to modify the properties of the glass. For example, calcium oxide (CaO) is introduced in the form of calcium carbonate ($CaCO_3$), usually extracted from limestone or chalk, to improve the glass's durability. It can also be supplied in the form of dolomite, which contains both calcium carbonate and magnesium carbonate ($MgCO_3$). Boron trioxide (B_2O_3) and lead oxides (PbO and Pb_3O_4) are used in the manufacture of borosilicate glass and crystal respectively. Finally, colourants such as iron oxide (Fe_2O_3), chromium oxide (Cr_2O_3) or manganese oxide (MnO) may be added to the mix. During melting, the corresponding metal oxides mix with the molten glass and the carbon dioxide from the carbonates is released, giving rise to process emissions.

2. Melting in the furnace

Once mixed, the preparation is placed in the furnace for the melting process. The very high melting temperature makes this the most energy-intensive stage in the process. The characteristics of the furnaces vary considerably in size and capacity, ranging from a few tonnes to several hundred tonnes per day, and operate continuously throughout their lifetimes of 3 to 20 years. There are three main categories of furnace, each with different energy sources: furnaces using fossil fuels, 100% electric furnaces and, finally, furnaces partially powered by electricity (electric boosting or hybrid furnaces). The latest hybrid technology differs from electro-boosting in that its electricity mix is greater than 50%.

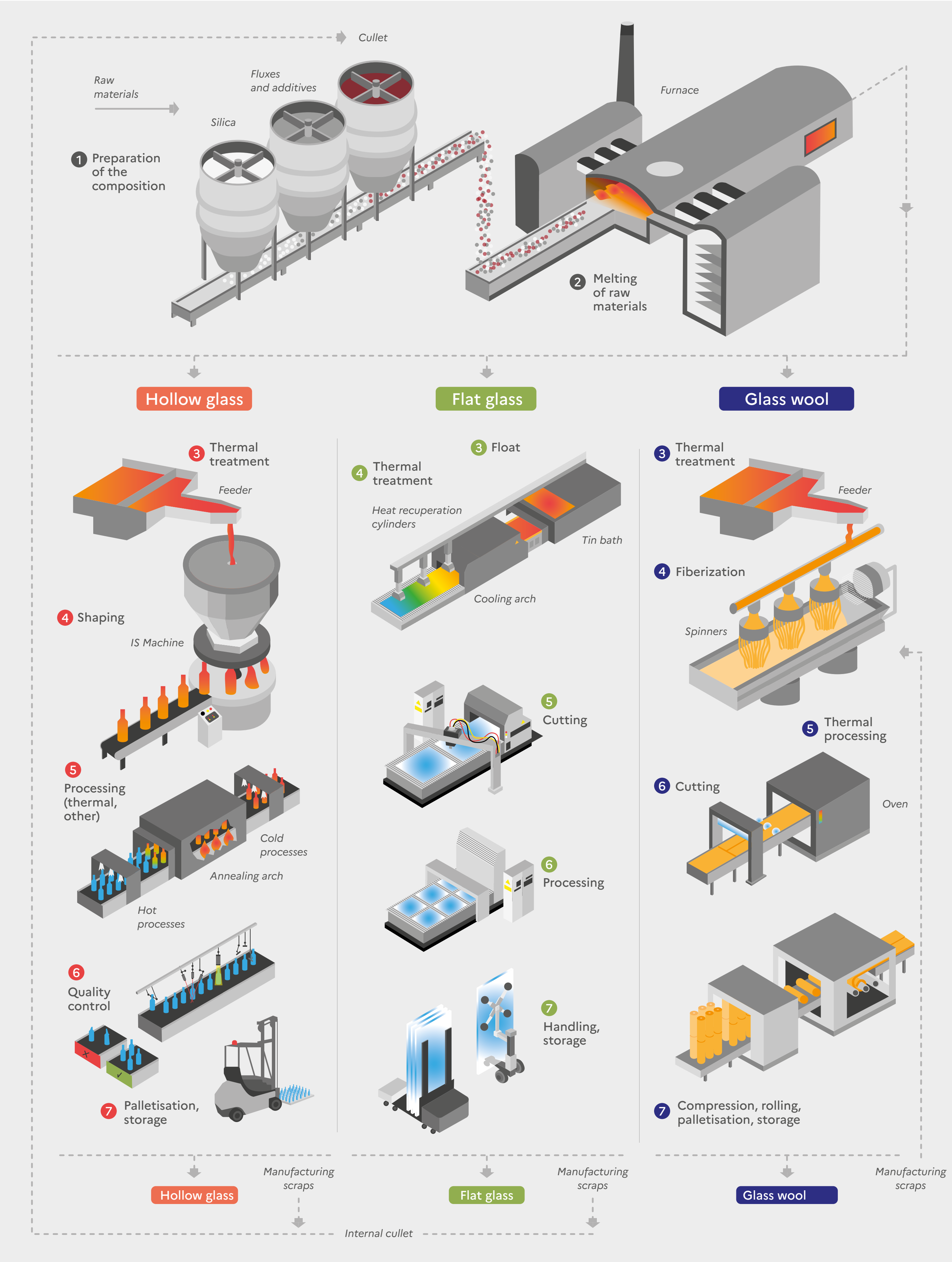
From this stage, the glass manufacturing chain differs depending on the market segment, but can be summarised in 4 main stages: **3. Conveying of the glass**, **4. Forming (i.e. shaping the glass)**, **5. Treatments** (e.g. heat treatment) and **6. Other finishing stages**, which are detailed below for each segment:

• For **flat glass**, the molten mixture is then poured over a bath of liquid tin, where the glass sheet forms by "floating". On either side, serrated rollers mechanically stretch the glass to the required thickness (4. Forming). On leaving the tin bath, a continuous ribbon of glass is formed and transported into an annealing lehr. The glass undergoes gradual, controlled cooling to guarantee its flatness and avoid any mechanical stress in its mass that could lead to risks of breakage (5 - Treatment). It comes out at room temperature, ready to be cut (6. Other finishing stages).

• In the **hollow glass** manufacturing process, the molten raw material is transported to its final processing location via distribution channels called feeders, made of refractory materials. The feeders are equipped with heating and cooling devices to bring the glass to the right temperature and viscosity level (3. Conveying). This channel ends with a mechanism for cutting the glass strand to form the glass gob, sometimes known as a parison, followed by a system for distributing the glass gobs thus formed into the forming moulds. The weight of the glass gob is defined by that of the final article, and its temperature is approximately 1150°C. The hollow glass is then shaped using two main methods: the "blow-blow" or "press-blow" forming process (4. Forming). The annealing arch then recovers the glassware, which must be cooled under specific conditions to avoid sudden temperature variations that could weaken its structure: this is known as the "annealing" process. Finally, the products undergo various treatments (flame polishing, tempering for toughened glass, hot and cold surface treatments, etc.) to enhance their qualities (5. Treatment). A final optional decoration stage results in the finished product - Other finishing stages).

• For the production of **glass wool**, the molten glass is then transformed into fibres a few microns in diameter by centrifuging in "spinners", which are discs with thousands of holes through which the molten glass escapes (4. Forming). Once out of the spinner, additives are sprayed onto the fibres, which are then deposited on a conveyor belt. This glass mineral wool mat is then sent to a polymerisation oven, where the glass fibres are bonded together (5. Treatment). After leaving the oven, the material is cooled and cut to form insulating panels, then compressed and rolled. (6. Other finishing stages).

Figure 11. Glass manufacturing.



1.3.2. Glass melting, the main source of energy consumption and greenhouse gas emissions

The glass industry's direct greenhouse gas emissions amounted to 2.8 $MtCO_2e$ in 2019, representing 3% of total industrial GHG emissions and 0.6% of France's emissions. Specific emissions per ton of glass have seen a significant decrease of 22% since 1990. This fall is due in particular to the increase in the recycling rate, and therefore in the use of cullet, with a 13% rise in volume over 18 years, as well as improvements in energy efficiency. In addition to this, the glass industry went from an energy mix of 35% fuel oil to 12% between 2000 and 2018[20] with the complete phase-out of fuel oil expected in the short term. Despite this fall in specific emissions, overall emissions from the sector have remained relatively stable since then, due to the increase in production across all sectors (see 1.1).

These emissions can be divided into two categories: emissions linked to energy consumption at glassmaking sites and process emissions linked to the decarbonation of raw materials. CO_2, which accounts for 95% of the sector's greenhouse gas emissions, is mainly released during the combustion of fossil fuels.

the composition of the glass, the quantity of cullet, the type and size of furnace, etc. Energy consumption per tonne of glass produced has been reduced by around 60% since the 1960s thanks to improvements in energy efficiency, to around 8 GJ per tonne of glass (or 2.2 MWh/t). However, this general consumption profile does not reflect the differences between segments: for example, bottles and jars account for more than half of the glass industry's total energy consumption. Nevertheless, in terms of energy intensity, this sub-segment consumes the least, with 1.8 MWh/t of molten glass.

The raw materials melting stage in the glass furnace plays a key role in this energy consumption and the associated GHG emissions. Glass melting accounts for 75% of en-

Figure 12. Breakdown of GHG emissions from the glass sector, by type, in France (2019).
Source: Calcul I CARE.

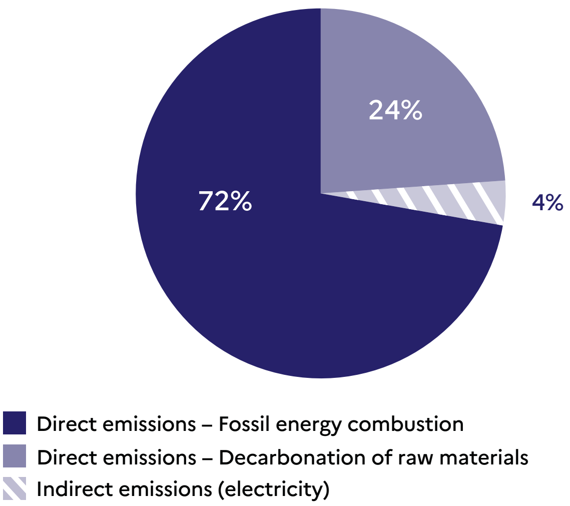
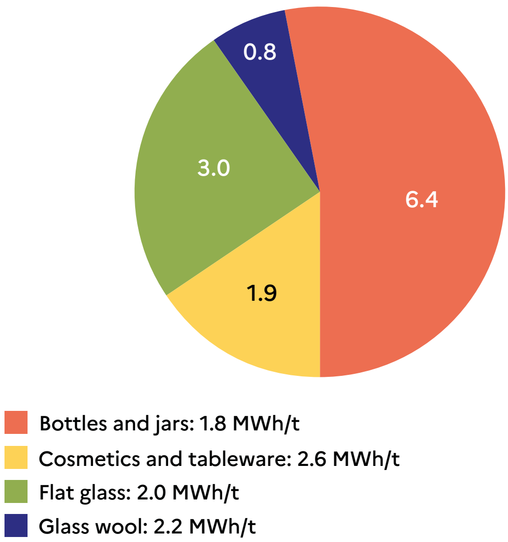


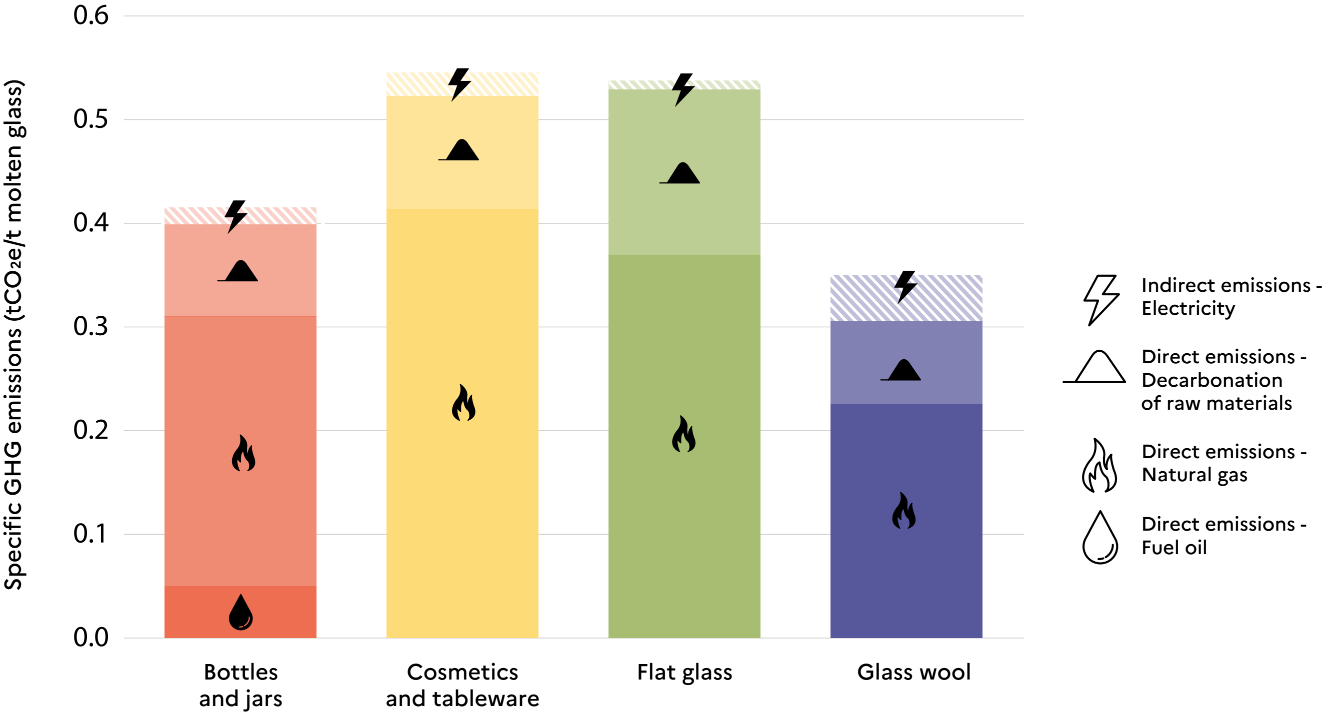
Figure 13. Breakdown of the glass industry's energy consumption (TWh/year LHV) and energy intensity (MWh/t LHV, per tonne of molten glass), by segment, in France (2019).
Source: Calcul I CARE.



The glass industry is energy-intensive, and even gas-intensive. In total, the French glass industry consumed almost 12 TWh of thermal and electrical energy to produce glass, representing 3% of industrial thermal energy and 2% of industrial electrical energy in 2017. Moreover, the majority of glass furnaces still run on gas, giving this fossil fuel a very significant place in the glass industry's energy mix. Natural gas accounts for 75% of the sector's total energy consumption, while electricity, while rising, still only accounts for 20%. Residual fuel oil completes the energy mix. At the level of the entire production process, energy intensity varies depending on several factors, including ergy consumption for bottles and jars, and around 92% for flat glass, the two largest segments. For glass wool, cosmetics and tableware, this figure is reduced to 30% and 40% respectively, due to the greater energy requirements downstream of the melting process. In addition, the technology and size of furnace have an impact on the amount of energy required. The energy efficiency of electric furnaces is significantly better than that of fossil fuel furnaces. The proportion of furnaces currently electrified is 9% for flat glass, 20% for bottles and jars and 30% for cosmetics and tableware. Most glass wool is produced in electric furnaces.

➜ Firing the raw material in a glass furnace © Shutterstock sergei kochetov

Figure 14. Specific CO_2 emissions, by source and by segment, in 2019 in France.
Mat.: raw materials. Source: Calcul I CARE.



Finally, the remaining emissions are process emissions linked to the decarbonation of carbonate raw materials (such as soda ash and calcium carbonate) required for the process, representing 24% of the sector's total emissions. However, incorporating cullet instead of raw materials reduces these process emissions. Here too, there are major differences between segments, with total cullet incorporation rates (internal + external) ranging from 34% for flat glass, to 36% for cosmetics and tableware, 45% for glass wool and 72% for bottles and jars.

[20] Fédération des Industries du Verre, Décarbonation de l'industrie du verre : de la théorie à la pratique, 2022 ("Decarbonisation of the glass industry: from theory to practice"), url: Microsoft PowerPoint - 2022-09-Décarbonation de l˘industrie du verre-de la théorie à la pratique[Compatibility Mode] (elfsightcdn.com)

1.4. ...which will require specific decarbonisation levers

1.4.1. 4 levers to reduce emissions linked to raw materials

Eco-design

This lever consists of producing glass articles that fulfil the same functions at a lower weight. As a result, it is possible to reduce the quantity of molten glass at constant demand, thereby cutting costs, energy and material requirements, as well as the associated emissions. In simple terms, reducing the weight of packaging by 10% reduces the emissions associated with its production by 10%. Eco-design is already widely practised and has, for example, led to a significant reduction in the weight of glass packaging over the years.

Improvement of glass yield

Industrial efficiency also helps to reduce emissions per tonne of glass produced, by improving the ratio between finished product and molten glass, commonly known as the Pack-to-Melt ratio. As a result, the proportion of molten material actually transformed into finished products increases, while the proportion of internal cullet (scrap) decreases. These losses can be avoided by optimising and improving management of processes, or by reducing colour change periods. In 2019, the Pack-to-Melt ratio averaged 84%, with wide disparities between segments.

➜ Parisons of melted glass © Saverglass

Improved incorporation of external cullet

The use of cullet as an input in glass manufacturing offers significant environmental and economic benefits. Firstly, cullet effectively replaces traditional raw materials, reducing process emissions by up to 10% for every 10% of cullet incorporated. It also lowers the melting temperature, resulting in energy savings of up to 2.5% for every 10% of cullet used. The use of cullet also avoids the extraction of natural raw materials, saving 1.2 tonnes of minerals per tonne of cullet and reducing the CO_2 emissions associated with their extraction and transport. However, despite these advantages, not all glassmakers have yet reached their maximum technical-economic integration limit for post-consumer cullet, mainly because of competition for access to the resource. Increasing the availability and quality of post-consumer cullet (via collection channels) is therefore a major challenge for decarbonising the sector.

Use of decarbonated raw materials

Glass process emissions linked to the decarbonation of raw materials account for around 25% of the sector's direct emissions. As well as replacing them with more cullet, the use of alternative decarbonated raw materials is currently being investigated as a way of reducing these process emissions. Another approach is to decarbonate standard fluxes upstream, at a centralised site equipped with carbon capture and storage (CCS) technology. This solution would enable large-scale, grouped decarbonation of raw materials at key sites close to CO_2 storage or transport sites. Direct installation of CO_2 capture technologies on glassmaking sites seems limited by their dispersion and geographical location, the low volumes of emissions and the low concentration of CO_2 in flue gases (less than 5%).

[21] Vercane: Public summary
[22] ADEME, 2024, Injection of dihydrogen in a borosilicate glass furnace (HYREX)
[23] https://www.energy4climate.nrw/en/topics/best-practice/hyglass
[24] https://www.nsg.com/en/media/ir-updates/announcements-2024/hydrogen-plant-in-uk
[25] https://www.lobservateur.fr/boussois-lusine-dagc-glass-europe-veut-miser-sur-lhydrogene/
[26] https://www.saint-gobain.com/sites/saint-gobain.com/files/media/document/20230330_Herzogenrath_VF.pdf
[27] https://h2-glass.eu/
[28] https://librairie.ademe.fr/7494-hyver-faisabilite-industrielle-de-la-combustion-du-dihydrogene-dans-la-mise-en-forme-du-verre.html

1.4.2. 4 technological levers focused on processes

Energy savings

For glass, the current rate of improvement in the energy efficiency of production facilities is around 1% per year. A number of technologies are envisaged to further improve these energy gains, such as preheating the composition and/or cullet, recovering waste heat from feeders, production lines or flue gases, devices providing real-time alerts of deviations in energy consumption and, lastly, some breakthrough solutions at the R&D stage that are considered promising (Selective batching, Pelletisation)[21].

Developments in furnace technologies (Box 4)

The development of new glass furnaces offers numerous opportunities for the sector to decarbonise. For several years now, the decarbonisation of the melting process has involved either the installation of electric furnaces for small-capacity facilities or the installation of hybrid gas-electric furnaces for large facilities. Large-scale adoption of electric and hybrid technologies faces a number of technical and economic obstacles such as the availability and maturity of the most ambitious technologies, limits on cullet incorporation, furnace lifetimes and access to low-carbon electricity and biogas at competitive prices.

Technological evolution for the other stages

In addition to electrifying furnaces, it is also possible to electrify other links in the production chain, such as glass transport channels (feeders) and annealing arches for hollow glass and curing ovens for glass wool production.

Replacement of natural gas with renewable fuels

The residual fossil gas used in hybrid furnaces and the other stages in the process should eventually be replaced by biogas, biomethane or hydrogen. The gradual integration of biomethane into the glass mix via the ongoing decarbonisation of the French gas network will help to reduce the emission factor of network gas. Glass manufacturers will be able to sign long-term Biogas Purchase Agreements with biomethane producers to secure a dedicated supply of renewable gas. For some sites, a direct connection to a nearby anaerobic digestion facility producing biogas or biomethane could also be considered. Finally, hydrogen can also be part of the energy mix, although its use as a simple fuel has technical and economic limits (Box 3).

Box 3

The role of hydrogen in decarbonising the glass industry

Thanks to its GHG emission-free combustion, the use of "low-carbon" or "renewable" hydrogen appears to be an interesting decarbonisation lever for the glass industry. Historically, glassmakers have already used hydrogen for certain processes (e.g. fire polishing), but questions arise regarding its potential for integration on a larger scale, due to the many technical, economic and logistical challenges that manufacturers have to overcome.

The technical challenges of replacing natural gas with hydrogen in glass melting are mainly (1) the deterioration of refractories, (2) the impact on the physico-chemical properties of glass and (3) the impact on NOx emissions. In 2022, La Maison Française du Verre in Châteauroux launched the HYREX project[22]. This project demonstrated the feasibility of integrating up to 20% (in terms of energy) of hydrogen mixed with natural gas, with no significant impact on the physico-chemical properties of the glass or the NOx content of the flue gases. Similar tests have been carried out by Saverglass (Feuquières) with up to 30% hydrogen. However, further tests are needed to characterise combustion with more than 30% hydrogen and the effect on refractory lifetimes. Other projects are underway to explore this solution for flat glass furnaces (HyGlass[23], NSG Pilkington[24], AGC Boussois[25], Saint-Gobain Herzogenrath[26]), and for other sectors and processes (H_2Glass[27], Hyver[28]).

However, the major barrier to the use of hydrogen today is more of an economic nature. The price of electrolytic hydrogen is not very competitive (170-220 EUR/MWh) compared to direct electrification solutions (75-90 EUR/MWh). It is also not very competitive compared to other renewable gases, such as biogas or biomethane (90-120 EUR/MWh), which have fewer technological and logistical constraints. The current economic model therefore limits the uses of hydrogen to high added-value products, and its more widespread implementation will also depend on other decarbonisation solutions.

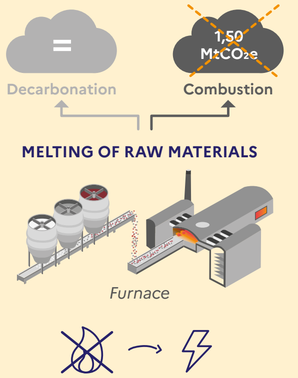
Box 4

Evolution of furnace technologies: from hybridisation to total electrification

Glass furnace technologies are moving towards increased electrification. This change in the energy mix of glass furnaces ranges from 100% electricity for an electric furnace, from 50 to 80% electricity for a hybrid furnace, and 10 to 20% for electro-boosting. Each technology has a Technology Readiness Level (TRL) and a maximum furnace size, which vary according to the segment concerned. The advantages and limitations of each technology are detailed below.

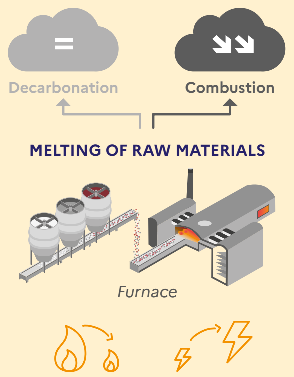
Figure 15. Electrification of furnaces: total vs hybrid electrification schemes.

Total Electrification



Segment	Furnace size	TRL
Glass wool, tableware	Small (< 150t/d)	8 – 9
Bottles and jars	Small	8 – 9
Bottles and jars	Medium (300 t/d)	2 – 4
Flat glass	Large (700 t/d) Medium (300 t/d)	1 – 2

Hybrid furnaces



Segment	Furnace size	% electrification	TRL
Glass wool, tableware	< 150t/d	80%	8 – 9
Bottles and jars	300t/d	80%	8 – 9
		90%	4 – 6
Flat glass	700t/d	50%	4 – 5
		70%	2 – 4

• **Total electrification.** Electric furnaces offer greater environmental benefits than furnaces using fossil fuels, thanks in particular to the low emission factor of electricity in France and better thermal efficiency. A modern heat recovery furnace has an overall efficiency of around 50% (60% maximum). In comparison, the thermal efficiency of electric furnaces offers energy savings of more than 20 percentage points compared to their fuel equivalents.

However, electric ovens face a number of technical challenges. The technology for electrifying small-capacity furnaces, with limited cullet rates (< 60%), is well established and effective, but concerns a small number of production units. In France, the largest electric furnace installed is for the production of glass wool by Isover, with a capacity of 190 tonnes per day. As things currently stand, the cosmetics, pharmaceuticals and tableware sectors are natural candidates for production in 100% electric furnaces, as they incorporate a low proportion of cullet and do not require a very large furnaces. One glass furnace manufacturer is working on two 100% electric furnace projects, one with a capacity of 75 t/day for Pochet du Courval, a specialist in perfume bottles for the luxury goods industry, and the other with a capacity of 140 t/day of packaging for Verallia's glass factory in Châteaubernard[29]. Above a certain capacity (depending on the segment being considered), it is necessary to change technology and move to a horizontal furnace.

• **Hybridisation.** Hybridisation is a new furnace technology, suitable for large-capacity furnaces, in which the energy input comes simultaneously from electricity (> 50%) and gas. This technology gives glassmakers greater flexibility in terms of energy supply and their ability to adapt to fluctuations in the energy market, as well as the capacity to disconnect from the electricity grid, compared to furnaces that run exclusively on electricity. However, unlike the latter, residual combustion emissions persist and require fossil fuels to be replaced by renewables (biogas, biomethane, H_2) to completely decarbonise the furnace. Hybrid technology is arriving on the market for the packaging sector, with the first furnace in operation in Germany since 2023 and numerous investment announcements in several European countries. It will be a few more years before it is available for flat glass.

• **Electro-boosting.** The latest technology differs from the previous one in that its electricity mix is less than 50%. For sectors that are still difficult to fully electrify or hybridise (such as flat glass), the challenge is to maximise electric boosting from the current 10% to 20% or 25% by 2030.

[29] In Châteaubernard, Verallia achieves a world first - Charente Libre.fr

2. Two contrasting scenarios to highlight decarbonisation issues

2.1. Construction of transition narratives for the glass industry

The construction methodology is identical for the two Glass Sectoral Transition Plans (STPs): the aim is to establish a decarbonisation trajectory, based on available or developing levers, in different transition contexts, and with the objective of achieving at least 81% reduction in emissions in 2050 compared to 2015 (SNBC2 target for the industrial sector). The scenarios outline possible transitions for the glass industry and are deliberately contrasting to illustrate the possible impact of technological, economic, regulatory or societal changes on the glass sector.

In this Sectoral Transition Plan, three structuring uncertainty factors have been selected, and different combinations of these have been used to define the two decarbonisation scenarios:

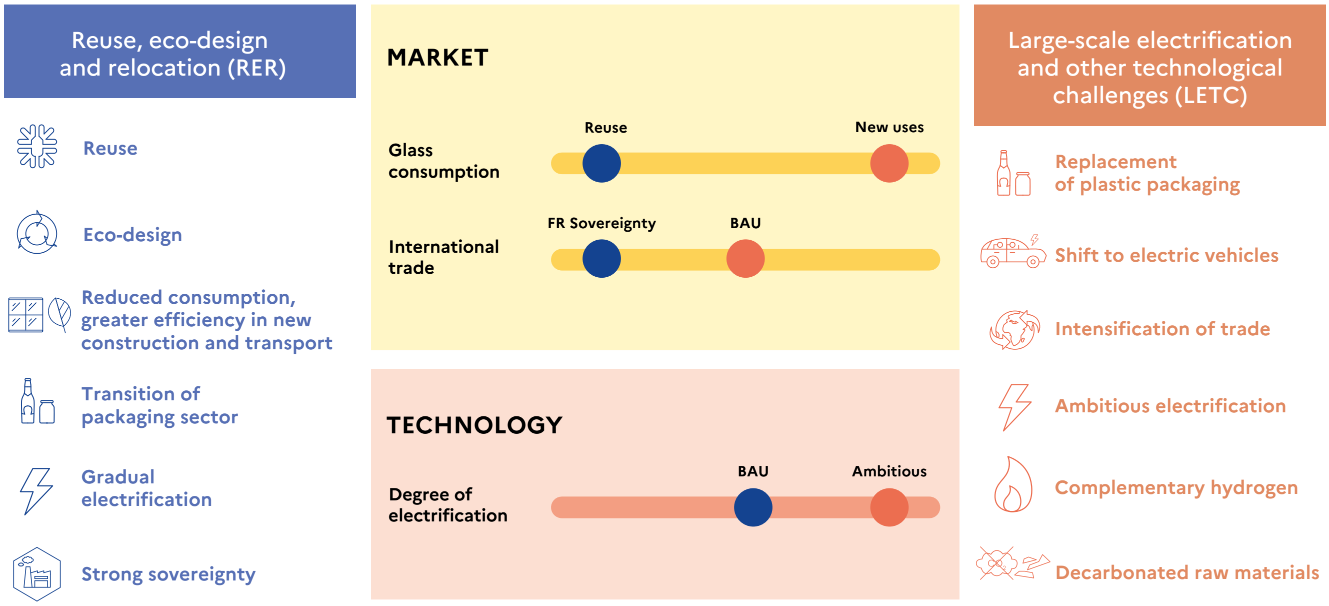
Glass consumption: In a society faced with the need to reduce its environmental footprint while continuing to meet its needs for housing, transport, energy and food, glass plays an essential role in the ecological transition. The renovation of buildings, the switch to electric vehicles, the large-scale deployment of solar panels and the replacement of single-use plastic packaging should increase demand for glass in France. These new uses may be accompanied by a change in consumption patterns, with a reduction in new building construction, a shift towards lighter forms of transport, the reuse of packaging and a reduction in the weight of glass items. These market changes will have a direct impact on glass consumption levels.

International trade: While the French glass sector benefits from a robust ecosystem and industries that are recognised in Europe and internationally, recent crises have highlighted its fragility and its exposure to new, rapidly growing players. Over the last 15 years, trade in glass has intensified; as fragile or low-density as it may be, glass is transported as a basic industrial commodity. Sovereignty issues arise for this material, especially in markets that are key to the ecological transition. Trends in glass imports and exports, combined with trends in glass consumption, will therefore be crucial for the French glass sector.

Electrification of processes: By replacing some or all of the fossil fuels consumed, the electrification of furnaces is the main way of reducing the carbon intensity of the glass industry. However, there are still many obstacles to overcome (technological maturity, economic profitability, market and electricity supply risks) and, at present, these technologies are in some cases at a disadvantage. The level of deployment of these solutions will therefore vary from one transition scenario to another, depending on their specific technical and economic conditions.

➜ Individual-section (IS) machine © Shutterstock, Anton Kurashenko

Figure 16. Transition environment and structuring factors for the two glass industry transition plan scenarios.



Based on structuring choices regarding the evolution of these three factors, two contrasting transition scenarios have been constructed, serving as a "backdrop" for industrial transitions in the glass sector.

In the ***"Reuse, eco-design and relocation" (RER)*** scenario, France firmly commits to the road of efficient use of resources and sovereignty. On the market side, the reuse of packaging is maximised, complemented by a significant reduction in the weight of single-use packaging. This reduced consumption and greater efficiency also apply to customer sectors, whose trends determine consumption levels. For example, a drastic reduction in new construction is projected in the RER scenario, but this is offset by a massive and ambitious acceleration in thermal renovation. In addition, a significant shift towards non-motorised and collective mobility and a reduction in the need to transport goods, thanks to short supply chains, are also favoured. Finally, significant efforts are made to maintain the industry's competitiveness while speeding up its transition, enabling lower consumption to be compensated by lower imports, which are still "carbon intensive". In terms of technology, electrification is progressing gradually, in line with current trends, with a wide range of technological solutions. Hybrid melting furnaces remain the preferred solution for the glass industry, offering greater flexibility in terms of energy supply, between biomethane, biogas, and "low-carbon" electricity.

In the ***"Large-scale electrification and other technological challenges" (LETC)*** scenario, France sees significant growth in its glass consumption. Packaging reuse increases more moderately than in the RER scenario, and the market gradually expands to include new forms of packaging; glass has become a central element in the packaging transition, in particular by replacing single-use plastics. Massive building renovation, combined with the need for new construction, significantly increases the market prospects for flat glass and glass wool. In terms of imports and exports, international trade evolves and continues, particularly with neighbouring European countries. On the technological side, this scenario is characterised by a strong prioritisation of the electrification of glass furnaces. This large-scale direct electrification is complemented by indirect electrification, for example by replacing residual gas with "low-carbon" hydrogen. Furthermore, manufacturers are gradually turning to alternative raw materials that emit less carbon dioxide during decarbonation. As a result, more technological challenges emerge in the LETC scenario, a scenario focused on innovation in contrast to the RER scenario, which is more focused on the use of less ambitious technological solutions.

2.2. Main transition assumptions for 2050

The table opposite summarises the scenario orientations, both in terms of potential market developments and the technological levers deployed. Details of the quantitative assumptions are presented in the full report.

Table 2. Narratives and main qualitative assumptions by scenario.
Details of quantitative assumptions in the full report.

	Reuse, Eco-design & Relocation (RER)	Large-scale Electrification and other Technological Challenges (LETC)
Replacement of plastic packaging with glass	Replacement of some single-use plastic packaging with reusable glass packaging.	Significant substitution of single-use plastic packaging and penetration of new markets (water and soft drinks, bulk purchase, takeaway, home delivery)
Energy-efficient renovation of buildings	Significant acceleration in the thermal renovation of buildings to LEB standards. Glass wool maintains its share of the insulation market.	Building renovation increases and then stabilises after 2030. Increased market share for glass wool compared with other insulation materials. Negligible use of triple glazing.
New construction and shift to electric vehicles	Drastic reduction in new construction. Significant shift in mobility requirements, reduced need to transport goods through development of local supply chains.	Moderate decrease in the need for new construction. Stable mobility requirements.
Re-industrialisation of downstream markets (construction, automotive, energy)	Major support to speed up the industry's transition while maintaining its competitiveness. Re-industrialisation of downstream markets (joinery, transport, renewable energies, etc.).	Continued intra-European trade. Stable imports/exports of flat glass and glass wool, and partial decrease in imports of glass packaging.
Increased reuse	Strong growth in reuse, particularly in the on-trade, beer and new markets.	Reuse growth continues current trend.
Reduction of product weights	Strong development of eco-design for single-use packaging and flat glass.	Continued trend in reduction of the weight of single-use packaging.
Optimisation of recycling	Increased recycling of packaging and development of recycling channels for flat glass and glass wool.	Increased recycling of packaging and development of recycling channels for flat glass and glass wool.
Electrification of furnaces	Gradual electrification of glass furnaces in line with current trends. By 2050, most flat glass and hollow glass furnaces are hybrid (50-70% and 80-90% electricity respectively). Glass wool furnaces are 100% electrified.	More ambitious and rapid electrification of glass furnaces. By 2050, flat glass and hollow glass furnaces are highly electrified (70% and 90-100% electricity respectively). Glass wool furnaces are 100% electrified.
Other technological levers and biogas	Equipment other than furnaces is partially electrified. The residual gas is supplied by the gas network, which is mostly decarbonised, or by biogas with direct connection to anaerobic digestion equipment.	Equipment other than furnaces is largely electrified. Decarbonised hydrogen can replace residual gas consumption, particularly for tableware and cosmetics.
Alternative decarbonated raw materials	Minimal replacement of carbonated inputs.	Strong development of upstream decarbonated raw materials and alternative "fluxes".

Comparison of these two transition projections highlights different paths for decarbonising the glass industry. They do not cover all possible scenarios, but offer reflection on possible alternatives. Their purpose is not to make predictions or to demonstrate that only these two scenarios are possible, but rather to shed light on the implications of different technological choices, market risks and opportunities, lessons for the industry and courses of action to accelerate its transition.

2.3. Results of the scenarios: a rapid and ambitious decarbonisation of the glass sector is possible

2.3.1. Reuse, Eco-design and Relocation (RER): decarbonisation objectives achieved, coupled with a sovereignty effort entailing significant investment costs

Stable glass production due to major efforts to reduce consumption and use resources more efficiently, offset by an adjustment of the trade balance.

Consumption

In the ***"Reuse, Eco-design and Relocation" (RER)*** scenario, glass consumption projections are positive for flat glass (+31% in 2030 and +14% in 2050 compared with 2015), for hollow glass (+6% in 2030 and +12% in 2050) and virtually stable for glass wool (+10% in 2030 and -4% in 2050). The building sector contributes to the rise in consumption of flat glass and glass wool, as a result of ambitious energy renovation programmes. By 2050, the emergence of the renewable energy sector, including photovoltaics, partially offsets the sharp fall in new building construction and the reduction in glass consumption in transport. The packaging sector is the main contributor to the increase in demand for hollow glass (notably through the development of reusable packaging to replace some single-use plastic packaging), while demand for tableware remains stable.

Imports and exports

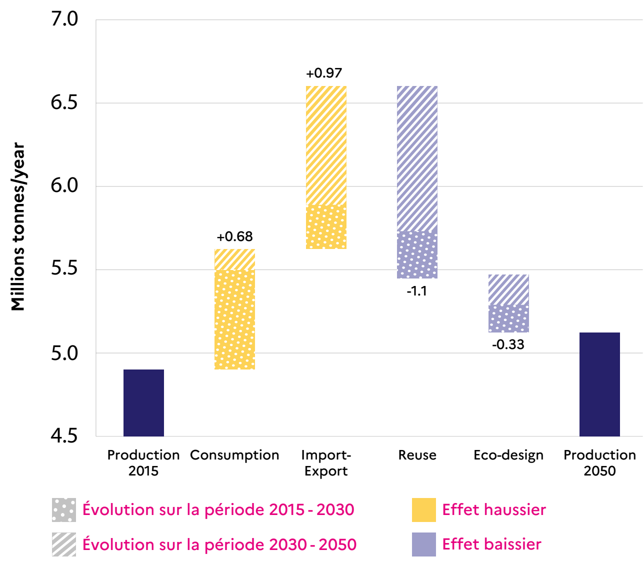
In addition to these changes in consumption, there is also a trend in imports and exports in the RER scenario, which is characterised by its sovereignty (a decrease in the import rate and a stabilisation of the export rate). Despite wide disparities between segments, the significant relocation of production, mainly driven by the packaging sector (+ 0.95 Mt/year between 2050 and 2015), enables the trade balance to be reversed from - 0.71 to + 0.52 Mt/year, making France a net exporter of glass in 2050.

Production

In this scenario, the reuse of packaging grows rapidly (15% by 2030 and 40% by 2050), replacing part of the production of single-use packaging. For single-use packaging, strong eco-design assumptions have been made, with a 10% reduction in the weight of single-use packaging and the widespread use of 3 mm double glazing. Finally, glass production is relatively stable in the RER scenario. Its slight increase of 4% averages many phenomena and heterogeneities by segment. Overall, the large-scale development of reuse and eco-design is offset by the increase in consumption, the advent of new markets and relocation.

Figure 17. Modelling of glass production levels in the RER scenario, by 2030 and 2050, in France.
In millions of tonnes per year (Mt/yr).

Mt / year	2015	2030	2050
Flat glass	0.80	1.11	0.98
Packaging	3.39	3.40	3.24
Glass wool	0.31	0.31	0.34
Tableware	0.28	0.32	0.35
Other	0.14	0.16	0.21
Total	**4.92**	**5.31**	**5.11**



Decarbonisation in 4 areas: reduction and efficiency, hybrid furnaces, cullet and biomethane.

By 2030

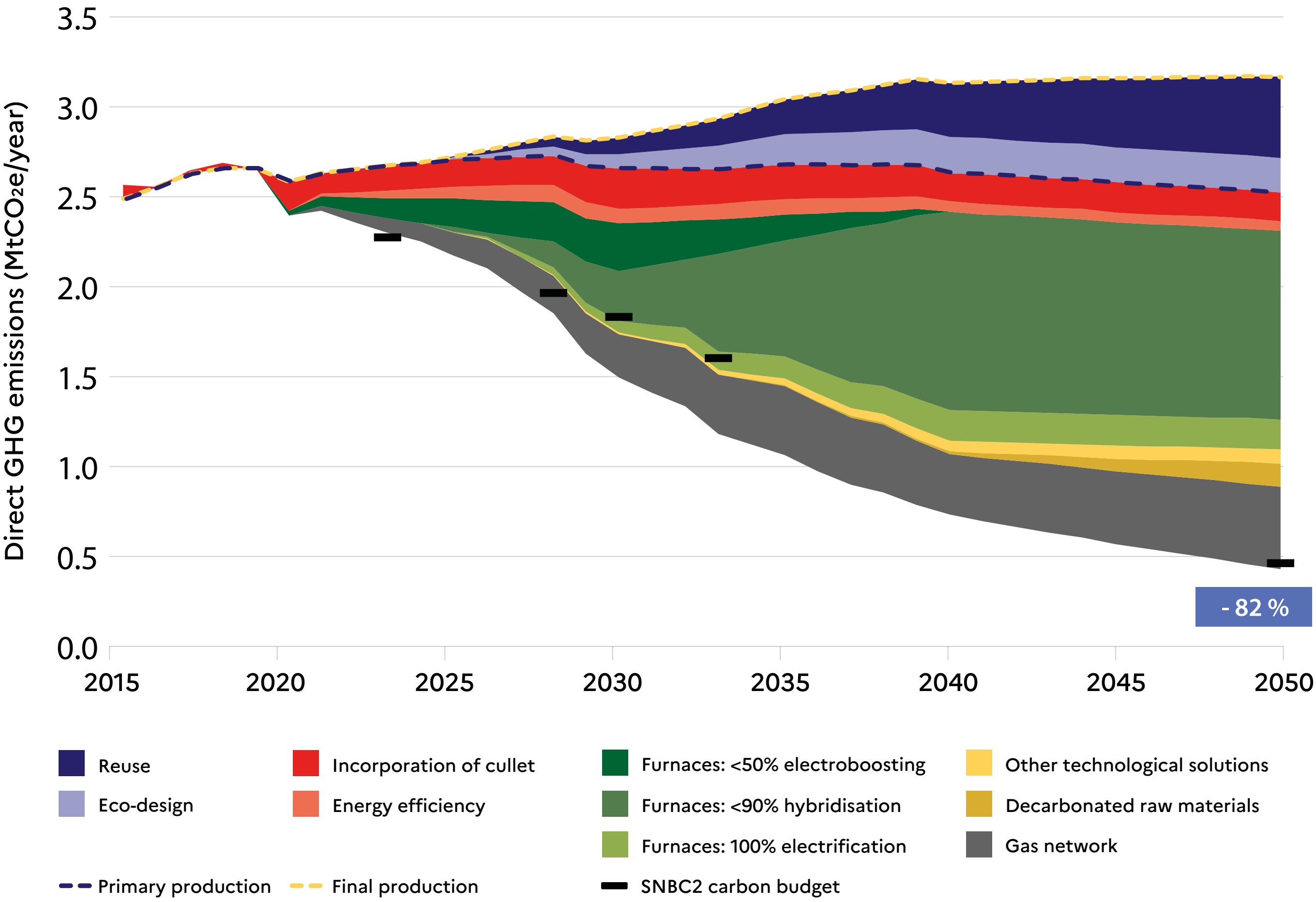
Emissions have been reduced by 41% compared to 2015, significantly exceeding the SNBC2 interim target of -35%. This is mainly due to the hybridization of the first hollow glass furnaces (21% of the decarbonisation effort), to electroboosting coupled with oxy-fuel combustion for part of the equipment still in service (20%), to the increased integration of cullet in the glass mix (17%) and to the gradual decarbonisation of the gas network (18%).

➜ Coloured glass © Shutterstock, Mark_0

By 2050

Subsequently, other levers emerge and gain in maturity. In addition to the development of reuse and eco-design (respectively 16% and 7% of decarbonisation), the two main levers that stand out are the hybridisation of furnaces (38%, deployed on a massive scale over the decade 2030-2040) and the decarbonisation of the gas network (17%, notably through the injection of biomethane into the network and the direct connection of glass plants to local biogas production units). These two levers alone account for more than half of the decarbonisation effort. Furthermore, the impact of the energy efficiency levers deployed in 2030 on gas-fired equipment will diminish as processes are electrified, becoming intrinsically more efficient. Similarly, efforts to recycle glass in France will only offer a moderate gain in direct emissions in 2050 (7%), due to pressure on sources of cullet, following the reduction in packaging imports. Finally, total electrification (6%) and the replacement of raw materials with decarbonated raw materials (5%) will complete an 82% decarbonisation of the glass industry in 2050 compared to 2015.

Figure 18. Change in direct GHG emissions from the glass industry between 2015 and 2050 in the RER scenario.
Emissions from other glass products, not modelled, are not represented here: approx. 0.19 $MtCO_2e$ in 2015.

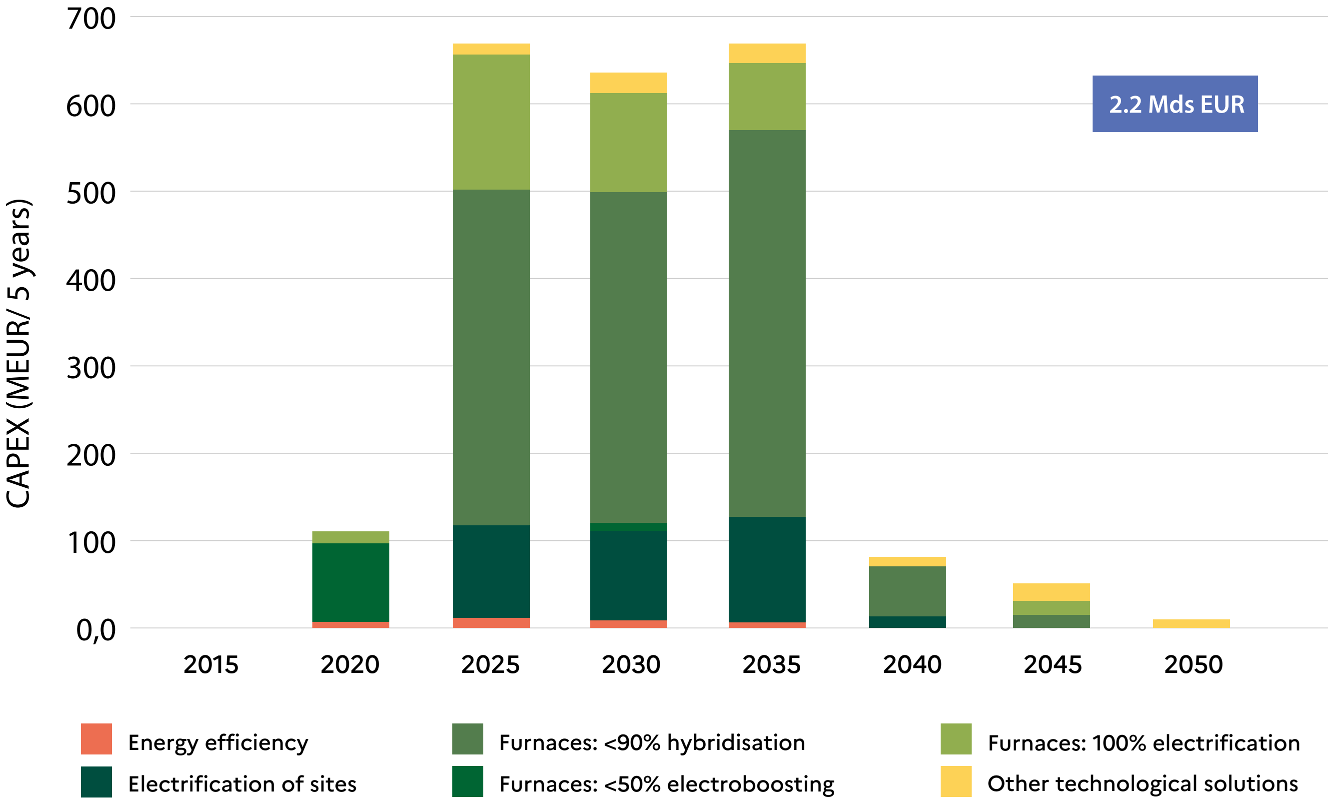


High levels of investment in a context of production relocation.

The difference in overall CAPEX in this decarbonisation scenario is around €2.2 billion (excluding electrical connection costs) compared to the "business as usual" CAPEX (which simply rebuilds the current furnaces at the end of their service life to meet projected demand without any change in technology), which amounts to €3.8 billion; i.e. a total of €6.0 billion in investment between 2019 and 2050. Most of this significant investment is directed towards costly hybrid and electric furnace technologies, and electrical reinforcement work at the sites required to integrate these technologies. Most of these investments take place between 2025 and 2040, making this period a key phase in the decarbonisation of the sector. This highlights the relative speed with which this sector can decarbonise, subject to access to competitive decarbonised energy, availability of funding and access to electrical infrastructure[30] at industrial sites. The cost of ensuring the sovereign decarbonisation of national facilities is high, but nevertheless offset by the massive development of reuse channels and eco-design efforts.

➜ Mould for forming glass bottles © Saverglass, G. Crochez

Figure 19. Investment timeline for the RER scenario between 2015 and 2050.
Extra capex linked to additional decarbonisation compared to BAU. Indirect investments (anaerobic digestion plants, CCS for decarbonated raw materials, reinforcement of the electricity grid) are not taken into account.



[30] The cost of connecting and reinforcing electrical networks external to the glassmaking sites is not quantified here.

2.3.2. Large-scale Electrification and other Technological Challenges (LETC): maximum decarbonisation enabled by high levels of investment in innovative solutions

Increased glass production due to substantial rise in consumption for new uses.

Consumption

In the ***"Large-scale Electrification and other Technological Challenges" (LETC)*** scenario, consumption of the three glass segments increases with the emergence of new uses for glass. In particular, flat glass consumption increases by 48% between 2015 and 2050, with major energy-efficient renovation of buildings, as well as the acceleration of photovoltaic panels after 2028. For the hollow glass sector, increased replacement of single-use plastics and the development of new packaging markets contribute to a 25% increase in hollow glass consumption. In contrast to the RER scenario, the market share of glass wool increases in this scenario, to meet persistent demand for new construction in 2050.

➜ Cutting glass wool mats © Shutterstock, Tursk Aleksandra

Imports and exports

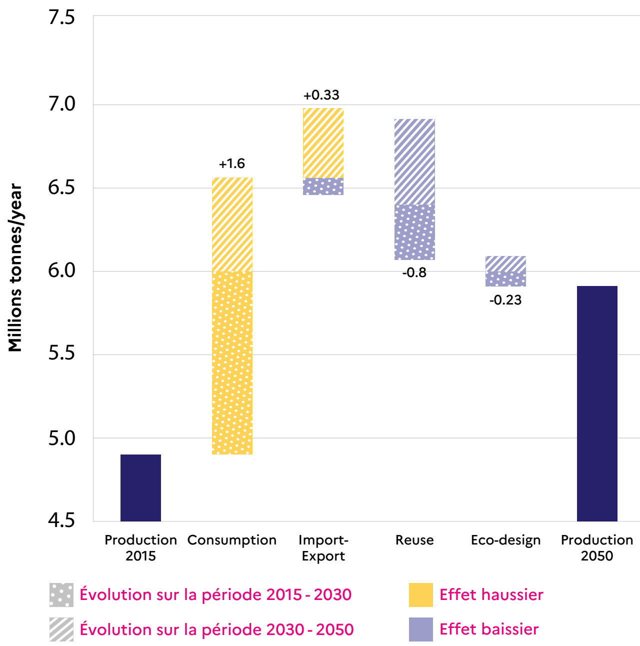
In the LETC scenario, relocation is less extensive and leaves more room for openness to European and international trade. In this context, trade in glass increases, except for imports of packaging, which are already substantial. Finally, the trade balance stabilises at - 0.23 Mt/year in 2050, with a fairly even trade balance for all segments.

Production

In addition to an increase in consumption across all sectors, reuse channels develop, but remain concentrated on professional packaging and the beer market. Similarly, the eco-design of single-use packaging evolves, but in balance with other non-environmental criteria (marketing, consumer acceptability). In the LETC scenario, the increase in consumption is so strong that it leads to an increase in production of 20% and the opening of two new 300 t/d hollow glass furnaces, despite less sovereignty and relocation than in the RER scenario.

Figure 20. Changes in glass production levels in the LETC scenario, between 2015 and 2050.
In millions of tonnes per year (Mt/yr).

Mt / year	2015	2030	2050
Flat glass	0.80	1.20	1.14
Packaging	3.39	3.55	3.89
Glass wool	0.31	0.34	0.38
Tableware	0.28	0.29	0.31
Other	0.14	0.16	0.19
Total	**4.92**	**5.55**	**5.90**



Decarbonisation enabled by ambitious deployment of electrification (total and hybridisation) and the use of decarbonated raw materials

By 2030

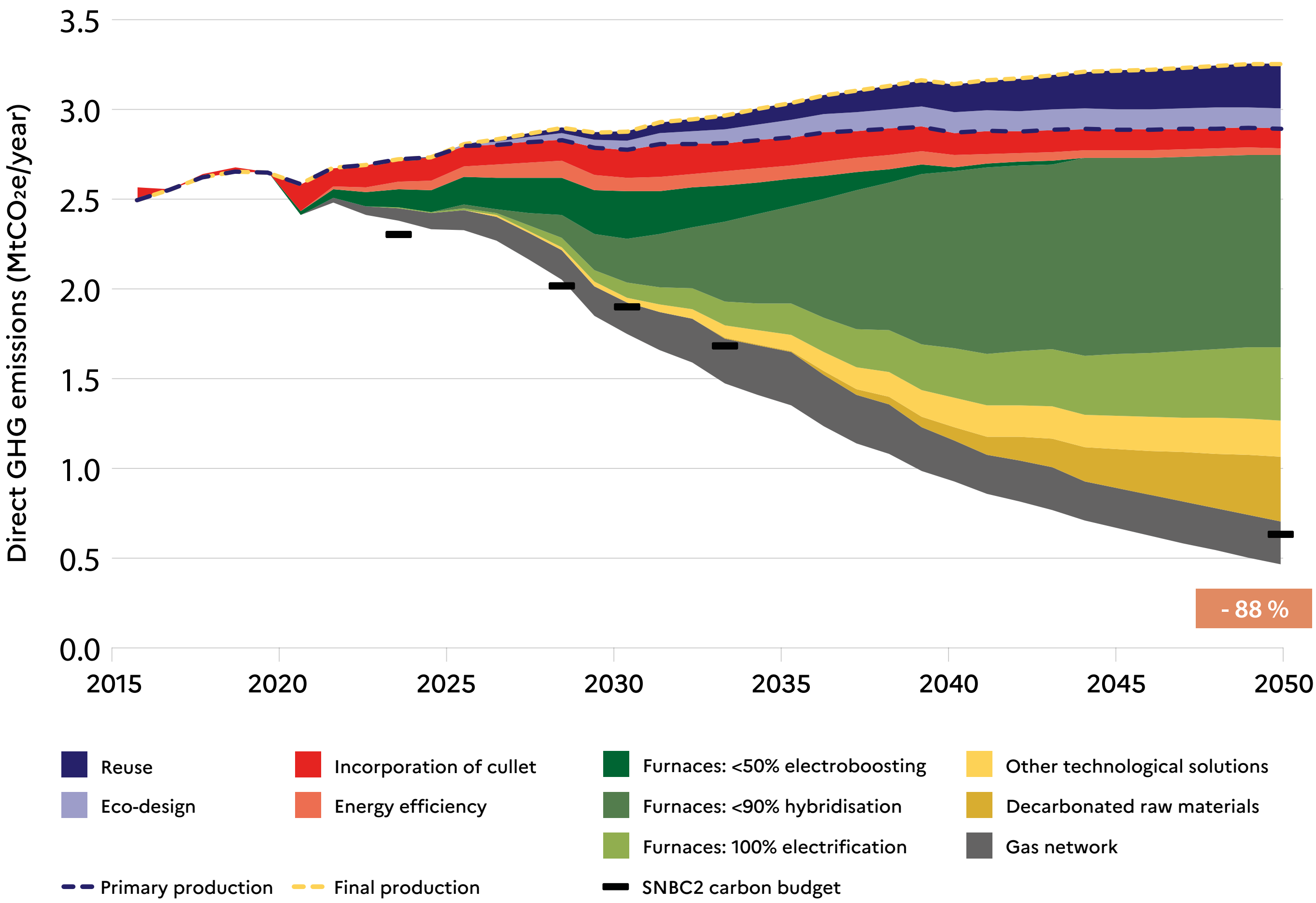
The interim target of 2030 has been exceeded, with a 34% reduction in emissions compared to 2015. This performance is attributable to several levers, including electroboosting coupled with oxy-fuel combustion (23% of the decarbonisation effort), hybridisation of the first hollow glass furnaces (22%), the use of cullet (14%) and the gradual decarbonisation of flue gases (15%), similar to the RER scenario.

By 2050

Beyond 2030, new levers come into play, in particular total electrification and the use of decarbonated raw materials, which are widely deployed in this scenario. The main drivers of decarbonisation are the hybridisation of furnaces (38% of the effort), total electrification (15%) and the use of decarbonated raw materials (13%). This scenario aims to push the glass industry towards high levels of electrification, to 100% or combining ambitious electric hybridisation, up to 90% for certain hollow glass furnaces and 70% for flat glass "floats", with progressively decarbonised network gas and renewable or low-carbon hydrogen. The composition of glass is also evolving towards decarbonated raw materials, which represents a major technological challenge. The availability of these raw materials is therefore crucial for achieving decarbonisation targets, particularly to reduce residual process emissions once the energy mix has been almost entirely decarbonised. The remaining levers are secondary, with reuse (9% of the effort), eco-design (4%), and the integration of cullet (4%) in line with current trends.

Nevertheless, the decarbonisation performance achieved in this scenario is slightly better, with a reduction in emissions of 88% in 2050 compared to 2015. This decarbonisation effort, which relies heavily on the technological ambitions of this scenario, is all the more notable given that final glass production in France increases compared to 2015, against a backdrop of emerging new markets and relatively limited reuse and eco-design initiatives.

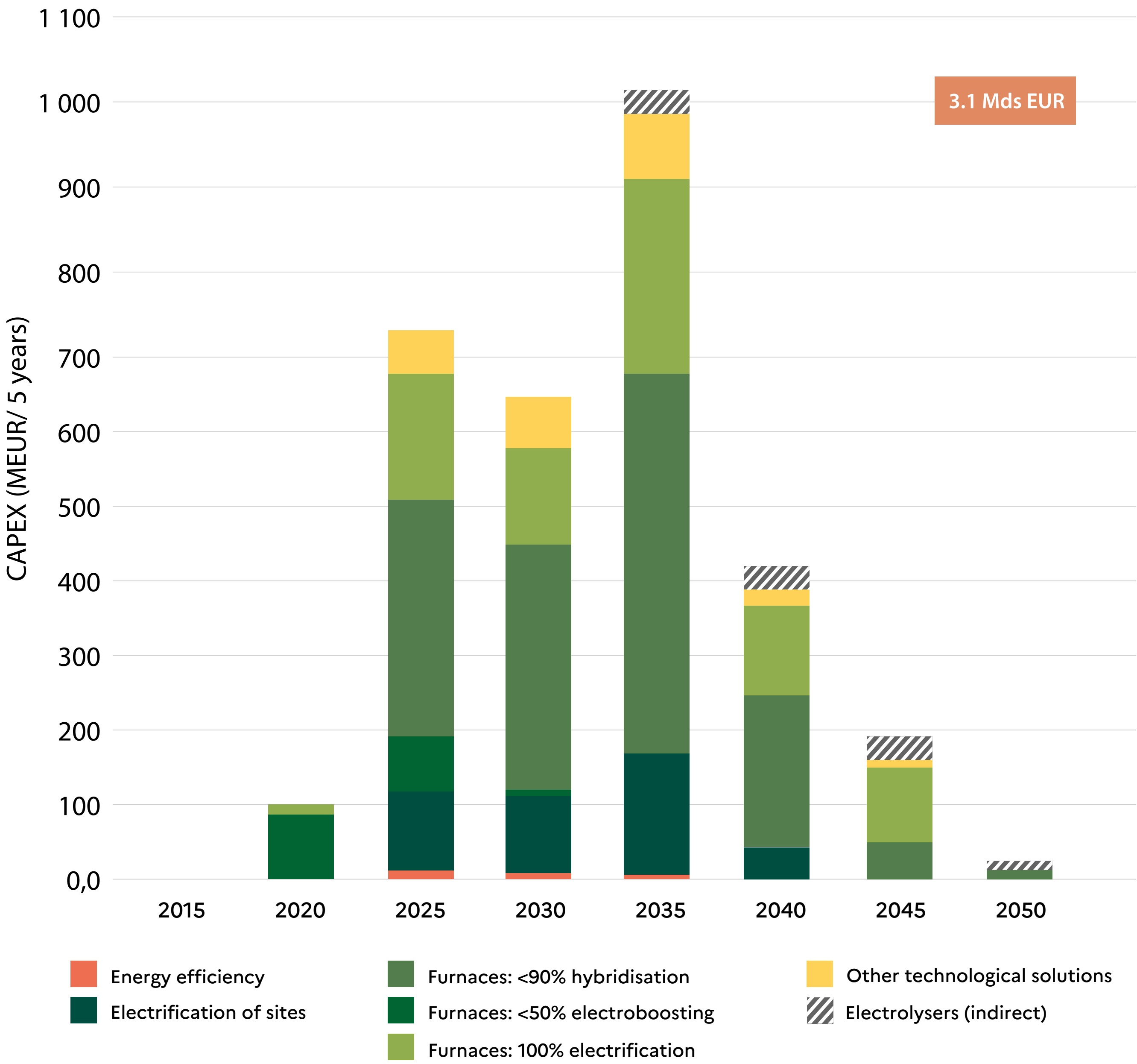
Figure 21. Change in direct GHG emissions from the glass industry between 2015 and 2050 in the LETC scenario.
Emissions from other glass products, not modelled, are not represented here: approx. 0.19 $MtCO_2e$ in 2015.



Major investment in technology

Achieving this ambitious decarbonisation objective will require technological investment that is all the more substantial given the increase in production that has been modelled. Overall CAPEX in this decarbonisation scenario comes to around €7.2 billion, i.e. an additional transition cost of €3.1 billion (excluding the cost of connection to the electricity grid) compared to CAPEX in the business as usual scenario (which follows market trends without any technological change) of €4.2 billion. This substantial investment mainly concerns hybrid and electric furnaces, in particular the opening of two new furnaces for the production of glass bottles and jars (2 times 300 t/d of new capacity), as well as the electrical reinforcement of the sites necessary for their development[31]. This time, investment is more spread out until 2045, when the last investments in hybrid furnaces for flat glass are made. The funding and electrical connection challenges linked to this electrification are also significant, and this time more continuous over time. In addition to this direct CAPEX for manufacturers, there are indirect CAPEX costs related to system investments. For example, this scenario entails indirect costs linked to electrolysers dedicated to H_2 production amounting to €0.1 billion over the entire analysis period.

Figure 22. Investment timeline in the LETC scenario between 2015 and 2050.
Extra capex linked to additional decarbonisation compared to BAU. Indirect investments (anaerobic digestion plants, CCS for decarbonated raw materials, reinforcement of the electricity grid) are not taken into account.



[31] However, the cost of connecting and reinforcing electrical networks external to the glassmaking sites is not quantified here.

2.4. Comparative analysis of decarbonisation scenarios and key cross-cutting points

Production

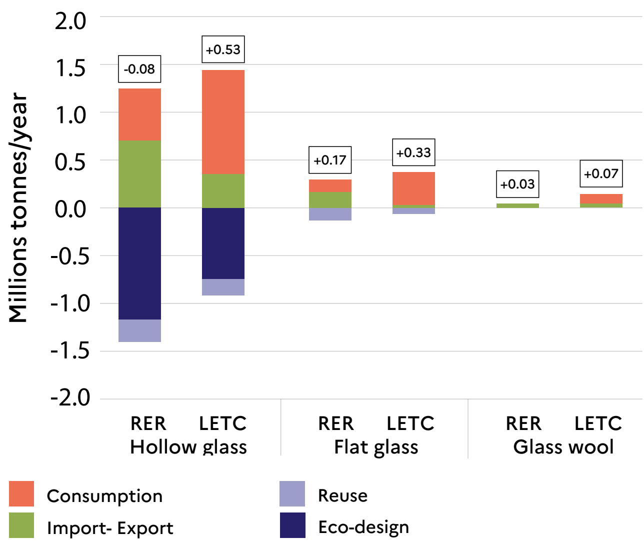
Glass production in France is expected to increase by 2030 (between 8% and 13%) and by 2050 (between 4% and 20%) compared to its 2015 level, but with differences between segments. Growth in flat glass production in 2050 could be the most significant (between 21% and 41%), thanks to a historically low level in 2015 and growing consumption by its customer sectors (construction, photovoltaic panels). Hollow glass production is expected to grow slightly (between -2% and +14%), with an increase in the consumption of glass packaging, associated with partial or complete relocation, despite the growth in reuse. Lastly, production of glass wool is also expected to rise (by between 10% and 24%), thanks to the relocation of some of the previously imported products, and growing demand from the construction sector.

Reuse and eco-design

Between 2015 and 2050, the rate of reuse of packaging produced and placed on the market in France grows significantly from 4% to 25% (LETC) and 40% (RER). The quantities of reusable glass produced could double or even triple over the coming decades, provided that an effective reuse ecosystem is developed throughout the value chain (regional coverage, optimised collection and reconditioning).

At the same time, the glass industry is moving towards lighter products (flat and hollow), which requires both the capacity of customer sectors to take up these innovations, and significant changes in consumer habits and standardisation, particularly in the flat glass sector (construction, transport).

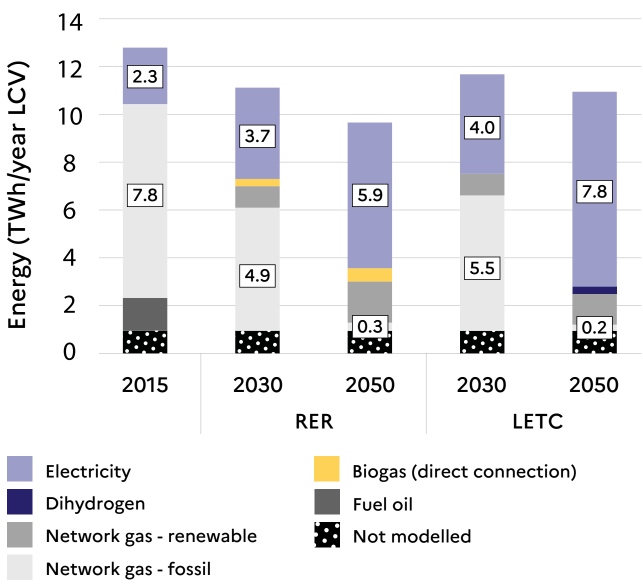
Figure 23. Breakdown of changes in glass production in 2050 compared to 2015, by segment and by scenario.
Labelling: change in total production in Mt/year (sum of the 4 effects).



Energy consumption and mix

Thanks to the energy efficiency provided by electric furnace technologies, energy consumption falls in both scenarios, by 23% (RER) and 12% (LETC) in 2050 compared to 2015. Specific energy consumption is very similar in the two scenarios, rising from 2.4 MWh/t glass produced in 2015 to 2.0 MWh/t in 2030 and 1.7~1.8 MWh/t in 2050. The energy mix varies significantly compared to 2015, with the share of electricity in the energy mix rising from 20% to 70% in RER and 81% in LETC. The rest of the energy is provided by the gas network, and the direct use of biogas (RER) and hydrogen (LETC) as a back-up. Dependence on fossil fuels has been greatly reduced, requiring both an ambitious decarbonisation of the gas network and the use of GPAs by glass manufacturers to secure their supply of renewable gas.

Figure 24. Energy consumption by the glass industry in 2030 and 2050, by scenario and by energy vector.
Labelling in TWh/year LCV (top): electricity; (bottom): fossil gas.



Between 2015 and 2050, electricity consumption is expected to more than double in the RER scenario and more than triple in the LETC scenario, representing an increase of between 3.7 and 5.7 TWhe/year. The deployment of electrification in the glass industry will be gradual and spread over several decades, due to the relative maturity of this lever, particularly for high-capacity furnaces; it is nonetheless pressing by 2030, with the first investments already announced and a large-scale shift by the industry in favour of these electric technologies.

Biogas

Renewable gas consumption increases significantly in both scenarios. While the glass industry favours active decarbonisation through the electrification of its processes, it nonetheless benefits from the gradual transition towards decarbonisation of the gas network. In the RER scenario, biogas consumption reaches more than 2.2 TWh in 2050, while in the LETC scenario, it amounts to 1.3 TWh. These volumes are mainly supplied by biomethanisation units connected to the network; they may also come in part from biogas production units directly connected to industrial sites (known as "direct connection"), in cases where this configuration is favourable in a given area. As the residual gas consumption is not negligible, the glass industry remains dependent on this supply, particularly in the RER scenario, to support the energy requirements of factories and hybrid furnaces in particular.

GHG emissions

Both scenarios manage to exceed the SNBC 2 targets for industry (-81%), with decarbonisation of -82% (RER) and -88% (LETC). This transition takes place very quickly, between 2025 and 2035, for hollow glass, but later for flat glass and glass wool, in line with the deployment of the most ambitious levers and their technological maturity. Despite this, all the levers taken together enable a significant reduction in the carbon intensity of glass production. In the RER scenario, this intensity falls from 0.54 tCO_2e/t of glass to 0.09 tCO_2e/t, while in the LETC scenario it reaches 0.05 tCO_2e/t. Residual emissions, linked to process emissions and the fossil content of network gas, remain difficult to reduce without the use of breakthrough technologies to offset decarbonation emissions (100% decarbonated raw materials, carbon capture and storage) and total replacement of fossil fuels.

Investments

The activation of technological levers is accompanied by an increase in investment in decarbonisation, between 2.2 and 3.1 billion euros. Nevertheless, this CAPEX represents a manageable additional cost (between 57% and 75%) in a capital-intensive glass industry, used to regularly renewing its furnaces (every 6 to 20 years depending on the type of furnace). On the other hand, the significant variation in energy prices and the timetable for connecting the glassmaking sites to the electricity grid have been identified as major obstacles to investment. Other major levers for decarbonising the glass industry are much less CAPEX-intensive, such as eco-design and increased reuse. "Indirect" investments, not quantified here, will nevertheless be necessary, both to reinforce the electricity network (production, transport and distribution outside the industrial site) and to develop the reuse sector (collection, sorting, cleaning, remarketing).

Recycling and cullet

The availability of cullet resources is crucial to the short-term decarbonisation of the glass industry. The incorporation of cullet into furnace mixes is technologically mature and requires little adaptation of current equipment. As a result, cullet consumption is set to rise considerably, reaching 3 million tonnes by 2030, then stabilizing until 2050. This increase is due to the recovery of waste from flat glass recycling sectors (construction, automotive, renewable energy), increased consumption of glass packaging, and imports of cullet to compensate for the reduction in packaging imports as the sector relocates. Finally, the rate of incorporation of total external cullet increases from 45% to between 51% (LETC) and 54% (RER) depending on the scenario. This limited increase further emphasizes the importance of an efficient recycling sector, involving collaboration between manufacturers, public bodies and consumers.

Figure 25. Changes in direct GHG emissions in 2030 and 2050, by segment and by scenario.

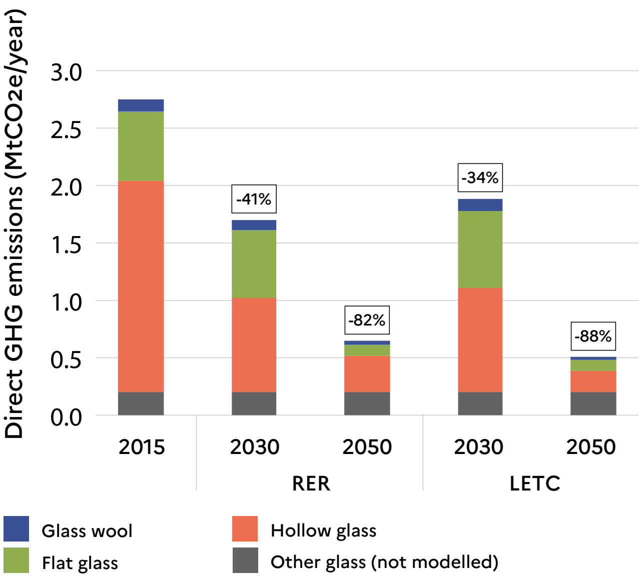


Figure 26. Collection and availability of external cullet in France, from recycling and import-export, in 2030 and 2050, by scenario.

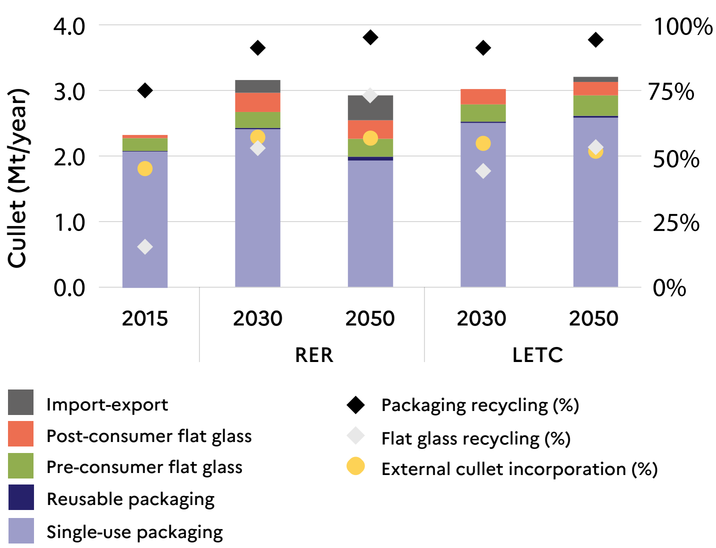


Table 3. Summary of the main results for the two scenarios in 2050.
Within the scope of the modelling.

	2015	RER 2050	LETC 2050
Glass production (Mt/year)	4.9	5.1	5.9
Incorporation of cullet (internal + external)	56 %	62 %	59 %
Gas consumption (TWh/year LCV)	7.8	2.5	1.5
Electricity consumption (TWhe/year)	2.3	5.9	7.8
H_2 consumption (TWh/year LCV) *additional electricity equivalent (TWhe/year)	—	—	0.31 *0,54
Direct GHG emissions ($MtCO_2e$/year)	2.5	0.44	0.30
Carbon intensity, direct emissions (tCO_2e/t)	0.51	0.09	0.05
$MtCO_2e$ évitées cumulées	—	51	51
Additional cumulative investment (EUR billion) compared to BAU CAPEX		2.2	3.1

➜ 100% electric glass furnace, Cognac © Verallia

3. Socio-economic analysis

3.1. Significant increases in production costs

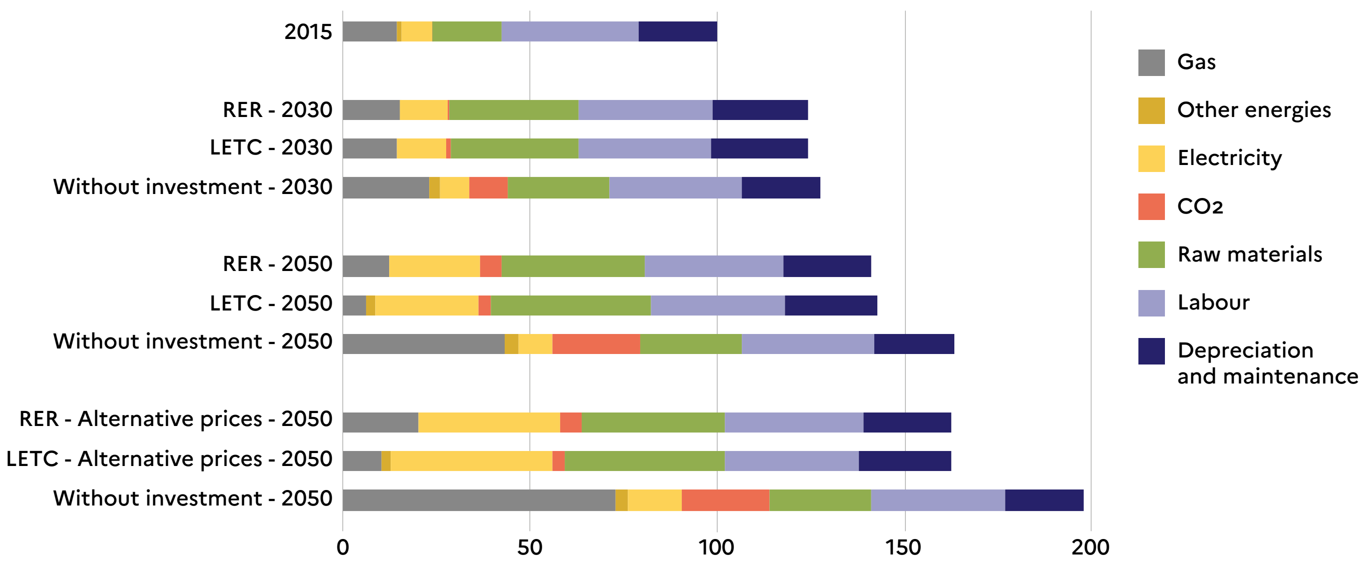
In 2015, energy accounted for around a quarter of glass production costs, with the other cost items being labour, raw materials, maintenance and depreciation for this capital-intensive industry. In 2022, the war in Ukraine highlighted the industry's extreme dependence on gas prices, leading some French sites to temporarily halt production. In structural terms, the price of electricity is also set to rise, in order to cover the investments needed to reinforce the grid. Furthermore, the expected rise in the price of CO_2 means that glass production costs will necessarily rise as the allocation of free quotas decreases (Box 5).

Compared to 2015, the cost of production rises by around 25% in both scenarios in 2030, mainly driven upwards by the increase in the price of energy and raw materials between 2019 and 2030. In this time frame, this increase is similar to a configuration in which no investment in decarbonisation was made. In 2050, the change in production costs is almost identical in both scenarios (+42% vs 2015), driven mainly by the change in energy mix from fossil fuels to electricity. In the LETC scenario, electrification technologies are deployed to a greater extent than in the RER scenario, but this does not create a real difference in the cost structure of these two scenarios, due to the overall shift towards electrification.

Analysis of alternative price scenarios highlights the risk of production costs spiralling out of control in the event of a rise in energy prices, particularly electricity prices. This dependence is all the more critical in a context of the general electrification of industry, with the consequent increase in the need for electricity and conflicts over its use.

Nevertheless, investment in the transition is always profitable and reduces the industry's dependence on fluctuations in fossil gas and CO_2 prices. Electrification is therefore a virtuous and resilient choice, provided that it is accompanied by access to decarbonised French electricity that is competitive in the short-medium-long term, with sufficient visibility to enable investment.

Figure 27. Projection of the specific production cost index for glass in 2030 and 2050 in the two scenarios and comparison with a scenario without investment in decarbonisation.
Sensitivity analysis with alternative prices: approximately +60% for gas and electricity. Base 100 vs 2015.
The "Other energies" item includes fuel oil (2015) and H_2 (2030 and 2050).



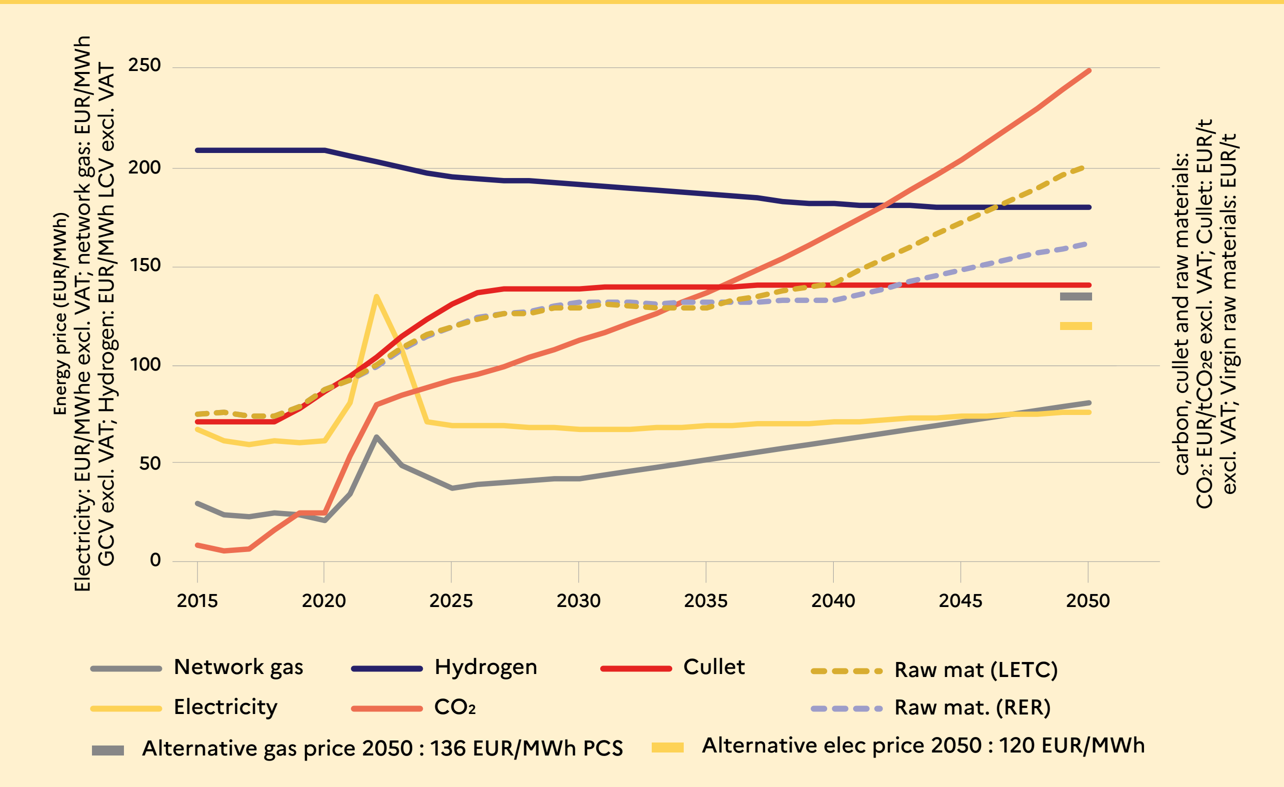
➜ Clear glass bottles © Shutterstock, lunamarina

Box 5

Assumptions for energy, materials and CO_2 prices

Price trends for the glass industry's main expenditure items are shown below. To facilitate analysis and comparisons, the assumptions are the same in both scenarios. Alternative, less "conservative" prices are also proposed to illustrate the sensitivity of production costs to variations in the price of gas and electricity.

Figure 28. Assumptions for energy, raw materials and CO_2 prices.
The price of network gas takes account of changes linked to its gradual decarbonisation, with the cost of injected biomethane fixed at EUR 90/MWh GCV excluding VAT.
Alternative prices in 2050 (around +60%), for sensitivity analysis.
Higher material prices in LETC due to greater use of alternative raw materials.



Sources: ADEME estimates, based on historical data from glass manufacturers (2015-2019), changes in energy prices from SDES, linked to the Covid crisis and the war in Ukraine (2020-2023) and projections from RTE (BP 2035 and Futurs Energétiques), EEX, the French Directorate-General for Energy and Climate (DGEC) and the International Energy Agency (IEA) (2024-2050). Materials: observed rate of increase of 10%/year (2018-2024) then stabilisation after 2028.

3.2. Abatement costs to clarify the comparison between levers

To assess the economic relevance of an investment in a decarbonisation solution, we can calculate its abatement cost which combines in a single indicator its decarbonisation efficiency per euro invested, taking

into account both its CAPEX and OPEX over its lifetime. It is measured in EUR/tCO_2. The estimated values are based on the calculation methodology detailed in Box 6. The analysis below compares the sensitivity of these abatement costs to the price of fossil gas, and thus explores the conditions under which investment in a decarbonisation technology becomes financially attractive for the following three cases:

- **Case 1:** Flat glass – Hybrid furnace 50% electric, 50% network gas.
- **Case 2:** Packaging – Hybrid furnace 80% electric, 20% network gas.
- **Case 3:** Tableware – 100% electric furnace.

NB: these abatement costs are theoretical average projections, which vary considerably according to price assumptions, and do not take into account non-economic indicators such as the respective level of maturity of the technologies, emissions targets and volume of CO_2 avoided, or other technological, logistical, and non-economic factors specific to each industrial site.

➜ Pile of cullet © Shutterstock, Mircea Moira

Box 6

Method – abatement cost of technologies

Two indicators can be used to compare the cost of developing technologies: their additional cost and their abatement cost.

The additional cost associated with a technology is defined as the difference between the expenditure associated with the application of a technology (the discounted sum, using a discount rate r, of the CAPEX and operating expenses (OPEX), over a fixed period T).

This indicator is used to assess the profitability of a technology. If the additional cost is zero, it will be profitable at the end of the project. If it is negative, it will be profitable before the end of the project. If it is positive, the project is not profitable. In particular, if the savings in operating costs are too small (or if ΔOPEX is positive), the investments may never pay for themselves, whatever the duration of the project.

$$Excess\ cost = \sum_{t=0}^{T-1} \frac{\Delta CAPEX_t + \Delta OPEX_t}{(1+r)^t}$$

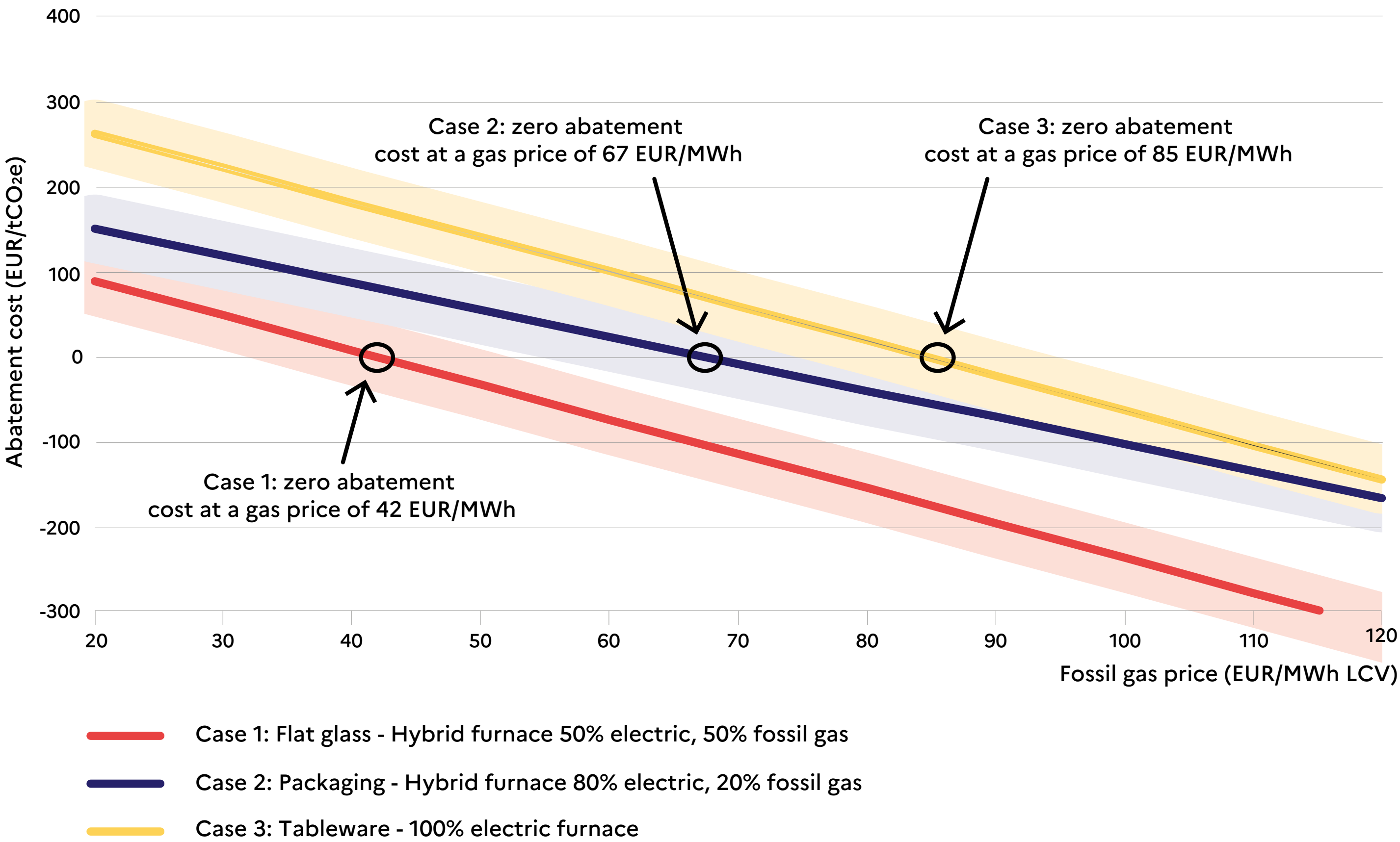
The abatement cost of a technology is defined as the additional cost of this technology in relation to the cumulative quantity of CO_2 that it avoids over the life of the project compared with the situation where the existing installations are maintained.

This indicator makes it possible to compare the cost-effectiveness of decarbonisation levers with a view to prioritisation, but it must be supplemented by other indicators such as maturity, the level of decarbonisation enabled by each technology or the way they are linked together[32].

$$Abatement\ cost = \frac{Excess\ cost}{\sum_{t=0}^{T-1} \Delta CO2_t}$$

[32] With the objective of total decarbonisation, rather than partial decarbonisation, the use of low-cost technologies that only partially reduce emissions can create a counter-productive technological lock-in.

Figure 29. Abatement cost of three hybrid furnace technologies (50% and 80%) and 100% electric, depending on changes in the price of fossil gas.
Abatement cost over 20 years, between 2019 and 2038. Electricity price: set at 75 EUR/MWhe. CO_2 price: 80 EUR/t
Sensitivity analysis (areas around lines): ± 15 EUR/MWhe. Technological assumptions in the full report.



The decrease in abatement costs indicates that electrification technologies become all the more profitable as the price difference between gas and electricity decreases. In a situation where electricity is set at €75/MWh, the abatement cost of the decarbonisation technologies studied (hybrid or electric furnaces) is cancelled out at a fossil gas price of between €40 and €90/MWh LCV: around the equilibrium point (zero abatement cost), a variation in the price of electricity of ± €15/MWhe, requires a variation of ±€5/MWh LCV in gas for case°1 and ±€10/MWh LCV for case°3. At the boundary conditions, in a situation in which electricity becomes very expensive (> €120/MWh, not shown on the graph above), and where the price of gas remains below €60/MWh, all the decarbonisation technologies studied here have positive abatement costs, despite the savings in OPEX (and CO_2 in particular).

The difference between the three cases of application is due to the increasing rate of electrification from case 1 (50%) to case 3 (100%), the abatement cost being more sensitive to the difference between the price of electricity and gas. The profitability of these technologies also varies according to the size of the furnaces and their lifespan: for small installations, such as case 3, with fewer economies of scale and a lifespan of around ten years, the extra investment cost is higher than the OPEX savings achieved; conversely, for case 1, the OPEX savings offset the extra investment in a longer-life technology (> 15 years) offering more favourable conditions for making the investment profitable.

➜ Manufacture of glazing © Shutterstock, Roman Zaiets

3.3. Jobs

Between 2015 and 2022, direct jobs in glass production rose very slightly, from 9,880 to 10,220. This relative stability is in line with a stable production level of around 5.2 Mt/year for all types of glass combined. The hollow glass sector accounts for slightly less than half the workforce and more than half the production. However, the most labour-intensive sector is cosmetic glass and tableware, which accounts for more than a third of the workforce despite representing only 8% of total glass production in France. This point highlights the significant differences in labour intensity in the different glass segments due to the disparities between production processes.

In 2015, the number of indirect upstream jobs in France totalled 3,260, mainly driven by the glass recycling sector, which accounts for almost two-thirds of indirect jobs. Energy is also a significant sector, with 790 jobs, largely associated with electricity consumption.

Production sites are not geographically concentrated, with an even distribution throughout the country. There are, however, a number of regional clusters, such as La route du verre et du cristal ("The Glass and Crystal Trail" in the Lorraine) and La vallée de la Bresle (known as "Glass Valley" in Normandy and Hauts-de-France), both of which are flagships of French expertise. Flat glass plants are closer to borders and industrial areas.

In the RER scenario, France retains industrial sovereignty. Despite a reduction in the weight of products, production of flat glass increases, driven by the need for building renovation and photovoltaic panels. Production in the glass wool sector follows this trend, driven by building renovation and despite competition from other insulation products and the sharp reduction in new construction. Hollow glass production for tableware and packaging also increases. Jobs associated with glass production are estimated to increase by 13%, from 9,880 in 2015 to 11,200 in 2050. Similarly, indirect employment is forecast to increase by 50%, mainly due to the doubling of electricity consumption and the increase in glass recycling. In addition to production jobs, the RER scenario develops the reuse sector, which should also generate jobs (not quantified here).

In the LETC scenario, flat glass and hollow glass production increases more strongly, but is accompanied by only a more moderate estimated increase in jobs, reaching 10,890 in 2050, an increase of 10% compared with 2015. This is explained by hollow and flat glass being less labour-intensive than tableware, whose workforce contracts more over this period. In terms of indirect jobs, the very strong growth in electricity consumption and the intensive use of cullet leads to an estimated increase of more than 60% in the workforce, reaching 5,310 jobs in 2050.

[33] Base Acoss Ursaff. The jobs included in this section relate only to the production of raw glass and not to shaping or decoration activities, which are generally included in the national classifications of sectors of activity '231: manufacture of glass and glassware'. These categories each accounted for around 11,000 jobs in 2015.

[34] The calculation of indirect jobs only takes into account upstream indirect jobs, i.e. those associated with the consumption of materials, including recycled materials, and energy.

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Acronyms and abbreviations

ADEME - French Agency for Ecological Transition
AGEC - "Loi Anti-gaspillage pour une économie circulaire" (Anti-Waste Act for a Circular Economy)
BPA - Biogas Purchase Agreement Contract to supply renewable gas
CAB - Abatement costs
CAPEX - Capital expenditure
CBAM - Carbon Border Adjustment Mechanism
CCS - Carbon capture and storage
CHR - Cafés-Hotels-Restaurants
CO_2e - Carbon dioxide - e for equivalent, in terms of GWP
EC - European Commission
ELV - End-of-life vehicles
EMPAP - EPR for Household Packaging and Graphic Papers
EPR - Extended producer responsibility (system)
EU - European Union
EU-ETS - EU-Emissions Trading System
GHG - Greenhouse gases
GWP - Global warming power
H_2 - Dihydrogen (also commonly known as hydrogen)
J - Joules. GJ (10^9)
LCV/GCV - Lower/Gross calorific value
LEB - Low Energy Consumption Building (Certification)
LETC - Large-scale Electrification and other Technological Challenges (scenario)
MEUR - Millions of euros
Mt - Millions of tons
NNTL - No Net Land Take (Act)
NOx - Nitrogen oxides
OPEX - Operating expenses
PPE - France's Multi-annual energy plan
PPWR - Packaging and Packaging Waste Regulation
R&D - Research and development
RER - Reuse, Eco-design & Relocation (scenario)
RTE - Electricity transmission network (operator)
SNBC - French National Low-Carbon Strategy
STP - Sectoral Transition Plan
TRL - Technology Readiness Level Technological maturity scale (1 to 9)
UNFCCC - United Nations Framework Convention on Climate Change
W - Watt MW (10^6); GW (10^9)
Wh - Watt-hour MWh (10^6); GWh (10^9); TWh (10^{12})

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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EXPERTISES

GLASS
Summary report

The glass industry, which is vital to a number of sectors including packaging, construction and transport, needs to transform if it is to meet the target of reducing the carbon footprint of French industry by 81% by 2050 compared to 2015, as part of the French National Low-Carbon Strategy (SNBC). The glass manufacturing process, which is energy-intensive and dependent on fossil resources and carbonated raw materials, generates a significant proportion of French industrial greenhouse gas emissions (3%).

With the acceleration of the ecological transition, this industry must work to deploy the solutions necessary to reduce its emissions, while at the same time maintaining its competitiveness. The glass sector has a number of effective levers available to enable a successful transition, including increased recycling, improved manufacturing processes, electrification of melting furnaces, eco-design and reuse of glass products. These major changes are all the more ambitious in a context of evolving demand due to the need for energy-efficient renovation of buildings and transition in the packaging sector.

This Sectoral Transition Plan presents two scenarios that illustrate the transition challenges and explore the conditions for ambitious decarbonisation of the glass industry.

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 their supervisors 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 choices.

The consortium, coordinated by the French Agency for Ecological Transition, also includes the French Ministry for Ecological Transition, 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

With the contribution of the European Union LIFE programme. The European Commission is not responsible for any use made of the information contained in this work.

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