GIFFT

Sustainable Glass Industry

Policy guidelines and regional action plans

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1 Introduction

The overall objective of GIFFT is to develop a sustainable, hybrid, and biofuel flexible heat production technology and process that can be integrated into industrial glass manufacturing through efficient use of plasma-assisted combustion and gasification systems.

The GIFFT technology and process constitute a complete rethinking of how hybrid process heat should be produced in an energy-intense industry, and how the use of green electricity and hydrogen energy can be combined with effective utilization of biomass residues. The novel and ground-breaking approach of GIFFT is to combine sustainable, hybrid and biofuel flexible heat production technology in an existing industrial glass manufacture process through efficient use of plasma-assisted combustion and gasification systems, thus relying on existing assets instead of heavy new investments that are required by conventional hybrid or all electrical furnaces.

The **European Green Deal** aims for climate neutral policies across Europe by 2050. The **Fit for 55 package** provides a concrete plan to put the European economy firmly on track, with the **REPowerEU Plan** accelerating the move away from fossil fuels. Alongside the **Circular Economy Action Plan**, this sets the framework for the transformation of the EU's industry for the net-zero age[1].

In 2024 the revised **Industrial Emissions Directive (IED)** officially came into effect. This Directive, a key component of the EU's environmental policy, aims to reduce pollution from large industrial installations across Europe. The revised directive sets out stricter emission limits to air, water, and soil from industrial processes. For the glass industry, this includes emissions from furnaces, where significant NO_x and SO_2 levels are generated during melting processes. The IED plays an important role in aligning the glass industry with the EU's Green Deal and Fit for 55 package, pushing towards net-zero emissions by 2050.

Energy-intensive sectors such as the glass industry will have to be decarbonized in less than three decades. As a result, there is a **clear need for new ground-breaking R&I solutions in Europe that can enable transition** towards the low-carbon and efficient glass industry.

Glass manufacturing is an energy-intensive process, where up to 75% of energy is used for raw material melting. Glass production typically utilizes various energy sources for different processes. The glass industry needs energy diversification. It uses primary and secondary energy sources, which rely on the consumption of traditional fossil fuels. The choice of energy source depends on factors such as the type of glass produced, furnace design, environmental regulations, and the cost and availability of energy resources in a specific region.[2] Energy demand and emissions in the glass sector are mainly associated with the glass melt furnace, which operates at up to 1600°C. Modern furnaces are predominantly fired by natural gas and charged with raw materials including sand mixed with lesser amounts of sodium carbonate, limestone and dolomite.[3] **The key to decarbonization in the EU glass industry is based on the change of energy sources for the provision of thermal energy through electricity and green gases (hydrogen, biogas, synthetic methane).**

The national energy and climate plans (NECPs) were introduced by the Regulation on the governance of the energy union and climate action (EU)2018/1999, agreed as part of the Clean energy for all Europeans package which was adopted in 2019. They include steps for decarbonization, energy efficiency, energy security, internal energy market research, innovation and competitiveness.[4] All member states have to submit a progress report every two years and provide necessary information.

[1] A Green Deal Industrial Plan eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0062

[2] GIFFT report, N. Striugas, A. Jancauskas Alternative gas production and their integration into glass industry D2.2_Alternative-Gas-Production-and-Their-Integration-into-Glass-Industry_Final_07.04-1-.pdf

[3] P.W. Griffin et al. Industrial energy use and decarbonization in the glass sector: a UK perspective (PDF) Industrial Energy Use and Decarbonisation in the Glass Sector: A UK Perspective

[4] NECPs National energy and climate plans

The European Commission monitors the progress towards achieving the targets set for all members states.

The decarbonization pathway relies on innovative solutions and R&D. Cross sectoral R&D is required for further emissions' savings. The glass sector has already identified R&D efforts needed for the transition: (1) the electrification of large-size furnaces with melting temperature above 1 000°C, (2) R&D in process emissions which cannot be reduced solely by energy-efficiency measures or energy switch, (3) R&D in heat transfer for large-size furnaces and for alternative carbon-neutral fuels, (4) R&D to investigate the possibility of carbon capture and storage (CCS), and carbon and capture utilization (CCU) on site.[5] To maintain the competitiveness of the glass industry in the transition phase it is crucial to ensure needed **framework conditions** for glass industry in terms of infrastructure, circular economy, competitiveness.

This document specifically focuses on the **development of policy guidelines and reginal action plans focused on technological, social and environmental affairs of the GIFFT technology.** The action plans and guidelines will take advantage of the project results, encouraging the reception and implementation of the developed flexible furnace by interested parties and communities.

The first issue of the report summarizes strategic directions of four GIFFT target countries (Lithuania, Germany, Sweden and UK) foreseen for energy intensive industries based on National energy and climate action plans (NECPs) and other relevant strategic documents on the national level. The upcoming versions will include concrete action plans and recommendations. The second version will be issued in September 2025. The final version of the report will be issued at the end of the project in September 2027.

[5] Position paper, Glass Alliance 2021-05-05-gae-position-paper-on-decarbonisation-v2_file.pdf

2 Lithuania

2.1 Current strategic policy framework

Several strategic documents create pathway towards carbon neutral industry in Lithuania:

- National energy and climate plan (NECP) of Lithuania (in October 2024 the updated national energy and climate plan (NECP) of Lithuania was published [6])
- National Energy Independence Strategy (updated in June 2024)

National energy and climate plan is closely linked to National Energy Independence Strategy[7]. The Strategy establishes the vision of Lithuanian energy sector as well as defines strategic directions, objectives and tasks. The vision for 2050 is a self-consumption and exporting country with a climate neutral and high-added energy industry. [8]

In addition, Lithuania established a collaborative research and development agreement between the Lithuanian Energy Agency and the U.S. Department of Energy's National Renewable Energy Laboratory. The agreement aims to identify 100% renewable energy pathways for Lithuania's power system. Cooperation is foreseen until 2027.

Lithuania's strategy for achieving a carbon-neutral industrial sector, as outlined in its **National Energy and Climate Plan (NECP)**, integrates several key elements.

1. **Transition to a climate-neutral economy**. It encourages the use of circular economy practices and industrial symbiosis, promotes innovative decarbonization technologies, including green hydrogen, CCUS (carbon capture, utilization and storage), and renewable electricity as well as plans to electrify processes currently dependent on fossil fuels.
2. **Industrial energy efficiency**. The focus is placed on reducing energy consumption through the adoption of innovative tools and advanced technologies. Strategies include decarbonizing energy sources as well as improving energy efficiency.
3. **Support for green technology innovation**. Lithuania aims to strengthen its green manufacturing capacity and enhance participation in the EU's clean technology value chain. Investment in climate-tech start-ups and research into sustainable industrial practices is prioritized.
4. **Policy framework.** Lithuania integrates climate-neutral targets into national legislation and strategic documents, such as the National Climate Change Management Policy Strategy and the Net-Zero Industry Act. Stakeholder cooperation including participation in EU-funded projects and initiatives is highlighted.
5. **Green hydrogen development**. Green hydrogen will be a key solution for decarbonization.

The National Energy Independence Strategy (NENS) of Lithuania formulates steps towards decarbonizing energy-intensive industries, with a strong focus on achieving climate neutrality by 2050. The key objectives of energy intensive industry decarbonization are:

1. **Transition to renewable energy sources (RES).** By 2030, 55% of total energy consumption is to come from renewables.
2. **Enhancing energy efficiency.** Promotion of energy-saving technologies and digitization to improve industrial energy efficiency.
3. **Green technology deployment:** Industries are encouraged to shift to low-carbon technologies, such as carbon capture, utilization, and storage (CCUS). In addition, integration of digital twin technologies and artificial intelligence to optimize processes and reduce energy intensity is mentioned.

[6] NECP, Lithuana Lithuania - Final updated NECP 2021-2030 (submitted in 2024) - European Commission
[7] National Energy Independence Strategy National_energy_independence_strategy_2018(1).pdf
[8] 100% Renewable energy study The Lithuania 100% Renewable Energy Study | International Activities | NREL

4. **Investments in innovation and competitiveness.** Financial support for research and development.

The target for energy intensive industries is until 2030 is 30% reduction in greenhouse gas (GHG) emissions compared to 2005 levels. Full climate neutrality in energy-intensive industries with zero-emission energy sources and innovative low-carbon technologies shall be reached by 2050.

2.2 Energy context

In response to sanctions imposed by EU Member States, the Russian Federation started to restrict natural gas supplies and decided to unilaterally change the terms of previous contracts by requiring payment in roubles for the supply of natural gas. The latter condition resulted in the Republic of Lithuania refusing to import pipeline natural gas from the Russian Federation since April 2022. Since July 2022 the import of Russian natural gas into Lithuania, as well as the import of liquefied natural gas through the Klaipeda Liquefied Natural Gas (LNG) terminal, have been banned. As a result, Lithuania completely renounced natural gas imports from the Russian Federation in 2022.[9]

In 2023, imports of natural gas amounted to 38 175 GWh, which was 6.9 % lower than in 2022 (41 006 GWh). In 2023, sales in the natural gas sector decreased by 31.91 % compared to 2022, from 35 523 GWh to 24 188 GWh. According to National Energy Independence Strategy (updated in June 2024) electricity consumption is estimated to increase more than 6-fold by 2050, from the current demand of 12 TWh to a projected 74 TWh. The largest share of the growth will come from **synthetic gas** production (35.5 TWh), industrial consumption (12.6 TWh), transport consumption (6.3 TWh), and the heat sector (3.4 TWh).

CO_2- based synthetic green fuels could become an important economic and environmental element to diversify energy sources and reduce dependence on fossil fuels. At present, it is not yet clear on the market which synthetic green fuels will be the most in demand and which specific green fuels will be needed in the future. The development of green fuels is influenced by various factors, such as market trends, fuel production costs, competition with other alternative fuels and advances in scientific innovation. Other hydrogen derivatives, such as ammonia, may also be produced in Lithuania, which can contribute both to national decarbonization objectives and to the export of energy products. Lithuania will aim to produce at least 2 TWh of hydrogen derivatives in2030, i.e. synthetic green fuels (the production of which would require around 0.4 million tons of biogenic CO_2), and at least 9 TWh in2050. It is likely that about one third can be used locally.

2.3 Environmental context

Lithuania provides fossil fuel and other environmentally harmful subsidies that could be considered for reform, while ensuring food and energy security and mitigating social consequences. Fossil fuel subsidies amounted to 198 million EUR in2021, leaving low- carbon alternatives without demand and support. In addition, fossil fuel dependency could be reduced by shifting to biogases[10]. In terms of tax policies, Lithuania is lagging behind EU countries as there is no annual pollution tax introduced yet.

2.4 Fostering science and innovation

Innovation by Lithuanian businesses is slowly progressing, but science-business linkages remain weak. By 2030, Lithuania will aim to invest EUR 10 million of public funds in clean energy research and innovation.[11]

Most of the expenditure in R&D comes from public funding, however, R&D intensity remains well below the government target of 1.5% of GDP for 2024. Lithuania currently does not have a credible plan for ensuring the sustainability of more investment in research and innovation beyond the RRP. Human resources are still lacking. Innovation by Lithuanian businesses is slowly progressing, but

[9] NECP, Lithuana Lithuania - Final updated NECP 2021-2030 (submitted in 2024) - European Commission
[10] European Commission, Country Report – Lithuania – 2023 LT_SWD_2023_615_en.pdf
[11] European Commission, Country Report – Lithuania – 2023 LT_SWD_2023_615_en.pdf

science-business linkages remain weak. In addition, insufficient public funding, a fragmented research and innovation (R&I) landscape and unattractive research careers have led to below the EU average science results.

The following **weaknesses** were identified in the NECP:

1. Low innovation capacity of SMEs;
2. Low level of internationalization of business and science (participation in transnational projects, networks);
3. Low -value-added enterprises and low ratio of business investment in research and experimental development and innovation relative to GDP.

The following steps were identified to **overcome the challenges**:

1. Strengthen research and innovation capacities by creating an enabling environment and conditions and developing the necessary skills and competences;
2. Develop and apply a high level of scientific knowledge, advanced technologies and innovation for the market uptake of new and sustainable technologies, products, processes, methods;
3. Promote active international cooperation and involvement in the creation and development of international value chains among actors in the R & I priority ecosystem.
4. Need for stronger cooperation between government, industry and financial institutions.

2.5 Industrial context

The National Energy and Climate Plan provides general goals for industry. Innovative RES technologies should represent at least 5% of newly installed renewable energy capacity, however this target is indicative. To encourage industry to become climate neutral industry needs to transform its technologies, products, services and processes. The reduction of import dependency and increase of resilience to crisis is highlighted in strategic documents. The European Commission's "2023 Country Report -Lithuania"[12] states that Lithuania's industrial sector and workforce are more resource- and energy-intensive than the EU average. Therefore**,** industrial transformation should focus on global sustainable development goals by promoting investment in research and technologies that reduce environmental pollution, improve resource efficiency and develop green products. Moving toward sustainable economic development based on scientific knowledge, cutting edge technologies, innovation and increasing the country's international competitiveness.

2.6 Alternative fuels in the industrial and industrial processes sector until 2030

Energy intensive industries are specifically mentioned in the NECP. The historically inherited structure of Lithuania's manufacturing industry is dominated by labour-intensive, resource- and energy-intensive technologies compared to the EU average. The industrial sector is highly dependent on natural gas. Industrial transformation will include reduced demand for carbon-intensive products through incentives. The use of renewable energy sources in industry should be increased.

According to the 2022 National GHG inventory, the industry sector is responsible for 12 % of total GHG emissions per year. The NECP clearly states that "the transformation to a climate-neutral industry has a multifaceted impact and is itself affected interlinked social, economic, legal, political, geographical, technological and other dimensions. Both in Lithuania and in any other country, a climate-neutral industry would have a clear positive environmental impact in terms of reducing and air pollution. This can also be a significant competitive strength of local industries, creating new jobs, markets, efficient use of raw materials and reducing dependence on external raw materials suppliers, etc.". However, the transition implies potential negative impacts and costs which are localized, therefore a **green industrial transformation strategy must be based on technological progress and related economic analysis**.

[12] European Commission, Country Report – Lithuania – 2023 LT_SWD_2023_615_en.pdf

Authorities coordinating the implementation of GHG reduction targets are the Ministry of Economy and Innovation and the Ministry of Environment. The obligations for industry related to the transition towards climate neutrality are set out in the strategic documents of the Republic of Lithuania:

1. The Law on Energy Efficiency Improvement. It foresees that the Ministry of the Economy and Innovation of the Republic of Lithuania is responsible for the implementation of energy efficiency improvement measures in the industrial sector to achieve an amount of at least 5 456 GWh.
2. The Law on Energy from Renewable Sources (2011).

2.7 SWOT analysis of the strategic framework for energy-intensive industries in Lithuania

Table 3: SWOT analysis, Lithuania, strategic framework conditions

STRENGTHS (INTERNAL) • **Defined targets are ambitious** (a clear goal to achieve climate neutrality by 2050; 55% RES in final energy consumption by 2030) • Elaboration of **supportive policies** (alignment to EU goals; financial incentives foreseen for green technologies) • **Renewable energy potential** (strategic focus on green hydrogen) • Emphasis on **circular economy** practices • **Energy security** (diversification of energy sources and the reduction of dependence on fossil fuels; infrastructure development for RES)	**W**EAKNESSES (INTERNAL) • **Limited financial resources** for large-scale projects and **high initial costs** for modernizing energy intensive industries (e.g. implementing innovative technologies) • Limited availability of **skilled professionals** to implement advanced technologies
OPPORTUNITIES (EXTERNAL) • **EU funding and new cooperations for joint efforts** (EU funding: Horizon Europe, LIFE, Innovation Fund) • Development of **flagship projects** in hydrogen and biofuels to attract international investment	**T**HREATS (EXTERNAL) • **Economic uncertainty** • **Geopolitical tensions** • **Readiness of industries** to adopt new technologies and practices

3 Germany

3.1 Current strategic policy framework

Germany's national climate goal is to reduce the greenhouse gas emissions by at least 65% by 2030 compared to 1990, at least 88% by 2040, and reach GHG neutrality by 2045. The industry sector will make a significant contribution to achieve this target. Glass industry is one of the most energy-intensive manufacturing sectors in Germany. German glass industry is Europe's largest glass industry and the fourth largest glass industry globally. Around 55 000 individuals are employed in the sector.[13] The Federal Association of the German Glass Industry (BV Glas) is the central organization representing policy interests of around 80% of German glass manufacturing companies.

In terms of renewable energy, **National energy and climate plan (NECP)** indicates the target to increase the share of RES in gross final energy consumption in 2030 to at least 41%.[14] In addition, **National Hydrogen Strategy**[15] is a key element of the decarbonization strategy which will be established as an important decarbonization option. In the strategy the Federal Government clearly indicates that only green hydrogen is sustainable in the long term.

The transition of an entire industry towards climate neutrality involves significant challenges as the final energy demand of the glass industry is covered approximately 80% by natural gas. Therefore, the glass industry requires a shift to technologies and processes that have mostly not been tested on an industrial scale. The National energy and climate plan (NECP) mentions **funding program for the "Decarbonization in industry"** (from 2024 Federal funding for industry and climate action). The main goal is to fund investments to cut process-related emissions in the field of emission-intensive industries. Projects should implement application-oriented R&D actions, commercial-scale trials and broad-based market launch of mature or new technologies.[16]

3.2 Fostering science and innovation

National energy and climate plan (NECP) highlights the importance of maintaining competitiveness for industry and preserving jobs in Germany. Therefore research, innovation and competitiveness are supported by the following key strategies and measures:

- 7th Energy Research Program – Innovations for the Energy Transition
- 8th Energy Research Program for Applied Energy Research
- Improved integration of start-ups. Activating the innovation potential of small and medium-sized enterprises and young companies is particularly important.
- Real-world laboratories for the energy transition and increased technology transfer
- Stepping up international cooperation
- Cross-system issues (e.g. sector coupling, digitalisation)
- Future strategy for research and innovation

3.3 Glass industry decarbonization roadmap: Glass 2045

In 2021 the German Glass Association assigned IER Institute of Energy Economics and Rational Energy Use[17] to develop a roadmap for the German glass industry, showing different decarbonization paths of the glass industry to reach GHG neutrality until 2045. This chapter summarizes the proposed pathway for glass industry in Germany.

[13] The Federal Association of the German Glass Industry (BV Glas) Annual Report BV GLAS
[14] NECP – Germany – Update 2024 Update of the Integrated National Energy and Climate Plan
[15] The National Hydrogen Strategy Nationales Reformprogramm 2020
[16] Decarbonisation in industry program Dekarbonisierung in der Industrie | Kompetenzzentrum Klimaschutz in energieintensiven Industrien (KEI)
[17] Glass 20245 Roadmap for a greenhouse gas neutral glass industry | IER Institute of Energy Economics and Rational Energy Use | University of Stuttgart

The production of glass in Germany produces approximately 4 million tons of CO_2 per year, which is mainly attributed to the firing of the melting tanks with natural gas and the process-related emissions from the chemical reactions of the raw materials used. **The required significant reduction in CO_2 emissions can only be achieved by transitioning manufacturing processes to innovative and CO_2-neutral melting methods.**

Decarbonization can be successful if the economic impact of implementing decarbonized melting processes does not negatively affect the competitiveness of the glass industry in Germany. Investments in innovative and CO2-neutral melting methods, which involve a fundamental restructuring and replacement of the current plant infrastructure, must not lead to competitive disadvantages in the short and medium term. The burdens of significantly higher costs associated with these new technologies should be balanced. This also applies to increased operating costs resulting from the use of energy carriers such as electricity and hydrogen, which are currently much more expensive than natural gas, but emissions-free. International competition in glass manufacturing should be also considered.

The roadmap provides four scenarios with different energy focuses (Table 4):

1. **Reference scenario**: no significant changes compared to the current state of the art in glass plants are assumed. This scenario serves as a baseline for comparison in analyzing the alternative development pathways, for which changes in energy consumption, CO_2 emissions, and costs were calculated relative to the reference scenario.
2. Two extreme scenarios: **electrification and hydrogen**, focusing on technologies utilizing electricity and hydrogen.
3. The **"hybrid scenario"** represents a medium transformation pathway, where no external focus on a specific energy carrier or technology was defined, allowing all considered decarbonization measures to be applied.

By 2045, the technologies currently in operation will be fully replaced by hybrid furnaces, super-hybrid furnaces, and fully electric melting furnaces. In the hybrid and super-hybrid furnaces, hydrogen will be used as a gaseous energy carrier by 2045 at the latest, reducing energy-related CO2 emissions in glass production to zero. As a result of replacing conventional melting furnaces with CO2-neutral melting technologies, natural gas consumption will be entirely substituted by the green energy carriers (electricity and hydrogen) by 2045. Depending on the scenario, electricity demand will rise to 15.5–31.3 PJ, and hydrogen demand to 2.8–28.4 PJ per year. The use of electricity and hydrogen as energy carriers will eliminate all energy-related CO2 emissions. By 2045, only process-related CO2 emissions of 780,000 tons per year will remain, due to a lack of alternatives for raw materials. Avoiding process-related emissions would require infrastructures for CO2 transport and storage, which will not be available at most glass plants by 2045. Therefore, a complete decarbonization of the glass industry by 2045 will not be achieved, but a reduction in CO2 emissions by 79% is possible.

The roadmap indicates the calculation of costs for the conversion of production processes in the glass industry to CO_2-free energy sources. **To retrofit the current equipment base of the glass industry with hybrid and fully electric melting furnaces, and to adapt energy infrastructures, investments of €3.2–5.6 billion will be required by 2045.** This investment sum exceeds the costs in the reference scenario by a factor of 2 to 3.5. The lower limit of €3.2 billion represents the investment requirement in the hydrogen scenario, which is attributed to the significantly lower effort needed to convert the melting furnaces and surrounding energy infrastructure by adapting existing gas pipelines. However, implementation is uncertain due to the unpredictable availability of hydrogen.

In addition to technological challenges, implementing transformation paths also poses economic and regulatory challenges for companies in the glass industry. The legally mandated goal of climate neutrality by 2045 is a clear target. To achieve this climate goal, appropriate framework conditions should be established to enable the transformation and prevent relocation or shutdown of operations. This applies to financial aspects and in particular to the expansion of the energy infrastructures required to provide CO2-neutral energy sources. These must be used in sufficient

quantities and at competitive prices. The decarbonization of glass production will lead to an increase in specific production costs. Additional operational costs could be softened through climate protection contracts or investment support for the implementation of decarbonization measures. This would decrease the financial burden on companies and help them overcome the challenges of decarbonization.

Table 4: Key findings of four scenarios for 2045

Transformation path	**Reference scenario**	**Electrification**	**Hydrogen**	**Hybrid scenario**
Number of Furnaces				
Conventional	115	0	0	0
Electric	7	108	0	36
Hybrid (H_2)	0	1	21	7
Super-Hybrid (H_2)	0	13	96	79
Energy Consumption [PJ/a]				
Natural Gas	43.3	0.0	0.0	0.0
Hydrogen	0.0	2.8	28.4	8.7
Electricity	7.0	31.3	15.5	30.0
Total	50.3	34.1	43.9	38.7
$CO_{2\,e}$missions [Million t/a]				
Energy-Related	2.4	0.0	0.0	0.0
Process-Related	0.8	0.8	0.8	0.8
Cumulative Investments [Billion €]	1.6	5.6	3.2	4.9

The results of this roadmap are available to glass companies as well as decision-makers as an orientation in the planning and design of the upcoming decarbonization of the glass industry to help in the decision-making process. The transformation process is linked to industrial, technical, economic and social factors, which are explained in the next chapter.

3.4 Challenges

The roadmap Glass 2045 mentions different challenges for the glass industry in Germany, which are described in this chapter.

Industrial challenge

Decarbonization of the glass industry requires a change from established production technologies to technologies and production processes that have not yet been tested on an industrial scale. The glass sector must therefore organize the transition during ongoing operations as well as test and implement innovative technologies. In addition, the glass industry is currently heavily dependent on natural gas.

The time frame for decision-making and implementation of decarbonization pathway should be also considered. The typical re-investment cycles for furnaces, the most important part of glass production, are between 12 and 15 years. This means that for a possible decarbonization by 2045 in some areas, there are just one or two windows of opportunity for change in technology. The timeframe for converting to a new technology from the decision-making phase to commissioning can take between 5 and 7 years. These two restrictions show that glass manufacturers must prepare and make decisions on the technological realignment of their plants by the end of this decade at the latest to be able to implement decarbonization.

Technical challenge

One of the possible measures for decarbonization is the electrification of melting furnaces. This would fundamentally transform the current melting concept from combustion-based to electric heat production. This technological shift would have process-related impacts. Additionally, the energy supply in subsequent process steps would also change, as the waste heat from combustion-based melting furnaces is utilized across processes. With the elimination of exhaust gas streams from combustion, electric melting furnaces generate significantly less usable waste heat. The absence of these waste heat quantities from the melting process results in an increased demand for external energy supply in the remaining process steps.

Even if the energy supply for glass production is fully decarbonized, the glass industry, like a few other industrial sectors (e.g., cement and lime), will still generate process-related CO_2 emissions. These emissions are produced in the melting furnaces through the reaction of the carbonates used. Process-related emissions can account for 20% (average for container glass) to 30% (average for flat glass) of total emissions. These process-related CO_2 emissions are difficult to avoid because the transformation products of the carbonates are essential for the chemical and physical properties of glass products. Currently, there are no alternative raw materials to replace the carbonates in use, meaning their substitution for full decarbonization of the glass sector is not foreseeable currently.

Economic challenges

To decarbonize the glass industry, current production facilities must be replaced with CO_2 neutral ones. As these involve innovative and research-intensive technologies, the associated investments will be significantly higher than those for comparable conventional facilities. In addition, adjustments to the energy infrastructure are required to operate with green energy carriers, leading to further investments in energy infrastructure. This will pose financial challenges, particularly for small and medium-sized enterprises (SMEs) as well as corporations with multiple sites.

The use of more expensive green energy carriers, such as electricity and hydrogen, will result in a significant increase in specific production costs. These operational cost increases will create a competitive disadvantage compared to international competitors, who can produce their products under different conditions.

Societal challenges

For the successful decarbonization of the glass industry, companies shall overcome both technical and economic barriers. Whether this can be achieved also depends on the society in Germany and the societal importance placed on climate protection. The green energy carriers essential for decarbonization - electricity and hydrogen - must be available in sufficient quantities and at all times of the year. When considering the projected demand for electricity and hydrogen from other sectors in Germany, it becomes clear that renewable energy expansion in Germany and Europe must increase significantly. Additionally, these green energy carriers must be able to reach the respective glass plants, requiring significant expansion of upstream electricity grids and the establishment of a comprehensive hydrogen network. Societal acceptance of the industrial transformation in Germany is therefore crucial for the successful transition of the glass industry towards greenhouse gas neutrality.

Political action options

Table 5 summarises political actions defined in the Glass 2045 Roadmap.

Table 5: Political action options

Framework conditions	Financial Support	Glass Products
Energy System: Provision of sufficient renewable energy carriers **CO_2 pricing:** Expansion of the EU ETS **Infrastructure:** Expansion of the energy infrastructure **Approval Processes:** Accelerated procedures for approval and implementation	**Climate protection agreements:** Compensation for operational additional costs **Investment Support:** Subsidies for investments in retrofitting and grid connection	**Circular Economy**: Increase in recycling rates **Green lead market** Creation of a market for green products

4 UK

The decarbonisation of the UK's glass industry is defined in several strategic documents. Comprehensive strategies have been developed to guide the industry in the decarbonisation pathway for reducing CO_2 emissions while maintaining industrial competitiveness. This chapter provides insights into available strategic documents.

4.1 Energy policy context

In 2015 a report **"Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050 - Glass"** outlined a strategy for reducing carbon emissions and increasing energy efficiency within the UK glass industry. It is emphasized that a long-term energy and climate change policy is key to investor confidence. In addition, there is a need for incentive schemes to become long-term commitments, as changes in policy can be damaging, particularly when the business case for investment is marginal and is highly dependent upon factors such as (fluctuating) energy related costs.[18] Options identified in the roadmap require development of new technologies and processes. Research and demonstration of new technologies was identified as an important enabler for decarbonization. The report identified actions for fuel and feedstock availability including biomass (e.g. investigating the use of on-site generated biogas or biomethane as a fuel substitution option for glass melting, space availability for biomass gasification units or air separation units at manufacturing sites should be considered when identifying suitable sites for locating/relocating glass making facilities). It highlights that there is a necessity to overcome barriers to biogas, biomethane, syngas and hydrogen, such as knowledge gaps around their technical suitability for glass melting.

In 2017 the **"Glass Sector Industrial Decarbonization and Energy Efficiency Action Plan"** was published. It provides a comprehensive strategy for reducing carbon emissions and improving energy efficiency within the UK glass industry. It provides an action plan for the glass industry. The action plan is divided into ten key areas:[19]

[18] Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050 – Glass Glass_Report.pdf
[19] Action plan Glass sector: industrial decarbonisation and energy efficiency action plan

1. **Leadership development**: establishing a leadership group to oversee decarbonization efforts, coordinate between stakeholders, and promote best practices across the sector.
2. **Government-industry collaboration**: strengthening partnerships between British Glass, the government, and other stakeholders to ensure policies align with industry needs and facilitate decarbonization.
3. **Enhanced recycling**: increasing the recycling of glass to reduce raw material usage and energy demands, while collaborating with local authorities to streamline collection and improve recycling rates.
4. **Energy-efficient technologies**: encouraging the adoption of advanced energy-efficiency technologies and practices, supported by knowledge-sharing mechanisms.
5. **Low-carbon energy sources**: exploring the feasibility of switching to low-carbon fuels such as hydrogen and biogas and increasing reliance on renewable energy.
6. **Market for low-carbon products**: creating demand for low-carbon glass products by addressing market barriers and raising awareness of their environmental benefits.
7. **Supply chain engagement**: enhancing collaboration across the glass supply chain to identify decarbonization opportunities and implement innovative solutions.
8. **Financial optimization**: improving access to public and private financing options to support energy-efficiency investments and decarbonization technologies.
9. **Skills development**: building a skilled workforce equipped to implement and manage new technologies and decarbonization strategies.
10. **Research and Innovation**: increasing investment in research and development, establish a demonstration facility for testing innovative technologies.

In 2019, the UK has legally committed to achieve **net zero greenhouse gas emissions by 2050** through the Climate Change Act 2008 (2050 Target Amendment) Order. The **Net Zero Strategy** was published in 2021.[20] The key policies relevant for the glass industry in the Net Zero Strategy are as follows:

- **Industrial Decarbonization and Hydrogen Revenue Support (IDHRS) scheme**, which provides funding for industrial carbon capture and low-carbon hydrogen production models
- **The £315 million Industrial Energy Transformation Fund (IETF)**, aimed at supporting industries to reduce emissions and improve energy efficiency
- Commitment to **establishing four carbon capture, usage, and storage (CCUS) clusters by 2030**, targeting emissions reduction in **industrial hubs**
- Support for low-carbon fuel alternatives, including the production and integration of **green hydrogen and biogas in industrial processes**
- Implementation of a **net-zero-aligned UK Emissions Trading Scheme (UK ETS)** to incentivize industries to **adopt cleaner technologies**
- **Promotion of innovation** through the Net Zero Innovation Portfolio, providing £1.5 billion to develop and **commercialize new low-carbon technologies**
- **Support for waste reduction and recycling initiatives** as part of the circular economy strategy, which directly aligns with **glass recycling efforts**
- Investment in skills development and workforce training to prepare industries for a low-carbon future, including **green skills initiatives for industrial workers**

These policies provide a framework for the glass industry to align with the UK's net zero targets. The strategy also mentions the role of innovation which is more than developing new technologies. It also includes new business models, financing approaches and regulatory framework. In the UK The Glass Futures project is a collaborative initiative focused on decarbonizing the glass industry by developing and implementing sustainable manufacturing solutions. An important project in the UK is **Glass Futures**, which aims to position the UK as a leader in sustainable glass manufacturing, setting a global benchmark for decarbonization in energy-intensive industries. It operates as a non-profit organization, bringing together stakeholders in the glass industry: manufacturers, academia, and government agencies. Glass Futures and ENCIRC **pilot project** showcased that new bottles can be made from

[20] Net Zero Strategy, UK net-zero-strategy-beis.pdf

recycled glass by using energy only from burning low carbon biofuels. Biofuels from waste organic materials are renewable and sustainable.[21]

4.2 Glass sector Net Zero Strategy 2050

The Glass Net Zero Strategy Update[22] (November 2024) provides an assessment of the progress made by the UK glass manufacturing industry since the publication of its Net Zero Strategy 2050 in 2021. The sector is in the process of decarbonization, but it is heavily dependent on government policy, infrastructure support, and investment incentives. The strategy states that fuel switching to electricity, hydrogen, and biomethane remains the primary pathway to decarbonization. The remaining barriers are high electricity costs, uncertainty in hydrogen infrastructure, and inadequate recycling policies affecting the availability of recycled glass (cullet). Glass manufacturers have benefited from Industrial Energy Transformation Fund (IETF) grants, however broader financial support and policy clarity are still required. In addition, the **strategy calls for clear and long-term policy frameworks, competitive energy pricing, and investment in infrastructure to enable the transition to net zero.** Table 6 summarizes different decarbonization pathways foreseen in the roadmap, Table 7 highlights strengths, weaknesses, opportunities and threats for the glass industry in the UK. Supportive energy policies are crucial to implement the decarbonization pathway.

Table 6: Decarbonization pathways according to the Net Zero Strategy 2050

Pathway	Description	CO_2 reduction
Switch to electricity	Transition from natural gas to electricity by upgrading furnaces and securing competitive electricity prices.	-0.343 tCO_2/t
Switch to hydrogen	Gradual replacement of natural gas with hydrogen, starting with blends and moving to full hydrogen where electrification is not possible.	-0.054 tCO_2/t
Switch to biomethane	Using biomethane as a low-carbon alternative to natural gas.	Varies by region
Increased cullet use	Boosting the availability and use of recycled glass to reduce process emissions and energy requirements.	-0.016 tCO_2/t
Use of calcined and alternative raw materials	Replacing some carbonate raw materials with alternatives to reduce process emissions.	-0.013 tCO_2/t
Carbon Capture Storage (CCS)	Implementing CCS for larger furnaces to capture CO2 emissions, especially in industrial clusters.	-0.045 tCO_2/t
Grid decarbonisation	Reducing the carbon intensity of the electricity grid through increased use of renewable energy and negative emissions technology.	-0.198 tCO_2/t

[21] ENCIRC project World's most sustainable glass bottles created in ground-breaking biofuel trial - Encirc
[22] Net Zero Strategy, 2024 Update British Glass - Net zero strategy update Nov 2024_0.pdf

Table 7: SWOT based on the Net Zero Strategy 2050

STRENGTHS (INTERNAL)	WEAKNESSES (INTERNAL)
• **Strong commitment** from the UK glass sector to decarbonization • **Ongoing investment** in electrification, hydrogen, and biomethane as alternative fuels • **Support** from the Industrial Energy Transformation Fund (IETF) for innovation • **Rising consumer and industry demand** for sustainable, low-carbon glass products.	• High **electricity costs** limit the feasibility of electrification • **Uncertainty on hydrogen infrastructure** and its commercial viability • Limited **government support** for operational costs of decarbonisation • **Long investment cycles** for furnaces slow down industry-wide adoption of new technologies
OPPORTUNITIES (EXTERNAL)	**THREATS (EXTERNAL)**
• Potential for **favorable policy reforms** to reduce energy costs and improve infrastructure • Expansion of **biomethane use** • Growing **demand for low-carbon products**, opening new markets • **Export potential** for sustainable glass manufacturing technologies and products	• Lack of **long-term policy certainty**, affecting investment • Rising **competition from imported** glass produced at lower costs • **Volatile energy prices**, reducing financial ability for decarbonisation investments • **Infrastructure constraints** and slow adoption of grid improvements

5 Sweden

5.1 Energy policy context

Sweden adopted the **Climate Act** in 2017, and it entered into force in January 2018. The long-term target for Sweden is zero net greenhouse gas emissions by 2045 at the latest.[23] After 2045 Sweden plans to achieve negative net emissions. In contract to Germany and UK, Sweden has no dedicated national roadmap to decarbonise its glass industry, but it aligns its policies with broader national and European goals.

In 2016, Sweden launched the **initiative 'Fossil Free Sweden'**.[24] It aims to support the transition towards fossil free welfare by building a strong industrial sector, creating more jobs and export opportunities by going fossil free. It brings together 500 stakeholders from business, public sector and civil society. In total 22 roadmaps were developed to reach the climate goals. In addition, 5 strategies were elaborated on the following topics and work on a CCS/bio-CCS strategy was also launched in 2023:

1. Sustainable Battery Value Chain Strategy (Strategy for a sustainable battery value chain - Fossilfritt Sverige)
2. Hydrogen Strategy (Hydrogen_strategy_for-_fossil_free_competitiveness_ENG.pdf)
3. Biostrategy (Bio-strategy - Fossilfritt Sverige)
4. Financing Strategy (Finance strategy - Fossilfritt Sverige)
5. Strategy for a more efficient use of energy and impact (Energy efficiency strategy - Fossilfritt Sverige)

In addition, the **Industrial Leap**[25] was introduced by the Swedish Government in 2018 to support the transition. The Industrial Leap comprised a total of 1 457 million SEK in 2024 and projects that run until

[23] Climate Act Sweden's Climate Act and Climate Policy Framework
[24] Fossil Free Sweden Initiative Start - English - Fossilfritt Sverige
[25] The Industrial Leap Energimyndigheten

2031 can be funded. The venture is part of the EU Recovery and Resilience Facility (RRF) and Next Generation EU. It provides support to technological advances that can contribute to the transition in the following areas:

- Reduced GHG emissions from the process industry
- Negative carbon dioxide emissions
- Strategically important initiatives within industry that contribute to the net zero emission transition on a societal level

Sweden submitted the updated **National Energy and Climate Plan (NECP)** in 2024.[26] However, glass industry is not specified explicitly and there is one category called 'industry'. It is expected that the glass sector in Sweden will shift to bio-based fuels, hydrogen and electricity. The table below provides an overview on the role of bioenergy and hydrogen in the decarbonisation pathway. Even though documents do not mention the glass sector specifically, it serves as a guideline also for the glass industry.

Table 8 provides an overview on the role of bioenergy and hydrogen in the decarbonization pathway for industries mentioned in strategic documents

Sector	Role of bioenergy	Actions (bioenergy)	Role of hydrogen	Actions (hydrogen)
Steel Industry	Provide low-carbon heat for processes	Use of biogas and biomass-based fuels in furnaces, hydrogen production through biomass gasification	Replace fossil-based coke with hydrogen as a reducing agent	Adoption of hydrogen-based direct reduction
Cement Industry	Substitute fossil fuels in kilns	Cofiring with biomass, use of bio-oils and bio-coal	Supplement or replace fossil fuels in kilns	Hydrogen combustion in high-temperature processes
Chemical Industry	Bio-based feedstocks for chemical production	Production of bio-based plastics, solvents, and chemicals	Feedstock for the production of ammonia, methanol, and synthetic fuels	Development of green hydrogen from renewable electricity
Heating Sector	Provide renewable energy for district heating and industrial processes	Integration of biomass boilers, biogas systems, and combined heat and power plants	Not a primary hydrogen role in current strategy	-
Transport Sector	Biofuels as a sustainable alternative to fossil fuels	Production of biodiesel, bioethanol, and aviation biofuels	Fuel for hydrogen fuel cells and production of synthetic fuels	Development of hydrogen fuel cell vehicles and hydrogen-powered ships

[26] NECP Sweden Sweden - Final updated NECP 2021-2030 (submitted in 2024) - European Commission

Electricity Sector	Complementary renewable energy generation	Cofiring biomass in power plants, production of biogas for electricity	Energy storage and power generation	Use of hydrogen in fuel cells and turbines
Forestry Sector	Maximize the use of forestry by-products for energy	Utilization of residues like branches, tops, and sawdust	Not a primary hydrogen role in current strategy	No specific action defined

6 Financing the transition to the Green Economy

Different EU funding programs and mechanisms exist to finance just transition to a green economy for energy intensive industries. A summary on available EU finding programmes and mechanisms is provided in this chapter.

6.1 Just transition fund

The Just Transition Fund (JTF) is an instrument of the Cohesion Policy 2021-2027, as the first pillar of the Just Transition Mechanism in the context of the European Green Deal aiming at achieving the EU climate-neutrality by 2050.The Just Transition Fund (JTF) is equipped with its own envelope of EUR 7.5 billion within the EU budget. The Just Transition Fund will benefit territories with high employment in coal, lignite, oil shale and peat production, as well as territories with greenhouse gas-intensive industries, which will be either discontinued or severely impacted by the transition. The level of support will reflect the magnitude of the challenges in these territories, in terms of the need for both economic diversification and transition towards zero and low-carbon activities with growth potential, and the reskilling of workers in view of equipping them with the necessary skills to take on new jobs. For example, support will be provided to employees seeking to attain skills and capabilities required for the future labour market; to SMEs, start-ups and business incubators intending to open new economic opportunities in these regions. Investments in the transition to clean energy, e. g. in energy efficiency will also be supported.

The objective of the special system of Just Transition under the InvestEU program is to pool investments of up to EUR 45 billion. The application of the system is aimed at attracting private investments that will be beneficial for the regions most affected by the transition, including investments in sustainable energy and transport systems, so that the regions are enabled to find new opportunities for economic growth.

Useful links:

1. **The Just Transition Platform (JTP) provides** a single access point to support and knowledge on Europe's transition to a sustainable, climate-neutral economy:

   https://ec.europa.eu/regional_policy/funding/just-transition-fund/just-transition-platform_en

2. **Just Transition Fund:**

   https://ec.europa.eu/regional_policy/policy/what/glossary/just-transition-fund_en

3. **InvestEU program:**

   https://investeu.europa.eu/index_en?prefLang=de

6.2 Modernisation Fund

The Modernisation Fund is a component of the European Green Deal Investment Plan, contributing significantly to the EU's goal of achieving climate neutrality by 2050. It complements other European instruments, such as the cohesion policy and the Just Transition Fund, by mobilizing significant resources to support investments aligned with initiatives like the REPowerEU Plan and the Fit for 55 package. The fund supports the following key areas:

1. Generation and use of energy from renewable sources
2. Energy efficiency
3. Energy storage
4. Modernization of energy networks, including district heating, pipelines, and grids
5. Just transition in carbon-dependent regions, focusing on redeployment, reskilling, and upskilling of workers, education, job-seeking initiatives, and support for start-ups

13 EU member states can apply for this fund: Bulgaria, Czechia, Estonia, Greece, Croatia, Latvia, Lithuania, Hungary, Poland, Portugal, Romania, Slovenia and Slovakia.

More information on the fund can be found under the following link:

https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/modernisation-fund_en

6.3 Innovation Fund

The Innovation Fund promotes innovative demonstration projects for climate-friendly technologies. The calls are funded by financial sources from the EU Emissions Trading System (EU ETS) and aim to strengthen manufacturing capacity and technological leadership towards decarbonization. The following areas are funded:

1. Innovative low-carbon technologies and processes in energy-intensive industries, including products that can substitute carbon-intensive ones
2. Carbon capture and utilisation – CCU construction and operation of carbon capture and storage (CCS) facilities
3. Innovative renewable energy generation
4. Energy storage

In December 2024 the Commission published two calls for proposals under the Innovation Fund. One of them is available for Net-Zero technologies (€2.4 billion). The deadline to submit the application is 24.04.2025.

More information on the fund can be found under the following link:

https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund_en