

CFM PLATFORM

Investments in climate-friendly materials to strengthen the recovery package



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The Climate Friendly Materials (CFM) Platform analysis the transformation of basic material production and use to achieve carbon neutrality by 2050. Its collective aim is to aid progress toward nationally-led industrial decarbonisation policy frameworks compatible with long-term EU strategy, and to capture the potential of a just and inclusive clean energy transformation.

Convened by Climate Strategies, the CFM Platform facilitates exchange between leading analysts, policymakers, industry leaders and other relevant stakeholders. It brings together leading think tanks and university research groups in Belgium, France, Germany, Hungary, the Netherlands, Poland, Spain and Sweden to enhance Europe's analytic understanding of how individual instruments fit together into a coherent policy package.

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Introduction

Supporting investments in climate-friendly production and recycling of materials as part of the European and national Covid-19 recovery package can both achieve the short-term objective of effective recovery spending for boosting the economy and creating jobs as well as deliver climate and long-term economic benefits. In order to realize the full economic and climate benefits of investment support, a rapid implementation of the policy package envisaged in the European Green Deal is required.

Supporting climate-friendly investments through the recovery package can help to ensure that stimulus measures are effective, i.e. meet the criteria of being *targeted, timely and temporary* (Kroeger et al. 2020).

Targeting public funding on new clean production processes and new sorting and recycling technologies ensures that the intervention triggers additional investments, leverages additional private capital, and thus achieves a high fiscal multiplier.

Timely implementation of many of the projects is possible, as companies and regulators have already begun exploring multiple technology options to achieve climate neutrality in recent years.

Temporary recovery support will be sufficient to provide resources for new actors in fragmented value chains and for companies struggling to fund new investments during the current crisis. A regulatory framework that provides long-term incentives and risk-hedging instruments can ensure that business cases for new investments lasts beyond the recovery package. The rapid implementation of the European Green Deal is essential.

In the longer term, investments in climate-friendly production and an increased recycling of materials have the potential to deliver three main benefits. This offers a further motivation for considering inclusion in a recovery package:

Inclusive Transformation creates new lead markets for climate-friendly production of materials as well as recycling services and low-carbon products, and thereby boosts the activity of innovative companies active in different EU member states. This can provide new opportunities for future-proof investments in all member states and thereby secure jobs and long-term competitiveness of all industrial sectors within the EU.

Scale-up of low-carbon technology will trigger demand for new production and sorting technologies at industrial scale. This can ensure that engineering and construction companies across Europe can retain staff throughout the crisis and dedicate their expertise towards the scaling-up of innovative low-carbon technologies for their use in industrial scale applications.

Resilience of integrated value chains in Europe against future crises, by ensuring that companies have access to climate-friendly materials while reducing their exposure to energy and raw material costs by enhanced recycling that closes the loop of the life cycle of products.

In order to support the design of the EU as well as individual member state recovery packages, this report aims at exploring whether investments in low-carbon projects could be accelerated to contribute to the recovery while jump-starting the decarbonization of the European basic materials industry and enhancing its competitiveness. We first assess viable low-carbon technology options for climate-friendly investments in the scope of the recovery package. For doing so, we reflect on the insights obtained from various interviews with industrial experts about viable technology options for climate-friendly production processes and enhanced recycling of steel, cement, aluminum and plastic, and on the main perceived challenges that hinder their development. Based on these insights we then highlight the necessary elements of a recovery package which could help to realize these investments and discuss how these investments can support recovery objectives.

Technology options for investment through the recovery package

The EU target of climate neutrality by mid-century will require additional investments in a portfolio of possible mitigation options within the basic materials sector. Such a portfolio has been established by multiple industrial roadmaps in various countries (e.g., BDI 2018 for Germany and Fossil Free Sweden Initiative 2018 for Sweden) and research (e.g. Neuhoff et al. 2019, Wyns et al. 2019, Mistra Carbon Exit 2020a, 2020b, 2020c), and underpins the long-term scenarios of the European Commission (EC 2018b). In particular, it is acknowledged that it will be crucial to cover the following three dimensions:

- A shift to climate-neutral, new production processes for steel, cement, plastic and aluminum;
- A rapid scale-up and improvement of material waste sorting and recycling;
- Enhanced material efficiency in manufacturing and construction and product design, as well as increased sharing, repairing and reusing of material-intensive products.

The aim of the analysis presented in this report is to explore whether and how investments in pilots, demonstration projects and the commercialization of low-carbon production and closed-loop recycling projects could be accelerated to contribute to the recovery while enhancing the competitiveness of the European basic materials industry and kick off the decarbonization of the sector. Advancements in material efficiency and improved repair and reuse are beyond the scope of our analysis.

We conducted 24 semi-structured interviews with industry experts across Europe.¹ Along a standardized questionnaire, we asked our interview partners about the climate-friendly technology options they consider to be particularly promising for the decarbonization of their sector, to what extent their accelerated deployment could contribute to an economic recovery and what challenges they see for their implementation.

This section provides the viability assessment of technology options obtained through the interviews and combines these insights with findings from the literature. For each material, the technology options for both low-carbon primary production and for sorting and recycling are reviewed

Primary production of basic materials

Steel production

An option for the decarbonization of primary steel production that has been increasingly emphasized in recent years is hydrogen direct reduction.² The technology is based on the direct reduction of iron ore using natural gas, which is an already established technology, but only more widely used in regions with access to cheap natural gas (e.g. Iran, Russia, Saudi Arabia) (Material Economics 2019, Midrex 2018). While this process is already less emission-intensive than the blast furnace route common in Europe, emissions can be largely avoided if green hydrogen is used instead of natural gas. The switch to direct reduction using hydrogen, however, requires large capital commitments. While recent literature estimates investment costs to be 574 million Euros per million ton of annual capacity (Vogl et al. 2018), interviewees suggested that overall investment volumes per million ton of annual capacity are closer to one billion Euros.

Initial demonstration projects using hydrogen are likely to be smaller, thereby requiring less investment per project, but higher relative cost per capacity installed.

Although considered technologically feasible, the use of 100% hydrogen in large-scale direct reduction processes is still challenging as is the implementation of this technology in an integrated steel work. Additionally, the availability of affordable green hydrogen remains the main bottleneck for this technology. Several interviewees argued that an option to avoid these issues, is to first operate direct reduction plants using natural gas while gradually increasing the share of green hydrogen used within the process and thereby phasing out the use of natural gas over time. This path would still result in immediate emission reductions and is technologically ready for large scale deployment. Additionally, it would also facilitate the incremental build-up of green hydrogen capacities.

Some interviewees argued, that during the transition period and until long-term solutions are fully deployed, some efficiency improvements of existing blast furnaces, for example through top-gas recycling, and partial substitution of coal with green hydrogen or biomass would be possible but constrained by the availability of green hydrogen and biomass. Furthermore, approaches to capture some of the carbon emitted from existing installations are discussed. The emission reduction potential, though, is limited and the question of what to do with the captured emissions is unclear (see discussion on captured CO₂ in cement production below). While investments in all these options within the next 2-3 years are considered possible, any public support towards such investments should not preclude the required overall shift towards climate-neutral production technologies.

Direct electrolysis of steel is viewed as a promising climate-neutral option by some interviewees, as it may be more energy efficient (see also Weigel et al. 2016 and Agora Energiewende and Wuppertal Institute 2019). However, the technology is still in the early development stage and it is arguably a solution for the mid- to long- term.

Due to the potentially large energy savings associated with this technology, R&D and small-scale pilot projects may require financial support within the next 5 years.

Cement production

Short-term improvements in the cement industry are based on using more biomass, low-carbon clinker, and additives to substitute clinker. Carbon capture will be needed to reduce emissions even further (EC 2018b, CEMBUREAU 2020).

Initial carbon capture projects for cement are being explored globally³ and in principle the technology is ready for implementation within the recovery time frame. The scale of investment required depends on the capture technology used. End-of-pipe measures such as amine scrubbing require an investment of about 76 million Euros per plant (1 million tons of clinker per year) and might be combined with direct solidification of CO₂ using residual concrete. More elaborate technologies such as Oxyfuel combustion could be installed during major refurbishment campaigns of existing cement plants. Carbon capture using Oxyfuel combustion would require an investment of about 130 million Euros per plant but comes with the benefit of a lower energy demand for production of CO₂ streams and therefore lower operational costs (Voldsund et al. 2018).

The main uncertainty concerns the use of the captured CO₂ streams. One option is to transport them to an underground storage facility, in case that transport infrastructure and suitable locations are within the plant vicinity and their exploitation is politically acceptable. Captured CO₂ can also be used to turn green hydrogen into synthetic hydrocarbons, although this requires sufficient green hydrogen to be available, which may be more likely outside of Europe. Furthermore, this option is only reducing emissions but not carbon-neutral if synthetic hydrocarbons are used as e-fuel for combustion or if it is basis for production of plastics that are incinerated at the end of their life, as the initially captured fossil CO₂ would still be emitted to the atmosphere.

Thus, carbon capture and utilization (CCU) based on CO₂ emissions from the cement sector may be only a transitional option to support early deployment of carbon capture technologies and e-fuels production capacities until complementary measures (storage infrastructure for CCS, establishing climate-neutral supply of carbon, e.g. from direct air capture or biomass) are implemented. Lastly, CO₂ can be stored by the solidification of residual concrete from demolished buildings and infrastructure (Monteiro et al. 2018). This might be the option with the lowest level of technological readiness, but can be seen as the best match for the decentralized and rural locations of many European cement plants. Exploiting this potential will only be possible if a structural transformation of the established process chains of the European cement industry takes place.

Chemicals production

More than 60% of today's direct and indirect emissions of the chemical industry are linked to petrochemical processes and steam crackers used for the production of basic chemicals, such as ethylene, propylene and other olefins (VCI 2019). An additional 7% of emissions is related to the production of ammonia (mainly fertilizers) and another 3% for chlorine and methanol production. The remaining activities in the chemical sector are 'only' responsible for about 30% of the total emissions, which are mainly linked to process heat provision.

Steam crackers for production of basic chemicals are the largest single-point source of emissions in the chemical sector due to the combustion of fossil fuels to reach high process temperatures. The produced olefins could instead be derived from synthesized methanol. Methanol-to-olefin plants are commercially available and require an investment of about 200 million Euro per plant (capacity of 1 million tons of HVC per year; adjusted from Agora Energiewende and Wuppertal Institute 2019). Methanol-to-aromatics plants are in development but not yet available at industrial scale. The main constraint is the availability of renewable energy required for the production of the additional volumes of methanol.

Methanol can be synthesized using green hydrogen and carbon from captured streams or biomass. While the technology is still in development, pilot and demonstration projects may need to be supported within the next 5 years.⁴ According to literature, a plant using green hydrogen and CO₂ to synthesize around 430 thousand tons of methanol per year - excluding the production of hydrogen and capture of CO₂ - would require an investment of about 70-250 million Euros (Schemme et al. 2020, Perez-Fortes et al. 2016). Based on the insights gained from conducted interviews, the lower estimate might be rather optimistic and higher installation costs (closer to the higher estimate) are expected.

Ammonia production can be decarbonized by producing the required low-carbon hydrogen from alternative sources rather than using conventional steam methane reforming of natural gas. Various options with low emission footprint are available and controversially discussed. All of them require large amounts of renewable energy. Given that the integration of ammonia production with later stages of the value chain is limited, and transport is feasible, new plants might be located in regions with good renewable resource potential.

The remaining 30% of emissions for all the other chemical activities are primarily related to the provision of process heat. Fossil or bio-fuel powered co-generation plants and boilers can be complemented with direct electrode boilers. This approach has been motivated by offering flexibility service into the power system auxiliary markets and was technologically successful but so far renewable penetration has not reached levels that ensure economic viability. Investments volumes are moderate and the technology is mature. The primary use of (renewable) electricity for heat production may require the installation of high-temperature heat pumps. This option has to be explored further in research and pilot projects, as it is a cross-cutting technology also relevant for other sectors.

Aluminum production

The production of aluminum needs large amounts of electricity, which implies that the decarbonization of the electricity mix will play a major role in reducing the sector's emissions.

However, even in case of decarbonized electricity supply, emissions of about 3-4 tons of CO₂ per ton of aluminum remain (Material Economics 2019, European Aluminium 2020). These emissions can be largely avoided by using carbon-free anodes. They would replace the energy-intensive production of carbon anodes and would eliminate the (direct) CO₂ emissions from the anode during the aluminum production. Furthermore, additional energy savings of 3 to 4% are expected, but so far the industrial-scale demonstration stage has not been reached (Wyns and Khandekar 2019).

Recycling of materials

Providing better incentives, as part of the recovery package, to increase recycling rates and material circularity is key not only to reduce the carbon emissions of the basic materials sector, but also to foster local value chains and create local jobs.

However, unleashing the full potential of recycling options faces various challenges. One of the biggest issues is that today's waste streams and sorting technologies do not provide sufficiently pure and reliable material flows and are therefore insufficient to reach the near 100% recycling rates (i.e. closing the loop). In the case of steel and plastic, for example, material recycling is largely limited to downcycling, i.e. the production of lower value products from high value recycling streams. Furthermore, recycling processes for other basic materials such as cement are not well established yet (van Lieshout 2015, Material Economics 2018). In order to improve recycling, innovation along the entire product life cycle is required.

Regulatory requirements concerning the product design (e.g. Eco-Design Directive⁵) need to improve the recyclability of products sold within the EU, whereas additional incentives are required for collection, separation and the recondition of recycling streams. A functioning European circular economy would also require a dynamic European industry, creating demand for recycled materials along the whole value chain. This may require a combination of financial incentives, e.g. through advanced disposal fees, and clearly defined recycling targets as well as transparent metrics for the content of materials that are in a closed loop.

Triggering the development of a more elaborate recycling industry can not only deliver climate benefits but also ensure the creation of new jobs. According to Hestin et al. (2015), meeting the recycling targets for plastics could create 80,000 direct jobs and 120,000 indirect jobs by 2025 within the EU economy.⁶ More broadly, studies expect a net positive effect of implementing a circular economy (EPRS 2017, Ellen MacArthur Foundation 2015). EPRS (2017) points to 400,000 new jobs that would be created by implementing existing legislation on waste prevention and management. According to WRAP (2015), a complete transformation could create up to 3 million jobs in the EU by 2030.⁷

Developing recycling activities is crucial for closing the loop, creating jobs and securing inputs, but should not be done at the expense of repair and reuse. Repair activities (e.g. machinery, household goods) make up about half of the circular economy jobs in EU-28, 2012 (EPRS 2017). In addition, supporting better recycling for example through local projects on innovative sorting systems and recycling plants can foster local supply chains and open a channel for resilience of EU supply chains.

Steel recycling

The production of steel with electric arc furnaces using scrap metal already plays a major role in today's steel industry and currently accounts for about one third of global production (Allwood et al. 2019a). The availability of scrap is projected to grow significantly reflecting the increased construction and manufacturing volumes in recent decades. Since recycling of steel requires significantly less energy than conventional primary steel production, emissions from the steel industry can decline with an increasing share of recycling.

A major challenge for an increase of recycling rates is the contamination of scrap with elements like copper, nickel and chrome. This implies that scrap is usually down-cycled to lower quality steel. This happens, first, because a range of elements is usually added to steel to create alloys to improve the functionality of steel.

At the end of product life, sorting processes to separate scrap into different alloys are not sufficiently used (Material Economics 2018). Second, when products like cars are shredded, steel scrap is contaminated, for example with copper from wires. Better technologies for sorting, separating or processing scrap may be able to mitigate this issue, but need additional financial support (Allwood et al. 2019a).

Aluminum recycling

Recycling of aluminum only requires about 5% of the energy consumed in the primary production process (Material Economics 2018). Increased recycling could therefore drastically reduce the demand for low emission electricity needed for decarbonizing the aluminum production⁸ (Wyns and Khandekar 2019). Additionally, re-melting aluminum reduces the process emissions caused by the alumina production from bauxite and by the degradation of the electrolyser anodes.

While for example already between 90-95% of aluminum in automotive and buildings is recovered for recycling, more significant potential for increased recycling exists e.g. in packaging and beverage cans, where recycling rates are only around 60% and 75%, respectively, although rates can vary regionally (European Aluminium 2016 and 2020).

Aside from losses due to insufficient collection systems, one principal challenge for aluminum recycling is the wide range of alloying elements, which only allows for downcycling if scrap is not sufficiently sorted. If separation into different alloys would be improved, aluminum can be a highly circular material. At the same time, the availability of post-consumer scrap is expected to increase significantly as a large share of the increased production over the past decades only becomes available as scrap in the coming years (and demand is projected to continue growing). Therefore it is possible that a significantly higher share of demand could be covered by recycled materials⁹ if enhanced sorting systems are able to provide a sufficient quality (Material Economics 2018).

Recycling rates and closed-loop recycling could increase significantly if better collection systems and additional modernized sorting and recycling capacities were available. Technologies improving the recycling process are available and can be deployed industry-wide until 2025 (e.g. Laser-Induced Breakdown Spectroscopy (LIBS), X-ray fluorescence spectroscopy, 3D detection). In some applications product requirements should be considered as well, limiting for example the variety of alloys used (e.g. for drink cans). Thus, without a loss of functionality, pure material streams could be ensured for closed-loop recycling.

Cement recycling

There is a significant potential for cement recycling. Currently cement is not processed at all from secondary concrete and concrete recycling rates are particularly low (see e.g. van Lieshout 2015). Generally, these materials are crushed and either dumped or transformed into low grade “aggregates” for other construction purposes. In order to reuse cementitious waste, sorting of deconstruction waste has to be improved. Technologies to achieve this are largely available but are not widely used.

A variety of options are explored for re-use of cementitious materials for new construction, with some assessments estimating that up to 30% of limestone could be replaced (Allwood et al. 2019b) and others that a SmartCrusher technology could potentially increase replacement rates up to 50% (Wyns et al. 2019). Furthermore, new technologies that allow the decentralized conditioning of currently dumped crushed fines can be combined with new processes for the production of alternative binders (like Celitement). These developments have the potential to close the cement loop but require additional support to move processes from the demonstration stage to commercialization. Economic incentives for reuse of cementitious material are low as long as primary cement production does not bear the full carbon cost.

Sorting efforts are higher where closed landfill capacities or high charges create incentives for effective sorting. This is a prerequisite for effective cement recycling.

Plastic recycling

The production of one ton of plastic, including feedstock provision, cracking and polymerization of petrochemicals, generates about 2.3 tons of CO₂ emissions. However, a similar amount of carbon (equivalent to 2.7 tons of CO₂ emissions) is embedded in the plastic product and released when incinerated at the end of its life (Material Economics 2019). Increased use of sorted plastics waste as an alternative feedstock, for example in steam crackers, can replace fossil hydrocarbons and substantially reduce emissions along the value chain.

Although close to 30% of plastic waste is collected for recycling in the EU, much of this is exported or not actually recycled in the end, for example due to contamination or insufficient sorting processes. In fact, recycled plastics only account for about 6% of today's material use in Europe (EC 2018a).

Mechanical recycling of plastics requires high-quality sorting operations for the different types of plastic resins. This is challenging due to the wide range of plastics and additives used, mixed collection streams and insufficient sorting and recycling processes. In order to increase recycling rates, sorting capacities need to be expanded and technologies upgraded to include e.g. sensor-based sorting and digitization (e.g. use of artificial intelligence).

The interviews pointed to the emergence of a healthy competition between mechanical and different chemical recycling approaches. This also matches expectations in the literature (Thunman et al. 2019). Experts and actors in sorting technologies can envisage mechanical recycling rates of 50-80% of packaging waste (which alone accounts for around 60% of total plastic waste (EC 2018a, EPRS 2017)) if appropriate improvements in product design are implemented.

On the other hand, actors in the chemical industry seem to anticipate a somewhat larger role for chemical recycling, raising concerns, for example, about thermo-mechanical material degradation in case of multiple recycling iterations and the difficulty to sort plastic (Ragaert et al. 2017).

Chemical recycling is inherently more energy-intensive as molecules are typically deconstructed and subsequently reconstructed. End of life plastics can be broken down into their initial components, in order to produce feedstock that can then be used again in steam crackers. Though this means that new plastics are produced based on recyclates, this is also the most energy-intensive option. Alternative, more energy efficient options are currently being developed, aiming at recovering specific molecules using lower temperatures. The more energy-intensive chemical recycling processes like pyrolysis are most advanced and could be deployed in projects matching the scale of decentralized recycling flows according to some interview partners already prior to 2025.¹⁰ Processes using lower temperatures, on the other hand, are less developed, but due to the number of actors active in this field, a considerable number of pilot and demonstration projects may be deployed within the next 5 years. Chemical recycling can be an option for the recycling of heterogeneous and contaminated plastics, if mechanical recycling is too costly or not technically feasible (Ragaert et al. 2017).

Enzymatic biorecycling of plastics is another option, which is currently in development, for example for PET (Tournier et al. 2020). Similar to chemical recycling, depolymerization can be achieved. Compared to chemical recycling, the main advantage of this technology is that enzymes are polymer-specific, hence extensive pre-sorting is not required, process temperatures are relatively low and no organic solvents are used (Marty et al. 2019).

Summary of new technology options for the recovery package

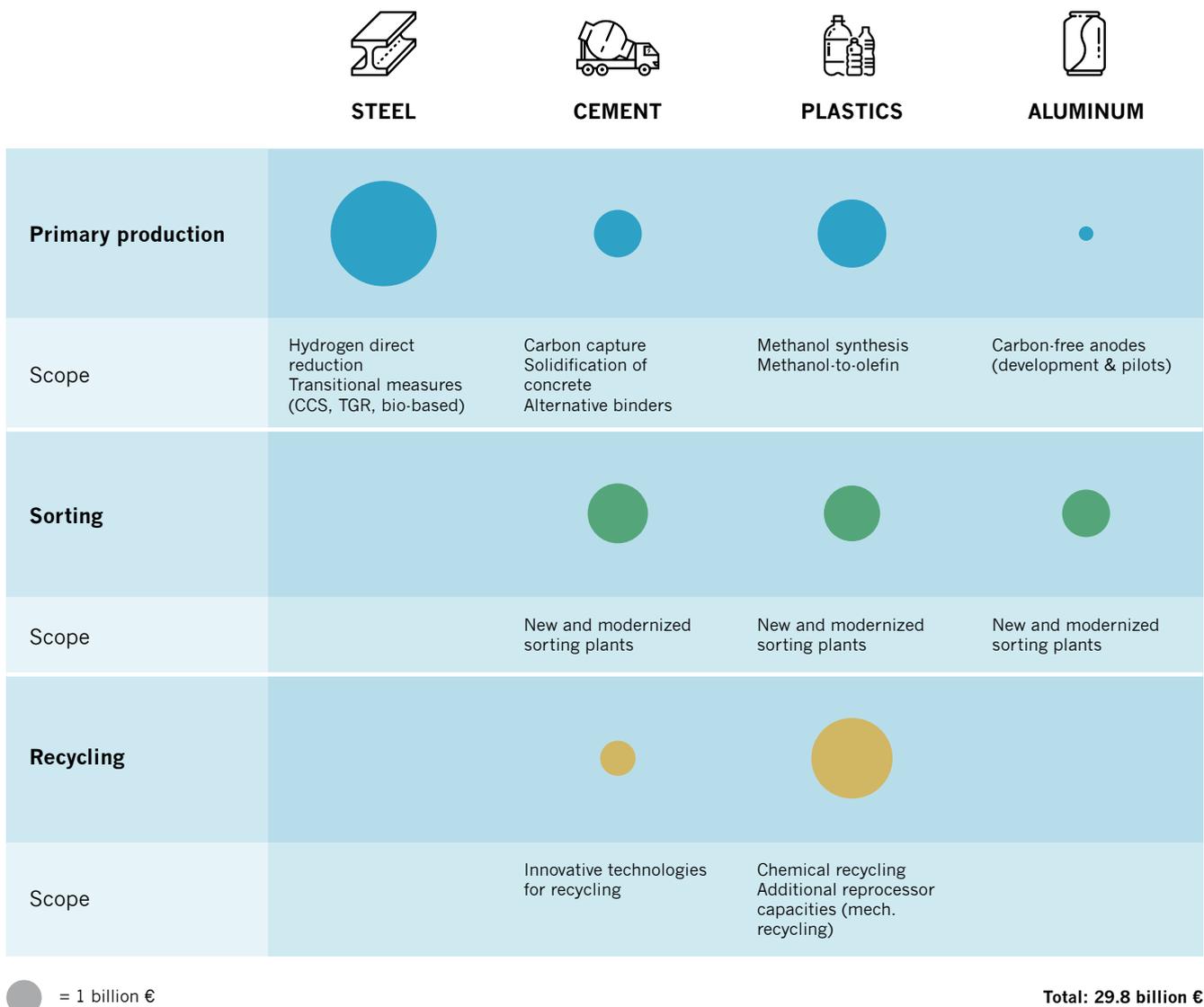
In our review we attempted to identify investment options that are so called "shovel-ready" and we thus complement more comprehensive reviews of options (see e.g. Gerres et al. 2018).

Figure 1 below summarizes the scale of potential investment until 2025 for options which are advanced in their development and can therefore be implemented in the scale of demonstration or commercialization projects within the recovery time frame.¹¹

Not only low-carbon production processes of steel, plastics and cement, but also sorting processes for aluminum, plastic and cement and new recycling processes for cement and plastic have large potential in terms of scale of investment opportunities.

FIGURE 1

Scale of potential investment into climate-friendly production, sorting and recycling processes for steel, cement, plastics and aluminum in the EU until 2025



How to unlock investments with a recovery package?

We asked our interview partners an open-ended question about the main challenges for the implementation of the technology options for low-carbon production and new sorting and recycling processes. These challenges were grouped by categories common across the different responses. Figure 2 shows for each of these common categories of challenges, what share of the interview partners mentioned this as one of her or his top three challenges (i.e. a "major" challenge).¹²

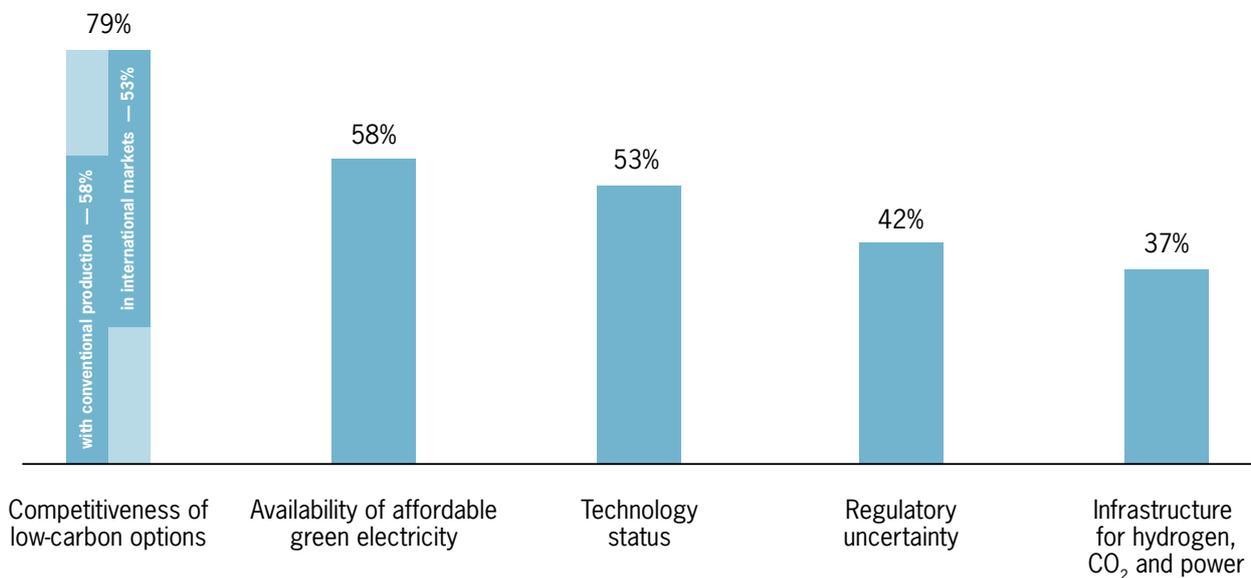
The remainder of the section discusses these challenges together with potential policy responses from the literature and our previous research (Neuhoff et al. 2017, Neuhoff et al. 2018, Chiappinelli et al. 2018, Neuhoff et al. 2019, Gerres et al. 2019a) to achieve the objectives of the European Green Deal and to unlock the investments through the recovery package.

Creating a business case for clean materials and recycling

79% of the interview partners see the lack of competitiveness of low-carbon options as a major challenge. Companies will only dedicate their core competencies and resources to an innovative project, and technology providers will only fully engage, if they see a business case, namely if there is a large market for a technological successful process or product.

FIGURE 2

Share of interview partners considering the respective challenges as one of the top three challenges for the implementation of climate-friendly technologies for production and recycling of steel, cement, plastics and aluminum.



However, most climate-friendly technologies for primary material production are expected to have higher operational costs than conventional technologies because, rather than using directly coal or gas as input, they require either the transformation of (renewable) electricity into hydrogen or high temperature heat, which causes significant energy losses, or they induce extra costs for capturing carbon.

For a clean production process to be cost competitive relative to a conventional process, a carbon pricing mechanism is needed that meets the following two requirements:

First, it needs to be credible that carbon prices can reach the level of incremental costs of clean production processes of 50 Euro/t CO₂ or more. However, 53% of the respondents voiced concerns about carbon leakage. This could potentially be triggered from asymmetric cost increases for EU producers resulting from increasing carbon prices and declining levels of free allowance allocation. This would likely trigger opposition, for example against a more stringent EU ETS cap. This limits confidence that the carbon price will reach the necessary level.

Second, the carbon cost of conventional processes needs to be reflected in product prices such that clean producers can recover incremental costs, and material efficiency, substitution and recycling can benefit from carbon savings. However, so far only a small and uncertain share of carbon cost is passed to material prices, due to the combination of free allowance allocation and international trade of commodities. Full carbon cost internalization is necessary to create the full incentives for climate-friendly options (see Neuhoff and Ritz 2019).

So far, reforms of the allowance allocation attempted in parallel to maintain high levels of free allowance allocation - to secure carbon leakage protection - and to reduce the level of free allocation - to enhance carbon cost pass-through. Achieving these two objectives with one instrument alone has not been possible.

Therefore, a reform of the EU ETS is urgent, and one of the priorities of the new European Commission. Two main options are currently being discussed:

A trade-based approach consists in implementing a Border Carbon Adjustment (BCA) to address carbon leakage risks in combination with a shift to full auctioning of CO₂ allowances to achieve full carbon cost internalization. A variety of options exist for the implementation.

The currently most likely option would only cover imports and might therefore trigger concerns in export-oriented industries about higher costs for materials that they would face compared to international competitors. Hence it would probably result in continued free allocation with low levels of BCA and, in turn, limited carbon cost pass-through and, as a result, persistent regulatory uncertainty. As a border-related approach, it may also trigger international retaliations and challenges under WTO.

An alternative, more comprehensive implementation option would also reimburse the carbon cost in the case of exports. The implementation would likely require a high level of international coordination with some WTO-type agreement to secure robustness to appeals by individual countries. While this option is more likely to deliver a sufficient and effective carbon price, it is unlikely to succeed prior to 2030.

A consumption-based approach, adding a Climate Contribution to the EU ETS, might be more suitable in the short term to create the necessary investment framework (Ismer et al. 2020). It envisages the continuation of EU ETS with benchmark based free allowance allocation as the basis for incentives for climate-friendly production processes. It would be combined with a Climate Contribution, i.e. an excise charge on final sales of basic materials (regardless whether produced domestically or abroad) at the same benchmark that is used for free allowance allocation to producers. Thus, this approach would allow to combine full carbon leakage protection with an effective carbon price signal for all actors along the value chain.

Building on experiences with other consumption charges, a WTO-compatible and administrative feasible implementation is viable also in the short-term.¹³

Life cycle perspective: An additional aspect that has to be taken into consideration concerns emissions caused after the end of life by waste streams. As mentioned in the previous section, most of the plastic used today is incinerated, causing substantial amounts of CO₂ emissions that are currently not covered by EU ETS. Increasing existing advanced disposal fees by the carbon cost of incineration of plastic and returning the revenue in instances of closed-loop recycling could ensure the internalization of these carbon costs and therefore change material choices within the production and packaging industry, as well as increase efforts for recycling of plastic (see examples of fee modulation in Joltreau 2018, Watkins et al. 2017).

A similar situation can be observed with regard to cement recycling: the lack of effective landfill fees disincentives investments into sorting and recycling of construction materials.¹⁴

Reaching technology readiness

53% of the interview partners, among them all of those from the chemical industry, suggested that some of the technologies they did consider have not reached the technology readiness level that would allow for investment in large-scale pilot, demonstration or commercialization projects within the next few years. For these technologies, the scale of required funding tends to be smaller and already better addressed through national and EU programs.

The scale of funding required for innovation increases with large-scale pilots, demonstration and early commercialization projects (Nemet et al. 2018), but few public funding options exist at member state and EU level.

Private firms, at the best of times, can only provide some of these innovation investments, but may struggle to do so if time frames to reach profitability are long, if the scale of required investment is relatively large, if homogeneous products limit the opportunity to create profitable lead markets, and if patents offer limited protection.

In the current crisis, in particular with uncertainty about the time-line and scale of recovery, companies reduce investments, including in innovation. Funding from a recovery package could support firms in taking forward the necessary investments in particular with respect to pilot, demonstration and commercialization projects to secure long-term competitiveness and climate objectives. Even with respect to earlier stage R&D, tough budget constraints may reduce the private co-funding and may warrant additional public support.

Making climate benefits bankable for investors

42% of interview partners considering investments in climate-neutral steel, cement, aluminum and plastic projects stated that regulatory uncertainty is one of the major challenges hindering the transition. The regulatory and political framework needs to ensure carbon prices high enough to justify the operation of climate-neutral production processes with long design life and inherently higher operational costs than conventional processes. Carbon price uncertainty is considered to be a major project risk, and therefore results in large discounts being applied to any future carbon savings for investment and financing choices. This uncertainty creates an option value and incentive to keep any investment decision on hold while waiting for more information on possible carbon price developments.

Government-backed Carbon Contracts for Differences can help investors in innovative clean production and recycling processes to hedge against regulatory risks and cover increased operational costs of climate-neutral processes.

With these contracts, the investors in an innovative low-carbon project (e.g., hydrogen-based steel production or cement recycling processes) are guaranteed a fixed revenue per ton of non-emitted CO₂ when compared to the process delivering the conventional product. As long as CO₂ prices in EU ETS are below this level, the difference is paid by the government. This would however require that corresponding expenditures are matched with additional revenues, e.g. from a Climate Contribution.

If CO₂ prices exceed this level, a corresponding repayment is required from the investor. This creates security for the operation and financing of climate-neutral investments, reduces the financing costs and thus avoids that companies hold back investments until CO₂ prices stabilize at a relatively high level.

Carbon Contracts for Differences reduce the need for public funding or can even ensure that government expenditures are recuperated in later years, when the CO₂ price rises (see Richstein 2017, Sartor and Bataille 2019).

Securing availability of affordable green electricity

58% of the interview partners consider the availability of sufficient affordable green electricity as a major challenge for the deployment of climate-friendly material production processes. Public auctions of Renewable Contracts for Differences eliminate regulatory uncertainties and allow project developers to secure low-cost financing and can thus reduce power generation costs by 30%. The provisions of such contracts can be passed on to energy consumers. With lower electricity costs, lower carbon price levels are required for climate-neutral technologies to compete with conventional ones (May et al. 2018).

Auctions for publicly backed Renewable Contracts for Difference or for publicly backed Power Purchasing Agreements also help to accelerate investments in wind and solar energy by eliminating the option value of waiting with the project implementation for favorable power price developments.

This is particularly relevant in times of high uncertainties about the evolution of power demand and with declining credit rating of counter parties to private Power Purchasing Agreements.

Providing infrastructure

37% of interview partners consider the provision of transport infrastructure for hydrogen, power and CO₂ as a major challenge for the transformation towards climate-friendly basic material processes. The development of this infrastructure is however inherently uncertain due to lack of understanding of the importance of climate neutrality. Therefore, it is crucial that policy signals are clear and credible, for example measures are put in place today that ensure long-term credibility.

Securing secondary material flows

All firms working on sorting and recycling emphasized that the variations of content and volumes in waste streams are a challenge for their use as input to industrial production processes. It was frequently mentioned that a particularly promising measure would however be to increase the digitization of sorting and recycling plants, which would allow for a better knowledge of, monitoring and optimization of material flows, as well as offer opportunities along the value chain. Already small (not very investment-intensive) measures involving digitization can potentially achieve large efficiency gains.

The quality and economics of closed-loop recycling declines with an increasing variety of different materials, alloys and additives, used for example in packaging, as they increase the scale of sorting requirements and the number of waste streams that have to be transported and treated. If for example all aluminum cans were to be produced from the same alloy, then sorting or down-cycling could be avoided without loss of value for consumers.

Likewise, for plastics in packaging currently 271 different additives are licensed under the REACH Regulation¹⁵, significantly exceeding the different properties required for the functionality of packaging. Reducing the negative externality that too many alloys and additives impose on the purity and economics of closed-loop recycling may warrant a coordinated approach, e.g. based on the Eco-design Directive.

Creating demand for climate-friendly and recycled materials

Several of the respondents see the transition period towards climate-friendly processes in the basic material sector as a classic "chicken and egg" problem. Without sufficient demand for climate-neutral products, there is limited investment in enhanced sorting and recycling capacity and clean production processes, which in turn implies that private companies are reluctant to commit to the use of such climate-friendly material options. This was particularly considered to be a challenge by interview partners active in sorting and recycling.

Labeling and standards can help to trigger low-carbon choices from climate-aware private consumers. However, the level of climate ambition of many European labels and standards is currently relatively low, as most of their focus lies on safety and functionality rather than environmental considerations (Gerres et al. 2019b).

Therefore, standards like the Eco-design Directive need to be revised and aligned with policy objectives of closed-loop recycling, enhanced repair and reuse, for example including clear mandatory requirements on product lifetime, reparability (e.g. availability of spare parts and repair information), and climate-neutral production processes. However, where materials are embodied in complex products or infrastructure, the effect is likely to be limited.

Quotas may oblige companies to use an increasing share of recycled materials (recyclates) in their production processes.

This would give sorting and recycling companies more security for investments in enhanced sorting capacity, which was argued to be a challenge across all interview partners active in sorting and recycling. As of today, such quotas are only adopted for recycled content in plastic beverage bottles (25% recycled plastics content by 2025 and 30% by 2030¹⁶).

Furthermore, the European Commission envisages further recycled content requirements in other plastic packaging, construction materials and vehicles (EC 2020). At the same time, some companies have already committed to such quotas on a voluntary basis.¹⁷

In the longer-term, governments can define the market for climate-neutrally produced materials through product carbon requirements by setting near-zero emission limits for the production of materials to be sold within a jurisdiction. Already the announcement of product carbon requirements can provide incentives for investments in climate-friendly options (Gerres et al. 2019b)

Green Public Procurement can ensure that sustainable aspects are the driving criteria for government purchases. In particular, Green Public Procurement plays an important role for guiding the green recovery post Covid-19, e.g. through the commissioning of infrastructure projects (e.g. railway) as well as measures to reduce the impact of climate changes, such as coastal protection, which are typically both material- and labor-intensive. Climate-friendly procurement practices that take into account the emissions embedded in materials allow public purchasers to leverage their purchasing decisions not only to reduce the carbon footprint of the projects in the scope of the recovery package but also to create lead markets for low-carbon materials, enhanced use of recycled materials and material efficiency in product design, construction and manufacturing (see Chiappinelli et al. 2019, Kadefors et al. 2019).¹⁸ By increasing the visibility of low-carbon options, Green Public Procurement can also trigger a behavioral effect in the economy, including influencing private procurement patterns. In the context of a green recovery this can be relevant for the climate-friendly implementation of projects such as wind farms and recycling plants. By supporting local projects on innovative sorting systems and recycling plants, procurement can also help creating additional local jobs.

Conclusion

Supporting investments in climate-friendly material production and recycling as part of the Covid-19 recovery package can both contribute to the short-term objectives of revitalizing the economy and creating jobs, as well as catalyze the transformation towards enhanced resilience of value chains and the climate neutrality of the economy.

The interviews across four of the main basic materials sectors, steel, cement, chemicals and aluminum, have illustrated that a portfolio of investment options is shovel-ready within the time frame relevant for the economic recovery. This includes large-scale demonstration plants for climate-neutral production processes for steel, cement and climate-neutral heat supply to chemical production, as well as piloting of new processes for aluminum and basic chemicals. Across all sectors, interview partners emphasized the big opportunities that result from a combination of enhanced sorting technologies and digitization of the management of waste streams, and, in the case of plastic and cement, novel recycling process technologies.

While the technology readiness varies across the different sectors, a resounding message across the interviews we conducted was that public funding could dramatically speed up the deployment of these technologies. Realizing the pilot, demonstration and commercialization projects discussed in the interviews for the different sectors and across climate-neutral production as well as sorting and recycling technologies in the EU would involve overall investments at the scale of about 30 billion Euro. Public innovation funding and investment support would in many cases be essential, even more so with the costs and uncertainties the Covid-19 crisis imposes on firms.

The recovery package of 750 billion Euro proposed by the EU Commission for the period from 2021 to 2024 can go a long way in addressing some of these funding needs.

At the EU level, the budget increase of Horizon Europe by 13 billion Euros can help to support additional pilot plants while the budget increase of the Investment Plan by 30 billion Euros may be more suited to support larger scale demonstration plants. The enhanced Just Transition Mechanism can empower industrial regions to pilot the adjacent infrastructure needed, while supporting training and coordination efforts to support the transition to climate-neutral production processes, materials and enhanced closed-loop recycling. The Strategic Investment Facility to generate investments of up to 150 billion Euro in strategic value chains may help to empower basic material producers to pursue much-needed investments to secure a longer-term perspective even at the times of the economic crisis.

The majority of the EU recovery funding will be dedicated to the Recovery and Resilience Facility (560 billion Euros) and made available to member states. With their national recovery and resilience plans, member states can determine the allocation of these funds – and can thus focus on activities to build on the strengths of their national economies. The various dimensions of sorting and recycling technologies seem particularly suitable for all EU member states as a foundation for local resource supply and jobs. So are dedicated strategies to shift to climate-neutral production processes and corresponding infrastructure.

In the case of innovative investments, it may be appropriate to combine direct EU innovation and investment funds that cover incremental investment costs with member states funding windows (including as part of the Recovery and Resilience Facility and Just Transition Fund).

The EU taxonomy, currently finalized as part of the sustainable finance agenda, as well as reporting on pathways to climate neutrality could strengthen the alignment of EU funding with European policy objectives and enhance long-term resilience.

However, grant support alone will be insufficient. A suitable policy framework that provides a business case for investments for the medium to long term is necessary to unlock private initiative, and attract capabilities and resources.

When asked about the main challenges to unlock investments, 79% of the interview partners referred to a lack of cost competitiveness of climate-neutral production and closed-loop recycling with conventional production processes both domestically and abroad. Climate-compatible investments require effective carbon pricing that ensures that (i) carbon cost is internalized along the value chain, and (ii) carbon prices can increase without triggering carbon leakage risks. A timely reform of the EU ETS addressing these objectives seems warranted, and requires complementing the EU ETS either with a Border Carbon Adjustment or a Climate Contribution. As the speed of implementation will determine the speed of project realization, a pragmatic approach based on a Climate Contribution may be warranted. Furthermore, carbon emissions at the end of product life, e.g. from incineration of plastic, need to be priced to encourage closed-loop recycling. This could be implemented extending for example existing advanced disposal fees.

Furthermore, 42% of respondents called for mechanisms to make carbon savings across the project life bankable, e.g. relevant for investment and financing choices. Project-based Carbon Contracts for Difference can achieve this objective and thus reduce the carbon price level and grant support required for climate-friendly projects to break even.

For 58% of the respondents sufficient availability of affordable green electricity is a major challenge and points to the importance of a continued policy focus on renewable deployment. With auctions for publicly backed contracts for difference or for publicly backed power purchasing agreements, some drivers for project delays and risks contributing to increased financing costs can be avoided.

Provision of infrastructure – including for power and hydrogen delivery, CO₂ transport and collection and recycling of materials was mentioned by 37% of respondents as a key challenge that governments need to address to unlock investments in climate-neutral production processes.

Finally, effective roll-out of the low-carbon production processes and circular economy options require not only appropriate economic incentives and infrastructure, but also a regulatory framework which enables the deployment of innovative technologies and business models. These include rules, norms and standards relevant for the hydrogen economy, closing the loop and upcycling of waste streams. For example, to realize the economic benefits of closed-loop recycling, interview partners involved in recycling explained the benefit of reducing and labeling the large variety of materials used, in particular in the context of packaging, so as to allow for purer sorting and improved handling of more concentrated waste streams.

The EU Green Deal and Circular Economy Action Plan comprise several policy initiatives that could in principle allow for a rapid implementation of an EU ETS reform to ensure cost competitiveness of climate-neutral technologies and recycling relative to conventional processes. Revising the EU Renewable Directive and the revision of the EU Energy and Environment State Aid guidelines in 2021 will also be an important enabler to make projects bankable and facilitate access to sufficient amounts of affordable green energy. Finally, the Eco-Design Directive could help to limit material variety to options required to meet functional requirements and thus enhance the economics of closed-loop recycling.

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Endnotes

- 1 16 out of 24 interviews were with management of primary production of steel, cement, aluminum, and chemicals companies; 5 with technology suppliers (3 for sorting, 1 for cement and 1 for steel plants); and 3 with associations. The interviews were conducted by phone from 11th of May until 17th of June 2020.
- 2 A number of steel producers have already initiated their own R&D projects and pilot plants are in construction or already operating e.g. in Sweden, Austria and Germany (Mistra Carbon Exit 2020a, Agora Energiewende and Wuppertal Institute, 2019).
- 3 In Europe, projects piloting carbon capture in cement plants exist e.g. in Norway, Germany and Belgium. Additionally, the technology has already been extensively tested in power plants (Mistra Carbon Exit, 2020b, Agora Energiewende and Wuppertal Institute, 2019).
- 4 Pilot projects testing the use of CO₂ to produce feedstocks (such as methanol) are underway e.g. in France and Germany (Agora Energiewende and Wuppertal Institute, 2019).
- 5 Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of eco-design requirements for energy-related products (Text with EEA relevance)
- 6 In the plastics recycling value chain, recycling labor-intensity is 30 times higher than energy recovery and landfilling (Hestin et al. 2015). Milios et al. (2018) estimates that 560 net direct jobs would be created in Sweden with the fulfillment of existing targets for plastics, but three times more if adding an incineration ban. In addition, high-quality and competitive recycling activities secures inputs and thus jobs of industries.
- 7 It is important to notice that these numbers refer to current recycling practices. Improved and modernized practices may have a lower labor intensity (and require less unskilled labor) but may allow for higher value use of the recyclates, thereby contributing to additional jobs.
- 8 For re-melting aluminum the electricity use per ton aluminum produced is 0.12-0.34 MWh, compared to 14-16 MWh for primary smelting (Wyns and Khandekar, 2019).
- 9 For example, in Germany, the available scrap accounts for half of the total aluminium supply - around 30% of this scrap is exported however (UBA 2019).
- 10 A range of pilot, demonstration and commercialization projects exists across Europe, e.g. in the Netherlands, Denmark, Italy, Austria, Spain and Germany (Agora Energiewende and Wuppertal Institute, 2019, Williams and Burrige 2019).
- 11 Estimates are based on the feasibility assessment obtained through the interviews (i.e. scale of potential deployment until 2025) and investment costs suggested in the literature and by interview partners. Technologies which are still at an early stage of development (e.g. direct electrolysis of steel) are not included in this quantification, but are still expected to require additional funding for R&D and pilot projects over the next years. Additionally, investment volumes for infrastructure, green hydrogen capacity and the decarbonization of process heat supply in the chemical sector are not in the scope of our analysis.
- 12 Challenges for the implementation of enhanced sorting technologies are not reflected in this ranking, and are instead indicated throughout the discussion on policy needs below.

- 13 *A detailed analysis of economic, administrative and legal aspects is available at <https://climatestrategies.org/projects/inclusion-of-consumption-in-emissions-trading/>.*
- 14 *While a landfill tax exists in many countries and the UK, the Netherlands and Belgium have a good spread of recovery facilities, there are hindering factors such as weak implementation, illegal fly-tipping etc.*
- 15 *Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH).*
- 16 *Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment.*
- 17 *In an initiative led by the Ellen MacArthur foundation in cooperation with UN Environment, for example, close to 200 businesses (representing over 20% of global plastic packaging use) have committed themselves e.g. to use on average at least 25% recycled in their plastic packaging, with some individual companies even committing to much higher rates (Ellen MacArthur Foundation & UN Environment, 2019).*
- 18 *Best practices in the low-carbon procurement of infrastructure include in tenders a shadow carbon price or functional requirements that leave flexibility to the suppliers on how to achieve emission reductions. Often these measures also lead to a decrease in cost relative to the BAU case ("cut emissions- cut costs"). Green Public Procurement can also facilitate the coordination along value chains, e.g. between design and construction phase, so that larger mitigation potentials can be detected and realized.*

