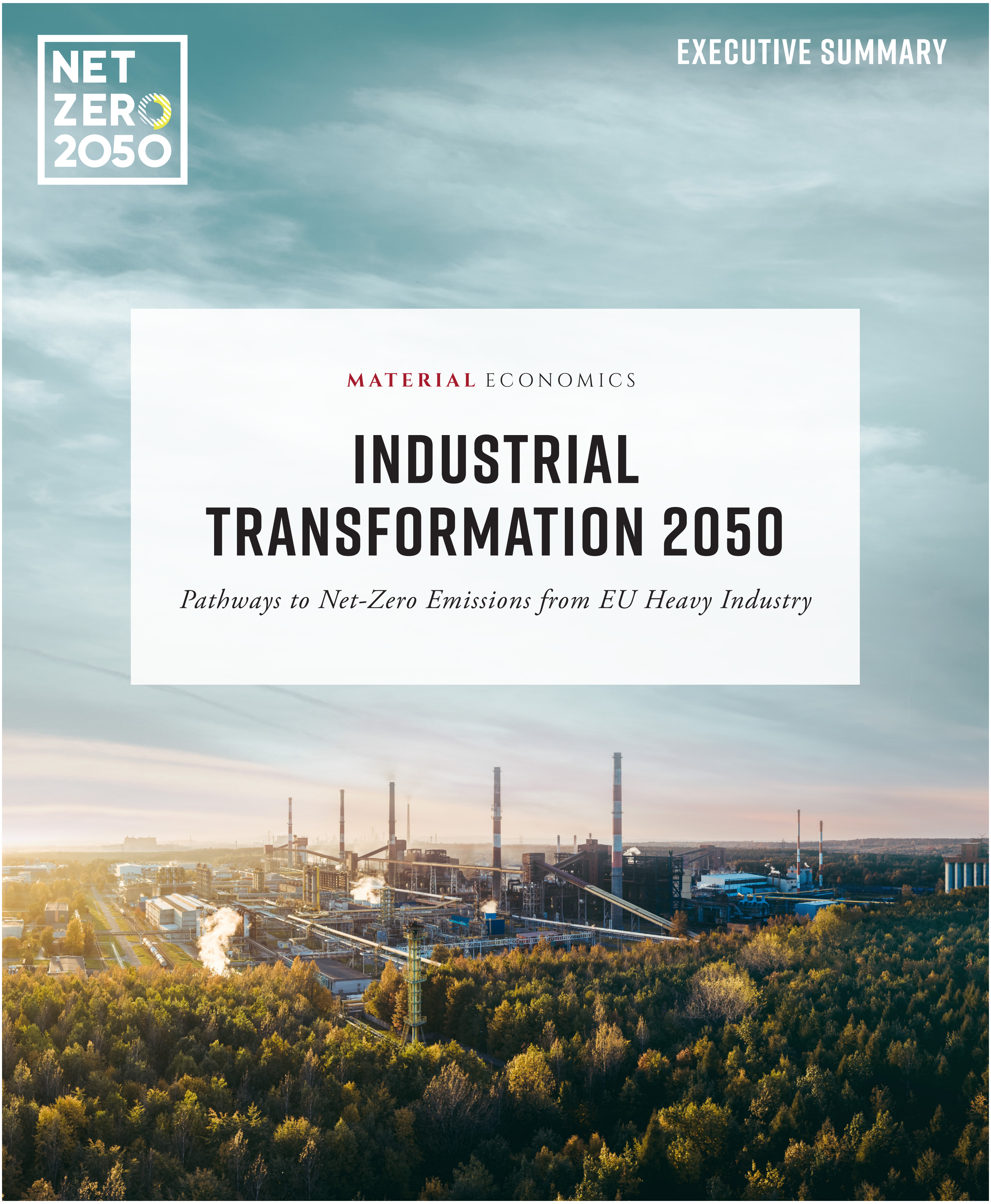
NET ZERO 2050

EXECUTIVE SUMMARY



MATERIAL ECONOMICS

INDUSTRIAL TRANSFORMATION 2050

Pathways to Net-Zero Emissions from EU Heavy Industry

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About Industrial Transformation 2050. This report is part of the *Industrial Transformation 2050* project, an initiative convened by the European Climate Foundation in collaboration with the Cambridge Institute for Sustainability Leadership, the Children's Investment Fund Foundation, Climate-KIC, the Energy Transitions Commission, RE:Source, and SITRA. It is published as part of the *Net-Zero 2050* series, an initiative of the European Climate Foundation.

Industrial Transformation 2050 seeks to work with industry and other stakeholders to set out pathways and policy options for net-zero heavy industry in Europe by 2050, achieving the objectives of the Paris Agreement while strengthening industrial competitiveness and the EU's overall economic development and performance.

The objective of *Net-Zero 2050* is to build a vision and evidence base for the transition to net zero emission societies in Europe and beyond, by mid-century at the latest. Reports in the series seek to enhance understanding of the implications and opportunities of moving to climate neutrality across the power, industry, buildings, transport, agriculture and forestry sectors; to shed light on near-term choices and actions needed to reach this goal; and to provide a basis for discussion and engagement with stakeholders and policymakers.

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This study explores multiple ways to achieve net-zero emissions from EU steel, plastics, ammonia and cement production while keeping that production in the EU. It quantifies the potential impact of different solutions and finds that emissions from those industries can be reduced to net zero by 2050, confirming the findings of the pathways presented in the Commission's *A Clean Planet for All*. Many new solutions are emerging, thanks to a more circular economy with greater materials efficiency and extensive recycling of plastics and steel, as well as innovative industrial processes and carbon capture and storage.

Many different industrial strategies and pathways can be combined to achieve net-zero emissions. The analysis finds that the impact on end-user/consumer costs will be less than 1% regardless of the path pursued – but all pathways require new production processes that are considerably costlier to industry, as well as significant near-term capital investment equivalent to a 25–60% increase on today's rates. Keeping EU companies competitive as they pursue deep cuts to emissions will thus require a new net-zero CO_2 industrial strategy and policy agenda. There is a need to accelerate innovation, enable early investment, support costlier low-CO_2 production, overcome barriers to circular economy solutions, and ensure that companies can access the large amounts of clean electricity and other new inputs and infrastructure they need. Time is short, with 2050 only one investment cycle away, and any further delays will hugely complicate the transition. As the EU ponders its industrial future, this transformation should be a clear priority.

NET-ZERO EMISSIONS FROM EU HEAVY INDUSTRY IS POSSIBLE BY 2050

The EU has set out a vision to achieve net-zero greenhouse gas emissions by mid-century as a contribution to achieving the Paris Agreement objectives of limiting global warming.

Resource and energy intensive industry holds a central place in this vision. The production of key materials and chemicals – steel, plastics, ammonia and cement – emits some 500 million tonnes of CO_2 per year, 14% of the EU total. Materials needs are still growing, and on the current course, EU emissions from these sectors might increase as well. Globally, these emissions are growing faster still, already accounting for 20% of the total. The EU needs to lead the way in combining the essential industrial base of a modern economy with the deep cuts to emissions required to meet climate targets.

To date, emissions from these sectors have been considered especially 'hard to abate'. Existing industrial low-carbon roadmaps left up to 40% of emissions in place in 2050. This would make industrial emissions one of the main roadblocks to overall net-zero emissions. The European Commission's *A Clean Planet for All* broke new ground by also considering pathways that eliminate nearly all emissions from industry.

This study confirms that it is possible to reduce emissions from industry to net zero by 2050. It reaches this conclusion by considering a much wider solution set than what is often discussed. Whereas most existing analyses have emphasised carbon capture and storage as the main option for deep cuts, a range of additional solutions are now emerging. A more circular economy is a large part of the answer. Innovations in industrial processes, digitisation, and renewable energy technologies can also enable deeper reductions over time.

Crucially, these deep cuts to emissions need not compromise prosperity. Steel, chemicals and cement fulfil essential functions, underpinning transportation, infrastructure, packaging, and a myriad of other crucial functions. The analysis of this study is based on the premise that all these benefits continue, and also that the EU continues to produce the materials it needs within its borders to the same extent as today.

A WIDE RANGE OF SOLUTIONS FOR NET-ZERO INDUSTRY IS AVAILABLE AND EMERGING

There are many paths to net-zero emissions, and a wide portfolio of options provides some choice and redundancy. At the same time, industry will need a clear sense of direction, so there is a need to debate and investigate the pros and cons of different options.

This study seeks to enable such discussion. It aims to be as comprehensive as possible in describing the available solutions and finds an encouraging breadth of available options. It explores multiple different pathways, each with its own benefits and requirements, and facing different roadblocks. All pathways reach net zero, reducing emissions by more than 500 Mt per year in 2050, but reflect different degrees of success in mobilising four different strategies for emissions reductions:

A. Increased materials efficiency throughout major value chains (58–171 Mt CO_2 per year by 2050). The EU uses 800 kg per person and year of the main materials and chemicals considered here. However, there is in fact nothing fixed about these amounts. This study carries out a comprehensive review of opportunities to improve the productivity of materials use in major chains such as construction, transportation, and packaged goods. All offer major opportunities for materials efficiency: achieving the same benefits and functionality with less material. The opportunity is surprisingly wide-ranging, including new manufacturing and construction techniques to reduce waste, coordination along value chains for circular product design and end-of-life practices, new circular business models based on sharing and service provision; substitution with high-strength and low-CO_2 materials; and less over-use of materials in many large product categories. For example, many construction projects use 30–50% more cement and steel than would be necessary with an end-to-end optimisation. Similarly, new business models could cut the materials intensity of passenger transportation by more than half, while reducing the cost of travel. Much like energy efficiency is indispensable to the overall energy transition, improving materials efficiency can make a large contribution in a transition to net-zero emissions from industry. In a stretch case achieving extensive coordination and a deep shift in how Europe uses materials, these solutions can reduce material needs from today's 800 kg per person per year to 550-600 kg, reducing emissions as much as 171 Mt CO_2 per year by 2050. In a more traditional pathway, emphasising supply-side measures instead, the reductions could be at a lower 58 Mt CO_2.

B. High-quality materials recirculation (82–183 Mt CO_2 per year by 2050). Large emissions reductions can also be achieved by reusing materials that have already been produced. Steel recycling is already integral to steel production, substantially reducing CO_2 emissions. The opportunity will grow over the next decades as the amount of available scrap increases, and as emissions from electricity fall. The share of scrap in EU steel production can be increased by reducing contamination of end-of-life steel with other metals, especially copper. With plastics, mechanical recycling can grow significantly but also needs to be complemented by chemical recycling, with end-of-life plastics that cannot be mechanically recycled used as feedstock for new production. Unlike most other forms of recycling, chemical recycling of plastics requires lots of energy, but is almost indispensable to closing the 'societal carbon loop', thus escaping the need for constant additions of fossil oil and gas feedstock that in turn becomes a major source of CO_2 emissions as plastic products reach their end of life. By 2050, a stretch case could see 70% steel and plastics produced through recycling, directly bypassing many CO_2 emissions, as steel and plastics recycling can use green electricity and hydrogen inputs. The total emissions reductions could be 183 Mt CO_2 per year in a highly circular pathway, but just 82 Mt if these are less successfully mobilised.

C. New production processes (143–241 Mt CO_2 per year by 2050). While the opportunity to improve materials use and reuse is large, the EU will also need some 180–320 Mt of new materials production per year. As many current industrial processes are so tightly linked to carbon for either energy or feedstock, deep cuts often require novel processes and inputs. Ten years ago, the options were limited, but emerging solutions can now offer deep cuts to CO_2 emissions. For steel, several EU companies are exploring production routes that switch from carbon to hydrogen. In cement, new cementitious materials like mechanically activated pozzolans or calcined clays offer low-CO_2 alternatives to conventional clinker. For chemicals, several proven routes can be repurposed to use non-fossil feedstocks such as biomass or end-of-life plastics. Across the board, innovations are emerging to use electricity to produce high-temperature heat. Many solutions are proven or in advanced development, but economics have kept them from reaching commercial scale. They now need to be rapidly developed and deployed if they are to reach large shares by 2050. In addition, large amounts of zero-emissions electricity will be needed, either directly or indirectly to produce hydrogen. In a pathway heavily reliant on new production routes, as much as 241 Mt CO_2 could be cut in 2050 by deploying these new industrial processes, falling to 143 Mt in a route that emphasises other solutions instead.

D. Carbon capture and storage / use (45–235 Mt CO_2 per year by 2050). The main alternative to mobilising new processes is to fit carbon capture and storage or use (CCS/U) to current processes. This can make for less disruptive change: less reliance on processes and feedstocks not yet deployed at scale and continued use of more of current industrial capacity. It also reduces the need for electricity otherwise required for new processes. However, CCU is viable in a wider net-zero economy only in very particular circumstances, where emissions to the atmosphere are permanently avoided. CCS/U also faces challenges. In steel, the main one is to achieve high rates of carbon capture from current integrated steel plants. Doing so may require cross-sectoral coupling to use end-of-life plastic waste, or else the introduction of new processes such as direct smelting in place of today's blast furnaces. For chemicals, it would be necessary not just to fit the core steam cracking process with carbon capture, but also to capture CO_2 upstream from refining, and downstream from many hundreds of waste incineration plants. Cement production similarly takes place at around 200 geographically dispersed plants, so universal CCS is challenging. Across all sectors, CCS would require public acceptance and access to suitable transport and storage infrastructure. These considerations mean that CCS/U is far from a 'plug and play' solution applicable to all emissions. Still, it is required to some degree in every pathway explored in this study. High-priority areas could include cement process emissions; the production of hydrogen from natural gas; the incineration of end-of-life plastics; high-temperature heat in cement kilns and crackers in the chemical industry; and potentially the use of off-gases from steel production as feedstock for chemicals. In a high case, the total amount of CO_2 permanently stored could reach 235 Mt per year in 2050, requiring around 3,200 Mt of CO_2 storage capacity. However, it also is possible to reach net-zero emissions with CCS/U used mainly for process emissions from cement production. In this case, the amount captured would be around 45 Mt per year.

Net-zero emissions from EU heavy industry are possible by 2050.

ADDITIONAL COSTS TO CONSUMERS ARE LESS THAN 1%, BUT COMPANIES FACE 20–115% HIGHER PRODUCTION COSTS

An analysis of the costs of achieving net-zero emissions reveals a telling contradiction. On the one hand, the total costs are manageable in all pathways: consumer prices of cars, houses, packaged goods, etc. would increase by less than 1% to pay for more expensive materials. Overall, the additional cost of reducing emissions to zero are 40-50 billion EUR per year by 2050, around 0.2% of projected EU GDP. The average abatement cost is 75-91 EUR per tonne of CO_2.

On the other hand, the business-to-business impact is large and must be managed. All pathways to net-zero require the use of new low-CO_2 production routes that cost 20-30% more for steel, 20-80% for cement and chemicals, and up to 115% for some of the very 'last tonnes' that must be cut. These differences cannot be borne by companies facing both internal EU and international competition, so supporting policy will be essential.

Cost alone is not a basis for choosing one pathway over another. Total costs are similar whether the emphasis is on CCS or on new production technologies. The attractiveness of solutions will vary across the EU, not least depending on electricity prices. A more circular economy and affordable electricity are among the most important factors to keep overall costs low.

Most EU companies know the current status quo offers little intrinsic advantage in a situation of trade uncertainties, global over-capacity, and often lower fossil feedstock and energy costs in other geographies. Low-carbon routes emphasising deep value chain integration, continued process and product innovation, and reliance on local end-of-life resources may well prove a more sustainable route for EU competitiveness. It will also offer a head start in developing solutions that will eventually be needed globally. In the longer run, low-CO_2 production systems may in fact be the more promising route to keep EU industry competitive.

A low-CO_2 industrial transition can offer similar employment levels as today, provided that economic activity does not migrate from the EU. Overall, circular economy solutions are more rather than less labour-intensive, so implementing them would create additional jobs in the overall value chains. Changes to industrial production, meanwhile, would likely still occur on current sites and in existing clusters, with little systemic impact on industrial employment.

THE TRANSITION WILL REQUIRE A 25–60% INCREASE IN INDUSTRIAL INVESTMENT, WITH IMPORTANT NEAR-TERM DECISIONS

All pathways also require an increase in capital expenditure. Whereas the baseline rate of investment in the core industrial production processes is around 4.8–5.4 billion EUR per year, it rises by up to 5.5 billion EUR per year in net-zero pathways, and reaches 12–14 billion EUR per year in the 2030s. Investment in other parts of the economy also will be key, including some 5–8 billion EUR per year in new electricity generation to meet growing industrial demand.

How much is invested and where depends on the pathway, with generally much lower investment requirements for materials efficiency and circular economy solutions than for traditional production. Some additional investment occurs because low-CO_2 routes are inherently more capital-intensive, but many others are one-off transition costs for demonstration, site conversion, and to provide redundancy in uncertain situations. Investment also will be required in infrastructure for electricity grids, CO_2 transportation and storage, and handling of end-of-life flows.

For society as a whole these are not, in fact, large amounts. They correspond to just 0.2% of gross fixed capital formation and would be fully covered, including a return on capital, by paying on average 30 EUR per tonne more for plastics and steel that often cost 600-1,500 EUR per tonne in today's markets.

For companies, however, the investment will be a major challenge. The case for investment in the EU's industrial base has been challenged for more than a decade. All investment relies on a reasonable prospect of future profitability. In capital-intensive sectors, choosing a low-CO_2 solution instead of reinvesting in current facilities can amount to a 'bet the company' decision – especially when future technical and commercial viability is uncertain. Investment in demonstration and other innovation often has highly uncertain returns. For all these reasons, strong policy support will therefore be needed in the near term.

In all pathways, EU companies will make important investment decisions in the next few years. Each will create a risk of lock-in unless low-CO_2 options are viable at these forks in the road. Changes to value chains and business models, meanwhile, may take decades to get established. There is time for deep change until 2050, but it will have to happen at a rapid pace, and any delay will hugely complicate the transition.

NET-ZERO INDUSTRY WILL REQUIRE LARGE AMOUNTS OF ELECTRICITY AND BIOMASS AS WELL AS A MORE CIRCULAR ECONOMY

Steel, cement, plastics and ammonia production together use 8.4 EJ of mostly imported oil, coal and natural gas. A major benefit of a more circular economy would be to reduce these needs by up to 3.1 EJ per year in 2050 through improved materials efficiency, new business models in major value chains, and large shares of materials recirculation.

Remaining needs would be replaced by sustainably sourced biomass (1.1–1.3 EJ), used primarily as feedstock, and large amounts of electricity (2.5–3.6 EJ), used directly or for the production of hydrogen. The remaining fossil fuels and feedstock would be as low as 0.2 EJ, though with high levels of CCS, 3.1 EJ could remain. All in all, Europe could become much less dependent on imports of inputs to its industrial production, even if some basic constituents (such as ammonia or hydrogen) were eventually to be imported.

Industry electricity demand will increase significantly. In a maximum case, an additional 710 TWh per year is required (for comparison, all of industry and manufacturing uses 1,000 TWh today). However, up to four times larger amounts are proposed in other analyses that envision a greater use of CO_2 and 'Power-to-X' as feedstock to decarbonise industry. Electricity must be all but zero-emissions, or emissions would simply migrate to the energy sector. It also needs to be affordable (the cost estimates presented here assume a price of 40–60 EUR per MWh, depending on the application). The main ways to reduce electricity needs is to achieve a more circular economy, which can reduce requirements by 310 TWh, or large-scale deployment of CCS, which can cut some 275 TWh.

Sustainable biomass is a scarce resource, and industry must prioritise how it is used. Nearly all biomass used in the pathways is as feedstock for chemicals, to enable a 'societal carbon loop' for plastics and other chemicals without new additions of fossil carbon from oil and gas. The 85–105 Mt required are within available resources, especially if non-conventional streams such as mixed waste can be mobilised. Still, it is key to minimise the amount of biomass required. The main ways to do so are high recycling rates (mechanical and chemical) for plastics, increased materials efficiency, innovation to enable new polymers suited to bio-feedstock, and CCS to enable some continued use of fossil feedstock.

There is time for deep change until 2050, but it will have to happen at a rapid pace. Any delay will hugely complicate the transition.

THE TRANSFORMATION REQUIRES STRONG SUPPORT ACROSS CLIMATE AND INDUSTRIAL POLICY

A successful transition will require concerted efforts by government, industrial companies, companies in major value chains, cities, civil society, and individuals. The transition is technically feasible but requires a step-change in support to be economically plausible. The next 5–10 years will be crucial in enabling EU heavy industry and major value chains to chart a low-CO_2 course.

Many EU industrial companies know that 'doing nothing' is a far from viable approach. Indeed, EU industry has long gravitated towards increased specialisation, performance and efficiency to counter pressures ranging from energy costs, trade practices or global overcapacity. A low-CO_2 track would be a continuation and acceleration of these trends. Low-CO_2 solutions pioneered and commercialised in Europe will eventually be needed globally in a world with large unmet materials needs. Meanwhile, the EU would transition to a much more secure position: a more materials-productive economy that is less reliant on imported fossil fuels and feedstock, and more attuned to domestic sources of comparative advantage: local integration, digitisation, end-of-life resources, etc.

Nonetheless, the first steps of this transition will not occur without a step-change both in policy and in company strategic choices. To launch a new economic and low-CO_2 agenda for EU heavy industry, major policy innovation and entrepreneurship will be required. The EU ETS provides a fundamental framework, but many stakeholders see limits to the credible commitments to future CO_2 prices that it can provide, not least given international competition. On its own, carbon pricing also does not provide sufficient incentives for innovation, nor does it address market failures that hold back many circular economy solutions.

While all pathways require broad policy support, requirements differ for different options. Effective policy therefore must start from a deep understanding of the change required, and the business case for different options. Just like the solution set for net-zero industry is wide-ranging, this policy agenda must have many parts, each addressing different aspects of the transition. Options currently not in use but which can be considered include:

- **Launch major new mechanisms for innovation.** This includes some industrial R&D 'moonshots' and mission-driven innovation. Equally important will be to support the later stages towards fully commercial solutions: define and embed an innovation agenda in all EU and national programs, provide direct public finance for demonstration, emphasise early learning by doing (deployment), and develop new joint public-private models for large demonstration plants.
- **Create lead markets for low-carbon production.** This starts with creating an initial business case to enable companies to make a near-term strategic choice for low-CO_2 production. It also requires a commitment to continued support. The EU ETS offers an option, but wider climate policy offers a broad menu of fiscal/financial support and regulatory instruments that could be deployed, such as contracts for differences for low-CO_2 production, standards for materials' or products' CO_2 performances, public procurement, and possible trade and investment mechanisms to ensure fair international competition.
- **Enable early investment and reduce the risk of lock-in.** Especially early in the transition, before technical and commercial risk can be fully resolved, financing instruments for direct investment supports will likely be required. Options include using public financial institutions, risk-sharing models, concessional finance, and early direct public investment. It also will be necessary to handle the risk of stranded assets.
- **Create systems for high-quality materials recirculation.** Both steel and plastics recycling are indispensable parts of any net-zero materials system, but incentives for clean end-of-life flows are skewed and insufficient. Regulatory change is required to open up waste flows as a major, large-scale feedstock resource, regulate against contamination of end-of-life flows, and optimise product design and end-of-life dismantling for high-quality recovery.
- **Integrate materials efficiency and new business models in key value chains.** As with energy efficiency, policy can help overcome barriers and market failures such as incomplete contracts and split incentives, large transaction costs and missing markets, and incomplete information. Standards, quotas, labelling and other approaches in energy efficiency policy need rapid translation to major materials-using value chains – while avoiding undesired outcomes of such regulations, including potential hidden costs.
- **Safeguard access to key inputs and infrastructure.** Key policy objectives in this area include public or regulated models for carbon transport and storage, hydrogen supply for major industrial clusters, an accelerating electricity system transition, and modified incentives for biomass use that maximise the benefits of its use. Policies that encourage industrial clusters and symbiosis for heat, hydrogen and other flows also can contribute.

Perhaps the most important near-term prerequisite for success will be to create a shared expectation: that, much like the energy sector now focuses nearly all its efforts on low-carbon resources, the EU heavy industry and major materials-using value chains will now direct innovation and investment towards solutions that enable deep cuts to CO_2 emissions. The sooner this is achieved, the greater the likelihood of success – and the greater the opportunity to build an EU industrial advantage in low-CO_2 production and in circular economy business models.

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INDUSTRIAL TRANSFORMATION 2050

Pathways to Net-Zero Emissions from EU Heavy Industry

There is intense debate about how to close the gap between current climate policy and the aim of the Paris Agreement to achieve close to net-zero emissions by mid-century. Heavy industry holds a central place in these discussions. The materials and chemicals it produces are essential inputs to major value chains: transportation, infrastructure, construction, consumer goods, agriculture, and more. Yet their production also releases large amounts of CO_2 emissions: more than 500 Mt per year, or 14% of the EU total.

Policymakers and companies thus have a major task ahead. There is an urgent need to clarify what it would take to reconcile a prosperous industrial base with net zero emissions, and how to get there in the 30 remaining years to 2050.

This study seeks to support these discussions. It characterises how net zero emissions can be achieved by 2050 from the largest sources of 'hard to abate' emissions: steel, plastics, ammonia, and cement. The approach starts from a broad mapping of options to eliminate fossil CO_2-emissions from production, including many emerging innovations in production processes. Equally important, it integrates these with the potential for a more circular economy: making better use of the materials already produced, and so reducing the need for new production. Given the uncertainties, the study explores several different 2050 end points as well as the pathways there, in each case quantifying the cost to consumers and companies, and the requirements in terms of innovation, investment, inputs, and infrastructure.

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