Mobilising the circular economy for energy-intensive materials

How Europe can accelerate its transition to fossil-free, energy-efficient and independent industrial production

STUDY

Agora
Industry

MATERIAL
ECONOMICS

Mobilising the circular economy for energy-intensive materials

PUBLICATION DETAILS

STUDY

Mobilising the circular economy for energy-intensive materials

How Europe can accelerate its transition to fossil-free, energy-efficient and independent industrial production

IMPLEMENTED BY

Agora Industry
Anna-Louisa-Karsch-Straße 2 | 10178 Berlin
T +49 (0)30 700 14 35-000
F +49 (0)30 700 14 35-129
www.agora-industry.org
info@agora-industrie.de

SUPPORTED BY

Material Economics
Per Klevnäs and Anders Falk

PROJECT MANAGEMENT

Nelly Azaïs, Oliver Sartor

AUTHORS

Oliver Sartor (lead), Nelly Azaïs,
Helen Burmeister, Paul Münnich,
Camilla Oliveira, Wido Witecka

Typesetting: Karl Elser Druck GmbH
Proofreading: WordSolid
Title picture: istock, Mike Kiev

254/03-S-2022/EN
Version: 1.0, March 2022

ACKNOWLEDGEMENTS

We would like to thank all Agora colleagues who made this project possible, in particular Nikola Bock, Robin Emelin, Mathias Fengler, Anita Gianelli, Urs Karcher, Maxi Matzanke, Paul Münnich and Ada Rühring for their support; Matthias Buck, Murielle Gagnebin, Simon Müller, Frank Peter and Jesse Scott for their comments. We are also grateful to all the workshops' participants and external reviewers for their insights, in particular Stéphane Arditi, Per Klevnäs, Michael Neaves, Donal O'Riain, Julie Paquay, Federica Pozzi, Adela Putinelu, Cloé Ragot, Zsolt Toth, Janek Vahk and Jonathan Volt. These experts do not necessarily endorse the findings of this report.

Agora Industry is solely responsible for this study and the conclusions and recommendations thereof. This study contains assumptions made by both Agora Industry and Material Economics. These assumptions are subject to uncertainties, and this report is provided without guarantee as to its accuracy or completeness.

Please cite as:
Agora Industry (2022): Mobilising the circular economy for energy-intensive materials. How Europe can accelerate its transition to fossil-free, energy-efficient and independent industrial production.

www.agora-industry.org

Preface

Dear reader,

The impacts of Russia's war on Ukraine have dramatically accelerated the urgency for Europe to phase down its use of fossil fuels, be more energy efficient and reduce the dependence of critical domestic industries. Key will be the transition of European industry to fossil free production based on domestic resources. 70 percent of EU industrial emissions come from the production of a few key carbon-intensive materials: iron and steel, aluminium, cement and lime, and plastics. These activities also account for a large and growing share of EU energy, and fossil fuel, consumption.

Existing approaches to the industrial transition tend to focus on reducing the carbon intensity of *virgin materials* production. However, the current European context requires a new approach maximising both industrial energy and resource efficiency with the same level of importance. Increasing and improving closed-loop recycling and developing more material-efficient value chains will be essential. Furthermore, it will play to the EU's long-term competitive economic strengths, such as digitalisation, logistics and advanced manufacturing technologies.

Material circularity and efficiency would not only reduce the economic costs of the transition but also ensure that the industrial transition is technically and politically feasible within the 2050 timeframe.

I hope you find this report stimulating.

Yours sincerely,

Frank Peter
Director, Agora Industry

Key findings at a glance:

1 **The current energy crisis makes it imperative to reduce the EU's dependency on fossil fuels and imported raw materials.** Industrial production of virgin plastics, steel, aluminium and cement alone accounts for 13 percent of yearly energy consumption and 581 Mt of annual emissions. The EU also imports very large amounts of gas, oil and coal to produce plastics and other energy intensive materials.

2 **Enhanced recycling and greater material efficiency hold enormous untapped potential for the transition to a fossil free production of energy-intensive materials, in both the short and long run.** With ambitious policies, annual EU industrial emissions could be reduced by up to 10 percent (70 Mt) by 2030 and by 34 percent (239 Mt) by 2050 compared to 2018 levels. Plastics production alone could avoid using fossil fuels equivalent to roughly 2.7 billion cubic metres of gas and 149 million barrels of oil annually by 2030.

3 **Realising these abatement and savings potentials must be a priority in the EU's new Circular Economy legislation. To synchronise energy security and climate neutrality, this legislation must spur demand for high quality recycling while boosting collection and supply of high quality recyclates.** Required policy instruments are *expanded quotas* for recycled content; *investment aid* for rapid deployment of innovative recycling technologies; as well as *labelling* and *best practice mandates* for collection, sorting, recycling and re-use.

4 **EU Member states can now implement key policy measures that effectively reduce greenhouse gas emissions already within the next 1 to 5 years.** Examples are wider bans on single use and non-recyclable plastics, the implementation of deposit-refund schemes for plastic packages, investments into ex-post re-sorting and state of the art recycling practices.

Contents

List of figures and tables 7

A "both-eyes-open" strategy for climate-neutral industry 9

1 The circular and resource-efficient economy: the "energy efficiency" of the industrial transition 13

2 CO_2 abatement levers, potentials and enabling conditions 25
  2.1 Potentials for enhanced recycling 25
    2.1.1 Steel 25
    2.1.2 Aluminium 29
    2.1.3 Plastics 32
    2.1.4 Cement and concrete 39
  2.2 Material efficiency 45
  2.3 Section summary 48

3 Nine policy options for the European Green Deal 53
  3.1 A need for twin "demand-creation" and "supply-enabling" policies 53
  3.2 Creating markets for circular and resource efficient products 53
    3.2.1 Mobilise carbon pricing incentives more effectively 53
    3.2.2 Quotas to kick-start markets for high-quality circular materials 55
    3.2.3 Embedded carbon limits on final products 58
    3.2.4 Product standardisation mustn't be a barrier to market entry for proven and safe technologies 60
  3.3 Enabling policies to increase the supply of high-quality recycled materials 60
    3.3.1 Measure recycling rates correctly 60
    3.3.2 Support the deployment of innovative circular materials technologies 61
    3.3.3 Best-practice requirements for separate collection and post-collection sorting and recycling 62
    3.3.4 Labelling, taxing or banning inefficient product design and waste management practices 63

4 Conclusions 65

5 Table of abbreviations 67

6 References 69

List of figures and tables

Figure 1 Industry share of total greenhouse gas emissions in the European Union in 2018 9
Figure 2 Additional power needs for the direct and indirect electrification of steel, cement and chemicals 13
Figure 3 Cement sector production capacities – locations across Europe 15
Figure 4 What is a circular and resource efficient industrial sector and how does it reduce CO_2 emissions? 16
Figure 5 CO_2 intensity factors of virgin (primary) vs. recycled (secondary) production routes (global averages) 17
Figure 6 Additional power needs for the decarbonisation of steel, cement and chemicals (high vs. low circularity scenarios) 18
Figure 7 Estimated low-carbon investments costs, new processes-dominant scenario versus enhanced circular economy scenario 19
Figure 8 Average CO_2 abatement costs for steel, cement and plastics under two scenarios 20
Figure 9 Share of emissions from the most CO_2-intensive basic materials by product value chain 22
Figure 10 Steel production, use and recycling statistics in the EU, 2019 25
Figure 11 Copper tolerances of different steel products 27
Figure 12 Production, use and end-of-life of aluminium products in the EU 30
Figure 13 Production, use and end-of-life management of plastics in Europe, 2019 33
Figure 14 Comparing reported recycling rates and actual recycling rates for plastics 34
Figure 15 How the end-of-life treatment of plastics could evolve in a high circularity scenario 36
Figure 16 Cement production, use and end-of-life statistics 40
Figure 17 The carbon footprint of clinker, cement and concrete 42
Figure 18 Estimated CO_2 abatement potentials from enhanced circularity and material efficiency by material or product in 2030 49
Figure 19 Estimated CO_2 abatement potentials from enhanced circularity and material efficiency by material or product in 2050 49
Figure 20 Comparison of costs for enhanced circularity solutions vs. current virgin production methods 54
Figure 21 Comparison of plastics demand vs recycled plastics demand 56
Figure 22 Impact of recycled content quotas on demand and value of recycled PET plastics 57
Figure 23 Embedded life-cycle emissions reductions required in new buildings under French RE2020 law 59

Table 1 Estimates of CO_2 reduction potentials from the main plastic circularity solutions 37
Table 2 Summary of main enhanced circularity, material efficiency and substitution levers and their technical CO_2 abatement potentials 51
Table 3 Possible practices to be labelled, taxed or banned 63

A “both-eyes-open” strategy for climate-neutral industry

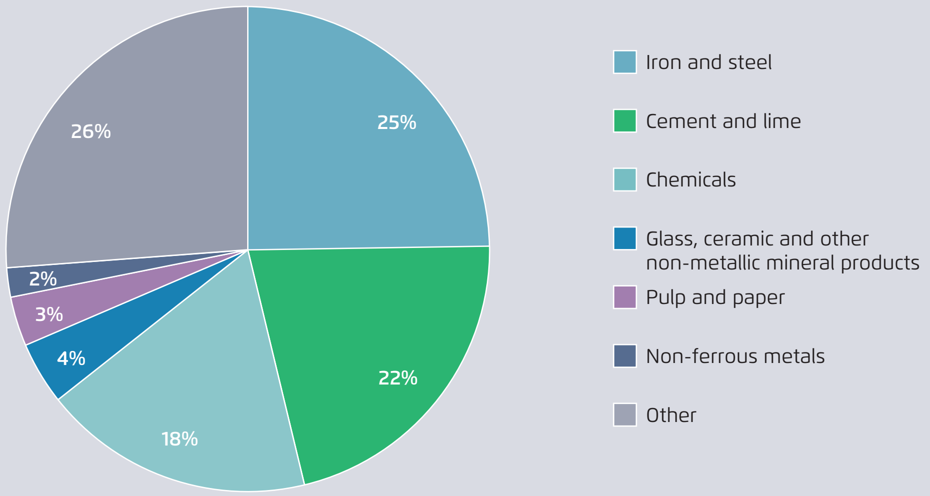
There is a growing focus on the need to accelerate the transition to climate-neutral industrial production. In November 2021 the COP26, saw new announcements of governments and private sector actors committing to buy or sell lower-carbon CO_2-intensive basic materials like steel and cement. The G7 announced plans to discuss the formation of an international carbon alliance, or “club” in the first half of 2022. The European Green Deal, together with an increasing number of new national commitments in Europe, has brought new proposals to promote low-carbon industrial production technologies and feedstocks (such as hydrogen).

These developments are welcome. Greenhouse gas (GHG) emissions from industry represented approximately 708 Mt of CO_2 in 2018, or 20 percent of the total annual net GHG emissions from the European Union. As Figure 1 shows, around 65 percent of these emissions came from the production of just a few key materials, namely iron and steel, cement and lime and basic chemicals (many of which are used for plastics production).

As such policies emerge, however, it is crucial that they add up to an overall strategy that is consistent with a viable pathway to climate neutrality by 2050. Decarbonising energy intensive industries is a difficult task. This paper argues that the emerging approach to decarbonisation is unduly lopsided. So far, policy discussions and proposals have focused most of their attention on reducing the CO_2 intensity of *virgin materials*, such as low-carbon primary steel and cement. Meanwhile, the need to reduce emissions

Industry share of total greenhouse gas emissions in the European Union in 2018

Figure 1



Agora Industry, based on data from UNFCCC (2018) by producing less virgin material – i.e. by developing more circular and resource-efficient value chains for products such as steel, aluminium, cement and plastics – has largely been forgotten.

The impacts of Russia's war against Ukraine, on the EU's border, have also raised the stakes for European energy and climate policy. While climate mitigation remains urgent, the current security and energy crises have underscored how dependent Europe is on imports of fossil fuels and other critical raw materials. The EU must therefore accelerate its efforts *not only* to reduce its fossil fuel imports, but also to make *smarter and more efficient use* of its limited domestic energy and material resources.

In this context, policies to enhance circularity and material efficiency must become a central part of the EU's strategy to transition to climate neutral industry. Doing so would not only accelerate the shift to fossil free production of basic materials, it would also make industry more resource efficient and strategically autonomous.

Sectors such as steel, aluminium, plastics and cement are not only CO_2 intensive, but also highly *energy and resource* intensive. In 2020, industry accounted for 26 percent of total EU final energy consumption, of which these four sectors alone accounted for approximately 50 percent (i.e. 13 percent of total final energy consumption). They consumed 41 million tonnes of oil equivalent (Mtoe) worth of natural gas, 14 Mtoe worth of oil products, and 9 Mtoe of solid fossil fuels, such as coking coal. A more circular and material efficient basic materials sector would thus be much more efficient. Recycled steel, aluminium or poly-ethyelene (PE) products can reduce energy consumption by a factor of between 5 and 17 compared to today's primary production processes (depending on the processes involved). The EU also currently imports large shares of basic materials, such as aluminium, ethane, ammonia and fertilisers, from Russia and other potentially unstable regions of the world.

Of course, some energy-intensive sectors have already incorporated some circularity into their value chains. For instance, there are relatively high rates of steel and aluminium recycling (although most is downcycled). During the past 15 years, the cement sector has begun to incorporate mixed waste for incineration as a heat source. However, as this paper explains, these measures do not reflect the full potential of the circular economy by any stretch of the imagination. What is needed now is a renewed industrial strategy to bring circular economy solutions to the next level.

This paper argues that failing to activate the enormous additional potential of the circular economy in Europe would be a major mistake. This argument has three levels:

1. **The circular economy can accelerate the achievement of climate, energy and environmental goals:** The pace and depth of decarbonisation efforts can be significantly increased by taking circular-economy and material-efficiency levers more seriously. In fact, as we argue in the following section, there is a good argument that achieving our climate goals in the industrial and energy sector will be technically, economically and politically unfeasible without significantly increasing the efficiency and re-use of materials.

2. **The circular economy is an essential part of an effective industrial strategy for autonomous and competitive energy-intensive industries:** The current energy price crisis, and the coronavirus crisis before that, have highlighted the need for majority domestic control over key industrial inputs to achieve industrial competitiveness. Our analysis shows that there is a clear industrial long-run competitive business case for combining climate-neutral virgin materials production with a much more ambitious use of the EU's large and growing scrap supply and new digital technologies to maximise circularity and

material efficiency potentials. Recent investment decisions by progressive European steel companies, such as SSAB[1] reflects steps in this direction already.

3. **The circular economy can be a key driver of green and digital innovation, investment, employment for modernised and competitive industrial value chains:** As noted throughout this paper, a range of highly advanced, innovative, and digital technologies will be needed to make a genuinely circular industrial value chains a reality. The EU can build new businesses and high-tech products in areas where European companies can play to their competitive strengths. These areas include digitalisation, logistics, additive manufacturing and other cutting edge technology development, industrial collaboration, new business models based on material services and policy-induced market creation.

This paper has three aims. Section 1 lays out the argument that the circular economy can contribute significantly to, and is essential for, the success of the transition to a climate-neutral industry in Europe. Section 2 helps to clarify exactly which CO_2 abatement potentials for the circular economy are likely to be the largest – both in the short and the long term. It outlines a quantitative analysis to help identify the massive scale of the potential in the circular economy for CO_2-intensive materials and the conditions to realise them. Finally, section 3 discusses concrete policy options to enable innovative businesses and newly created markets for realising these potentials.

---

[1] See https://www.ssab.com/news/2022/01/ssab-plans-a-new-nordic-production-system-and-to-bring-forward-the-green-transition?utm_source=twitter&utm_medium=social&utm_campaign=communications_ffs&utm_content=nordic_si

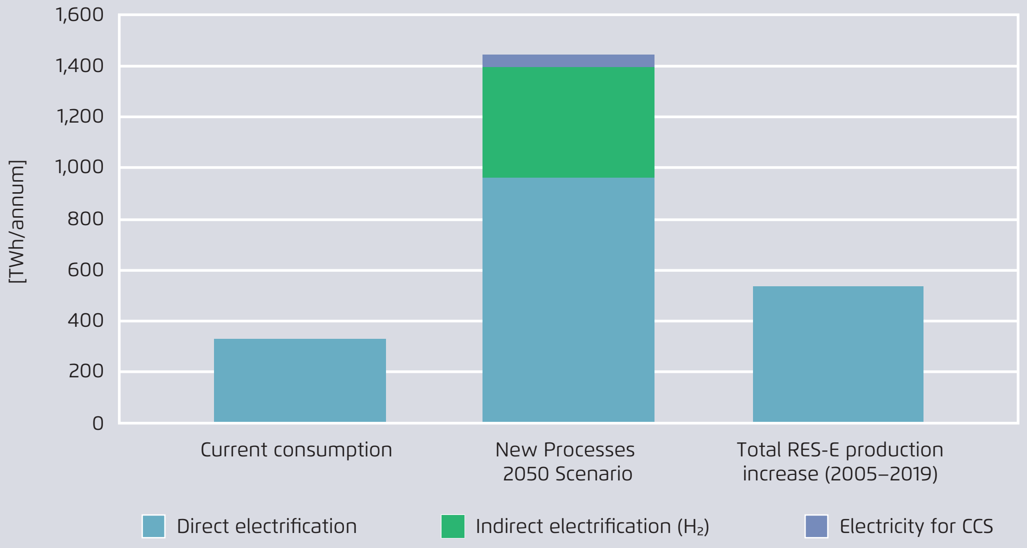
1 The circular and resource-efficient economy: the “energy efficiency” of the industrial transition

A risky strategy
A strategy focused only on new lower-carbon technologies for decarbonising virgin material production has a high likelihood of failing to deliver a European climate-neutral industry by 2050. The main reason for this is that European industry faces significant constraints in moving forward with decarbonisation to a level consistent with achieving climate neutrality by 2050. These constraints are likely to be much easier to overcome if the quantity of *primary* materials that need to be produced can be managed via more circular and resource-efficient industrial value chains.

One of the main constraints facing the *current* approach to climate-neutral European industrial production is that it requires very significant, and in some cases, potentially unrealistic levels, new infrastructure development. The demands are most immediately apparent in the electricity sector, where the combination of direct and indirect electrification of industrial processes is expected to add massively to industrial power consumption. For instance, scenarios run by Material Economics in 2018 estimated that by 2050, if strong circular economy policies are not pursued, industrial carbon-free power consumption for the steel, cement and chemicals sectors *alone* could be as high as 1443 TWh per annum (Figure 2). To put this in perspective, these sectors currently consume only around 333 TWh per annum (not counting the rest of industry).

To understand how large this is, consider that the growth in renewable electricity production in Europe between 2005 and 2019 has only added 538 TWh of

Additional power needs for the direct and indirect electrification of steel, cement and chemicals Figure 2



Agora Industry, based on data from Material Economics (2019), Eurostat (2021) additional production during this 15-year period. Adding an additional 1100 TWh of renewable power just for the purposes of supplying industry – and while also electrifying transport, heating and cooling in buildings, and producing hydrogen for the purposes of stabilizing power supply – is therefore going to be a very challenging equation.

In fact, the central scenario of the European Commission's Long-term Strategy for a Climate-Neutral Economy from 2018 suggests that total installed electricity generation capacity would need to increase in the order of 180 percent between 2015 and 2050 in order to electrify all the relevant end -usages[2] In this context, it is easy to see how, if industry chooses a more energy intensive pathway, it may be difficult for the EU to install sufficient, and affordable, renewable-based power. While partial imports of hydrogen could help, they would not change the fundamental equation that a large share of electricity will need to be generated in Europe. (Moreover, the more the EU imports, the less low-carbon hydrogen will be available for the decarbonisation efforts of other large economies.)

Similar challenges exist for other forms of infrastructure. Consider carbon capture and storage (CCS). Many scenarios for the decarbonisation of the cement sector still include a role for very large amounts of CCS. For instance, Cembureau's climate neutrality roadmap suggests that over 50 percent of emissions reductions from cement and clinker production by 2050 would come from CCS and carbon capture and use (CCU) (Cembureau, 2020). In practice, however, such a strategy implies very challenging infrastructure requirements. While CCS and CCU technologies undoubtedly have a role to play in the decarbonisation of the cement sector (Agora Energiewende, 2020), major challenges – public support, technical and economic barriers – stand in the way of connecting such a large share of EU clinker and cement production to CCS or CCU infrastructure. These problems are made harder by the fact that the cement sector's production is spread across the entire European continent (Figure 3). Sites suitable for CCS require specific geological configurations(generally either near the coastal areas or major inland riverways to allow for offshore carbon storage).

Another key constraint on the transition to climate-neutral industry is that key natural and material resources are limited. Most notably, biomass will be required to provide non-fossil carbon sources, generally in the form of biogas (or its derivatives such as bio-naptha), for the production of climate-neutral virgin chemicals or steel. However, while necessary as a partial solution, the availability of sustainable biomass is likely to be limited, and several scenarios suggest that demand could massively outstrip supply. For instance, Material Economics (2021) has estimated, based on key demand scenarios for achieving a climate-neutral energy system by 2050 in the EU, a 40–100 percent surplus demand relative to the plausibly available supply.[3] The same report also noted that increasing imports of sustainable biomass by such amounts may be difficult. These conclusions remain valid even if one includes non-"virgin" biomass sources such as organic waste and methanisation solutions.

These scenarios suggest not only that biomass use needs to be limited to no-regret end usages (as an input in materials production, say) but also that the lower European industry demand for biomass is, the less strain would be placed on this limited natural resource.

In short, the scale of the challenges induced by focusing almost exclusively on decarbonising existing production processes for *virgin* or *primary* materials raises significant risks that the transition will not be achieved at the necessary scale or in the necessary

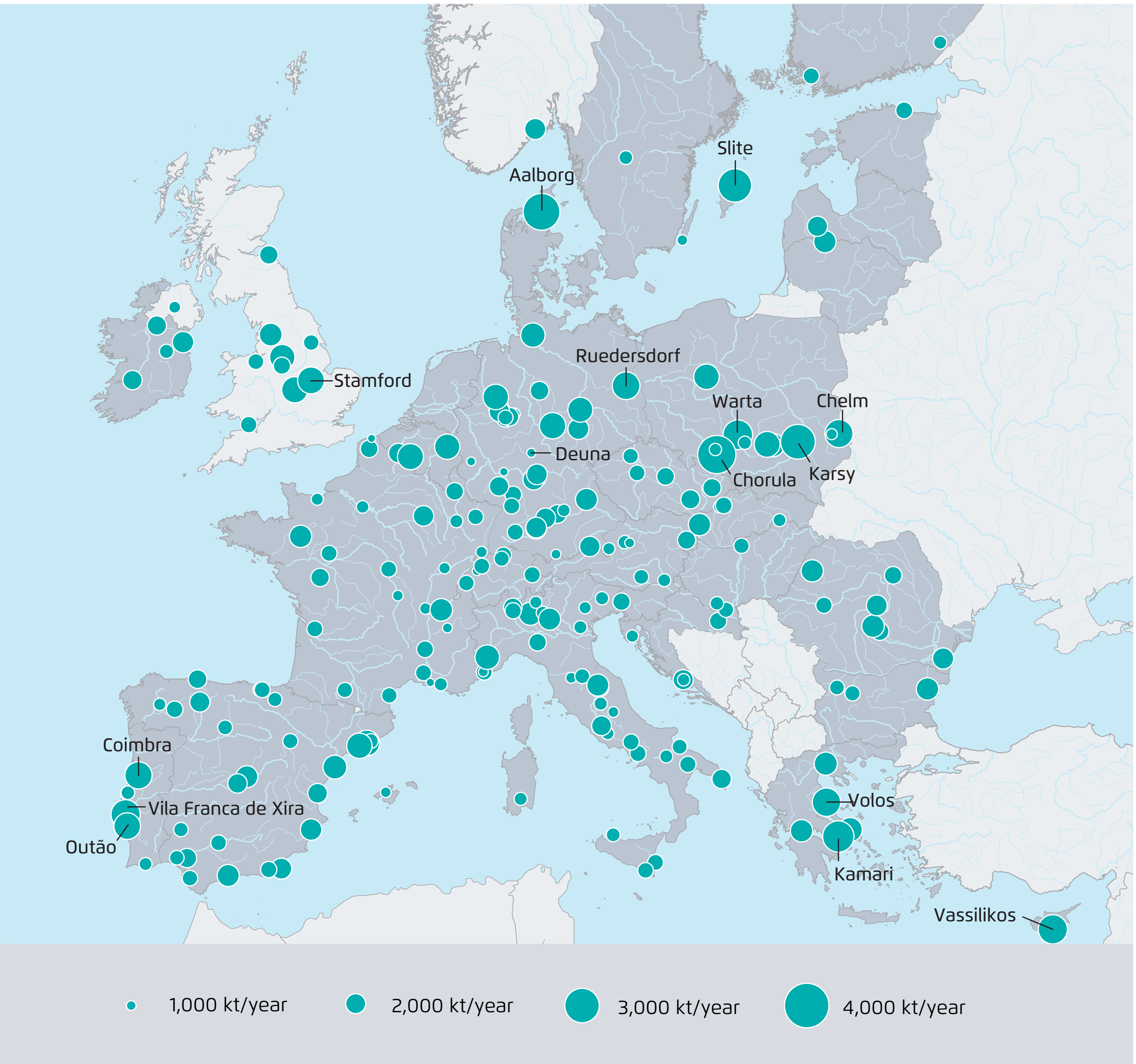
---

[2] European Commission (2018 B): In-depth Analysis in Support of the Commission Communication COM (2018) 773 "A Clean planet for all: A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy". See in particular p. 77, TECH1.5 Scenario.

[3] See Material Economics (2021): "EU Biomass use in a net zero economy", p. 26.

Cement sector production capacities – locations across Europe

Figure 3



Note: Green dots represent cement production sites, while sizes reflect capacity levels

Agora Industry, based on Wuppertal Institute data (2020)

timeframe. The EU or industrial sectors – even those with *notionally* high recycling rates today should not think that their current level of material circularity will be sufficient to reach European 2050 climate goals.

A strategy focused primarily on virgin material production is risky not only from an environmental perspective. It also represents a structural risk to European industry's long-term business strategy. It is increasingly clear that the European industry wants to insulate itself from future risks to its market share and its regulatory costs by decarbonising its production. But if industrial sectors do not have technically feasible options to decarbonise at the desired rate due to the above-mentioned constraints, then they will be unable to mitigate the risks effectively.

By contrast, the circular economy has the ability to unlock substantial economic value, investment and jobs, as supplying sustainable materials and products will increasingly become an arena for commercial competition between industrial product manufacturers.

Circular economy is an essential component of the industrial climate-neutral transition

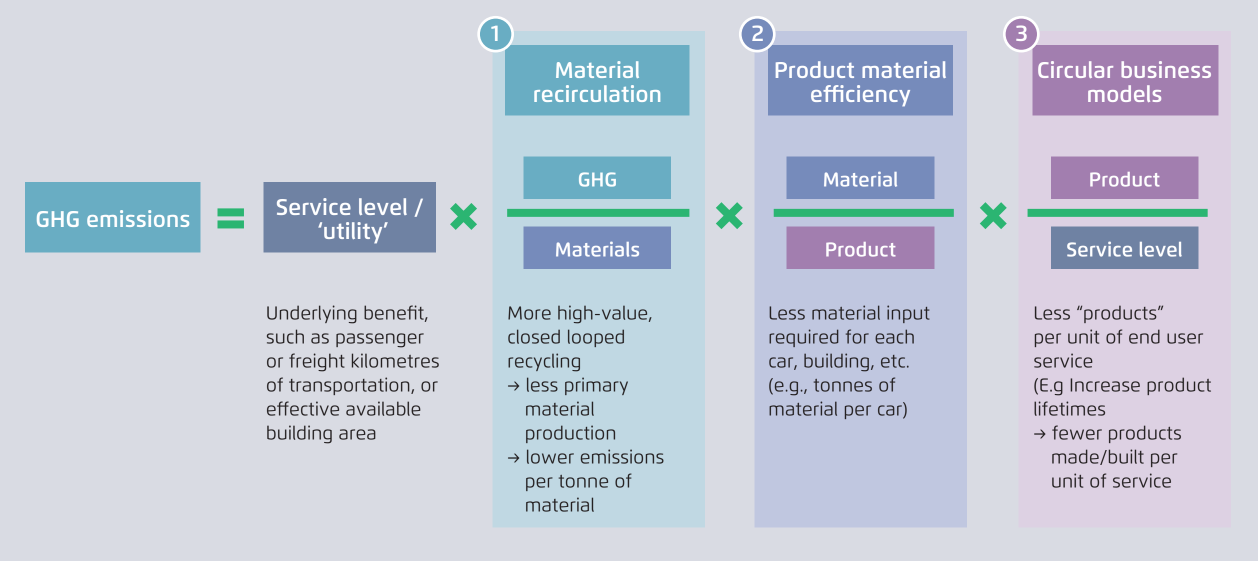
Including a stronger role for circular economy and materials efficiency in the policy toolbox for the most CO_2-intensive materials would allow European industry to significantly reduce the scale of the challenges described above. But what exactly is a "circular and resource-efficient" economy and how should we understand the main ways it can contribute to reducing CO_2 emissions reductions?

What is a circular economy for CO_2-intensive basic materials?

A basic answer to this question is illustrated in Figure 4. Greenhouse gas (GHG) emissions from basic materials production and use are a function of the amount of services or "utility" provided to consumers, multiplied by the GHG emissions per unit of materials produced, by the amount of materials consumed per unit of product produced and by the amount of products consumed to provide the demanded level of consumer services. Generally speaking, it is not a desirable policy goal for governments to reduce the level of economic services to consumers (although some special case exceptions exist[4]).

However, it is possible to reduce GHG/material ratios in various ways. With regard to the circular economy,

What is a circular and resource efficient industrial sector and how does it reduce CO_2 emissions? Figure 4



Underlying benefit, such as passenger or freight kilometres of transportation, or effective available building area

More high-value, closed looped recycling
→ less primary material production
→ lower emissions per tonne of material

Less material input required for each car, building, etc. (e.g., tonnes of material per car)

Less "products" per unit of end user service (E.g Increase product lifetimes
→ fewer products made/built per unit of service

Material Economics (2021)

---

[4] An example is when specific services are harmful on balance to social welfare unless regulated or taxed appropriately (e.g. smoking tobacco).

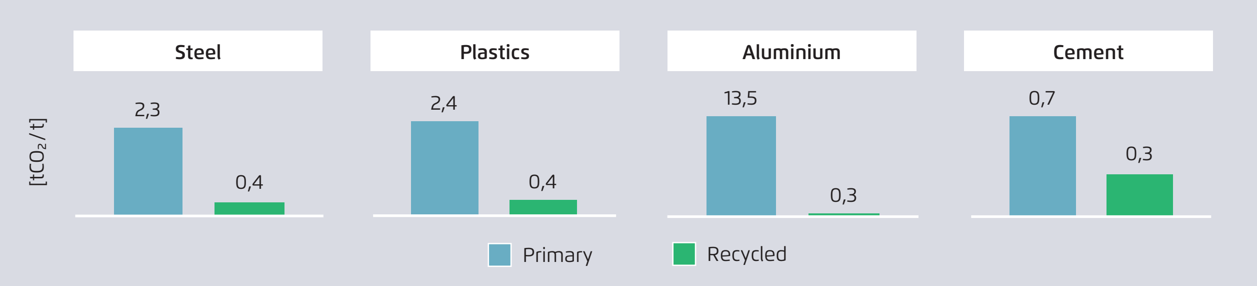
this is where closed-loop recycling comes in. **Closed-loop recycling** (or other high-value recycling solutions) can help to reduce the need for the same level of virgin material products to be used to produce the same level of materials with much lower GHG emissions as Figure 5 shows. However, it is critical to distinguish between closed-loop and high-value recycling options, on the one hand, and downgraded and low-quality recycling solutions, on the other. Downgraded recycling may provide some overall reduction in material intensity in some cases, but its environmental benefit and value for the climate can often be an order of magnitude lower than high-value recycling solutions. As we explain below, downgrading of recycling materials means that much higher levels of new virgin materials still need to be produced to dilute contamination and restore overall material quality to produce the same products.

Another way to reduce GHG emissions/material ratios is via product substitution and optimisation. This ensures a reduction in the most CO_2-intensive materials per unit of a given product. For instance, sustainably harvested wood can lower the amount of cement used in construction, as can the optimisation of cement exposure classes in use.

In additional to high-value material recirculation and closed-loop recycling, the second key component of a "circular and resource-efficient" economy is to **use less materials per unit of final product** (point 2 in Figure 4). This can be achieved by using materials more efficiently during the manufacture of key products such as vehicles or buildings or packages. It can also include a range of other less obvious solutions such as designing products to be less materials intensive while providing the same performance.

Finally, a resource-efficient industrial economy can also be understood to include solutions that reduce the total level of products needed per unit of service. This often relates to new business models that seek to squeeze the same economic value in terms of services to consumers out of a smaller amount of physical products.[5] A good example might be business models that offer consumers one long-lived appliance that can be regularly serviced and repaired over time by the company, rather than selling multiple short-lived products over the same period. The EU's ban on single-use plastics might fit into this category, as might policies to extend warranties on products, establishing a right to repair electronic goods, or ensuring that buildings have longer lifetimes.

CO_2 intensity factors of virgin (primary) vs. recycled (secondary) production routes (global averages) Figure 5



Note: These data are based on global averages

Material Economics analysis (2021), based on Wood Mackenzie and S&P Global Platts Analytics

---

[5] See RECLAIM (2021): D4.1 Circular Economy-driven lifetime-extension strategies. RECLAIM Project. European Commission.

How does a circular economy for CO_2-intensive basic materials help to make the industry transition to climate neutrality feasible?

At the most basic level, recycled materials emit much less CO_2, and these emissions can be reduced to virtually zero in most cases as energy and other inputs are decarbonised. Figure 5 uses global data to illustrate the extent to which the closed-loop recycling of CO_2-intensive materials can contribute to dramatic reductions in the CO_2 and energy intensity of basic materials production.

But our analysis shows that introducing circular economy and materials efficiency in the production of steel, aluminium, plastics and cement would also allow EU member states to substantially reduce electricity and green hydrogen needs as well as GHG emissions, while providing multiple co-benefits. As such, the development of a more energy-efficient and circular economy would be a major source of energy efficiency for industry as it transitions to climate neutrality.

This result is shown in Figure 6, which expands on Figure 2. It shows that, for the steel, cement and chemicals sectors, the "circular economy" scenario (i.e. a scenario including a stronger role for enhanced recycling and material efficiency) has the potential to reduce total electricity demand in 2050 by over 400TWh/annum relative to a techno-centric scenario that relies on the decarbonisation of virgin materials. This is roughly equivalent to the total additional output of new renewables capacity in Europe for all technologies between 2005 and 2019. Put another way, it would require the installation of roughly an additional 60 000 wind turbines to provide this amount of power.[6]

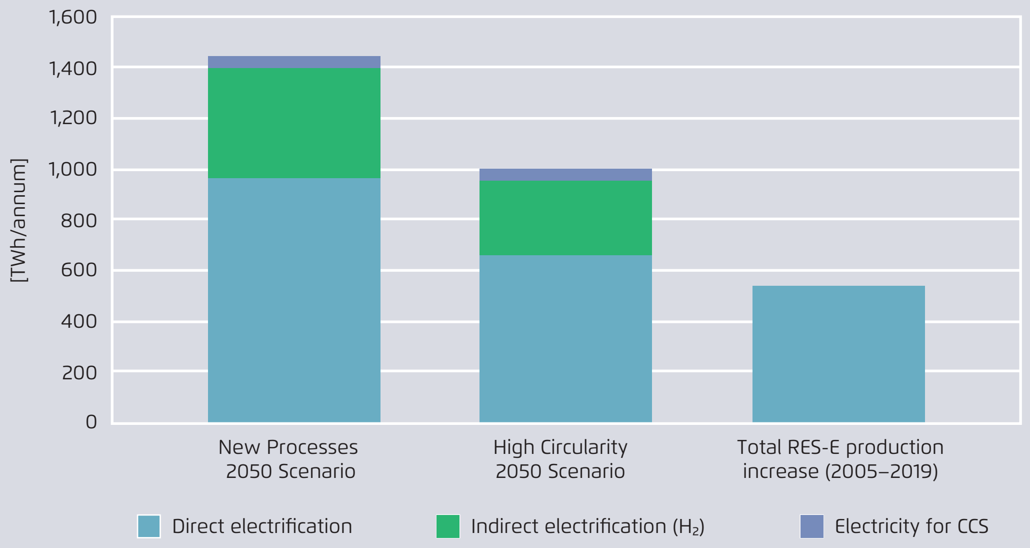
It should be noted, moreover, that even in the circular scenario, very significant increases in industrial power consumption are needed: a tripling from 333 TWh

---

[6] This assumes an average capacity of 2 GW and an annual load factor of 0.38.

Additional power needs for the decarbonisation of steel, cement and chemicals (high vs. low circularity scenarios)

Figure 6



Agora Industry (2022), based on data from Eurostat (2021), Material Economics (2022) today to 1000 TWh in 2050 in these sub-sectors alone from. This highlights just how difficult the infrastructure challenge will be for the industrial transition without measures to reduce excess energy demand.

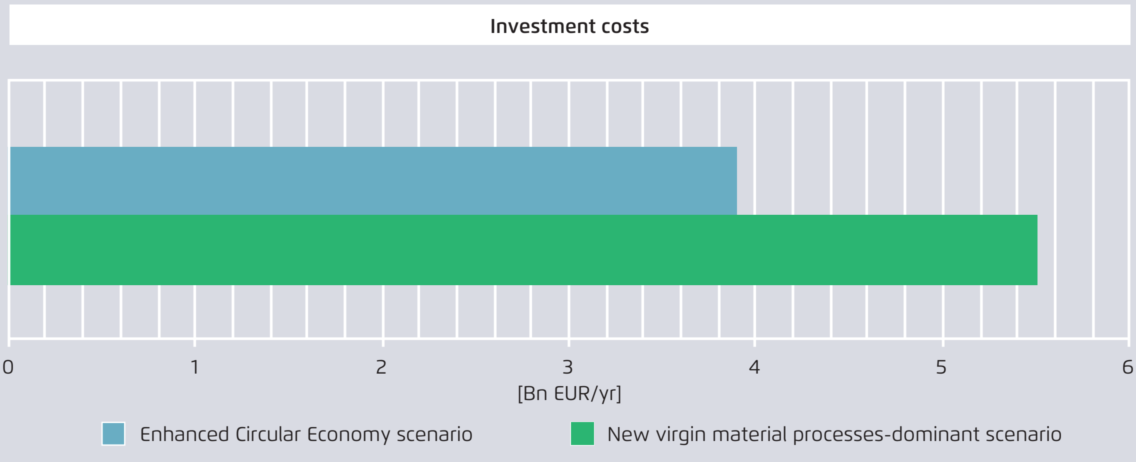
Figure 6 also shows that the circular scenario would significantly reduce the need for hydrogen in the cement, chemicals and steel sectors, thus reducing the need to import or add as much additional hydrogen production storage and transport infrastructure in the EU. Under the new processes (techno-centric) scenario, approximately 433 TWh of hydrogen are needed. Current analyses highlight the challenges in delivering such high volumes in the timeframe required with the expected scarcity of future supply.[7] The circular materials scenario suggests that as little as 293 TWh of hydrogen may be needed, a 33 percent reduction.

Similar analysis is also available for carbon capture and storage. The same scenario analysis from Material Economics described above found that a scenario that pushed circular economy and material efficiency policies to the limit could massively reduce the need for CCS infrastructure – potentially reducing fossil-based CO_2 captured and stored from as much as 235 $MtCO_2$/yr to just 47 $MtCO_2$/yr.

Of course, a reduction of investment in certain kinds of infrastructure for decarbonised virgin material production does not necessarily mean that some offsetting infrastructure investments would not be needed to promote a more circular economy. In general, however, it is the reduction of an overreliance on any one kind of infrastructure that is important, especially when it comes to costs and public support. Figure 7 below shows estimates from Material Economics suggesting that compared to a strategy where new processes are dominant, more circular economy-policy heavy scenarios should reduce total new infrastructure investment costs

Estimated low-carbon investments costs, new virgin material processes-dominant scenario vs. enhanced circular economy scenario

Figure 7



Note: These figures are cumulative for the sectors of cement, steel and plastics only

Agora Industry, based on data from Material Economics (2019)

---

[7] See Agora Energiewende (2021 B): 12 Insights on Hydrogen; and Material Economics (2018) Circular Economy: A powerful force for climate change mitigation.

substantially for the steel, cement, aluminium and chemicals sectors. Partly as a consequence, the enhanced circular economy scenarios would reduce total average abatement costs for decarbonising industry.

While the above analysis is by no means exhaustive, it already serves to highlight the extent to which the circular economy is too important for the industrial transition to climate neutrality to be ignored.

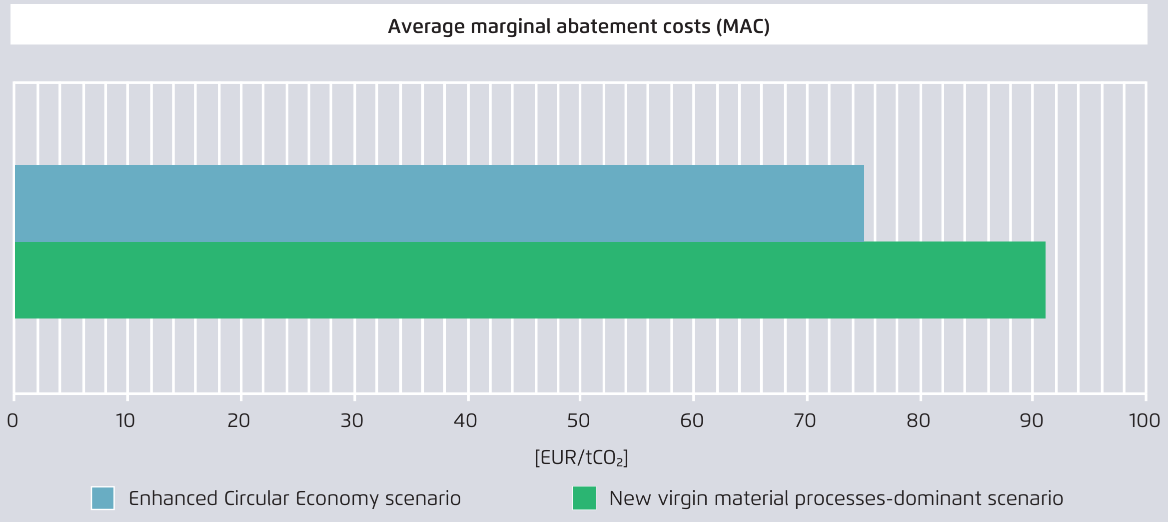
Recent progress: good on paper …

In the EU in recent years, some undeniable progress has been made towards improving the management of end-of-life products. For example, the EU's first Circular Economy Action Plan – which was first communicated by the Commission in 2015 and whose resulting legislation was formally adopted in 2018 – included a number of new pieces of legislation that contributed positively to the goal of a circular economy.

For instance, the so-called "Waste Package" of 2018, set targets for member states to increase the aggregate amount of recycling of municipal solid waste from 55 percent in 2025, to 60 percent and then 65 percent by 2030 and 2035, respectively. It set sub-targets for 2025 and 2030 to increase the rate of recycling of packaging (65 percent by 2025, 70 percent by 2030), plastic (50 percent, 55 percent), wood (25 percent, 30 percent), ferrous metals (70 percent, 80 percent), aluminium (50 percent, 60 percent), glass (70 percent, 75 percent), and paper and cardboard (75 percent, 85 percent). It also set targets for reducing landfill and avoiding unnecessary landfilling.[8]

A new methodology proposed by the European Commission in a revision in 2018 of the EU Pack-

Average CO_2 abatement costs for steel, cement and plastics under two scenarios Figure 8



Agora Industry, based on data from Material Economics (2019)

---

[8] See https://www.consilium.europa.eu/en/press/press-releases/2018/05/22/waste-management-and-recycling-council-adopts-new-rules/; European Union 2018 A, B, C and D.

aging and Packaging Waste Directive (PPWD)[9] measures recycled quantities at a later stage of the recycling process (at the final entry into the production of the recycled materials rather than the initial waste collection point), to limit the inclusion of losses during the recycling process in the reported recycling volume. While a step forward, this did little to address the much larger concern about simply misallocated and uncounted waste – a key issue for plastic waste in particular, given its high tendency to fail to reach the appropriate recycling waste stream.[10]

Complementing these targets, the European Commission put in place an amendment to the Landfill Directive[11] to advance the goal that by 2030 all waste "suitable for recycling or recovery" will no longer be accepted in landfills. Furthermore, since January 2021, EU member states have been prohibited from exporting plastic waste to non-OECD countries, increasing the pressure to recycle domestically.

In addition, the Single-Use Plastics Directive[12] introduced a number of new laws to limit single-use plastic waste, including:

- Bans on certain kinds of single-use plastic goods where an alternative exists (such as plastic plates, cutlery, cotton swaps, straws and sticks for balloons);
- obligations for member states to introduce measures to reduce the use of plastic food containers and drink cups;
- requirements for producers of plastic goods to pay for the costs of waste management and the clean-up of plastic litter, for instance through including a wider range of plastics (especially packaging) in EPR schemes;
- targets for member states to separately collect 77 percent of single-use plastic drink bottles by 2025 and 90 percent by 2029;
- targets for companies to incorporate a minimum of 25 percent of recycled plastic in PET beverage bottles starting in 2025, and 30 percent of all plastic beverage bottles starting in 2030; and
- labelling for certain products like sanitary towels, wet wipes and balloons, providing guidance on disposal.

… But major gaps remain for developing genuinely circular CO_2-intensive materials

Nevertheless, there remains major gaps in the EU's efforts to develop genuinely circular and resource-efficient value chains for the main CO_2-intensive basic materials. It's true that the EU's existing legislation places recycling objectives on a range of products and waste streams that do include the most CO_2 intensive materials, including vehicle, construction and packaging waste materials. These are indeed the most significant value chains in terms of CO_2 emissions in industry (See Figure 9). However, these recycling value chains remain far from optimal.

One of the main problems with these value chains is that, while there is recycling in principle, there is enormous downcycling of materials during the recycling process, leading to far too little displacement of virgin materials production. For instance, under the EU's Waste Framework Directive, 70 percent of construction and demolition waste are to be recycled, re-used or prepared for other material recovery.[13] One might therefore assume that significant CO_2 savings from the reduction in the use of new virgin cement occur due to this policy. In practice, however, that is not the case. The vast majority of construction and demolition waste is recycled in low-grade construction applications

---

[9] Directive 2018/852, European Union 2018 D.

[10] Material Economics 2022.

[11] Directive 2018/850, European Union 2018 B.

[12] Directive 2019/904, European Union 2019.

[13] https://ec.europa.eu/environment/topics/waste-and-recycling/construction-and-demolition-waste_en ; Directive 2008/98/EC, European Union 2008.

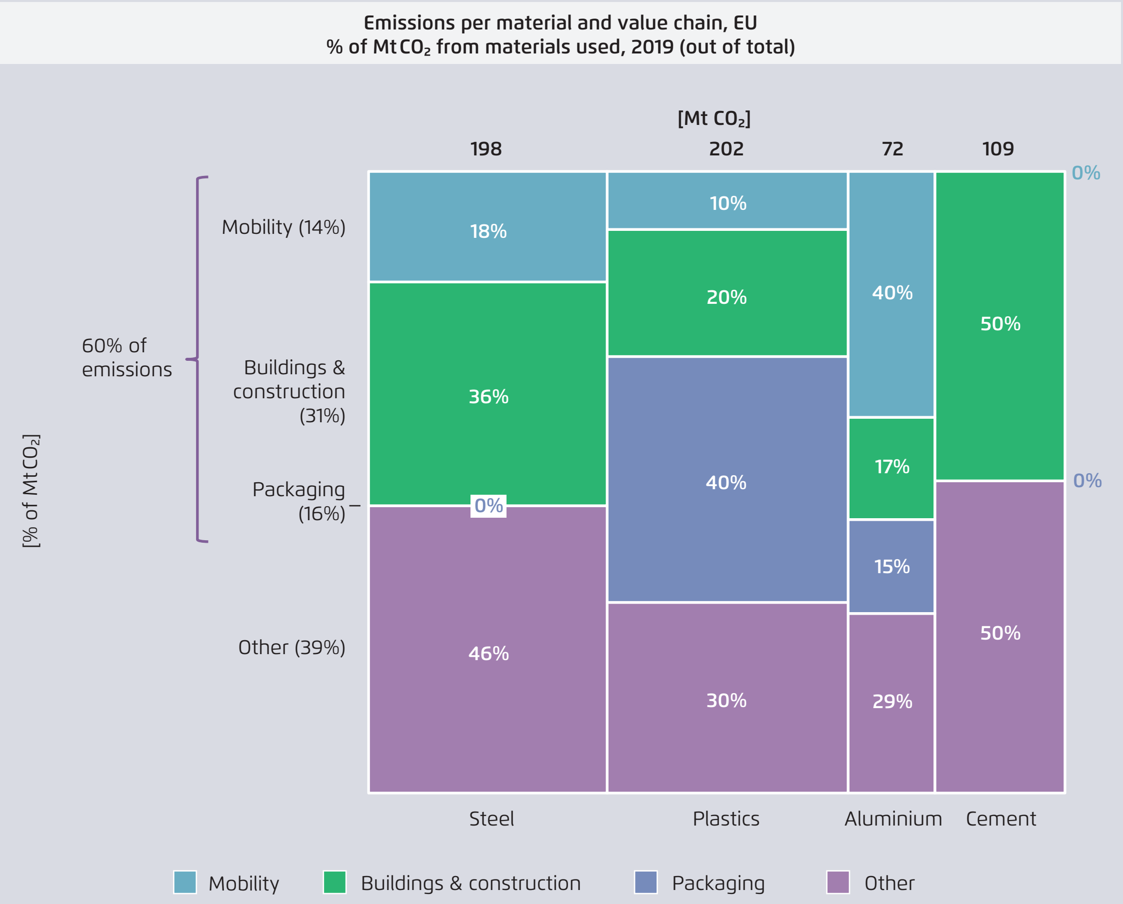
such as back-filler for roadworks (Zhang, et al, 2021). In fact, the Netherlands, which recovers an impressive 100 percent of construction and demolition waste, is estimated to downcycle 95 percent of that same waste material. Thus, key building materials such as cement and concrete do not make it back into new buildings despite technically being "recycled".Similarly, serious problems from downgrading steel, plastics and aluminium products recovered from construction, vehicle and packaging waste are the norm in other waste streams (see section 2).

The downgrading problem is all-the-more troubling in the EU's current approach to recycling policy because it is arguably "built-in" to the underlying logic of key policy tools that the EU and its member states rely on to manage end-of-life waste. For example, the EU's recycling targets currently incentivise only the quantity of recycling, but they remain silent on the quality of recycling (the one exception being the quotas for recycled PET bottles).

This situation is exacerbated, in turn, by a strong reliance on Extended Producer Responsibility (EPR)

Share of emissions from the most CO_2-intensive basic materials by product value chain

Figure 9



Agora Industry, based on data from Material Economics (2019) schemes for financing and managing the achievement of recycling targets in certain regulated waste streams, like plastic packaging, without complementing them with other policies to promote closed-loop recycling. EPR schemes are necessary and important. For instance, they are generally quite effective at funding the recycling value chain via advance disposal fees.[14] However, EPR schemes depend critically on in-built design criteria to drive closed-loop recycling, and the political incentives in these schemes can disfavour the adoption of such designs. Thus, in the absence of complementary policy packages and targets to drive their effective implementation, EPR schemes encourage recyclers to maximise throughput that can be considered recycled material, no matter how poor or downgraded. Thus, as presently implemented in most places, EPR schemes and recycling targets alone do little to create high-quality, *closed-loop* recycling of basic materials.

The EU still does a poor job of separately collecting sufficient quantities of end-of-life products for recycling and thus these are not counted in plastic waste statistics as unrecycled plastics. Material Economics (2022) has estimated that the EU uncounts by roughly 50 percent the total quantity of end-of-life plastic materials, largely because they are misallocated to general waste. For the purposes of calculating member state recycling rates, this misallocated waste is effectively excluded from the denominator.

EU policy currently does relatively little to incentivise material efficiency or substitution when designing and manufacturing final products. For instance, carbon prices in the EU ETS do not flow into the relevant value chains due to a combination of trade pressures and free allowance allocations. CO_2 standards for products like buildings and vehicles still focus on CO_2 performance in use rather than on embedded carbon in manufacture.

Perhaps the biggest weakness of circular economy policy in the EU is that it remains largely disconnected from the EU's green industrial strategy. This is particularly true for the EU's approach to industrial decarbonisation. For instance, the EU's New Industrial Strategy from 2020[15] (and its revised Industrial Strategy from 2021[16]) made little mention of the circular economy. On the contrary, the document focused mainly on the infrastructural, regulatory and financial conditions for developing breakthrough technologies to replace one virgin production process with another.

The EU's circular economy policies to date have tended to address a range of important environmental concerns linked to waste management, but they have not necessarily focused on maximising gains for CO_2 mitigation. For instance, the Waste Package of 2018 and the Single-Use Plastics Legislation of 2019[17] introduced a range of new targets to limit landfilling, to reduce plastic waste in water ways and to finance waste collection and management. However, with some notable exceptions, the issues of downcycling or improving the quality of waste streams have gone largely unaddressed. But downcycling and the contamination of waste streams remain one of the greatest barriers to improving the closed-loop recycling process and limiting CO_2 emissions linked to the production of virgin materials.

Even the EU's new Circular Economy Action Plan from 2020[18] does not seem to integrate industrial decarbonisation and circular economy priorities very closely in practice[19]. For instance, while it has a strong focus on strengthening legislation for plastic waste,

---

[14] See the Ellen MacArthur Foundation at https://plastics.ellenmacarthurfoundation.org/epr

[15] European Commission 2020 C.

[16] https://ec.europa.eu/commission/presscorner/detail/en/IP_21_1884 ; European Commission 2021 A.

[17] European Union 2018 C and D, 2019.

[18] European Commission 2020 A and B.

[19] There is a request for a report on this subject to be prepared – but no active implementation agenda at this stage.

textiles, electronics, and even end-of-life vehicles, there is relatively little detail on the most CO_2-intensive materials such as steel, aluminium, cement and concrete. With regard to cement and concrete, the package pledged only to develop a non-legislative "strategy" for a more circular built environment by 2023 – a plan that was subsequently deleted from the Commission's work programme. Similarly, the language in the planned revisions to the End-of-Life Vehicle Directive focuses mainly on improving the tracking of vehicles and vehicle plastics rather than on improving the quality of recovered CO_2-intensive materials, such as steel or aluminium alloys.

The neglect of the circular economy in the emerging proposals for industrial decarbonisation measures is increasingly evident across various parts of the overall Green Deal package. For instance, the first tenders of the EU ETS Innovation Fund for large-scale projects saw no funds awarded to enhanced circularity or material efficiency solutions.[20] Discussions on strategic energy infrastructure spending under regulations like TEN-E do not consider the circular economy infrastructure for cross-border cooperation. To its credit, the new Batteries Regulation[21] includes minimum recycled content quotas for recycled materials, but the new proposal for the Energy Performance in Buildings Directive[22] or the newly proposed Vehicle CO_2 Standards Regulation does not.[23]Meanwhile at the national and international level, emerging discussions on new public procurement obligations for "low-carbon"materials typically do not mention closed-loop circular materials as meriting equivalent treatment, making it unclear whether they are to be included.[24]

Conclusion

In March 2022, the European Commission is due to deliver on the final set of legislative proposals under the European Green Deal. Some of the most significant pieces of legislation for the circular economy will be determined in that package. The remainder of this paper argues that it is essential that the forthcoming circular economy and sustainable products packages forge a much closer alignment between the EU's industrial decarbonisation goals and the EU's circular economy strategy. The following section begins by outlining the specific GHG abatement potentials, barriers and needs for the main material sub-groups. Section 3 then discusses concrete policy options.

---

[20] https://ec.europa.eu/clima/eu-action/funding-climate-action/innovation-fund/large-scale-projects_en

[21] https://ec.europa.eu/environment/topics/waste-and-recycling/batteries-and-accumulators_en ; European Commission 2020 D.

[22] https://ec.europa.eu/energy/sites/default/files/proposal-recast-energy-performance-buildings-directive.pdf ; European Commission 2021 B.

[23] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en ; European Commission 2021 C.

[24] See, for instance, the new German Coalition Treaty Agreement, or the Industrial Deep Decarbonisation initiative (IDDI) "You Make It, We'll Buy It" initiative announced at COP26:https://www.spd.de/fileadmin/Dokumente/Koalitionsvertrag/Koalitionsvertrag_2021-2025.pdf ; https://www.cleanenergyministerial.org/sites/default/files/2021-11/IDDI percent20Green percent20Procurement percent20Press percent20Notice percent20Nov percent202021.pdf ; https://www.cleanenergyministerial.org/news-clean-energy-ministerial/press-release-launch-industrial-deep-decarbonisation-initiative-iddi

2 CO_2 abatement levers, potentials and enabling conditions

One of the main challenges facing policy frameworks for a circular economy is that there is often significant uncertainty about the relative impacts of different policy actions. This section seeks to provide some insights on that question. For each key material category – steel, aluminium, plastics, and cement and concrete – it maps the current status quo for the circular and resource-efficient use of materials in Europe. Moreover, for each material, we identify and seek to quantify the circularity and resource-efficiency potentials in terms of CO_2 reductions by 2030 and 2050, along with the enabling conditions needed to achieve these potentials. These potentials serve as the basis for our policy recommendations in section 3.

2.1 Potentials for enhanced recycling

2.1.1 Steel

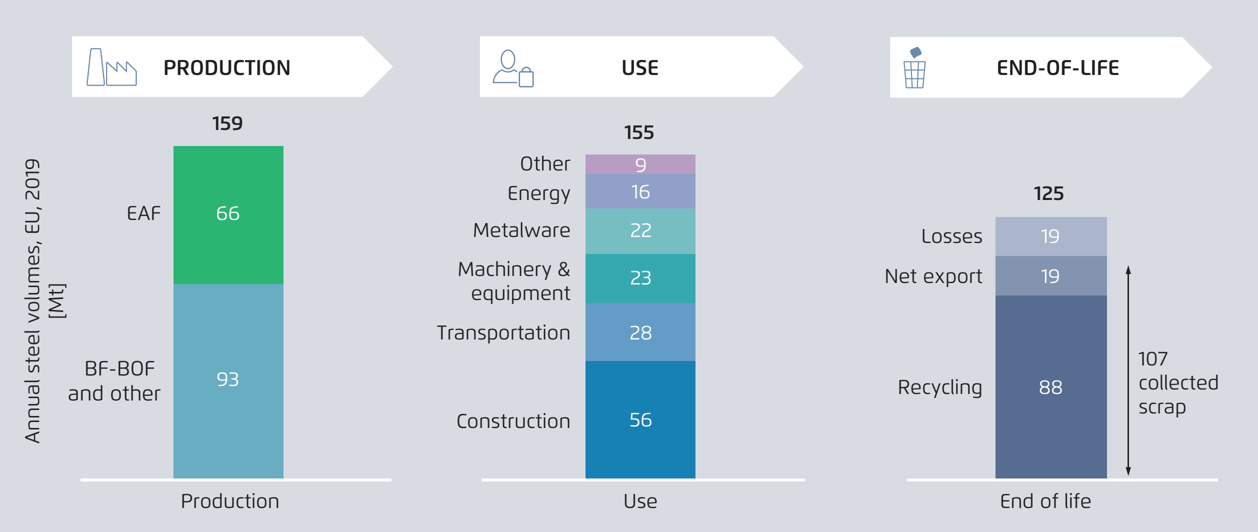
The status quo

In 2019, 159 million tonnes (Mt) of steel were produced in the EU 27, of which 58 percent came from primary steel production from iron ore via the integrated blast furnace route. The remaining 42 percent resulted from secondary steel production in which steel scrap is melted in electric arc furnaces to produce steel.

A lot of steel in the EU is recycled today – as shown by Figure 10 – but downgrading is a major issue.In the EU27, around 86 percent of steel scrap (107 Mt) was collected in 2019. However, due to contamina-

Steel production, use and recycling statistics in the EU, 2019

Figure 10



Note: Scrap losses based on 85% effective recovery rate, based on Pauliuk (2013) and World Steel Association (2009)

Material Economics (2021), based on Eurofer (2020), European Steel in Figures 2020; Pauliuk et al. (2013), The Steel Scrap Age; Pauliuk et al. (2013), Steel all over the world: Estimating in-use stocks of iron for 200 countries; World Steel Association (2009), The Three Rs of Sustainable Steel tions of steel scrap with copper and other elements, most steel made from steel scrap today can only be used in a very limited number of applications. The phenomenon is known as downgrading. Even if the stock of scrap steel grows over time in the EU, replacing some share of primary steel production with secondary steel production will only be possible if secondary steel can be used in the same use applications as primary steel.

Potentials to enhance recycling and reduce CO_2

With the uptake of hydrogen-based Direct Reduced Iron (DRI), the distinction between primary and secondary steelmaking will become increasingly blurry over time**.** This is because in the future any share of DRI and scrap steel will be able to be melted together to produce steel with higher levels of secondary steel than in a conventional blast furnace. In the hydrogen-based primary production route (DRI-EAF), the cleaner the scrap available, the less DRI will be required to produce high-quality steel grades, making it potentially more cost-competitive relative to primary steel with higher shares of DRI. In scrap-based secondary steelmaking, adding some DRI to an electric arc furnace along with steel scrap may help to improve the quality of secondary steel for specific usage, even if the steel scrap was not 100 percent clean. Nevertheless, EAF high-quality 100 percent scrap recycling is possible.[25]

The boundaries of primary and secondary steel could thus become more fluid in the future and provide flexibility to both primary and secondary steelmakers. The availability of clean scrap will be an important asset for both. To accelerate the process, it is important that DRI capacities and capacities to remelt and make high-grade secondary steel products be developed in tandem. In particular, some steelmakers note the lack of mini-mills in Europe (compared with the United States for example, which sources roughly two-thirds of its steel demand from recycled scrap[26]) and the lack of capacity to process recycled steel into both “flat” and “long” products, creating possible bottlenecks from recycled steel to final product.

However, maintaining clean steel scrap flows to maintain the quality of recycled steel will be key. This is demonstrated in Figure 11, which shows that some products, such as rebar (bars for reinforcing concrete) can enable a relatively high copper content (0.4 percent of weight), while other products, such as structural steel, fine wires and drawings have much lower copper tolerances. Maximising the share of recycled steel that can be used on the market thus requires maintaining copper levels below those limits.

To limit the need for new virgin steel when diluting steel scrap contaminated with copper, a number of actions are required. This includes both the design phase of a product so that copper components can be easily separated during disassembly, but also scrap collection and shredding practices once the product reaches the end of its lifetime. Clean scrap can be used for high-quality secondary steel production or to lower the amount of DRI needed in primary steel production. In the first case, clean scrap could replace the need for primary steel production altogether, while in the second case it would lower the amount of DRI needed in primary steel production – and thus lower the amount of clean hydrogen required to produce larger amounts of DRI.

The medium- and long-term CO_2 emission reduction potentials for increasing the share of secondary steel in the EU are very significant. A model for EU steel market material flows built especially for this project suggested that, beyond 2030, the EU will have a growing amount of steel scrap available. In fact, by 2050, as much as 80–90 percent of the EU’s steel demand could in theory be met by recycling scrap flows. However, assuming that the average copper

---

[25] See ESTEP 2021.

[26] US Department of Energy (n.d): https://www.energy.gov/eere/amo/steel-industry-profile.

content cannot rise beyond 0.12 percent per tonne of steel (because of maximum tolerances related to key products), the copper contamination of newly available scrap would place a constraint on the extent to which secondary steel could replace virgin steel.

By 2030, the possible gains from keeping copper content below key tolerance levels are already as high as 16 Mt of steel per year (equivalent to around 24 $MtCO_2$ saved). In practice, however, much of these gains will not be able to be realised by 2030 because new capacity investments in EAFs and mini-mills to transform steel scrap into high-value products require scale up. However, by 2040 and 2050, we estimate that up to 35 Mt of virgin steel could be replaced by solving copper issues. This would be roughly equivalent to a CO_2 reduction of 63 $MtCO_2$ in the EU due to increases in substitutability between recycled scrap and virgin steel.[27]

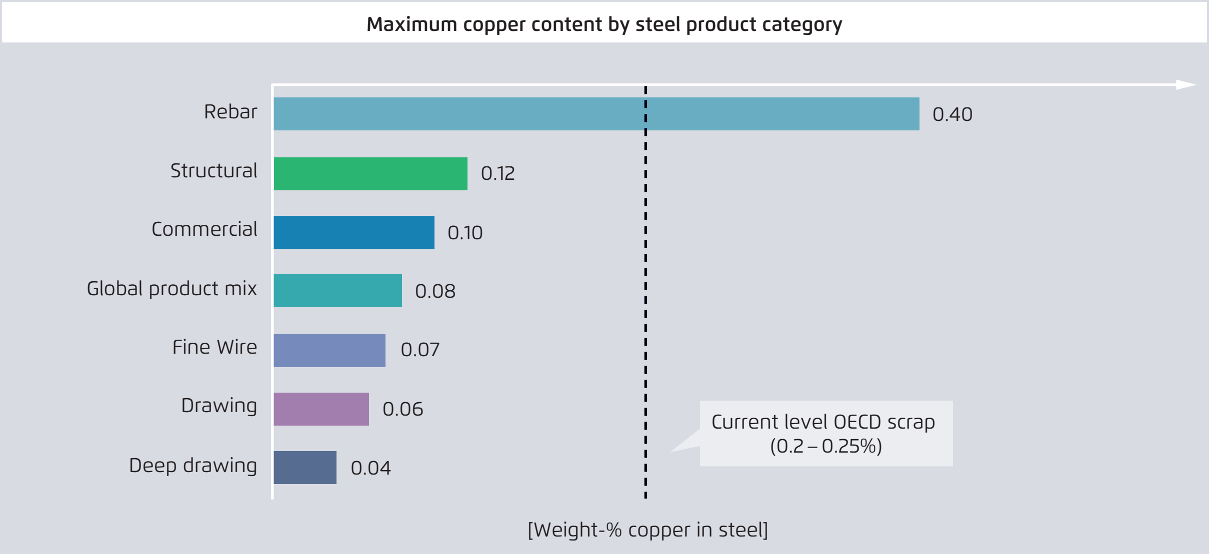
One (simplistic) argument against the idea of efforts to improve steel quality is that the EU is currently a net exporter of steel scrap to developing countries. Thus, the argument goes, if Europe used more scrap for recycling at home, more primary steel production would be induced in foreign countries, offsetting the gains. This argument ignores the fact that copper contamination and the need to maintain high-quality steel scrap quality is a global issue – the world gains nothing by not addressing the problem. On the contrary, if the EU demonstrates a viable model to limit copper contamination, the solution can be replicated globally, thus increasing the global circularity of steel use.

Enabling conditions

However, copper contamination will not disappear by itself. There is a set of important enabling conditions that are necessary to fully exploit the potential of the circular economy in the steel industry[28]:

Copper tolerances of different steel products

Figure 11



Material Economics (2018)

---

[27] Note: We assume that the CO_2 intensity of secondary steel-making will decline to 0.1 tCO_2/t steel by 2050 as the power sector decarbonises and energy-use emissions are further reduced.

[28] For more information, see Allwood, et al 2021.

- **Articulate a long-term vision for much higher-quality materials recovery from end-of-life vehicles (ELVs) than is currently the norm.** This could be done at the EU or at the national level to inform future circular economy and vehicles legislation. Without such a vision, there is a risk that efforts to address concerns will only ever be partial and insufficient.
- **Support innovation and development of advanced copper removal technologies from steel.** Some promising technologies are being developed but may need further support to mature technically and gain widespread market acceptance.
- **Develop a business case for advanced copper separation and steel alloy sorting technologies.** The new advanced copper separation technologies that are currently being developed should be brought to the market as fast as possible. In some cases, recyclers have invested in state-of-the-art technologies both for copper separation and the sorting of steel alloys. However, such investments are capital intensive and need to become the norm, rather than the exception. For this to occur, there needs to be a higher value attached to the use of post-consumer recycled scrap as a steel-making input.
- **Eliminate inefficient end-of-life recycling practices to maximise the overall EU scrap supply while maintaining clean scrap flows**. This covers practices such as Illegal dumping/scrapping of vehicles, suboptimal car shreddingthat does not avoid steel scrap contamination and the elimination of construction waste landfilling.
- **Design products (e.g. vehicles) for ease of copper component separation:** Some products are designed in a way that makes the separation of steel and copper components impossible.
- **Ensure demand for off-taking high volumes of recycled steel scrap in Europe so that recyclers can find a robust market for their scrap (and ensure access to high-quality steel scrap and reliable volumes for steel recyclers).** Today, there is kind of chicken-or-egg problem in taking the EU's steel recycling market to the next level. One of the main income streams for steel recyclers is shipments of scrap abroad, including in China where there is a large and growing demand for scrap. To invest in relatively costly new assets for high-quality recycling technologies, therefore, EU recyclers need some guarantee that there will be markets paying the "right" price for their steel. Conversely, steel producers (who could incorporate more scrap in their production) are nervous that the scrap market is small and fragmented and that they need to potentially compete with Chinese demand and prices. A guarantee of demand might be provided by quotas and support for investment in high-quality production.
- Develop **integrated DRI and EAF production technologies to facilitate the blending of high shares of scrap into integrated primary and secondary steel production routes**. In addition, **EAF mini-mills** must be developed that are capable of processing growing quantities of steel scrap into a range of steel products in addition to long products for construction.
- **Create a level playing field between primary and secondary routes linked to the EU ETS**: Today, primary steel producers receive free allocation allowances to protect them from carbon leakage, but this also mutes the carbon price signal in the EU ETS. This creates a disadvantage for secondary steel production in the EU because the higher CO_2 costs of primary production costs are not internalised. This could be addressed by gradually introducing a carbon border adjustment mechanism while free allocation is phased down, as proposed by the European Commission.[29]
- **Appropriately incentivise recycled post-consumer steel.** One concern of some actors is that recycled steel is often defined as including both post-consumer scrap and new scrap. The distinction, it is argued, is important because producing high-

---

[29] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12228-EU-Green-Deal-carbon-border-adjustment-mechanism-_en ; European Commission 2021 D.

quality post-consumer recycled steel is more challenging and investment-intensive, but is also better for CO_2 outcomes. On the other hand, new scrap is essentially primary steel that never found its way into a product due to inefficiencies in the production process (and as such should be disincentivised as counting towards the "recycled" or "low-carbon" categories).

→ **Replace copper by alternative materials in certain appropriate applications** (e.g. optic fibre, aluminium) to reduce contamination during the recycling process.

Higher circularity: an attractive commercial strategy for the steel sector?

In the future, clean scrap flows will become one of the most important, if not the most important, competitiveness factor for the EU steel industry. Currently, EU steelmakers focus primarily on switching to hydrogen-based primary production routes. To date, EU steel companies have announced plans to build 28 Mt of hydrogen-based DRI capacity before 2030.[30] However, in the long-run, the competitiveness of hydrogen-based DRI production will be primarily determined by the cheapest costs to produce abundant renewable hydrogen. DRI will become a globally traded commodity and today's iron ore exporters with abundant renewable energy potential such as Australia and Brazil are expected to move soon into green DRI production and exports. In anticipation of this development, domestic clean scrap resources to produce high-quality steel grades will be one of the most important competitiveness factors for the European steel industry. In fact, one particularly progressive European steel company, SSAB, recently announced a plan along these lines.[31]

Scrap is an EU domestic resource. A higher share of scrap-based steel production in the EU will increase the resilience, energy efficiency and resource efficiency of the EU steel industry. The EU already has a large stock of steel scrap, which is projected to increase further in the future. In fact, today the EU is a net exporter of steel scrap. In 2019, its net exports of scrap steel (mostly lower quality) to non-EU countries totalled 19 Mt.[32] If new steel scrap flows from virgin steel production can be kept clean and the existing stock of contaminated scrap flows can be purified through new copper separation technologies and better end-of-life treatment practices, the EU can use its growing scrap supply for a competitive advantage. Countries such as the US, which has a secondary steelmaking share of 73 percent, show the long-term potential of such a strategy. Because the secondary steel production route is about 5 to 6 times more energy-efficient than the primary production routes, it will also facilitate the transformation of the EU steel industry while keeping it competitive.

2.1.2 Aluminium

Many of the same principles laid out here for the steel sector also apply for the aluminium sector, but there are some important differences.

The status quo

Aluminium is an important basic material in a number of key applications. In 2019, aluminium consumption in the EU totalled 13 Mt. The most important use sectors are light-weight applications in the transport sector (38 percent), aluminium use in the building and construction industry (15 percent) and packaging (15 percent). In 2019, the EU produced 9 Mt of aluminium, of which 4 Mt were virgin primary aluminium, 2 Mt were secondary aluminium production based on pre-consumer scrap and 3 Mt were from post-consumer scrap.

---

[30] Global Steel Transformation Tracker, Agora Industry 2021; https://www.agora-energiewende.de/en/service/global-steel-transformation-tracker/

[31] Seehttps://www.ssab.com/news/2022/01/ssab-plans-a-new-nordic-production-system-and-to-bring-forward-the-green-transition?utm_source=twitter&utm_medium=social&utm_campaign=communications_ffs&utm_content=nordic_si

[32] Global Steel Transformation Tracker, Agora Industry 2021; https://www.agora-energiewende.de/en/service/global-steel-transformation-tracker/

Since the early 2000s, the EU has gone from producing virtually all of its own aluminium to being a major net importer.In fact, the EU imported 4 Mt of aluminium in 2019, more than 40 percent of its total consumption.

Like the steel industry, the CO_2 emission intensities of primary and secondary production differ significantly: while conventional primary aluminium production globally typically emits 13–16 tCO_2 per ton of aluminium (depending, in particular, on location and CO_2 intensities in the power sector), secondary aluminium production emits only 0.3 tCO_2 per tonne of aluminium.

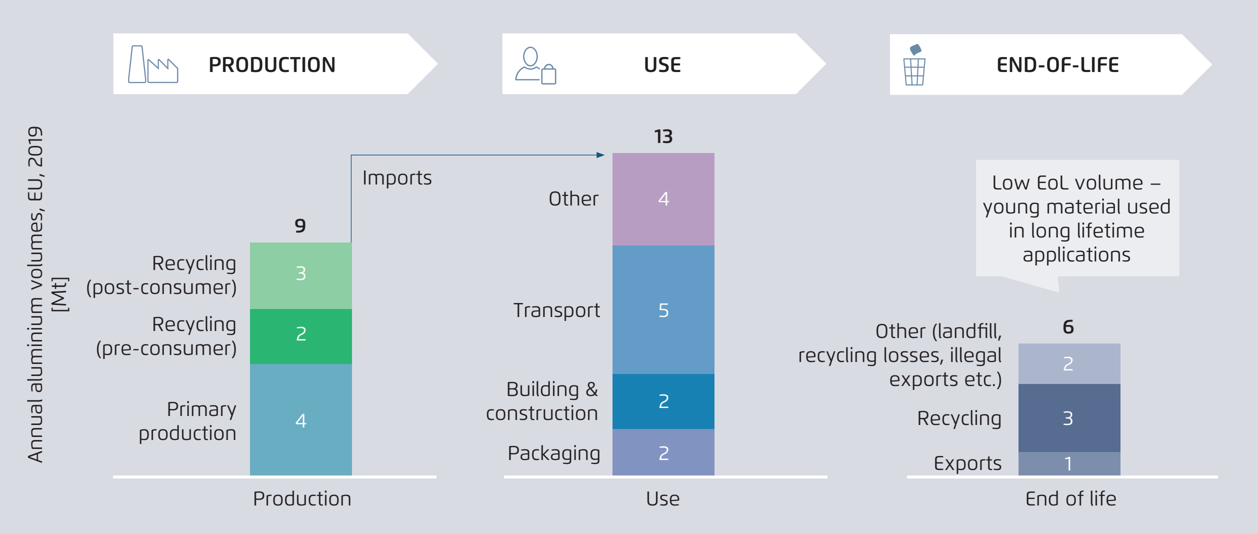
Aluminium is a relatively new material that is used in both short-life products like food packaging and foils but also in longer-lived applications such as construction and vehicles. Aluminium use and aluminium stock are increasing rapidly in the EU, but because it is typically used in applications with long product lifetimes, the end-of-life volume of aluminium scrap is limited. Over time, however, the larger amounts of aluminium in use are going to reach the end of their lifetimes, significantly increasing Europe's recycling potential and creating the need for quality recycling processes.

In 2019, 5 Mt of aluminium reached its end-of-life. Roughly 3 Mt of aluminium were recycled, but 2 Mt either ended up in landfills, were lost during inefficient recycling processes or illegally exported. Due to the enormous difference in the CO_2 intensity of primary and secondary aluminium production routes,it is very important that the EU ensure high collection rates and keep aluminium scrap flows clean in order to limit downcycling and maximise the circularity potential.

Most recycled aluminium is downcycled into cast aluminium products, since these products have higher tolerances for impurities. However, as explained below, a market for cast aluminium goods is expected to disappear in the future – increasing the need to find better ways to recycle post-consumer scrap into high-quality closed-loop value chains.

Production, use and end-of-life of aluminium products in the EU

Figure 12



European Aluminium (2020), Circular Aluminium Action Plan

Potentials to enhance recycling and reduce CO_2
If the growing stock of aluminium in products is to become end-of-life waste that can be recycled efficiently in closed-loops, maintaining clean and pure scrap flows will be key. As with plastics or steel, this is partly a matter of product design. For instance, aluminium cans can contain material components that limit their recyclability in a closed loop. However, for aluminium contained in construction and demolition waste, some experts believe that selective deconstruction and de-pollution are crucial.[33]

One of the specific characteristics of aluminium (partly shared with steel) is that it is often not sold as a pure aluminium product, but is often transformed into a broad range of metallurgical alloys for different applications. Effective end-of-life recovery and recycling of aluminium consists to a significant degree in identifying and sorting these sub-alloys into their respective qualities. For example, certain mixed metal fractions that remain after the main aluminium parts have been recovered can be sorted into alloy groups. These, in turn, can then be used for different grades of aluminium for different use cases. Doing so enables more closed-loop recycling of aluminium sub-grades and avoids contamination.

But maximising the potential of closed-loop aluminium recycling requires state-of-the-art technologies for shredding, identifying and sorting aluminium grades. Such technologies are emerging, but often require significant new capital investments and changes to the production process chain at recycling facilities. A strong business case is needed for recyclers to undertake such disruptive investments.

According to projections by Agora Industry, increased circularity has significant potential to reduce emissions in the EU's aluminium sector. Relative to a business-as-usual scenario, the EU aluminium industry could reduce its emissions by roughly 5 $MtCO_2$ (-10 percent) in 2030 and by 15 $MtCO_2$ (-30 percent) in 2050.[34] These numbers correspond to gains in the ratio of secondary to primary aluminium produced and assume that the above barriers are addressed head on.

Main enabling conditions
In principle, many of the enabling conditions that apply to more circularity in the steel sector apply to the aluminium sector. There are also several differences, however:

- → **Develop a sectoral vision for a much more circular aluminium sector (as for steel).**
- → **Support the rapid development and deployment of advanced sorting technologies for post-consumer scrap.** As with steel, this is a key climate technology priority, but currently it is not supported as such.
- → **Develop a business case for the widespread commercialisation of advanced aluminium alloy sorting technologies:** New advanced copper separation technologies currently under development should be brought to the market as fast as possible. In some cases, recyclers have invested in state-of-the-art technologies for the efficient separation and sorting of alloys. However, such investments are capital intensive and must become the norm, not the exception.
- → **Design for deconstruction & recycling to minimise contamination.** In the case of aluminium this is especially relevant for products such as cans, vehicles, electronic appliances, information technology goods and construction materials.
- → **Eliminate inefficient end-of-life recycling practices:** Some existing recycling practices such as the shredding of cars or the non-separated collection of construction and other waste can be improved to maintain clean aluminium flows.

---

[33] Discussion with Michael Neaves, ECOS, pers. comm. (January 2022).

[34] These Figures include direct and indirect emissions from electricity production.

Why is higher circularity an interesting strategy for the aluminium sector?
Aluminium scrap is a domestic resource and the EU aluminium industry could benefit from it. As the aluminium stock in the EU reaches the end of its product lifetime, EU aluminium producers have a chance to increase the share of secondary aluminium production relative to primary production. This will not only significantly save CO_2 emissions and contribute to meeting EU climate targes; it will also require significantly less clean energy than the primary production. (Introducing reuse where feasible could help further effective resource management and achieve higher environmental benefits.)

The vast majority of aluminium that is recycled is downcycled into cast aluminium products, which have higher tolerances for impurities. However, significant changes in the market for cast aluminium goods are expected in the future. For example, as vehicles electrify, the market for many products made of cast-aluminium recyclates for combustion engine cars are expected to disappear. Maintaining markets for recycled aluminium goods will therefore require significant improvements in the quality of recycling as cast product demand declines. In other words, quality recycling is an issue affecting not only the environment but also competitiveness and industrial strategy.

The EU aluminium sector also faces structurally high energy costs in Europe, which have been exacerbated by the current energy crisis. As such it will always struggle to compete with parts of the world with abundant, cheap and stranded energy. Achieving higher rates of recycling would help to mitigate this competitive disadvantage, since recycled aluminium uses an order of magnitude less energy than primary smelting.

With the introduction of a carbon border adjustment mechanism (CBAM), and similar initiatives to create markets for lower-carbon aluminium, the EU's aluminium sector will increasingly need to reduce not just power emissions but also process emissions if it is to remain competitive. Current technologies to eliminate process emissions from aluminium production – such as inert or bio-carbon based anodes – are still relatively immature. Thus, some of the greatest potentials for short-term reductions in the (direct) CO_2 intensity of EU production may come from enhancing the share of secondary aluminium in total production sold.

2.1.3 Plastics

The status quo
In the EU, the plastics industry has a linear and fragmented value chain based on fossil feedstocks. In Europe, where 78 percent[35] of the plastic's feedstock is naphtha, plastic production begins with oil refining and is followed by the production of naphtha in oil refineries, the cracking of naphtha into monomers in petrochemical plants, the synthesis of polymers and transformation of polymers into plastic products. Then, the plastic products are distributed to a brand owner, to the automotive sector, to the construction sector, etc. Next, plastic products are sold to end consumers who dispose the product after use. The linear value chain of plastics ends with waste plastic being incinerated, landfilled, or exported to other countries.

Despite legislative efforts to incentivise a circular plastics economy (see section 1 above), the EU's performance in recycling plastics is still surprisingly poor. As shown in Figure 13, 63 Mt of plastics were produced in 2019, 51 Mt were used in products sold on the European market – that number is growing – and approximately 45 Mt have reached their end-of-life. The difference between production and use arises from the exports of plastics and plastics embedded in intermediate and final products to third countries as well as losses from the conversion of plastic into useable products.

---

[35] Deloitte 2019.

Box 1. Europe's missing plastics – a major circular economy governance gap

In fact, there is significant uncertainty regarding the correct amount of plastic in Europe that reaches its end-of-life each year due to the lack of data. In 2022, a new report by Material Economics suggests that the best estimate for more recent years is around 45Mt. This is 45 percent higher than the EU's reported level of EoL plastics in 2019 of 29Mt/yr.*

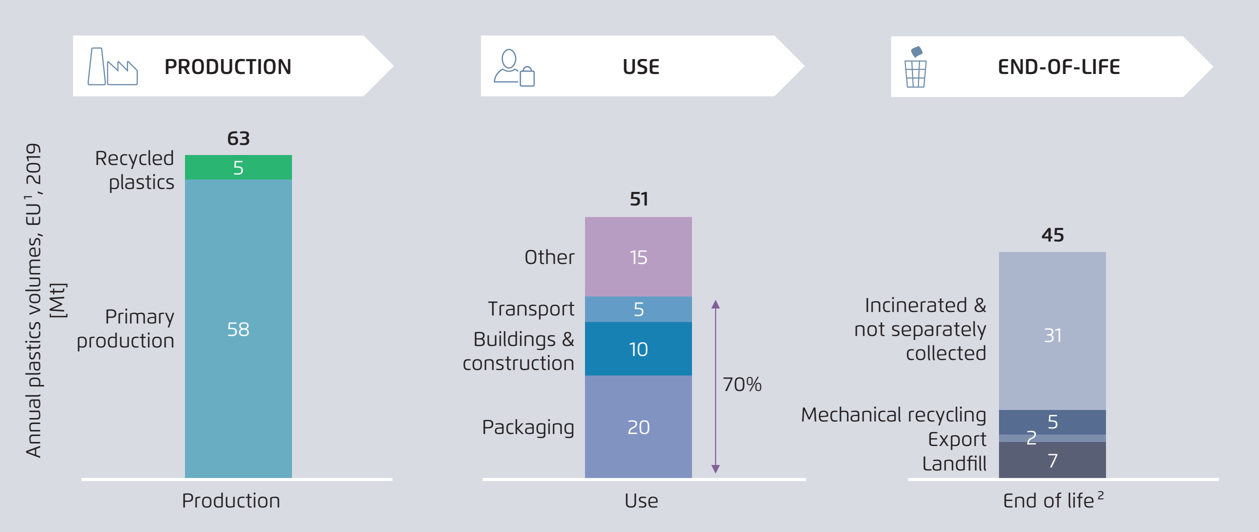
The embedded carbon content of the missing plastic is estimated to be around **125 million tonnes of CO_2 per year**, or in the order of 18 percent of total industrial CO_2 emissions in the EU in 2019. Incineration is believed to occur for more than 90 percent of this volume. The current inability to accurately measure end-of-life plastic in the EU is, therefore, a major governance and policy gap in Europe's current measures to promote the circular economy and plastic waste management.

---

* Material Economics (2022), "Europe's Missing Plastics".

Of the approximately 45 Mt of plastic reaching end-of-life in 2019, only a fraction – 5 Mt – as recycled.[36] The remainder was either not separately collected (and thus either landfilled or incinerated), or it was separately collected by was either incinerated or exported. In other words, despite the headline statistics, and despite the focus on plastics collection and recycling in recent years, as of 2019

Production, use and end-of-life management of plastics in Europe, 2019 Figure 13



1 Also including Norway and Switzerland; Note: Assuming ~50% of plastic waste collected for recycling is used for production of plastics based on Deloitte and Plastics Recyclers Europe (2015), Increased EU Plastics Recycling Targets: Environmental, Economic and Social Impact Assessment. Assuming end-of-life plastics volume is 30-40% higher than collected plastics (29 Mt 2019) based on Geyer et al. (2017), Production, use, and fate of all plastics ever made. Sources: Plastics Europe (2020), Plastics – the Facts 2020; European Commission (2020), Plastic waste shipments: new EU rules on importing and exporting plastic waste
2 Exact volume of end of life plastics not classified as plastic waste is uncertain

Material Economics (2022)

---

[36] This includes the United Kingdom, Norway and Switzerland.

the EU was recycling only about 15 percent of its total end-of-life plastics each year via mechanical recycling methods.

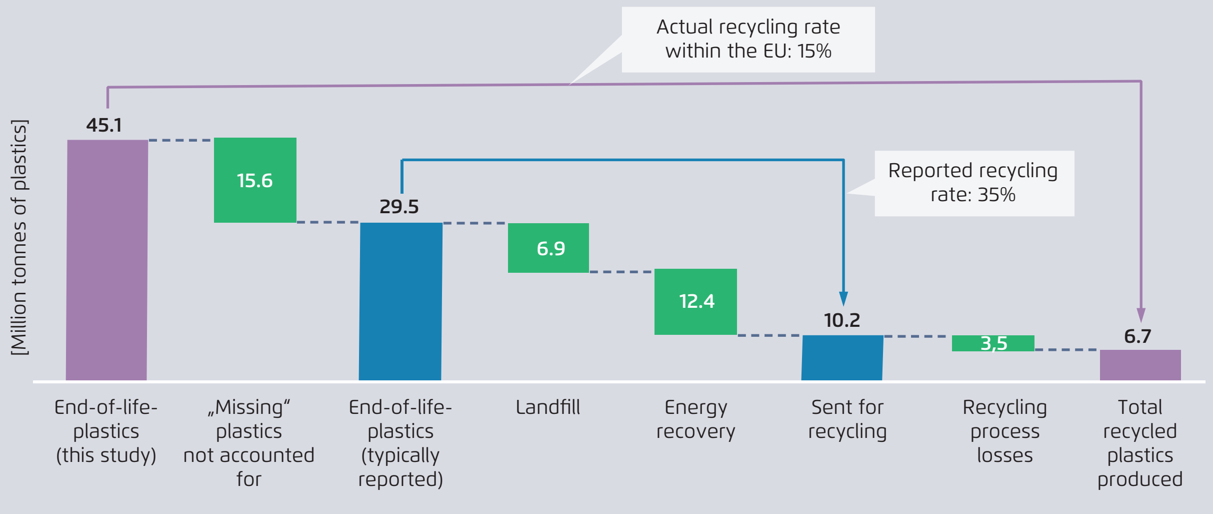
The problem of poor EU plastics collection and missing waste statistics

The collection of waste poses the first challenge to implementing a more efficient circular economy and increasing recycling rates (Figure 14). Data from Plastics Europe for 2020 indicates that, of the approximately 45 Mt of plastics that reached their end-of-life (EoL), one-third were not separately collected, but collected in mixed waste streams, and thus not sent for recycling. From the 30 Mt of plastics that were collected separately, 41 percent were incinerated, 24 percent were landfilled and 35 percent were sent for recycling. However, from the 10 Mt of plastics that were collected for recycling, only 6.7 Mt (60 percent) were recycled, with the rest exported as plastic waste or lost in the recycling process. *Ultimately, therefore, only an estimated 15 percent of the plastics that reached their EoL were recycled in the EU in 2020. This is a far cry from the 35 percent officially reported, which ignores uncollected and exported plastic waste and losses in the recycling process.*[37]

Comparing reported recycling rates and actual recycling rates for plastics

Figure 14

Treatment of end-of-life plastics in Europe (EU28 + NO/CH), 2020



Note: Includes end-of-life plastics leaked to the environment (including plastic pipes not in use but left in the ground), plastic products illegally exported, illegal waste treatment of waste (e.g., end-of-life vehicles), or plastics part of mixed waste streams that are not reported as collected plastics

Material Economics (2022), based on Plastics Europe, Plastics the Facts 2021. An analysis of European plastics production, demand and waste data (2020); Material Economics data and modelling (2022)

---

[37] A new methodology proposed by the European Commission in a revision of the 2018 EU Packaging and Packaging Waste Directive (PPWD) measures recycled quantities of all packaging (including plastics) at a later stage of the recycling process. With this approach, the share of plastic packaging recycling was 35 percent instead of 45 percent. But this methodology still neglects the amount of waste, including plastics, that is not counted due to inclusion in mixed waste. It is under these statistical accounting rules, therefore, that one should interpret the 2018 revision of the PPWD, which also introduces a new plastic packaging recycling target of 50 percent by 2025 and 55 percent by 2030.

From landfilling and incineration – a growing CO_2 problem

The European Commission put in place an amendment to the Landfill Directive[38] to ensure that by 2030 "all" waste "suitable for recycling or recovery" will no longer be accepted in landfills. Furthermore, in November 2021, the European Commission proposed a new regulation on waste shipments[39] " to ensure that the EU does not export its pollution abroad and waste is treated in a sustainable way, within and outside the EU, while supporting the move to an innovative circular economy". Under the new regulation, EU member states will face constraints on exporting plastic waste to non-OECD countries, increasing the pressure to recycle domestically. Most send their waste to Turkey (which is in the OECD). Interestingly, however, recyclers cite the new recycled plastics mandate under the Single-Use Plastics Directive (SUP) as the main factor reducing exports since 2018 because it has increased internal EU demand.

Despite its good intentions, the new landfilling rules have significantly increased the amount of incineration of plastic waste – its related life-cycle emissions, if better recycling incentives for this waste is not forthcoming. While from a holistic environmental point of view, the ban on landfilling is a reasonable action, the EU's incineration problem still needs tackling. Incinerated plastics typically release 2.8 kg CO_2/kg of plastic, and each year the EU incinerates in the order of 25-30 million tonnes of plastics, after accounting for misallocated waste in mixed waste streams. *Thus, the problem of incineration could be as large as 70–84 million tonnes of* CO_2 *per year. These numbers are expected to grow in the future under business-as-usual policies, in which both plastic use and incineration rates increase.*

Potentials to enhance recycling and reduce CO_2

Incentivising a holistic circular economy can develop a resource-efficient and climate-friendly plastics economy while ensuring the long-term competitiveness of the EU. This can be done by pulling the following key levers:

First, the highest priority is to avoid the use of unnecessary and short lifetime plastic and to incentivise the re-use of plastic materials. We conservatively estimate that suitable support schemes for reduce-and-re-use approaches could reduce emissions by around 8 $MtCO_2$ in 2030 and in 2050, compared to business-as-usual scenarios. Scenarios by SystemIQ[40] have indicated that higher levels might be possible.

Second, mechanical recycling is the most energy-, material- and cost-efficient recycling technology but it relies on relatively pure waste streams. We estimate that the current recycling rates of 15 percent[41] sustained by mechanical recycling could theoretically be pushed to 35 percent, which could result in a CO_2 reduction of as much as 12 $MtCO_2$ in 2030 and 27 $MtCO_2$ in 2050 against a business-as-usual baseline.

To achieve these levels of mechanical recycling, certain conditions must be in place. Increasing mechanical recycling means significantly improving separate collection rates and improving the sorting and data monitoring of end-of-life plastics to ensure the necessary amounts of adequate waste streams. Significant improvements in collection is needed, especially when it comes to the *separate collection* of alternative plastic types. Wider use of tools such as Deposit Refund Schemes (beyond bottles) to promote much higher rates of separate collection via economic incentives will also be necessary given the high levels of "lazy sorting" of plastic into general waste. In addition,

---

[38] Directive 2018/850, European Union 2018 B.

[39] European Commission 2021 E.

[40] SystemiQ 2022 (forthcoming).

[41] This is from end-of-life to recycled product.

Ecodesign policies must be strengthened to maximise the potential of mechanical recycling by eliminating contaminants and chemical polymer types not suitable for mechanical recycling.

Third, while mechanical recycling potentials should be maximised as a first priority –it is likely in general to be the most energy- and CO_2-efficient and the least environmentally impactful way to recycle materials – it must be recognised that there are limits to mechanical recycling. Such limits include inherent challenges related to the logistics of separate collection and sorting, the current physical impossibility of mechanical recycling for all plastic types, downgrading concerns inherent to certain mechanical recycling processes, the inconvenient location of mechanical recycling units and the lack of necessary scale to cope with certain waste supply streams.

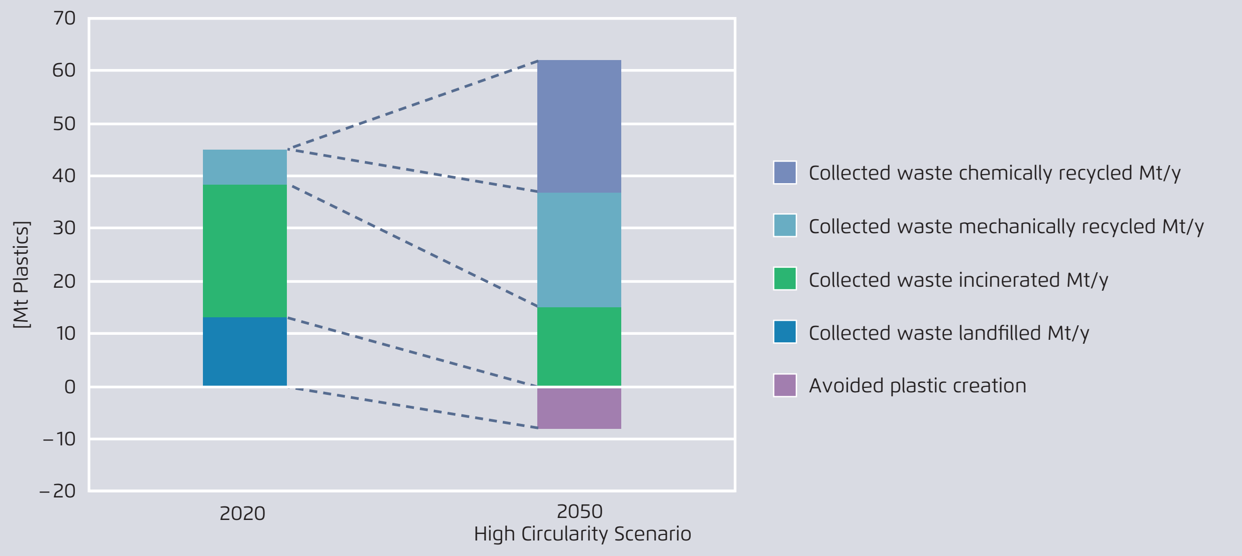
To process plastic waste streams that cannot be mechanically recycled, a comprehensive system for *sustainable and high-quality* chemical recycling must be established. If this is not done, then the EU will have no choice but to incinerate very large and growing amounts of plastics. We estimate that the incineration of plastics in the EU today releases around 70 $MtCO_2$ per year and could rise to as much as 112 $MtCO_2$ by 2050 if not addressed. Absent large-scale chemical recycling, it is difficult to see how to eliminate these CO_2 emissions in a climate-neutral way. While some very specific sites may have a certain degree of CCS or CCU potential, eliminating 112 $MtCO_2$ per year is an altogether different magnitude of problem.

The ideal scenario would enact the following hierarchy of actions:

1. Maximise the amount of mechanically recyclable plastics via Ecodesign and smarter product conception (and better separate collection practices).
2. Recycle all mechanically recyclable plastics
3. Chemically recycle as much of the residual plastic as possible

How the end-of-life treatment of plastics could evolve in a high circularity scenario

Figure 15



Agora Industry (2022)

4. Use bio-based carbon in the plastic polymers to ensure than any residual incineration is carbon neutral
5. Capture and store CO_2 from incinerated plastics – whether bio-based or not (for long durations as a first priority, and for short durations as a last resort).

A key enabling condition for unlocking the potential of chemical recycling is to maximise the amount of plastics collection from mixed waste streams. In reality, even the best separate collection schemes at the point of consumer disposal will not capture a massive share of plastics, which continue to end up in general mixed waste. *Our estimates are that 75 percent of the plastics in this mixed waste can be retrieved and can still be viable for chemical recycling.* What is key is to create a business case for widespread investment in the separation of materials from mixed waste and in capacities to receive and process the waste via chemical recycling. Such technologies are already in development in Sweden, the Netherlands and Norway.

But chemical recycling, while important, is not a magic bullet. It must be pursued with caution because the level of CO_2 reductions compared to virgin plastic production depends on the way in which chemical recycling is done.[42] Chemical recycling can also have other under undesirable environmental impacts depending on the technological approach adopted.[43] To gain market access, it is essential that chemical recycling be appropriately regulated to ensure that only the most sustainable technologies and processes are enabled. Critical issues include ensuring that there is high degree of efficiency in converting waste plastics to recycled plastics – e.g. a good mass balance performance with low conversion losses; the prevention of waste plastics from being converted to transport fuels or other short-lived carbon recycling products – and ensuring that the energy used to power the process is carbon-free. If these and other environmental conditions are met, we estimate that the widespread deployment of chemical recycling could lead to a CO_2 reduction of 4 Mt by 2030 and of 44 $MtCO_2$ reduction by 2050.

We also assume that it will possible to reduce emissions for plastics that cannot be mechanically or chemically recycled by using plastics from bio-materials or replacing them with alternative materials.

Estimates of CO_2 reduction potentials from the main plastic circularity solutions — Table 1

	Emissions saving potential vs BAU
Reduce and re-use; Avoid unnecessary and short-lived plastics	2030: – 8 Mt CO_2 2050: – 8 Mt CO_2
Mechanical recycling; Increase share from 15 % to 35 %[1]	2030: – 12 Mt CO_2 2050: – 27 Mt CO_2
Chemical recycling; Increase share for non-mechanically recyclable polymers from 0 to 40 % of plastic use	2030: – 4 Mt CO_2 2050: – 44 Mt CO_2

[1] That is, from end-of-life to recycled product

Agora Industry (2022)

---

[42] Lux Research (2020).

[43] Zero Waste Europe (2020).

Enabling conditions

The plastics industry consists of many stakeholders that process plastics at different life-cycle stages. Unlocking the full potential of a circular plastics economy requires action at each stage.

40 percent of plastics are used for packaging applications in Europe – and dealing with packaging is a key part of the problem. While a mindset shift is already taking place in some branches of the plastic packaging world, comprehensive targets must be developed that incentivise innovative business models to reduce plastic waste or enable the re-use of packaging. Achieving those targets depend on funding the development of new product formats and the creation of more consumer awareness.

In an ideal world, the potential of mechanical recycling is fully exploited and no recyclables end up in chemical recycling or at incineration plants that could otherwise be mechanically recycled. But even under ideal circumstances, chemical recycling will need to be prioritised and optimised to ensure that a large share of the remaining plastics is still recycled. Enabling conditions for both mechanical and chemical recycling need to be tackled in parallel while still maximising the potential of mechanical recycled waste flows.

To increase the proportion of waste plastics eligible for mechanical recycling (and for chemical recycling), the *collection* and purity of waste streams must be improved. This must be a core objective of the current revision of the EU's plastics waste legislation. Current EPR schemes, while helping to achieve many goals such as funding key recycling infrastructure, do little to promote high-value plastics recycling. A revision of the EPR schemes could improve collection and separation, creating a higher share of plastic waste that can be mechanically and chemically recycled. In the long term, the CO_2 price for virgin materials must be internalised in favour of recycled materials. In the short term, recycled content requirements (quotas) are the only truly effective option to ensure value chain conditions that increase the share of mechanically recycled materials, and are thus desperately needed (see section 3).

Another important enabling condition to maximise the potential of both mechanical and chemical recycling is optimising design for recyclability. In this respect, Ecodesign policies can be extremely important.[44]

Chemical recycling is only now becoming an integral part of waste management. Investment support for a first wave of projects may help to move beyond demonstration plants and accelerate the establishment of chemical recycling. Despite its novelty, however, chemical recycling must start being incorporated into current waste management schemes.

It is also important that clear, robust and stable sustainability requirements and standards be developed for chemical recycling. In particular, the EU's Industrial Emissions Directive and other measures must ensure the greatest possible life-cycle emissions reductions vis-a-vis incineration.[45] This would not only help to make chemical recycling deployment consistent with broader environmental and climate goals; it would also provide long-term certainty for investment.

In addition, like mechanical recycling, chemical recycling needs much better separate collection of various plastic types in order to avoid the contamination of waste streams.This could be prioritised

---

[44] https://www.plasticsrecyclers.eu/design-recycling

[45] This is not to neglect other existing environmental standards for chemical recycling, such as the full environmental permitting process required for each facility, which requires cooperation with local and national authorities. There is also significant R&D work being done to reduce the impact of these technologies through better energy efficiency and new systems such as electrification. Such technology standards would need to be incorporated into the Industrial Emissions Directive and other governmental measures.

under the EPR scheme, which could help to ensure that the waste collection system funds logistics and sends sorted waste streams to mechanical and chemical recyclers.

Chemical recycling also requires sufficiently strong economic incentives to be competitive with virgin plastics production. Currently, the EU ETS and other incentives for waste-to-heat generation do little in this regard. For example, the free allocation of allowances mitigates any possibility of higher costs for virgin plastics. Meanwhile, rather than taxing the incineration of plastic waste, state support and renewable energy aid is given to incinerators for burning mixed waste, and incinerators are not currently governed by the EU ETS. Chemical recycling thus needs stronger economic incentives for the integration of recycled plastic into final products and disincentives for inefficient collection (such as carbon pricing for incineration).

Another important enabling condition facing both mechanical and chemical recycling is the need for a reliable and large-scale supply of high-quality feedstock. While quality issues relate to the questions of product design and sorting at the point of disposal and collection, they also imply high levels of (separate) collection for plastic waste streams.Deposit refund schemes and the adaption of the collection infrastructure to local circumstances are therefore critical for ensuring that the business model of chemical and mechanical recycling works.

Finally, as with cement, chemical recycling requires adjustments to product standards, which currently limit all but non-virgin plastics from being used in certain applications.

Why is this interesting from an economic perspective?
The transformation of the plastics industry towards a circular plastics economy requires decisive action in many areas, but it also offers massive advantages for the environment and the economy. In a circular economy, waste plastic is a valuable resource. The efficient recirculation of EoL plastics into the value chain reduces CO_2 emissions and environment pollution, but it also reduces dependence on imports of virgin feedstocks.

Preliminary estimates by Agora Industry suggest that exploiting the full potentials for enhanced plastic savings (see section 2.2) and recycling as outlined above could save on the EU’s use of oil-based hydrocarbon feedstocks the equivalent of around 149 barrels of oil by 2030 (compared to current policy settings). The EU’s use of hydrocarbons sourced from natural gas, such as ethane, propane and butane, could also be reduced by around 2.7 billion cubic meters (bcm) by 2030 and by significantly greater amounts by 2050.

By making the EU’s growing pile of plastic waste more valuable, higher circularity gives the EU access to large stocks of key raw material inputs into its own production without needing to import fossil fuels or its derivatives. In light of the current energy crisis, together with growing concerns by citizens about the environmental footprint of consumables, higher rates of recycling will enable the European plastics sector and downstream value chains to operate and market clean products to consumers from a long-term competitive position. Finally, local production, use and recycling will spark innovation and create jobs. By moving decisively into a circular plastics economy, the EU stands to become an international technology leader.

2.1.4 Cement and concrete

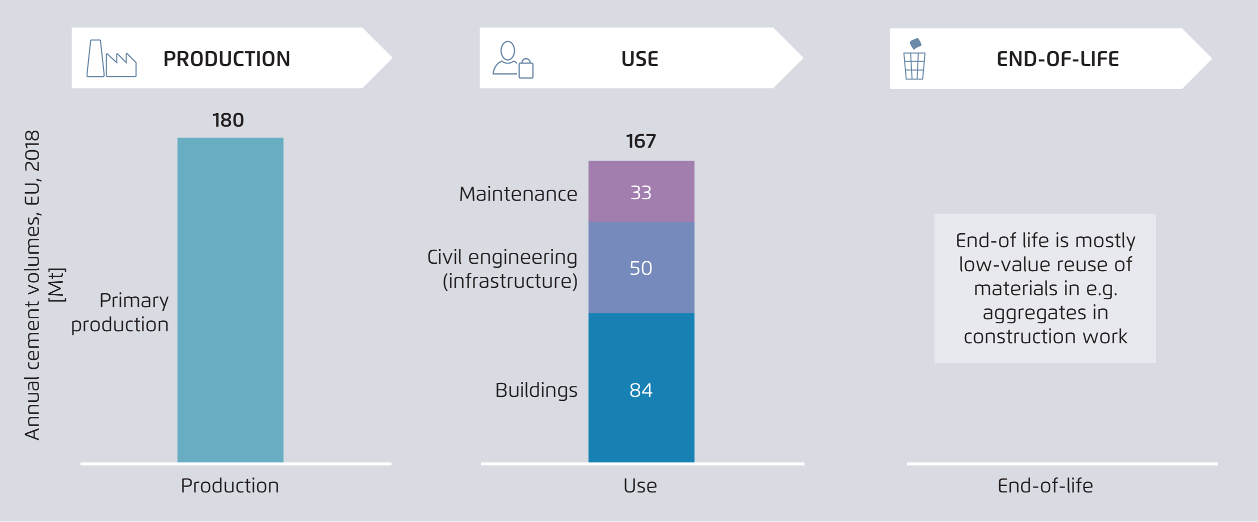
Concrete is the fundamental structural component of many buildings and a large amount of infrastructure existing today. It consists of a mix of cement, water and aggregates and can also contain small quantities of chemical admixtures. The cement content in concrete varies between 7–20 percent, depending on the compressive strength and other qualities and on the efficiency with which it is applied. (Greater efficiency is often possible, especially in developing countries where the lack of industrialisation and standardisation of concrete product leads to excess binder use.[46]) Cement is made by grinding clinker with a small amount of gypsum and other materials. Ordinary Portland Cement can contain up to 95 percent cement clinker, but typically OPC producers substitute a small share of clinker with other, supplementary cementitious materials. The average clinker content in EU cement is 73.7 percent[47]. The purpose of cement is to bind fine sand and coarse aggregates together in concrete and mortar. It acts as a hydraulic binder, which means it hardens when water is added.

The clinker contained in cement is responsible for a major part of embedded CO_2-emissions in concrete. Clinker is made by calcining a mixture of approximately 80 percent limestone (for calcium) and 20 percent aluminosilicates. Raw materials are then heated to 1450 °C, transforming limestone to calcium oxides and sintering the mixture. The carbon dioxide released in the chemical reaction accounts for 65 percent of the clinker CO_2 footprint. The remaining 35 percent arise from the burning of fossil fuels to provide heat for the kiln.

The cement sector still has a long way to go towards a fully circular scenario. At present, cement is not recycled to be re-used as a binder substitute. Instead, it is re-directed to low-value usages such as backfiller. Annual cement production in the EU currently amounts to 180 million tons – 84 million tons of which are used for buildings, 50 million tons for civil engineering and 33 million tons for maintenance. 50 percent of emissions emanate from buildings and construction, the other 50 percent come from other

Cement production, use and end-of-life statistics

Figure 16



Note: Relative sector split based on Favier et al. (2018), A sustainable future for the European Cement and concrete industry

Material Economics (2018)

---

[46] See UNEP (2018) Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry. https://www.researchgate.net/publication/311980992_Eco-efficient_cements_Potential_economically_viable_solutions_for_a_low-CO₂_cement-based_materials_industry

[47] Cembureau (n.d.): https://lowcarboneconomy.cembureau.eu/5-parallel-routes/resource-efficiency/clinker-substitution/

sources. The cement sector currently accounts for 16 percent or around 115 Mt of European industrial sector's CO_2 emissions.48 Given that the cement sector is one of the major emitters in the sector, achieving stronger circularity is key.

Advanced recycling innovations and enhanced recarbonation techniques

In terms of recycling models, new kinds of advanced recycling technologies offer potentially new and interesting solutions to remake high-quality recycled cement using the intelligent separation of concrete constituents into separate waste streams of gravel, secondary sand and cement stone. For example, according to pilot testing done by the company Smartcrusher[49] and the project Fastcarb,[50] more effective techniques may exist for reseparating end-of-life concrete into its constituent components and for recarbonating them and remaking clinker, which can then be placed in a virgin cement binder via a closed CO_2 loop (more on this below). The amount of possible recycling projected differs depending on the company and the expert, but meaningful CO_2 savings are expected to be possible by 2030 and by 2050. A key co-benefit of such processes is that they can reduce the global use of other scarce resources, such as sand and limestone.

The ability to recycle cement in this way depends on the availability of end-of-life concrete versus the demand for new concrete (the ratio of demolition to new build) and the relative locations of demolition versus construction. At least in Europe, such ratios are likely to be very favourable in major urban areas, where a large share of construction occurs. In a sector that is typically regarded as extremely difficult to abate, and where complicated solutions such as CCS or CCU are often promoted as the main 'backstop' technology, improved cement recycling and high clinker efficiency in new cement mixes would appear to make sense as part of a broader portfolio of solutions.

One alternative binder solution using recycled cement is "Celitement" (now owned by Schwenk Cements). The process makes hydraulic binding agents with similar properties to cement. Compared to classic Portland cement clinkers, however, they use lower amounts of limestone. This reduces CO_2 emissions from CaO during clinker production and enables lower processing temperatures (saving energy). The process is believed to be capable of a 50 percent reduction in clinker per unit of cement.[51] Celitement is a virgin cement production process, but could in principle be produced in part using recycled cement and concrete fines – opening the door to low-carbon production processes.

Another source of circularity in the cement sector is concrete product fabrication and waste management techniques that enhance the natural tendency of cement to "recarbonate" – i.e. for calcium-rich hydrated fines to reabsorb CO_2. Because recarbonation is a naturally occurring phenomenon, two issues arise: the accurate measurement of the carbon sink and enhancing the level of CO_2 stored in the mineralisation process. A range of different technologies exist addressing these issues. One option consists in exposing finely crushed end-of-life concrete to the air to maximise its rate of CO_2 absorption (although this is limited by the need for large surface areas close to construction markets and by the total end-of-life concrete available[52]). Another option consists in heating the fines in a CO_2-rich environment to speed up the recarbonation rate, as explored by the Fastcarb Project.[53]

---

[48] Agora Energiewende (2021 A): Breakthrough Strategies for Climate-Neutral Industry in Europe: Policy and Technology Pathways for Raising EU Climate Ambition

[49] See www.slimbreker.nl; Ottolé, Schenk. Available at: https://www.slimbreker.nl/publications.html

[50] See https://fastcarb.fr/en/home/

[51] https://celitement.de/en/

[52] https://ethz.ch/en/news-and-events/eth-news/news/2020/08/neustark-binding-carbon-dioxide.html

[53] https://fastcarb.fr/en/home/

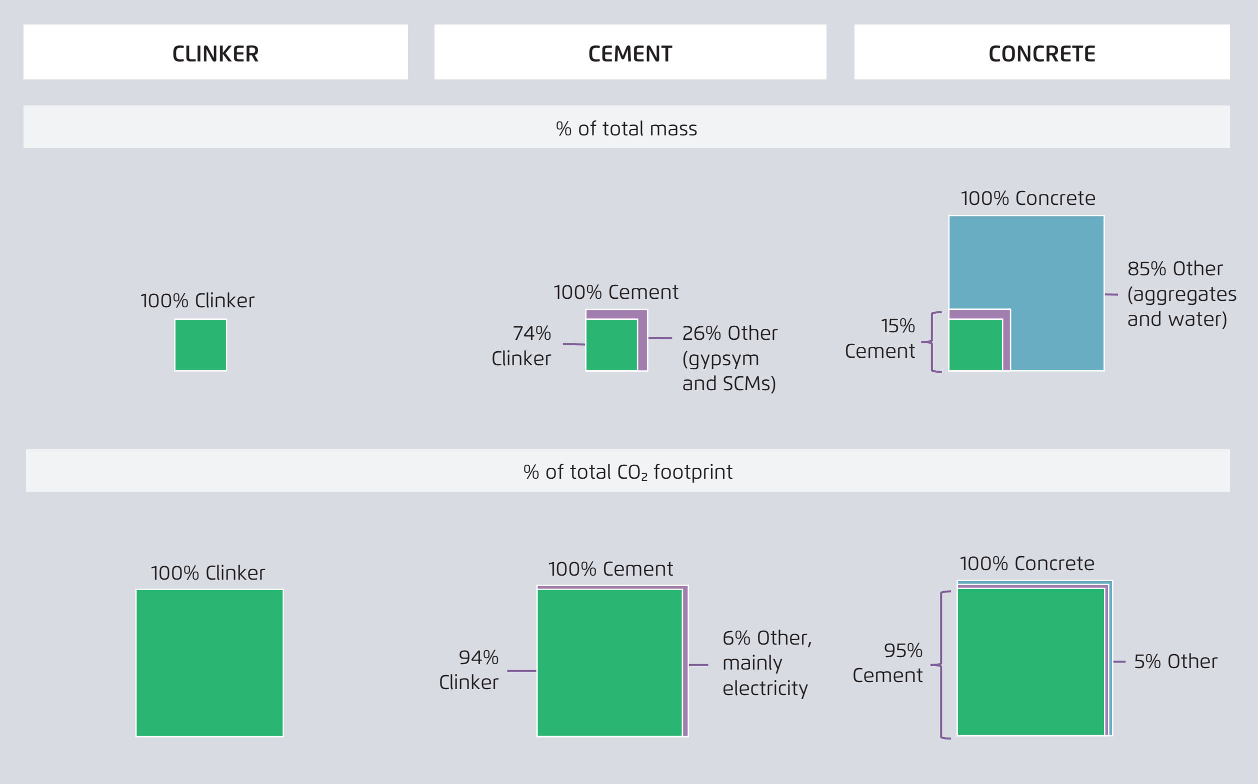
Material efficiency, optimisation of cement and concrete formulas and substitution of materials
One of the main levers for reducing the CO_2 intensity of cement lies in reducing the cement-to-concrete and clinker-to-cement ratios. As seen in Figure 17, the clinker ratio is the determining factor for cement sector emissions. A reduction of the clinker-to-cement-ratio can be enabled through various modifications to existing concrete and cement paste formulations so that low-binder concretes can enter the market. These options can reduce clinker content per unit of ready-mixed concrete by various amounts, depending on the technology and the availability of raw materials. Widely used fillers such as ground blast furnace slag (GBFS), fly ash and other pozzolanas can substitute 30–50 percent of clinker compared to CEM I cement types (or 15–30 percent compared to typical Portland cements).[54] So-called "LC3" cements (which use a combination of limestone and calcined clay instead of clinker) can reduce clinker content by similar or greater amounts in some cases. LC3 cement types may be helpful to replace fly ash and GBFS because these resources will be reduced or modified by the phase out of coal and coal-based steel production.

---

[54] In principle, an over 50 percent reduction in clinker relative to CEM 1 is possible if clinker substitute materials are used, water-use control is in place and particle sizes are reengineered. See Vanderlay et al (2018).

The carbon footprint of clinker, cement and concrete

Figure 17



Note: 'Other' CO_2 emissions from concrete include the manufacturing of concrete and emissions from other materials than cement. Transport emissions are excluded from these figures.

Material Economics (2019)

However, more ambitious technologies are also under development. One such example is a new set of formulations based on more-efficient packing and ready-mix concrete materials. For instance, Ecocem[55] promotes a technology that it claims can replace 80 percent of clinker using a combination of techniques in parallel: ground blast furnace slag (a steel by-product), optimised particle sizes and the replacement of clinker using other engineered geopolymers. Vanderlay et al (2018) describe several solutions that have important advantages over other clinker substitutes. Not only do they achieve much lower levels of clinker content but they also use simple and readily available alternatives such as plasticisers and advanced engineered fillers. So while they require process changes at the plant, they do not need new infrastructure (as with CCS or CCU). Such technologies, if scalable, could produce significant clinker-to-cement ratio reductions in the future. One question with regard to these technologies is their reliance on ground blast furnace slag as a key component, which is a limiting factor due to its relative scarcity. Interviews with Ecocem suggest that the company believes that steel slag can be replaced using other geopolymers should available slag become a limiting factor. However, cement producers differ on how easy this will be to achieve.

To the extent that new formulations and enhanced circularity in cement are unable to deliver net-zero emissions, the cement and construction sector will also need to consider material substitution. This can happen within product classes (e.g. optimising the right cement type for the right usage, or reducing reinforced concrete use to limit the use of CO_2-intensive concrete types) or across material types (e.g. replacing cement with). We say more about materials in the “material efficiency” section below.

Circular economy potentials

Our estimates suggest that the emissions reduction potential of low-clinker cement and concrete formulations as well as circular approaches in the cement sector is significant. For instance, we estimate that new binder formulations alone could reduce up to 10 million tons of CO_2 in the sector by 2030, a 9 percent reduction compared to the business-as-usual scenario. By 2050, 31 million tons of CO_2 could be saved, which would constitute a 30 percent CO_2 reduction relative to BAU. This is just one solution, however.

Additional emissions reductions in the order of up to 16–24Mt of CO_2 per year by 2050 could be possible if genuine cement recycling, along the lines of either Smartcrushing and/or Fastcarb technologies, achieved commercial demonstration and wide adoption. This estimate assumes that between 60 percent to 100 percent of cement fines in existing concrete waste are fully recovered each year and are re-used to displace virgin cement clinker in one way or another. It also assumes that approximately 32 million tonnes of cement are recovered per annum from the approximate 210 million tonnes of concrete demolition waste that the EU produces each year. Since the cement sector emits in the order of 114 $MtCO_2$ per annum in the EU, the combined savings – 31 Mt and 16 Mt of CO_2, respectively – would represent up to a 41 percent reduction in cement-related emissions.

Furthermore, additional CO_2 savings could be achieved by utilising a range of other circularity and material efficiency levers. In terms of circularity, another key possibility is the direct reuse of in-tact concrete components such as concrete slabs or beams. Indeed, by designing such products in more modular ways, and building material databases (the materials passporting concept), greater re-use of existing components could be made. Materials Ecomomics (2018) has estimated that up to 7 $MtCO_2$ of additional CO_2 might be saved by the re-use and recirculation of construction

---

[55] https://ecocem.fr/en/ According to Ecocem, the company filed an application for a European technical assessment in September 2021. For more details on the broader class of technology used by Ecocem, see Vanderley et al (2018).

components in the cement and concrete sectors. We discuss these and other possibilities in section 2.2 below.

Enabling conditions

At present, few major cement producers use low-binder cement formulations or engage in smart-crushing and the recycling of cement fines – not at a meaningful scale, at any rate. This picture is gradually changing, however, and EU cement companies have set more ambitious goals for reducing emissions starting in 2030.[56]

Several barriers exist to achieving the technically feasible reductions in the cement sector.

First, regulations and standards play a crucial role in the transformation of the cement sector towards climate neutrality, but they currently hinder the use of innovative technologies. Cement must be manufactured according to the harmonised European Standard EN 197-1, while concrete must meet non-harmonised national standards (linked to EN 206).[57] Changing harmonised standards such EN 197-1takes decades and can be cumbersome. Alternatively, cement producers can undergo a EU technical evaluation, which allows them to sell new and innovative cement with the CE mark that is not in line with existing standards. However, non-harmonised national standards for concrete can still prevent concretes without the CE label from entering the market. The challenge therefore lies in changing standards across all 27 EU member states.

Second, current regulations and standards reflect in part the conservativism of the construction sector, which can be reluctant to use new technologies. Incentivising the use of alternative materials through, say, demonstration projects and better communication, can be an important enabling condition for spurring change in the sector.

Another key condition for enabling more material efficiency in the building sector is a revision of the current EU emissions trading system (ETS).[58] In its current form, cement producers receive free allocations based on the defined benchmark for clinker. Unlike the steel sector, free allocations are given both to conventional as well as to low-carbon technologies. While such a design does not discriminate against low-carbon primary production, it does have a distorting effect on strategies for material efficiency by subsidising primary production. A possible way forward to eliminate this distortion is to price products according to their carbon intensity and phase out subsidies for primary production, which would provide a level playing field for different decarbonisation strategies ranging from low-carbon primary production to circular economy strategies for material efficiency. The phase-in of a carbon border adjustment mechanism (CBAM), by eliminating current subsidies, would also provide a solution.

Price and market demand are key factors in increasing the use of low-binder concretes materials. The public sector can play an important role in fostering innovative and circular low-carbon materials and practices. Policies such as quotas for recycled concrete or embedded carbon limits on new buildings can be another option (see section 3).

---

[56] For instance, Cembureau has pledged to achieve an emissions reduction of just 30 percent by 2030 relative to 1990. Keep in mind that emissions had already declined in 2017 by about 15 percent relative to 1990 thanks to upgrades at existing sites (such as the replacement of outdated wetkiln technologies). See https://cembureau.eu/media/kuxd32gi/cembureau-2050-roadmap_final-version_web.pdf

[57] Cembureau (n.d.) Available at: https://lowcarboneconomy.cembureau.eu/5-parallel-routes/resource-efficiency/clinker-substitution/

[58] See https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets/revision-phase-4-2021-2030_en ; European Union 2018 E.

Why is higher circularity an interesting strategy for the cement sector?
Circular approaches in the cement sector reduce the need for other decarbonisation strategies such as carbon capture utilisation storage (CCS) and make the most efficient use of available material. While there are unavoidable process emissions in the cement sector, these could be reduced when minimising clinker-cement and cement-concrete ratios. These material efficiency approaches could also reduce the amount of CO_2 stored via CCS. Infrastructure for CCS still needs to be built, and the new regulations will have to be implemented. These processes will require years, but material efficiency approaches could in theory be implemented today. Also, material efficiency measures would reduce the urgency of deploying other technologies such as CCS.

2.2 Material efficiency

The circular economy is not only about saving emissions via enhanced recycling. A significant amount can also be done by improving material efficiency in the design and fabrication of material-intensive products and, in some cases, by substituting CO_2-intensive materials for less CO_2-intensive ones.

The discussion of material efficiency or even material substitution in industry decarbonisation is sometimes seen as a "taboo" topic. This is because of the belief in certain parts of the industrial sector that industrial business models today rely on maximising the total volume of basic materials production. Thus, if materials are used more sparingly to produce the same output, or if material substitution occurs, traditional industry may no longer be profitable.

The idea that material efficiency is bad for business is somewhat ironic, however. Indeed, an entirely different way of thinking prevails in the energy sector. Since the oil shocks of the 1970s, the energy sector has regarded energy efficiency – achieving the same level of industrial production with less energy – as an important and desirable policy objective for both economic and security reasons. In the context of the energy transition, there is no shortage of energy efficiency legislation and policy measures at national and European levels. For example, the EU has directives on energy efficiency, energy labelling, Ecodesign requirements for electrical goods, energy performance in buildings and binding targets on energy efficiency, etc. But very little of that legislation applies to material efficiency (with the possible exception of the ban on single-use plastics). How can it be the case that material efficiency is not seen as a strategic pillar of industrial policy, while energy efficiency is? In a world where basic materials are becoming scarcer and scarcer, this approach makes no sense.

The view that material efficiency or substitution is "bad for business" is not as accurate as it may appear at first blush. As the discussion in this section will make clear, material efficiency or substitution does not necessarily mean abandoning the production of conventional basic materials such as steel, cement or plastics. On the contrary, efficiency measures should be thought of as important elements in a package of solutions that enable sustainable production and continued materials use.

While it is true that many companies producing basic materials have business models that are at least partly based on material throughput, a large share of their value added is often generated in the production of higher-value downstream products. For such products, the total amount of material embedded in a product is often less important than the product's functionality. Thus, even if total prices are now quoted in tonnes of materials, it is possible to imagine a future in which material product prices are based on the shape, section, length or other characteristics corresponding to the functionality of such goods. After all, an equivalent development has begun to take place in the energy sector, where the "energy services" model has emerged in response to growing attention on energy sellers for energy savings.

Of course, the challenge for companies when shifting from a "total throughput" model to one based on material (or energy) services is that it implies significant changes to company assets, operations and labour skills. While it is not an all or nothing proposition – basic cement, steel and plastics will still be needed in the long term – a period of adjustment and learning will nevertheless be required when introducing a model centred on material services and recycling, which can lead to mistakes. On the other hand, nothing about that proposition is intrinsically riskier than clinging to conventional carbon-intensive assets as regulation and consumer tastes evolve

As Figure 9 showed, over 60 percent of the EU's emissions from producing steel, aluminium, plastics and cement are linked to materials that ultimately end up in construction products, automotive and mobility products and packaging products. We therefore explored the main levers for reducing GHG emissions through greater material efficiency and substitution in these sectors. The following potentials we identified were the most significant:

In the **construction** sector, several changes can reduce the use of CO_2-intensive materials without decreasing economic value generation. For instance, projects can stop the practice of overordering materials to limit delays on-site. Or they can achieve the same structural performance by using less material- intensive, but higher-strength components (often the case with steel or concrete). CO_2-intensive components can be used in a more tailored way by, say, using different concrete types in the right places to minimise average CO_2 content. Similarly, steel and concrete beams are sometimes over-specified for actual loads due to the fact that a "one-size-fits-all" approach can save on labour and logistical costs during assembly. In some cases, the cement-intensive concrete needed for protecting steel rebar from corrosion can be avoided by using alternative techniques to limit corrosion.

Current building regulations in member states across the EU prescribe the use of reinforced concrete for foundations and structures, and as such they may act as another potential limiting factor for optimising structural performance. This can be a problem for reducing the CO_2 intensity of cement applications because today's reinforced concrete involves higher cement-to-clinker ratios to reduce porosity and thus protect against the corrosion of embedded steel, which can lead to cracking and eventual failure.

In many cases, building projects could reduce the CO_2 intensity of construction materials with designs that take into account CO_2 optimisation. Indeed, the design phase is often one of the most important single actions that can be taken, since the choice of materials can be limited by architectural and engineering specifications earlier on in the project phase. (Ensuring that building information models are optimised for CO_2 in materials is one possible solution but achieving it would require additional incentives.)

For building retrofits, energy audits could be used to identify carbon-optimal renovation measures for each specific building, taking into account the effects not just on energy performance but also on embedded CO_2 in materials. Such concepts would need to inform any EU policy seeking to precipitate a wave of retrofits across the building sector.[59]

The concept of "material passports"[60] could also be used to enable a higher level of recycling and to prolong the lifetime of buildings and their parts. Material choices and substitutions can then be made at the building & building elements level, depending on their purpose and function.

---

[59] European Commission (n.d.) https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

[60] Buildings as material banks: Integrating materials passports with reversible building design to optimise circular industrial value chains. See: https://cordis.europa.eu/project/id/642384

The average lifetime of buildings also has a significant impact on overall material efficiency. For instance, it has been estimated that the average building lifetime in the EU is closer to 50–70 years,[61] while in China the number is closer to 25–30 years.[62] However, certain kinds of buildings in Europe can have lower-than-average lifetimes, especially when they are not designed for ease of renovation or when the disincentives for demolition are not strong enough to incentivise deep renovation with existing structural components. It is important, therefore, that the EU meet several key objectives when designing or renovating buildings. These include flexibility in use, adaptability, modularity and climate change resilience.

Finally, material substitution is possible some construction locations and applications that can reduce stress on CO_2-intensive resources. In some cases, carbon can even be stored for significant periods using biobased materials, such as wood. Of course, a range of related concerns must be kept in mind, including the acoustic and thermal performance of the overall structure, the limits of wood to replace concrete or steel in foundations, tunnels and water environments, the availability of sustainably harvested wood, and the full value chain and life-cycle emissions from transport, expected structure lifetimes and the treatment of materials. Nevertheless, in certain cases woody biomass or other alternative mineral-based solutions such as loom can serve as sustainable substitution options.

Of course, regulating for each of the individual abatement levers described above is likely to be very challenging. As discussed in section 3, however, this won't necessarily be the case. What is crucial is thatkey actors in the construction value chain – from architects and structural engineers to builders and sub-contractors – have shared incentives and the necessary information to optimise the CO_2 intensity of construction and material performance.

If governments incentivise many of the changes listed above, Agora has estimated that the EU building sector can save 15 Mt of CO_2 emissions relative to the business-as-usual scenario by 2030, or 12 percent saving compared with the total annual embedded CO_2 in new building and construction today. By 2050, we estimate that the sector can save up to 23Mt of CO_2 emissions against the business-as-usual baseline. The changes represent significant additional levers of abatement and should be part of a portfolio of measures to decarbonise the value chain.

The **mobility** sector also has several potential levers for reducing the quantity and CO_2 intensity of materials. Some of the main levers include the production of lighter weight materials (used to meet CO_2 performance standards and gain range); the reduction of the average growth rate for vehicle size; and the substitution of primary materials such as virgin steel with secondary steel for flat surface components.

In the future, greater use of "near-net shape casting" of metallic components could reduce new scrap rates produced during the manufacture of vehicle shapes and sections. Material Economics reports that new scrap rates can often be as high as 35 percent. A challenge to lowering new scrap rates is the continued use of commodity-based flat steel products for manufacturing components, which are typically produced by complex integrated steel mills that lack flexibility. A combination of investments in more flexible mills capable of near-net shape casting and further advancements in the use of three-D printing would likely be needed. However, the economics of such investments would need to be justified by the savings from reduced waste.

Agora estimates that up to 12 Mt of CO_2 emissions could be saved by improving the material efficiency

---

[61] Agora's estimates are based on data from the European Commission: https://ec.europa.eu/energy/eu-buildings-factsheets_en

[62] China Daily (2010): https://www.chinadaily.com.cn/china/2010-04/06/content_9687545.htm

and maximising the substitution potential of metal and plastic components in the mobility sector by 2050. This represents a savings of approximately 14 percent compared to the business-as-usual scenario – a non-negotiable amount given the difficulty of decarbonising the sector.

Material efficiency and some degree of product substitution are also likely to be important levers in a broader portfolio of abatement measures in the **plastic packaging** sector. As with construction or vehicles, of course, material solutions will continue to play a key role. However, as we have argued in section 2.1, mechanical and chemical recycling alone – even if pushed to their maximum potentials – are unlikely to tackle more than around 70 percent of the total abatement challenge. Additional solutions will thus be needed to eliminate the remaining 30 percent of emissions.

To tackle these residual emissions, a portfolio of solutions is needed. The portfolio will almost certainly have to include the following elements:

- → Greater use of bio-based plastic solutions. They do not necessarily reduce waste or ensure greater material efficiency, but they can help. Depending on sustainable biomass management policies, bio-based plastic can ensure that bio-genic carbon remains stored for longer periods in plastic products (leading to negative emissions) and that residual incineration or landfilling of bio-based carbon does not lead to net CO_2 increases in the atmosphere.
- → A far more efficient use of plastics – especially greater levels of re-use and less single-use plastic.
- → Carbon capture and storage or carbon capture and use (ideally resulting in long-lived storage in final products) for residual emissions from the incineration of plastics.

In practice, the substitution of plastic with alternative plastic types or new fibres is a highly technical and complex topic, which is made more complicated by the broad range of products and categories available. Accordingly, a thorough analysis lies beyond the scope of this report. Nevertheless, we estimate that significant potentials exist in this area, and believe that it is worthy of further consideration and analysis. The initial projections by Material Economics suggest that the potential for emissions savings through the reduction and re-use of plastics in packaging could be in the order 8 $MtCO_2$ by 2030 and 2050. These numbers would represent approximately an additional ca. 11 percent and 10 percent of the total plastics sector emissions (full value chain) in 2030 and 2050, respectively. Once again, these numbers should be taken as indicative of the fact that reductions and re-use do not necessarily obviate the need for plastics in the future. Rather, such solutions could have a meaningful role to play in a broader portfolio of CO_2 abatement solutions.

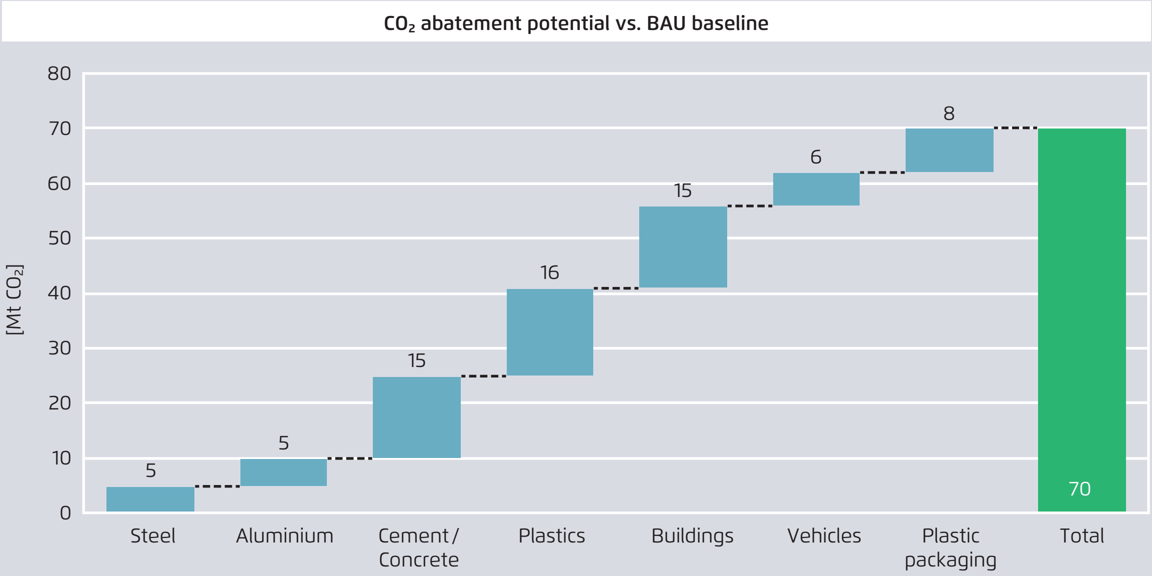
2.3 Section summary

The discussion below highlights the range of quantitatively significant CO_2 abatement potentials for basic materials due to enhanced circularity and material efficiency. Figure 18 summarises the results. Cumulatively, by 2030, up to 70 $MtCO_2$ of technical abatement potential exists across the steel, aluminium, cement, plastics, buildings, vehicles and plastic packaging sectors. To put this in perspective, 70 $MtCO_2$ represents 10 percent of total EU-wide industrial emissions in 2030 under our baseline scenario without additional circularity policies. As another point of comparison, the European Commission, in its 2030 Climate Target Plan, estimates industrial abatement potentials (excluding circularity measures) of 22–25 percent between 2015 and 2030. It should be clear, therefore, that enhancing circularity and material efficiency in CO_2-intensive sectors is too big a potential for policy makers to ignore.

The potentials for further CO_2 abatement from a more circular and resource efficient economy are even larger if one examines the 2050 picture. Figure 19 shows that, by 2050, most material

Estimated CO_2 abatement potentials from enhanced circularity and material efficiency by material or product in 2030

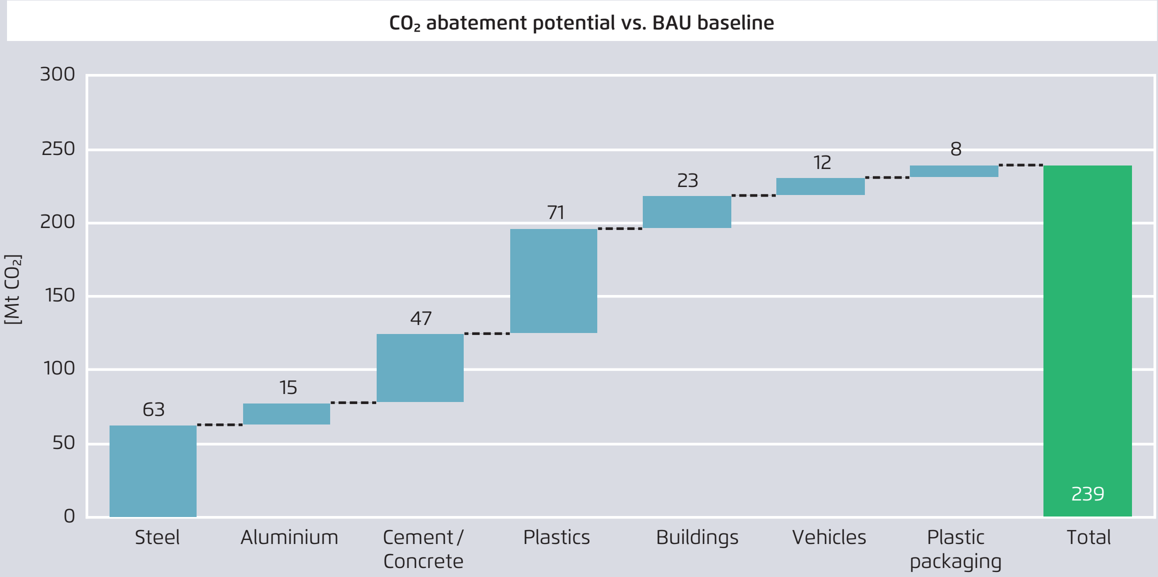
Figure 18



Agora Industry (2022), based on modelling tools provided by Material Economics

Estimated CO_2 abatement potentials from enhanced circularity and material efficiency by material or product in 2050

Figure 19



Agora Industry (2022), based on modelling tools provided by Material Economics categories have much larger annual CO_2 abatement potentials than those estimated for 2030. In total up to 196 $MtCO_2$ worth of abatement could be generated from enhanced recycling and low-clinker cement formulations. Added to the material efficiency potentials estimated for the buildings, mobility and packaging sectors, this could drive as much as 239 Mt CO_2 worth of annual abatement compared to business as usual by 2050. This is equivalent to approximately 34 percent of current yearly industrial CO_2 emissions in the EU.

The higher potentials in 2050 compared to 2030 reflect the fact that certain circularity measures – such as maintaining cleaner flows of steel, plastics, or aluminium scrap – will require time to bear fruit. For instance, in the case of steel scrap, it takes time scrap volumes to build up as a share of total final steel demand, and for companies to shift a share of re-investments into EU sites from primary into secondary production. This is why steel recycling is estimated to offer up to 63 $MtCO_2$ of abatement potential by 2050, but just 5Mt in 2030. Scale up in investment into key new circular technologies and capacities would also take time.

However, these lead times for payoff in some sectors, such as steel, does not mean that the policies should be ignored until later. On the contrary, the long-lived nature of products in key sectors such as vehicles and buildings, and the time it takes to transform assets and value chains, mean that the task is actually quite urgent. Taking the example of steel and aluminium once again: if products are not designed and fabricated in a manner that enables ease of separating metal contaminants (especially copper) at end-of-life, or if incentives for recyclers to invest in state-of-the-art separation technologies today, then future closed-loop recycling potentials will be diminished due to downgrading and downcycling of materials. Hence, a circular economy in 2050 must be prepared in the 2020s.

Table 2 provides more detail on the high-level numbers provided in the figures above. The table underscores several points:

- → First, there are very significant industrial CO_2 abatement potentials from taking the circular economy and related measures more seriously.
- → Second, the abatement levers that need to be unlocked range from enhancing the quality of materials available for recycling to encouraging material efficiency in product conception and design and incentivising material substitution in some instances. Intelligent policy approaches will need to create an appropriate set of incentives for private and public sector participants to enable this combination of behavioural changes and investments.
- → Third, to realise these potentials, a range of measures are needed, across several materials and value chains. While excessive and unnecessary regulation must be avoided, neither is there a single magic bullet. Circular economy policy packages that aim directly at the challenges of CO_2-intensive materials are required. But the multiplicity of barriers that exist means that the quality of data for monitoring the transition to a genuinely closed-loop economy will be critical. Carefully and well-defined policy objectives will need to be set to facilitate effective tracking of progress towards the desired outcomes. At present, it is not clear whether the EU or its member states have the necessary clarity of vision and tracking tools to govern the circular economy transition.

Summary of main enhanced circularity, material efficiency and substitution levers and their technical CO_2 abatement potentials

Table 2

Sector	**Enhanced circularity or material efficiency lever**	**Combined potential emissions savings for 2030 & 2050, in $MtCO_2$/year (share in percentage vs. BAU)**	**Type of lever**
Steel	• Increase recycling capacity (esp. scrap share in DRI- and EAF-based production) • Maintain clean-scrap flows (copper)	2030: – 5 $MtCO_2$ (2.4% savings) 2050: – 63 $MtCO_2$ (30% savings)	Enhanced recycling
Aluminium	• Increase closed-loop recycling into high quality consumer products • Maintain clean scrap flows	2030: – 5 $MtCO_2$ (10% savings) 2050: – 15 $MtCO_2$ (31% savings)	Enhanced recycling
Cement & Concrete	• Substitution with low binder formulations • Recarbonation and recycling of cement fines as inputs into circular cement production	2030 & 2050: – 10 $MtCO_2$ & – 31 $MtCO_2$ (10% and 30% savings respectively) 2030 & 2050: – 5 $MtCO_2$ and – 16 $MtCO_2$ (5% and 15% savings respectively)	Material efficiency, Enhanced recycling
Plastics	• Increase mechanical recycling to 35% (from 15% today) • Increase chemical recycling to 30 – 40% (from 0% today)	2030 & 2050: – 12 & – 27 $MtCO_2$ (18 – 27% savings) 2030 & 2050: – 4 & – 44 $MtCO_2$ (6 – 44% savings)	Enhanced recycling
Construction	• Reduce material waste (new scrap) in design & construction • Optimize application of CO_2-intensive materials • Substitution	2030: – 15 $MtCO_2$ (12% savings) 2050: – 23 $MtCO_2$ (15% savings)	Material efficiency, Substitution
Vehicles	• Reduce material waste (new scrap) in manufacture • Reduce weight via high-strength materials • Increase integration of circular components • Reduce average vehicle size	2030: approx. – 6 $MtCO_2$ (7% savings) 2050: approx. – 12 $MtCO_2$ (14% savings)	Material efficiency, Substitution
Packaging	• Reduce and re-use (esp. single-use plastics) • Switch to fibre-based materials	2030: –8 $MtCO_2$ (10% savings)* 2050: –8 $MtCO_2$ (11% savings)*	Material Efficiency, Substitution

* This refers to the reduction and re-use of plastic packaging only

Agora Industry (2022), with support from Material Economics

3 Nine policy options for the European Green Deal

3.1 A need for twin “demand-creation” and “supply-enabling” policies

To unlock the circular economy levers described in section 2, several barriers will need to be overcome. Some of the barriers are purely economic. For instance, it is possible for steel and aluminium recyclers to invest in state-of-the-art recycling technologies in order to provide a higher share of high-quality materials for closed-loop recycling. However, in practice, the value of recycled materials is often too low to justify the cost of doing so. Similarly, material efficiency and the substitution with low-carbon materials are unlikely to happen unless there are concrete economic or regulatory incentives that drive a shift from the status quo. Such issues highlight the need to create demand and markets for recycled materials and to improve the prices of recycled material relative to virgin materials production.

At the same time, however, simply creating demand for recycled materials or an additional cost to producing virgin materials does not single-handedly eliminate all the barriers. As highlighted in the preceding section, a range of non-economic enabling conditions exist. These include:

- → improving product design to eliminate inefficient practices that affect recyclability or material efficiency
- → improving separate post-consumer collection for end-of-life products
- → mandating the use of post-collection re-sorting of mixed waste to recover lost plastics (75 percent of which could be recycled chemically)
- → developing better statistics on plastic waste to appropriately define recycling targets
- → getting new recycled and re-use products recognised and certified by existing product standards
- → supporting the development and demonstration of new and potentially disruptive technologies
- → helping the construction insurance sector to change their risk perceptions and assessments of brown vs. green construction practices and products
- → achieving greater economies of scale in certain recycling value chains
- → appropriately defining recycled materials and recycled carbon to incentivise post-consumer recycling and material efficiency in production (e.g. the old-scrap vs. new-crap issue in metals production).

It should be clear, therefore, that a combination of measures is needed. Indeed, in interviews conducted for this project, some company representatives argued that placing new obligations on them to increase rates of recycling (e.g. via recycled content quotas) might only be manageable if accompanied by other policies to support the fulfilment of those obligations.

This section breaks down the challenge into two categories. First, we discuss policy options related to creating markets and improving the economics of circular materials and resource-efficient products. Second, we discuss enabling policies to support the efficient functioning of markets and economic incentives.

3.2 Creating markets for circular and resource efficient products

3.2.1 Mobilise carbon pricing incentives more effectively

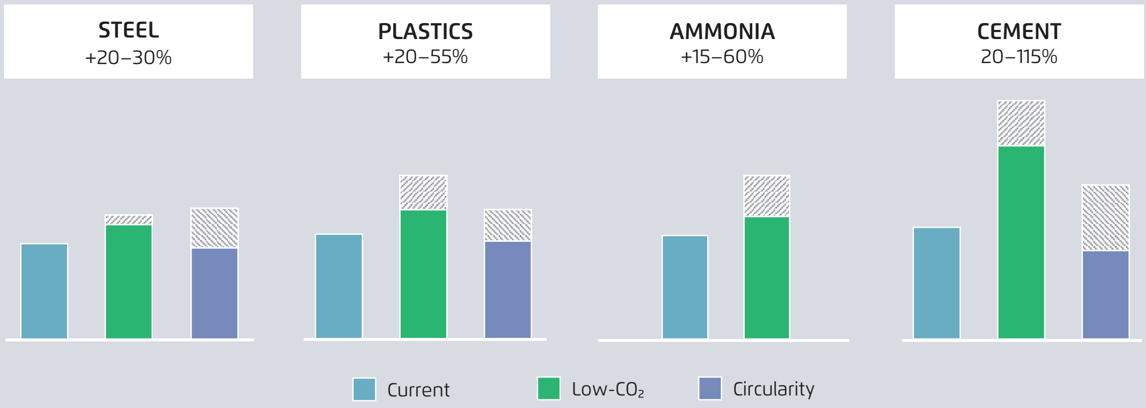
Perhaps the most immediately obvious option to improve the economics of recycled materials and to incentivise material efficiency and substitution is to reinforce the effectiveness of existing EU carbon pricing. Figure 20 shows the extent to which many circularity solutions for carbon abatement can generate higher production costs than those of current virgin production. While carbon prices in the EU Emissions Trading Scheme (EU ETS) have risen in recent years, the carbon price still provides little to no signal for enhanced recycling or material efficiency.

Currently, emissions from the incineration of waste are not covered by the EU ETS, and thus no carbon price is paid. In fact, often, incinerators receive subsidy payments for energy production due to the fraction of biomass that is burned for heat and power. Incineration could and should be covered by the EU ETS. Complementary policies (also discussed here) would need to be put in place to avoid creating perverse incentives. Notably, incentives would be needed to ensure that currently incinerated waste is not either landfilled or exported to countries with lower environmental standards. Experience with existing policies suggests that recycled content quotas for PET have already had an effect at lower exports of some incinerated plastics (they also would disincentivise landfilling). However, stricter export conditions than those currently in place (which limit exports effectively just to OECD countries) and stronger controls on landfilling should also be explored as complementary policies.

A second weakness of the existing carbon price incentives for enhanced circularity and material efficiency concerns carbon cost pass through. The free allocation of ETS allowances (together with state aid for indirect carbon costs for electro-intensives) means that producers of primary materials do not have to pass on carbon costs in their prices. Consequently, recyclers do not see any improvement in their cost competitiveness compared to virgin production and any incentives for material efficiency or material substitution further down the value chain are blunted. (In fact, in some cases, such as cement clinker production, the ETS free allocation system actually gives

Comparison of costs for enhanced circularity solutions vs. current virgin production methods

Figure 20



CO_2 abatement cost [EUR / t CO_2]

STEEL	PLASTICS	AMMONIA	CEMENT
57–150	32–139	39–215	28–89

Material Economics (2019), Industrial Transformation 2050 allowances based on the actual level of clinker production – so even the opportunity cost incentives for low-clinker cement production are blunted.)

While not solving all problems, incentives for circularity and material and CO_2 efficiency would certainly be enhanced by reforming the EU carbon pricing system so that CO_2 prices can be passed on through product prices. The most likely option to do so at present is the European Commission's proposal for the implementation of a Carbon Border Adjustment Mechanism coupled with the removal of free ETS allowances during the 2026–2035 period. The CBAM proposal is of course a complex one for several reasons. Adequate protection would need to be provided for exporters (such as through continued free allowances to exported products). Moreover, competitiveness impacts for aluminium producers related to resource shuffling abroad would need to be managed through careful instrument design. In practice, dealing with such challenges is not impossible, but they are likely to require significant time for implementation. (See the discussion in Agora Industry 2021.)

A key weakness of a pure carbon-pricing approach is that it is dependent on CBAM and on a free allocation phase-down. Hence, recycling incentives linked to carbon cost pass-through alone may be limited prior to 2030, if not well into the 2030s. Another challenge with carbon pricing is that, in complex value chains like construction or vehicle manufacture, carbon costs will not always be 'felt' to the same extent by different actors. For instance, in construction projects, most of the flexibility for material efficiency occurs at the project design and conception phase, but architects and structural engineers are not subject to the ETS. Moreover, carbon costs as a share of total project price are often too small relative to other factors of production (labour, project delays) to take into account. For these reasons, carbon cost pass-through in basic material costs is an important condition for a functioning circular economy, but it is also unlikely to be a sufficient and adequate solution in the near term.

Concrete policy recommendation: The EU ETS should (gradually) be reformed in two ways. First, waste incineration must be included in the system. However the timing must be carefully managed. Emissions obligations should be phased in parallel to policies to create demand for high quality recycling and other regulations to eliminate risks of a rebound in the level of exports and landfilling.

Second, there must be a shift from a system of free allowances to full auctioning coupled with a carbon border adjustment mechanism. However, the transition should be progressive and the risks should be managed carefully, especially when it comes to indirect costs and exporters.

3.2.2 Quotas to kick-start markets for high-quality circular materials

In the absence of adequate carbon cost pass-through, alternative ways to kick-start markets and demand for circular materials will be needed. One of the most plausible alternatives is to enlarge the EU's existing use of recycled content quotas. While quotas are unlikely to be a sufficient and uniquely appropriate solution to achieve very high rates of recycling, they do offer several practical advantages as a means of kick-starting early markets for closed-loop recycling.

By guaranteeing demand via the regulatory obligation on downstream product producers to include minimum levels of recycled content, quotas can break the "chicken and egg" problem, i.e. when lack of demand leads to a lack of supply of high-quality recycled materials and a lack of demand and willingness to pay for recycled materials, etc. Evidence of this breakdown in the collection and supply of high-quality recycled materials can be seen in the plastics sector in Figure 21.

There is strong evidence that recycled content quota policies can be effective. One example is the EU's PET plastics recycling quota, which requires that 25 percent and 30 percent of plastic bottles are made from recycled PET by 2025 and 2030, respectively[63]. This policy has led to a dramatic rise in prices of recycled plastics, indicating that the policy – as intended – has created robust demand and a willingness to pay for high-quality recycled PET materials (Figure 22).

Another successful example of a recycled content quota is the city of Zurich's public procurement requirements to include recycled concrete materials in all public building projects. In 2005 it became mandatory for all public buildings in the city to be built with recycled concrete. Under Zurich's procurement policy, all concrete products must contain at least 25 percent recycled aggregates in total mass. Interviews with the Zurich authorities suggest that such a recycled content mandate has been highly effective in creating an efficient recycling industry for concrete recycling in Zurich (European Commission, 2019).

Recycled content quotas can also serve as an overarching governance tool for kick-starting markets for closed-loop recycling. While they do not eliminate all barriers along the supply chain, by placing a regulatory requirement on certain product producers to achieve a given level of recycled content, they strongly motivate companies and policy makers to work together to find solutions to these other problems. For instance, in the case of plastics quotas, companies subject to the obligation have begun lobbying national governments to implement better plastic waste collection rates and improve sorting/separate collection, etc. This appears to be a key advantage. Indeed, it is difficult to see how such a political economy could be achieved unless the sector receives clear regulatory targets for compliance.

Another important advantage of recycled content quotas – at least as a way to kick-start markets – is that, if defined correctly, they can guarantee that closed-loop recycling occurs. Downgrading is a major

Comparison of plastics demand vs. recycled plastics demand

Figure 21

CISL (2021), based on data from the European Commission

---

[63] See European Union 2019.

weakness of current recycling policies based on Extended Producer Responsibility (EPR) schemes. EPR schemes tend to be designed around the achievement of (often) loosely defined recycling and recovery targets. So far, these targets tend to incentivise the quantity or volume of recycling over quality. Thus, EPR schemes remain a force for downgrading when any form of recycling or recovery of the materials will do, even if it is not closed-loop recycling and hence does not ultimately reduce the need for new virgin material inputs. On the contrary, recycled content quotas can target the replacement of virgin material by the equivalent recycled material in a given product, which is the right policy goal.

Of course, recycled content quotas must also be evaluated carefully and used proportionately. As arestrictive regulatory policy on private-sector production, it is important that quotas are able to be met from available or anticipated feedstocks, and that the requirements are phased in with appropriate lead times. Quotas are best seen as a temporary means to kickstart missing value chains and markets, rather than as a once-and-for-all-solution to achieving extremely high recycling rates, something that would tend to distort production choices excessively. The definition of recycling is critical to incentivise the right kinds of recycling.[64] For multi-material products, quotas should not limit or distort material choice in design – as such, they are perhaps best defined per share of a given material category (e.g. X percent per kg of metals used, Y percent per kg of plastics used) and applied in parallel across basic material categories.

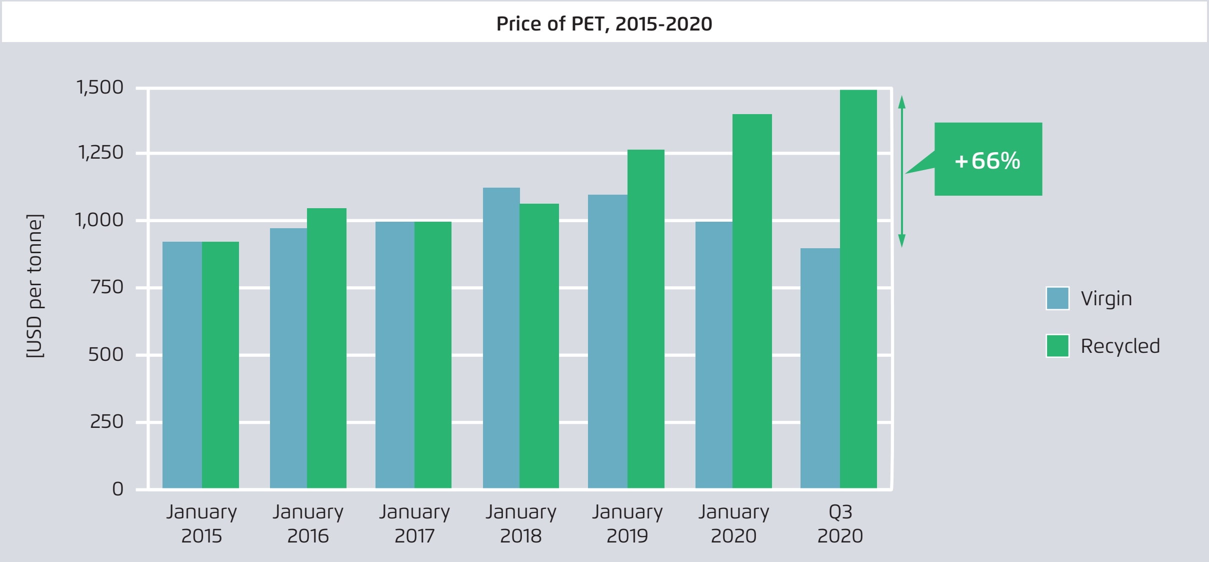
Concrete policy recommendation: The EU should define minimum (post-consumer) recycled content requirements for the re-use of secondary metals (steel and aluminium), plastics and cementitious

---

[64] For instance, some car companies already use up to 50 percent "recycled" steel when counting pre-consumer (new) scrap from the steel mill. The goal of a circular economy, however, is to promote post-consumer scrap recycling.

Impact of recycled content quotas on demand and value of recycled PET plastics

Figure 22



Data from Material Economics (2021)

materials in key value chains. Specifically, recycled content quotas should be phased in by 2030 for

- → the main plastic packaging product subtypes
- → the use of metals and plastics in the production of new vehicles sold in the EU (CO_2 Vehicle Performance Regulation)
- → the use of cement and concrete containing high rates of recovered and recycled (including recarbonated) cement binder materials in production new construction of public buildings and public works (Energy Performance in Buildings Directive and Construction Products Regulation)

In the case of concrete materials for construction, the availability of recycled cementitious material is likely to be limited through 2030 due to the relatively immature status of the technologies and the need for locally supplied demolition materials. Therefore, as a preliminary step, we suggest the use of recycled or low-carbon concrete (not cement). Moreover, we suggest that such rules should at first apply only to public buildings and public works – so that experience can be gained.

In setting the relevant quotas for these subcategories, market-based data should be collected during the 2025–2030 period in order to set appropriate benchmarks. One possibility for doing this is the Sustainable Products legislative initiative, which reports data on post-consumer recycled content under the Ecodesign Directive.

3.2.3 Embedded carbon limits on final products

While recycled content requirements can help to kickstart markets for closed-loop recycling, they do not necessarily provide a pathway for maximising recycling potential. Moreover, recycled content requirements only incentivise recycling. They do little to promote incentives for material efficiency or material substitution. As noted, carbon pricing, while helpful, is likely to be an insufficient solution to overcoming all the barriers to maximising material efficiency and substitution. In this context, limits on embedded carbon in final products potentially complement the policy 'package' to create markets for circular and resource-efficient products and materials.

Embedded CO_2 policies involve putting regulatory limits on the embedded life cycle emissions of materials used in the manufacture or construction of certain goods. Here again, one can think about embedded carbon limits on the CO_2 used in the materials for a new building, vehicles or packaging. Embedded CO_2 limit policies thus offer a way to encourage downstream product manufacturers to reduce the overall CO_2 footprint of the materials in their final product. This, in turn, creates technology-neutral incentives for whatever combination of measures is most economically efficient, whether they are high rates of recycled material use, material efficiency in the design and fabrication of the product or substitution with low-carbon virgin materials. The incentivised alternative abatement solutions compete along the supply chain to decarbonise the final product.

Since they are technologically neutral, embedded carbon limits, unlike recycled content quotas, can be scaled over time. In principle, embedded carbon limits could be gradually ratcheted down from present best-performance benchmarks to virtually zero-net emissions by 2050. As such, these kinds of policies can greatly increase future demand for decarbonisation and circular solutions to upstream value chains supplying relevant material inputs.

The EU also has increasing experience with embedded carbon limits at the member-state level, with several existing policies demonstrating their feasibility. A prominent example of a mandatory embedded carbon scheme is France's new 'RE2020' regulation[65] (Figure 23). This requires builders to report both total energy consumption performance and total embedded lifecycle emissions in construc-

---

[65] Ministère de la Transition Ecologique et Solidaire (MTES) (2020): Réglementation environnementale RE2020. Retrieved from: https://www.ecologie.gouv.fr/reglementation-environnementale-re2020

tion materials. The limits for embedded CO_2 emissions are expressed in $kgCO_2/m^2$, with assumed building lifetimes of 50 years, and are set to be progressively tightened over time.

France is not alone in starting to implement national regulations on embedded CO_2 in buildings. In 2018, Sweden's National Board of Housing, Building and Planning introduced mandatory reporting requirements for most buildings for climate impacts expressed in $kgCO_2e/m^2$ BTA (all upfront emissions, exclusive of operational or end-of-life emissions), with binding limits expected to be introduced in 2027.[66] Since 2015, Denmark has offered a freely available life-cycle assessment tool for buildings before the introduction of mandatory requirements in 2023.[67] Finland also launched a public consultation in 2018 on how to approach whole-life carbon footprint assessment for construction, which is slated to become mandatory for new buildings by 2025.[68] In 2018, the Netherlands first introduced embodied carbon reporting at the building-permit-application stage for new residential and office buildings over 100 m^2, and set a cap on the building's total environmental profile, which includes embodied carbon.[69]

---

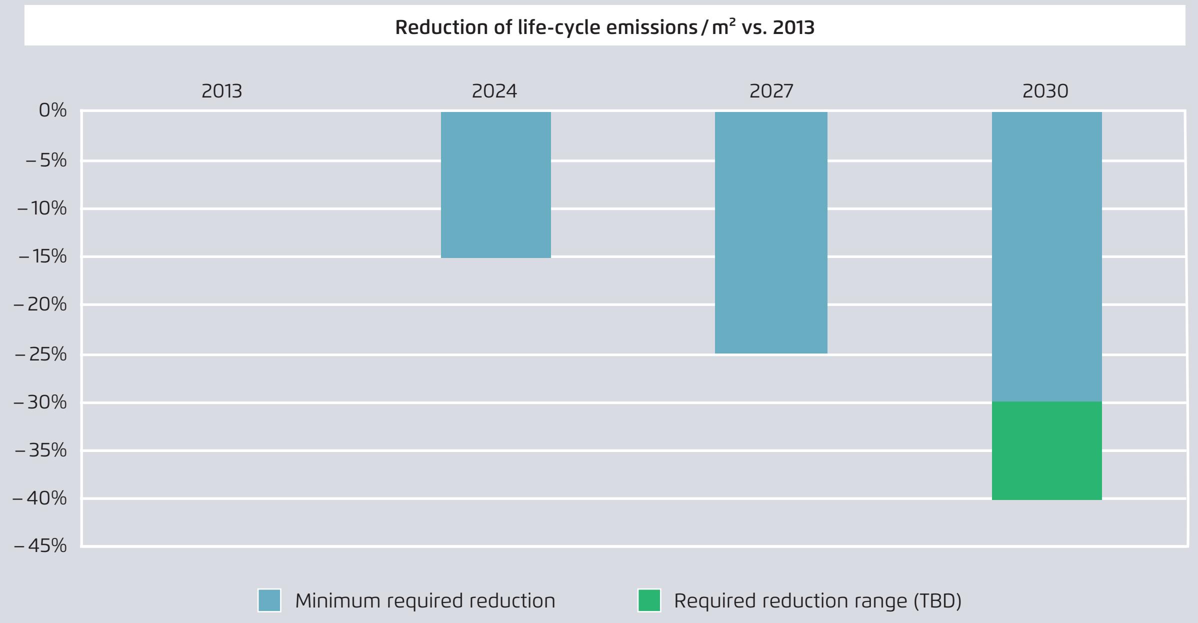
[66] Boverket (2020): Tidsplan för insatser och åtgärder inför krav på klimatdeklarationer.

[67] Zero Waste Scotland (2019): Embodied Carbon. Status Quo and Suggested Roadmap. For new builds over 1,000 m^2, at 12 kg CO_2 eq/m^2/year, along with a voluntary option for industry at 8 kg CO_2 eq/m^2/year. See Ministry of the Interior and Housing 2021 p. 26 https://im.dk/Media/637602217765946554/National_Strategy_for_Sustainable_Construktion.pdf

[68] Zero Waste Scotland (2019).

[69] See p. vi https://www.naturallywood.com/wp-content/uploads/2020/08/embodied-carbon-of-buildings-infrastructure_report_zizzo-strategy-brantwood-consulting.pdf

Embedded life-cycle emissions reductions required in new buildings under French RE2020 law Figure 23



CISL & Agora Energiewende (2021)

Concrete policy recommendation: Since 2018, the EU has been testing out the new LEVEL(s) framework, which attempts to create a harmonised European methodology for evaluating the sustainability performance of buildings across several indicators, including embedded CO_2 emissions in materials. The EU should build on this methodology to create a regulatory framework for embedded carbon, beginning with buildings. Specifically, the new Energy Performance in Buildings Regulation should require member states to collect data on embedded carbon in new buildings starting in 2025. In addition, it should require under the EPBD that member states put in place policies that place limits on the embedded carbon in new buildings from 2030 onwards. These limits should decline to almost zero-net emissions by 2050.

In addition, the EU should implement similar embedded carbon reporting requirements to those under the LEVEL(s) framework for the vehicles and packaging sectors, with a view to establishing harmonised EU-wide embedded carbon limits in the future. This should be introduced via the Sustainable Products Initiative and should establish a harmonised GHG accounting methodology for compliance, based on the EU's product environmental footprint methodology.

3.2.4 Product standardisation mustn't be a barrier to market entry for proven and safe technologies

One of the key challenges facing some recycled products is that existing product standards effectively prevent new low-carbon or recycled-product formulas from adhering to existing EU and national standards. In addition, changing existing standards is often extremely complicated, political, and extremely long. In cases where a product is deemed particularly innovative, back door routes to obtaining the 'CE' mark are possible after 18 months by following the European Technical Assessments process. However, this by itself is sometimes not enough. For instance, in the case of new cement formulations, even if an ETA grants approval to a novel cement type, non-harmonised national concrete standards will still exclude the same cements from being used in national concrete applications. Similarly, in the plastics sector, current standards for ensuring the quality of food-grade plastics effectively limit the application of recycled content due to the manner in which the standard is defined.

Policy recommendation: To address such concerns, the EU should guarantee an expedited market pathway for innovative, environmentally friendly products that are proven to meet the necessary performance requirements for given applications. In the case of cement and concrete, one option may be to require that any products that are granted the CE label under the ETA processes should be considered compliant with national product standards unless member states object. In the case of plastics and other products, the Commission could perhaps use the ETAs to establish another fast-track solution for enabling rapid market entry.

3.3 Enabling policies to increase the supply of high-quality recycled materials

As noted in section 3.1, policies to create demand for closed-loop-recycling and material CO_2 efficiency will not be successful unless several enabling conditions are tackled in parallel. It is beyond the scope of this report to provide comprehensive solutions to all of the barriers. Below, however, we identify several options that we believe merit further investigation.

3.3.1 Measure recycling rates correctly

Section 2 showed that current statistics on plastics recycling are likely to overreport actual recycling rates by a significant degree, since so much end-of-life plastic is simply not counted in total waste-plastic statistics. If the EU is going to govern its transition to a circular plastics sector effectively, it will need to have more reliable statistics on plastic waste and recycling rates. At the very least, the EU should collect data on the amount of plastics in end-use products in various member states, so that collection and recycling targets can be set based on the data. A key priority for the EU and its member states must be to create a reporting infrastructure that can better track flows of plastics in the economy.

It is also important that the EU's recycling targets reflect its overarching goals in moving to a more circular economy. At present, recycling targets exist for member states for several packaging products.[70] Similarly, rules on construction and demolition waste also require that at least 70 percent of it be re-used or recycled.[71] However, these targets do not necessarily track progress in increasing the share of closed-loop recycling and the ratio of recycled to primary material over time. On the contrary, any form of basic "recycling", whether downcycling or not, can count towards the targets.[72]

Concrete policy recommendation: In developing tracking indicators of progress towards a circular economy, it is important that the EU tracks the core objective: the ratio of post-consumer recycled material to primary material in the relevant product markets. In fact, one can argue that future sectoral recycling targets should be set, at least in part, based on the ratio of secondary to primary materials production.

3.3.2 Support the deployment of innovative circular materials technologies

Developing a more circular and resource-efficient economy will also require the deployment of innovative technologies for recycling and material efficiency. Critical technologies that will need to be further improved and developed include:

- → Advanced mixed-waste sorting technologies to maximise the recovery of misallocated chemically recyclable plastics
- → New cement and concrete recycling and recarbonation solutions
- → Advanced and innovative steel and aluminium scrap shredding, copper separation and alloy sorting technologies to maximise the quality of recovered materials and enable closed-loop alloy recycling flows
- → Highly efficient chemical recycling technologies for plastic waste
- → 3D-printing of metallic product components

To date, however, much of the attention on innovation and technology support in European industry has tended to focus on primary material production technologies, such as the hydrogen-based production of steel, CCS, CCU, etc.

But while innovation in primary materials production is urgently needed, more attention must also be paid to other, equally interesting solutions in the circular economy. In the effort to support industrial sites as they transition to much-hyped low-carbon technologies, government may inadvertently lock in excessive levels of primary materials production, at the expense of potentially cheaper and more efficient recycling technologies.

Consider the European steel sector. With a growing amount of available scrap over the coming decades, the sector is well placed to invest in recycling infrastructure. However, if policy ultimately focuses on the shift to the hydrogen-based production of virgin steel,manufacturing using recyclable steel may receive too little investment.

Concrete policy recommendation: We would recommend that both EU and national policy makers strive to put support for "circular economy" innovations on equal footing with support for primary production. This might be done in the following ways:

First, EU and national funds supporting the deployment of key low-carbon technologies, such as carbon contracts for difference, should allocate 50 percent of

---

[70] European Union 1994, 2018 D.

[71] European Union 2008.

[72] See legislation byEuropean Union 2018 D.

their funds for the support of projects and technologies that lead to a more circular and resource-efficient use of CO_2-intensive materials. For instance, the EU ETS Innovation Fund could earmark a minimum share of funds for circular economy projects in EU ETS sectors. Similar rules could also be applied to the allocation of R&D funding for industrial pilot and R&D projects under Horizon Europe.

Second, in establishing award criteria for state or EU aid to industrial decarbonisation projects, priority should be given to projects that improve the circularity of materials. For instance, in the steel sector there is great potential to integrate larger shares of steel recycling in hydrogen-based DRI-EAF production technologies than is possible with current blast-furnace-based production routes. However, it is equally possible that projects will not seek to go to the additional expense and trouble of investing in using higher rates of scrap. However, if funding to such projects were conditional on, or if they at least prioritised, the adoption of technologies that integrate higher levels of circular materials than conventional processes, it would be possible in principle to create such incentives.

3.3.3 Best-practice requirements for separate collection and post-collection sorting and recycling

One of the main challenges for the establishment of more circular material flows is the paucity of highly efficient *collection* infrastructure, which leads to large amounts of materials simply not being collected. This is especially true for products such as plastics and aluminium due to their extensive use in packaging for short-lived consumer goods. As such, they are frequently misallocated to general waste rather than recycled.

Furthermore, for all the materials examined in this paper, the quality of recycling could be significantly improved by the widespread adoption of best available technologies for the *sorting* of recovered end-of-life materials. In the plastics sector, some of these problems can be solved by the chemical recycling of plastics, which is likely to be part of the solution (as noted in section 2). But chemical recycling is also significantly more energy-intensive and expensive than mechanical recycling, which is why the potential of the latter should be maximised as a first priority.

Incentives to improve the quality collection and sorting infrastructure can be created to some extent by policies that create markets for more closed-loop recycled materials (see discussion above). However, such policies may not always be sufficient. It has already been noted that EPR schemes tend to prioritise the quantity rather than the quality of recycling. Moreover, when EPR schemes are based on recycling targets that are defined on the basis of collected waste (rather than all waste), they will not necessarily incentivise improvements in the quantity of collection. Recycled content quotas create incentives for product manufacturers to incorporate recycled content, and can thus encourage investment in improved recycling technology. But there may be a time lag between demand and supply, and they do not automatically translate into incentivises for authorities to establish more effective collection systems.

Concrete policy recommendation: Policies to require the implementation of best-practice collection and sorting technologies need further development. For instance, in the case of plastics, the use of deposit refund schemes has been widely shown to be effective at ensuring very high rates of waste collection for plastic bottles.[73] Under EU plastics legislation, such schemes might be extended to other places within Europe and to additional forms of plastics prone to misallocated in general waste.

---

[73] See https://www.renewablematter.eu/articles/article/making-empties-count-deposit-return-schemes-across-the-world ;https://galapagosconservation.org.uk/deposit-return-schemes/; and https://www.oecd.org/stories/ocean/deposit-refund-schemes-58baff8c

The EU and its member states should also follow the lead of Norway, Sweden and the Netherlands and mandate the adoption of mandatory post-collection re-sorting of mixed waste to ensure maximum recovery of recyclable plastics. This could be introduced in line with a strategy for the phase-in of chemical recycling so that both demand and supply are coordinated.

The sorting of CO_2-intensive metals, such as aluminium and steel alloys, can be significantly improved by state-of-the-art sorting techniques for scrap that separate waste into alternative alloy sub-types. This allows higher levels of closed-loop recycling into sperate grades of material flows. Furthermore, the contamination of post-consumer steel scrap can be limited by requiring the separate removal wherever feasible of copper components in products (notably vehicles).

In placing stricter requirements on the provision of key waste recycling infrastructure, it is essential that the means exist to pay back such investments. Such costs might be covered by the advanced disposal fees linked to EPR schemes. They might also be covered by the creation of new markets (and thus the willingness to pay a premium) for closed-loop recycled materials. However, attention will need to be paid to possible gaps in the financing of such investments and in their support from European funds.

3.3.4 Labelling, taxing or banning inefficient product design and waste management practices

There are also a range of inefficient practices that contribute to the challenge of developing closed-loop material value chains. Some could be targeted for elimination through regulatory bans or other disincentives. For example, the EU has already taken steps to ban a range of single-use plastics, wherever alternatives exist. However, a range of other practices are potential targets for incentivisation – although the exact form (labelling, taxation under EPR schemes or outright banning via eco-design) needs further analysis. The key issues to be addressed via appropriate disincentives are listed in Table 3:

Of course, the regulation of product design is a complex task and there are likely to be technical and political limits to how far regulators can go in actively banning certain kinds of product design practices. In general, companies tend to resist the regulation and

Possible practices to be labelled, taxed or banned

Table 3

Problem to be addressed:	**Possible disincentivisation tools:**
the overuse of materials in packaging applications	labelling and taxation under national EPR schemes
the incineration of plastic waste	carbon taxation, inclusion in the EU ETS (assuming accompanied by appropriate policies to reduce risks of unwanted diversion to landfilling or exports)
the placement on the market of non-recyclable or difficult to recycle materials (for instance the use of plastic types that are not mechanically recyclable where alternatives exist)	combination of labelling, taxation or banning depending on the use case
the fabrication of short-lived, but material intensive, products (such electronics, white goods, plastic goods, etc.)	labelling and eco-design requirements
the shredding of vehicles without efficient processes for removal of copper content	mandates

Agora Industry (2022)

design of their products, unless there are readily available alternatives for substitution. In some cases, banning certain practices would also add some level of additional cost. In other cases, certain practices may not be justifiably banned due to the absence of available alternatives. There may be reasonable exceptions where taxes may be a more appropriate means of disincentivisation. Obviously, such considerations would need to be weighed against the expected environmental benefits on a case-by-case basis (which lies beyond the scope of this paper).

Despite these caveats, the potential role of bans or taxes on inefficient use or treatment of CO_2-intensive materials should not be discounted out-of-hand. The Single-Use Plastics Directive has already demonstrated that banning inefficient practices can, in certain cases, be a very direct and effective way of delivering significant environmental benefits without a meaningful loss of product choice for consumers or manufacturers.

Box 2. Key policies for the creation of highly circular and resource-efficient markets for energy-intensive materials

Market and demand creation policies

1. Expand the use of recycled content quotas to a wider set of plastic products (not just PET Bottles); to steel, aluminium and plastics in vehicles; and to cement and concrete used in public construction projects.
2. Limit the embedded life-cycle carbon emissions of construction materials in new buildings, in vehicles and in packaging.
3. Mobilise carbon pricing more effectively: Include waste incineration in the EU Emissions Trading Scheme (ETS), gradually shift from free allocation to full auctioning and introduce a Carbon Border Adjustment Mechanism (CBAM) in order to strengthen price incentives for recycled materials.
4. Reform product standards for materials to remove existing barriers to innovation for CO_2 efficient or recycled materials (notably for concrete and plastics), at European and if necessary national levels.
5. Ban exports of EU waste to countries not adopting equivalently stringent recycling targets and practices (beyond the current relatively loose restrictions that currently apply for OECD countries).

Enabling policies to maximise the supply of high-quality recycled materials

6. Review recycling rates measurements, especially for end-of-life plastics, based on bottom-up analytical methods to take uncounted plastics waste misallocation into account and revise current recycling performance rates and targets.
7. Massively scale up support for breakthrough technologies to the circular-economy and the new virgin material production routes for energy-intensive industry.
8. Require the adoption of best practice waste collection infrastructure and best available material sorting technologies at the recycling plant, including post-collection re-sorting of mixed waste to extract and send for recycling the up to 75 percent of the plastics than can be recycled in that mix.
9. Label, tax or ban inefficient material use and waste management practices, including overuse of packaging, sale of short-lived products, incineration of unsorted plastic waste, shredding of vehicles prior to copper content removal.

4 Conclusions

This study has examined the current status of the EU's performance in providing a circular and resource-efficient economy for specific, CO_2-intensive basic materials: steel, aluminium, plastics and cement and concrete. We have shown that, despite a certain amount of existing recycling, and despite certain new measures concerning specific plastic sub-types under the first circular economy package, the overall performance of these CO_2-intensive material value chains can be substantially improved.

This is a major industrial policy issue for the EU. Indeed, this paper has argued that the current EU industrial policy cannot hope to transition European industry to climate neutrality by 2050 unless it leverages the full CO_2 mitigation potential of a circular and resource-efficient economy. With well-targeted policies, the circular use of materials could contribute up to 70Mt of CO_2 abatement by 2030, and 239 Mt by 2050. As such, the circular economy could contribute as much as 10 percent and 34 percent of the total industrial abatement effort in the EU by 2030 and 2050, respectively.

To unlock these potentials, the EU must make the circular economy an integral part of its policy strategy for the decarbonisation of key CO_2-intensive industrial value chains. While the EU is pursuing additional circular economy policies under the new Circular Economy Action Plan (CEAP 2.0), to date it has not integrated the topics of circular economy and CO_2 reduction in carbon-intensive basic materials sectors. Robust circular economy policies are currently missing for key materials and products, including steel, aluminium, cement and even plastics, where actual performance is not as good as existing statistics make it seem, because statistics on misallocated end-of-life plastics are unreliable (See our related study "Europe's Missing Plastics", by Material Economics and Agora Industry, 2022).

Under the CEAP 2.0, the EU needs to prioritise much more ambitious regulatory policies for CO_2-intensive materials. This paper has argued that the highest single priority is to create markets for genuine closed-loop recycling of key CO_2-intensive materials. In particular, it argues that recycled content quotas on packaging, on new vehicles and on new buildings are likely to be the single most-effective instrument to kick start closed-loop value chains. In contrast to existing EPR schemes, quotas promote actual closed-loop recycling. By guaranteeing demand, they also break the chicken-or-egg problem that plagues early investment in enhanced recycling value chains.

As a medium and longer-term strategy, this paper also concludes that embedded carbon limits on buildings, vehicles and packaging should be developed. This would help to promote climate-friendly and material efficient design more effectively than direct regulation via, for instance, Ecodesign policies.

However, while market creation is the key to kick starting the transition, complementary policies will be needed to unlock the full potential of the circular economy over time. Several key enabling conditions will need to be put in place here. Interesting pathways for future policy development include:

- → Allow a gradual phase-out of free allocations under the EU ETS by adopting a carbon border adjustment mechanism and full auctioning (to allow carbon cost pass-through and raise the cost of virgin materials relative to recycled materials).
- → Support circular and materials-saving breakthrough technologies in equal measure for virgin material production technologies under EU and national industry decarbonisation funding programmes.
- → Measure recycling rates correctly, especially for plastics where existing statistics ignore the high

degree of waste misallocation and thus dramatically overstate recycling performance rates.

- → Reform European and, if necessary, national standards for materials to avoid outdated product standards impeding innovation for CO_2-efficient or recycled materials (especially for concrete and plastics).
- → Require the adoption of best-practice waste collection infrastructure and best-available material sorting technologies at the recycling plant.
- → Ban or tax inefficient material use and waste management practices. These might include excessive packaging, the sale of short-lived products, the incineration of unsorted plastic waste and the shredding of vehicles prior to removal of copper content.

5 Table of abbreviations

Abbreviations	
BAU	Business-as-usual
BF-BOF	Blast furnace-basic oxygen furnace
BTA	Brutto-area
CaCO	Calcium carbonate
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CDW	Construction and demolition waste
CEAP	The EU's Circular Economy Action Plan
CISL	Cambridge Institute for Sustainability Leadership
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DRI	Direct reduced iron
EAF	Electric arc furnace
EoL	End-of-life
EPR	Extended producer responsibility
ETAs	European Technical Assessments
ETS	Emissions Trading System
GHG	greenhouse gas
GW	Gigawatt hour
IEA	International Energy Agency
LC3	Limestone calcined clay cement
Mt	Megatonne
MTES	Ministère de la Transition Ecologique et Solidaire
OECD	Organisation for Economic Co-operation and Development
PET	Polyethylene terephthalate
PPWD	Packaging and Packaging Waste Directive (Directive 2018/852)
R&D	Research and development
tCO_2	Tonne of carbon dioxide
TEN-E	Trans-European Networks for Energy
TWh	Terawatt hour
UNFCCC	United Nations Framework Convention on Climate Change

6 References

Agora Energiewende (2020): *Breakthrough Strategies for Climate-neutral industry.*
https://www.agora-energiewende.de/en/publications/breakthrough-strategies-for-climate-neutral-industry-in-europe-summary/

Agora Energiewende and Wuppertal Institute (2021 A): *Breakthrough Strategies for Climate-Neutral Industry in Europe (Study): Policy and Technology Pathways for Raising EU Climate Ambition, Agora Energiewende & Wuppertal Institute.*
https://www.agora-energiewende.de/en/publications/breakthrough-strategies-for-climate-neutral-industry-in-europe-study/

Agora Energiewende (2021 B): *12 Insights on Hydrogen.*
https://www.agora-energiewende.de/en/publications/12-insights-on-hydrogen-publication/

Agora Industry (2022): *Getting the transition to CBAM Right: Finding pragmatic solutions to key implementation questions.*
https://www.agora-energiewende.de/en/publications/getting-the-transition-to-cbam-right/

Allwood, J. M., Dunant, C., Lupton, R., & Cabrera Serrenho, A. (2019): *Steel arising: Opportunities for the UK in a transforming global steel industry.*
https://doi.org/10.17863/CAM.40835; https://ukfires.org/reports/

Brütting, J., De Wolf, C. and Fivet, C. (2019): *The reuse of load-bearing components. In IOP Conference Series: Earth and Environmental Science (Vol. 225, No. 1, p. 012025). IOP Publishing.*
https://iopscience.iop.org/article/10.1088/1755-1315/225/1/012025/pdf

Bertin, I., Lebrun, F., Braham, N. and Le Roy, R. (2019): *Construction, deconstruction, reuse of the structural elements: The circular economy to reach zero carbon. In IOP Conference Series: Earth and Environmental Science (Vol. 323, No. 1, p. 012020). IOP Publishing.*
https://iopscience.iop.org/article/10.1088/1755-1315/323/1/012020/pdf

Boverket (2020): *Tidsplan för insatser och åtgärder inför krav på klimatdeklarationer.*
Retrieved from: https://www.boverket.se/sv/om-boverket/publiceratav-boverket/publikationer/2020/tidplan-for-insatserochatgarder-infor-krav-pa-klimatdeklarationer/

Cembureau (2020): *Cementing the European Green Deal: reaching climate neutrality along the cement and concrete value chain by 2050.*
https://cembureau.eu/media/kuxd32gi/cembureau-2050-roadmap_final-version_web.pdf

Cembureau (n.d.).
Available at: https://lowcarboneconomy.cembureau.eu/5-parallel-routes/resource-efficiency/clinker-substitution/

CISL and Agora Energiewende (2021): *Tomorrow's markets today: Scaling up demand for climate-neutral basic materials and products, Agora Energiewende and CISL, Cambridge.*
https://www.agora-energiewende.de/en/publications/tomorrows-markets-today/

Deloitte (2019): *The future of petrochemicals: Growth surrounded by uncertainty.*
https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-the-future-of-petrochemicals.pdf

ESTEP (2021): *Improve the EAF scrap route for a sustainable value chain in the EU Circular Economy scenario (Roadmap): An evolution document for a strategic look to the future of European EAF steel-making. European Steel Technology Platform, June 2021.* https://www.estep.eu/assets/Uploads/Improve-the-EAF-scrap-route-Roadmap-Final-V2-3.pdf

European Commission (2015): *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Closing the loop – An EU action plan for the Circular Economy, COM/2015/0614 final* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614

European Commission (2018 A): *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A European Strategy for Plastics in a Circular Economy, COM/2018/028 final.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0028

European Commission (2018 B): *In-depth Analysis in Support of the Commission Communication COM(2018) 773 "A Clean Planet for all: A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy".*

European Commission (2018 C): *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, COM/2018/773 final* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773

European Commission (2018 D): *REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS on the implementation of EU waste legislation, including the early warning report for Member States at risk of missing the 2020 preparation for re-use/recycling target on municipal waste COM/2018/656 final.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2018:656:FIN

European Commission (2019, May): *A low carbon, circular economy approach to concrete procurement: City of Zurich (Switzerland). GPP In Practice, 88.* Retrieved from: https://ec.europa.eu/environment/gpp/pdf/news_alert/Issue_88_Case_Study_168_Zurich.pdf

European Commission (2020 A): *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A new Circular Economy Action Plan For a cleaner and more competitive Europe, COM/2020/98 final.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:98:FIN

European Commission (2020 B): *Directorate-General for Communication, Circular economy action plan : for a cleaner and more competitive Europe, Publications Office, 2020.* https://data.europa.eu/doi/10.2779/717149

European Commission (2020 C): *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A New Industrial Strategy for Europe COM/2020/102 final.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0102

European Commission (2020 D): *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020, COM/2020/798 final.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020PC0798

European Commission (2021 A): *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS, Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe's recovery, Brussels, 5.5.2021, COM(2021) 350 final.* https://ec.europa.eu/info/files/communication-updating-2020-new-industrial-strategy-building-stronger-single-market-europes-recovery_en

European Commission (2021 B): *Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the energy performance of buildings (recast) Brussels, 15.12.2021 COM(2021) 802 final 2021/0426 (COD).* https://ec.europa.eu/energy/sites/default/files/proposal-recast-energy-performance-buildings-directive.pdf

European Commission (2021 C): *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulation (EU) 2019/631 as regards strengthening the* CO_2 *emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition COM/2021/556 final.* https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52021PC0556

European Commission (2021 D): *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a carbon border adjustment mechanism, COM/2021/564 final.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52021PC0564

European Commission (2021 E): *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on shipments of waste and amending Regulations (EU) No 1257/2013 and (EU) No 2020/1056, COM/2021/709 final.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0709

European Commission (2021 F): *Commission Notice Technical guidance on the application of 'do no significant harm' under the Recovery and Resilience Facility Regulation 2021/C 58/01, C/2021/1054 , OJ C 58, 18.2.2021, p. 1–30* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021XC0218(01)

European Commission (n.d.). Sustainable Product Policy & Ecodesign. https://ec.europa.eu/growth/industry/sustainability/sustainable-product-policy-ecodesign_en

European Union (1994): *Consolidated text: European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste.* http://data.europa.eu/eli/dir/1994/62/2018-07-04

European Union (2008): *Consolidated text: Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance).* http://data.europa.eu/eli/dir/2008/98/2018-07-05

European Union (2018 A): *Directive (EU) 2018/849 of the European Parliament and of the Council of 30 May 2018 amending Directives 2000/53/EC on end-of-life vehicles, 2006/66/EC on batteries and accumulators and waste batteries and accumulators, and 2012/19/EU on waste electrical and electronic equipment (Text with EEA relevance) PE/9/2018/REV/1, OJ L 150, 14.6.2018, p. 93–99.* http://data.europa.eu/eli/dir/2018/849/oj

European Union (2018 B): *Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste (Text with EEA relevance) PE/10/2018/REV/2, OJ L 150, 14.6.2018, p. 100–108.*
http://data.europa.eu/eli/dir/2018/850/oj

European Union (2018 C): *Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (Text with EEA relevance) PE/11/2018/REV/2, OJ L 150, 14.6.2018, p. 109–140.*
http://data.europa.eu/eli/dir/2018/851/oj

European Union (2018 D): *Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste (Text with EEA relevance) PE/12/2018/REV/2, OJ L 150, 14.6.2018, p. 141–154.*
http://data.europa.eu/eli/dir/2018/852/oj

European Union (2018 E): *Directive (EU) 2018/410 of the European Parliament and of the Council of 14 March 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814 (Text with EEA relevance.) OJ L 76, 19.3.2018, p. 3–27.*
http://data.europa.eu/eli/dir/2018/410/oj

European Union (2019): *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 (Text with EEA relevance) PE/11/2019/REV/1, OJ L 155, 12.6.2019, p. 1–19.*
http://data.europa.eu/eli/dir/2019/904/oj

European Union (2021): *Consolidated text: Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste.*
https://eur-lex.europa.eu/eli/reg/2006/1013/2021-01-11

Hopkinson, P., Chen, H.M., Zhou, K., Wang, Y. and Lam, D., (2018): *August. Recovery and reuse of structural products from end-of-life buildings. In Proceedings of the Institution of Civil Engineers-Engineering Sustainability (Vol. 172, No. 3, pp. 119–128). Thomas Telford Ltd.*
https://www.icevirtuallibrary.com/doi/pdf/10.1680/jensu.18.00007

Lux Research (2020): *The sustainable plastics roadmap: Recycling, bioplastics, & alternatives.*
https://www.luxresearchinc.com/the-sustainable-plastics-roadmap-recycling-bioplastics-and-alternatives

Material Economics (2018): *The circular economy – A powerful force for climate mitigation.*
https://materialeconomics.com/publications/the-circular-economy

Material Economics (2019): *Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry.*
https://materialeconomics.com/publications/industrial-transformation-2050

Material Economics (2021): *EU biomass use in a net zero economy: A course correction for EU biomass.*
https://materialeconomics.com/publications/eu-biomass-use

Material Economics (2022): *Europe's missing plastics; published by Material Economics, Stockholm and Agora Industry, Berlin.*
https://materialeconomics.com/publications ;
https://www.agora-energiewende.de/en/publications/

Ministère de la Transition Ecologique et Solidaire (MTES). (2020). *Réglementation environnementale RE2020.*
Retrieved from: https://www.ecologie.gouv.fr/reglementation-environnementale-re2020

Ottelé, M. , K. Schenck (2020):
The Smart Crusher Quarry,
www.slimbreker.nl

RECLAIM (2021): *D4.1 Circular Economy-driven lifetime-extension strategies. European Commission.* https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5db5b6032&appId=PPGMS

SystemiQ (2022): *"Reshaping plastics – Pathways to a circular, net zero emissions European plastics economy",* (forthcoming).

UNEP (2018): *Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry, UNEP.*
https://www.researchgate.net/publication/311980992_Eco-efficient_cements_Potential_economically_viable_solutions_for_a_low-CO_2_cement-based_materials_industry

Vanderley M. J., B. L. Damineli, M. Quattronea, R. Pileggi (2018): *Fillers in cementitious materials — Experience, recent advances and future potential, Cement and Concrete Research 114 (2018) 65–78*

Wuppertal Institute (2020): *Infrastructure needs for deep decarbonisation of heavy industries in Europe, Policy Brief.*
https://wupperinst.org/fa/redaktion/downloads/projects/INFRA_NEEDS_Policy_Brief.pdf

Zero Waste Europe (2020): *Understanding the environmental impacts of chemical recycling – Ten concerns with existing life cycle assessments*
https://zerowasteeurope.eu/library/understanding-the-environmental-impacts-of-chemical-recycling-ten-concerns-with-existing-life-cycle-assessments/

Zero Waste Scotland (2019): *Embodied Carbon. Status Quo and Suggested Roadmap.*
Retrieved from: https://zerowastescotland.org.uk/sites/default/files/Embodied_carbon_spreads%20final.pdf

Zhang, C., M. Hu, F. Di Maio, B. Sprecher, X. Yang, A. Tukker (2022): *An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe, Science of The Total Environment, Volume 803, 10 January 2022, 149892*

Publications by Agora Industry

IN ENGLISH

Getting the Transition to CBAM Right
Finding pragmatic solutions to key implementation questions

The EU's Carbon Border Adjustment Mechanism
Challenges and Opportunities for the Western Balkan Countries

Transitioning to a climate-neutral EU buildings sector
Benchmarks for the success of the European Green Deal

12 Insights on Hydrogen

Global Steel at a Crossroads
Why the global steel sector needs to invest in climate-neutral technologies in the 2020s

The Future of Lignite in the Western Balkans
Scenarios for a 2040 Lignite Exit

Phasing out coal in the EU's power system by 2030
A policy action plan

Making renewable hydrogen cost-competitive
Policy instruments for supporting green H_2

EU-China Roundtable on Carbon Border Adjustment Mechanism
Briefing of the first dialogue on 26 May 2021

Towards climate neutrality in the buildings sector (Summary)
10 Recommendations for a socially equitable transformation by 2045

Matching money with green ideas
A guide to the 2021–2027 EU budget

Tomorrow's markets today
Scaling up demand for climate neutral basic materials and products

Breakthrough Strategies for Climate-Neutral Industry in Europe (Study)
Policy and Technology Pathways for Raising EU Climate Ambition

Towards a Climate-Neutral Germany by 2045
How Germany can reach its climate targets before 2050

Publications by Agora Industry

IN GERMAN

Energiesicherheit und Klimaschutz vereinen
Maßnahmen für den Weg aus der fossilen Energiekrise

Klimaschutzverträge für die Industrietransformation (Gesamtstudie)
Kurzfristige Schritte auf dem Pfad zur Klimaneutralität der deutschen Grundstoffindustrie

Die deutsche Braunkohlenwirtschaft 2021
Historische Entwicklungen, Ressourcen, Technik, wirtschaftliche Strukturen und Umweltauswirkungen

Die Energiewende in Deutschland: Stand der Dinge 2021
Rückblick auf die wesentlichen Entwicklungen sowie Ausblick auf 2022

Öffentliche Finanzierung von Klima- und anderen Zukunftsinvestitionen

Ein beihilfefreies und schlankeres EEG
Vorschlag zur Weiterentwicklung des bestehenden Erneuerbare-Energien-Gesetzes

Windenergie und Artenschutz – Wege nach vorn

Der Photovoltaik- und Windflächenrechner
Ein Beitrag zur Diskussion um die Ausweisung von Flächen
für Photovoltaik- und Windenergieanlagen an Land

Klimaschutzverträge für die Industrietransformation (Stahl)
Analyse zur Stahlbranche

Das Klimaschutz-Sofortprogramm
22 Eckpunkte für die ersten 100 Tage der neuen Bundesregierung

Zukünftige Anforderungen an eine energiewendegerechte Netzkostenallokation

Abschätzung der Klimabilanz Deutschlands für das Jahr 2021

Stellungnahme zum Szenariorahmen Gas 2022-2032 der Fernleitungsnetzbetreiber
Konsultation durch die Fernleitungsnetzbetreiber

Politikinstrumente für ein klimaneutrales Deutschland
50 Empfehlungen für die 20. Legislaturperiode (2021-2025)

All publications are available on our website: www.agora-industry.org

254/03-S-2022/EN

About Agora Industry

Agora Industry is a division of Agora Energiewende that develops strategies and instruments for climate-neutral industrial transformation – in Germany, the EU and globally. Agora Industry works independently of economic and partisan interests. Its only commitment is to climate action.

Agora Industry
Anna-Louisa-Karsch-Straße 2 | 10178 Berlin, Germany
P +49 (0)30 700 14 35-000
F +49 (0)30 700 14 35-129
www.agora-industry.org
info@agora-industrie.de