Scaling Technologies for Greening Heavy Industry

A NetZero Pathfinders Report

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Contents

Section 1.	Executive summary	1
	1.1 Overview	1
	1.2 Key findings	3
Section 2.	Scaling up emerging technologies	5
	2.1. The state of play	5
	2.2. Scale of investment	10
Section 3.	Policy solutions	13
	3.1. Cross-cutting solutions	14
	3.2. Incentives (carrots)	17
	3.3. Regulations (sticks)	27
	3.4. Demand-reduction solutions	35
	3.5. Circular economy solutions	39
Appendix A. Glossary of terms		43
Appendix B. Policy mechanism evaluation methodology		44
About us		45

Table of figures

Figure 1: Direct CO_2 emissions by sub-sector, based on BNEF's Net Zero Scenario 1
Figure 2: Direct CO_2 emissions from selected heavy industry sectors, based on BNEF's Net Zero Scenario 1
Figure 3: Global end-use sector CO_2 emissions and abatement technologies, based on BNEF's Net Zero Scenario 5
Figure 4: Cumulative emissions abatement by technology for steel, 2023-2050 7
Figure 5: Cumulative emissions abatement by technology for cement, 2023-2050 8
Figure 6: Cumulative emissions abatement by technology for petrochemicals, 2023-2050 9
Figure 7: Global annual investment in the clean energy transition by sector.... 11
Figure 8: Global investment in sustainable materials by sector, based on BNEF's Net Zero Scenario 11
Figure 9: Cumulative hydrogen and CCUS investments required by 2050, by sector, BNEF's Net Zero Scenario 11
Figure 10: Emissions covered in the EU ETS by sector 16
Figure 11: Free allocation under the EU ETS by sector 16
Figure 12: Hydrogen subsidy mechanism used by region 19
Figure 13: Targeted support for hydrogen by demand and supply 19
Figure 14: Nth-of-a-kind carbon capture cost with the US Inflation Reduction Act credit 21

Figure 15: Illustrative two-way contract for difference for green steel production 23
Figure 16: Illustrative two-way contract for difference for green steel production 23
Figure 17: Illustrative monthly revenues and carbon price payments for a fossil steel plant........ 24
Figure 18: Illustrative monthly revenues for a green steel plant with a carbon contract for difference........ 24
Figure 19: Announced cumulative annual hydrogen production volume in Germany by production type and expected commissioning year 26
Figure 20: Buy Clean California Act global warming potential limit and average emissions intensity per metric ton of steel in the United States 29
Figure 21: The average embodied emissions of 769 EU buildings in 2022..... 31
Figure 22: France's RE2020 residential building embodied emissions thresholds for the production and construction-related emissions........ 31
Figure 23: EU renewable hydrogen quotas for industry in the Renewable Energy Directive versus 2030 EU target for all hydrogen uses 33
Figure 24: Marginal cost of green, blue and gray ammonia in select European countries in 2030........ 33
Figure 25: BNEF estimate of China's steel sector emissions, historical and projected 34
Figure 26: Steel capacity swaps to be commissioned by 2025 34
Figure 27: New Zealand's annual agriculture emissions breakdown and nitrous oxide mitigation potential from policy intervention........ 37
Figure 28: Greenhouse gas emissions reduction via Japan's direct payments for environmentally-friendly agriculture........ 38
Figure 29: Plastic recycling rates in the EU and the Netherlands 40
Figure 30: The Netherlands' plastic recycling rate and packaging tariff 40

Table of tables

Table 1: Most prominent policy interventions for industry decarbonization currently 2
Table 2: Overview of decarbonization challenges facing heavy industry by subsector 6
Table 3: Breakdown of fertilizer value chain 10
Table 4: Comparison of select policy solutions available for industry decarbonization........ 13
Table 5: Analysis of cross-cutting policy solutions available for industrial decarbonization........ 14
Table 6: Select cross-cutting policy solutions available for industrial decarbonization........ 14
Table 7: Carbon tax snapshot 15
Table 8: Emissions trading system snapshot........ 17
Table 9: Analysis of incentives available for industrial decarbonization 18
Table 10: Select incentives available for industrial decarbonization........ 18
Table 11: Output-linked supply-side credit snapshot 20
Table 12: Investment-linked supply-side credit snapshot........ 22
Table 13: Demand-side hydrogen credit snapshot 22

Table 14: CCfD snapshot 24
Table 15: Analysis of regulations available for industrial decarbonization 27
Table 16: Select regulations available for industrial decarbonization 27
Table 17: Public green procurement mandate snapshot 29
Table 18: Embodied emissions standards snapshot 30
Table 19: Green expedited permitting snapshot 32
Table 20: Demand-side hydrogen consumption mandate snapshot 32
Table 21: Production cap and capacity swap mandates 34
Table 22: Analysis of demand-reduction solutions available for industrial decarbonization 36
Table 23: Select demand-reduction solutions available for industrial decarbonization 36
Table 24: Farm levy snapshot 36
Table 25: Direct payments snapshot 38
Table 26: Analysis of circular economy solutions available for industrial decarbonization 39
Table 27: Select circular economy solutions available for industrial decarbonization 40
Table 28: Extended producer responsibility snapshot 41
Table 29: Recycled-content mandate snapshot 41
Table 30: Terms and definitions 43
Table 31: Policy rating criteria 44

Section 1. Executive summary

24%

Share of global CO_2e energy emissions from industry in 2022

3%

Share of global investment in the energy transition that went to nascent technologies for industrial decarbonization in 2022

15

Case studies highlighting measures that can accelerate industrial decarbonization in this report

Global supply and demand for green industrial products, such as net-zero steel, cement and fertilizers, will be crucial to delivering on international climate targets. While the technologies to decarbonize these hard-to-abate sectors exist, their commercialization is still at early stages. Just 3% of the global investment in the energy transition tracked by BloombergNEF in 2022 went to low-carbon technologies for industry.

Policymakers must create enabling environments to accelerate the commercialization of key emerging technologies for the industrial transition, so that industry can deploy clean solutions at pace and scale in the 2030s. A wide range of policy interventions are available that can help industry and offtakers to begin this process, including incentives, regulations, and demand-reduction and circular-economy measures.

This report is part of the NetZero Pathfinders initiative. It assesses some of the most promising policy solutions to scale up the technologies needed to decarbonize the hard-to-abate industrial sectors. This analysis is delivered through 15 success stories, where policies are already demonstrating potential to drive technology deployment or emissions abatement.

(Correction on November 20, 2023: It has been clarified on page 4 that China is implementing a top-down supply-side mandate by restricting the expansion of steel production capacity, unless old production units are swapped for more efficient units.)

1.1 Overview

Industry accounted for 24% of global CO_2-equivalent energy emissions, while the process emissions from steel, cement and petrochemicals alone comprised 13% of global CO_2 emissions in 2022 (Figure 1). These sectors are considered among the most challenging parts of the global economy to decarbonize, largely due to the nascent status and prohibitive cost of zero-emissions technologies. BNEF research shows that it is imperative to finance and construct commercial-scale, net-zero steel, cement and chemicals plants this decade.

Figure 1: Direct CO_2 emissions by sub-sector, based on BNEF's Net Zero Scenario

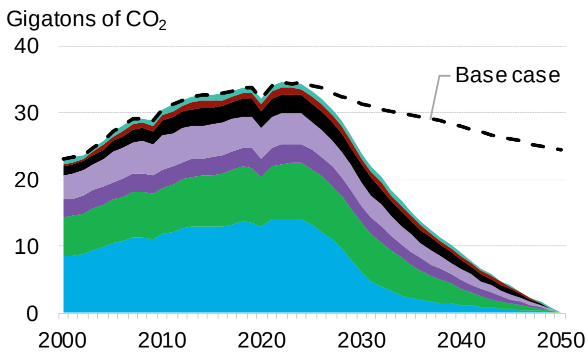
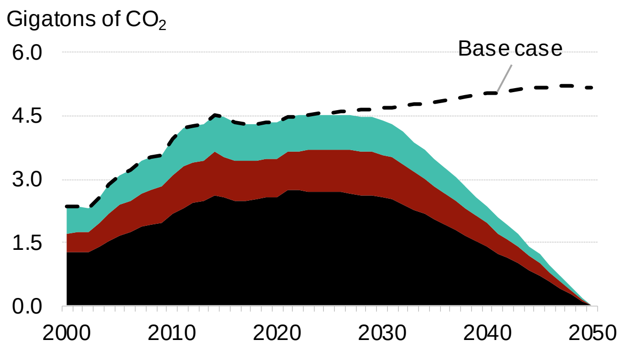


Figure 2: Direct CO_2 emissions from selected heavy industry sectors, based on BNEF's Net Zero Scenario



Source: BloombergNEF. Note: 'Base case' refers to the Economic Transition Scenario, which represents no additional long-term policy intervention; for full methodology, see New Energy Outlook 2022 (web | terminal). 'Other' refers to all other industrial sectors.

Green hydrogen, green ammonia, process electrification, recycling and carbon capture, utilization and storage (CCUS) are some of the key technologies required to accelerate industrial decarbonization and achieve net-zero emissions by 2050. Without intervention, many companies and consumers will continue to pursue the least-cost option, and industrial CO_2 emissions will likely continue to rise through 2050 (Figure 2).

Policymakers have offered much less support for hard-to-abate sectors than for renewable power and electrified transport, despite industry requiring their backing to invest in low-carbon technologies. Some 97% of all investments in the energy transition in 2022 tracked by BloombergNEF went to more mature clean energy technologies, such as renewable energy projects, electrified transport, clean heating in homes and energy storage. Decades of subsidies for solar, wind and electric vehicles allowed these technologies to become increasingly competitive with traditional fuels and internal-combustion engines, but it took substantial public-sector support to arrive at that point.

Governments have plenty of options at their disposal to enable the deployment of green heavy-industry technologies. Some already have technology-specific policies in place, while others are targeting a specific sector or activity. Governments can directly hand out incentives to attract new investors or reduce costs for decarbonization (policy 'carrots'), or they can gradually raise penalties on consumers or companies to get them to reduce emissions (policy 'sticks'). Alongside these, governments can implement policies that tighten lifecycle emission thresholds for materials, reduce material demand and increase recycling. Despite a diverse catalog of tools available to address industrial emissions, most interventions are underutilized across these sectors (Table 1).

Table 1: Most prominent policy interventions for industry decarbonization currently

Policy interventions	Steel	Cement	Plastics	Fertilizers
Cross-cutting solutions Carbon pricing mechanisms to reduce emissions	Applied in this sector	Applied in this sector	Varying application	Varying application
Incentives (carrots) Subsidies, grants, tax credits to support low-emissions technology	Applied in this sector	Applied in this sector	Lacks uptake in this sector	Lacks uptake in this sector
Regulations (sticks) Agreements, standards and mandates for green procurement	Varying application	Varying application	Varying application	Lacks uptake in this sector
Demand-reduction solutions Taxes, fees and incentives that reduce material demand	Applied in this sector	Lacks uptake in this sector	Lacks uptake in this sector	Applied in this sector
Circular economy solutions Measures to promote recycling that reduces primary materials production	Varying application	Lacks uptake in this sector	Applied in this sector	Not applicable

Intervention status: Applied in this sector · Varying application · Lacks uptake in this sector · Not applicable

Source: BloombergNEF. Note: 'Applied in this sector' is not inclusive of all geographies.

1.2 Key findings

Carbon pricing is one of the most impactful tools for encouraging industries to adopt new technologies and reduce emissions, but prices must be high enough. The market should also create a level playing field between domestic and international producers.

- An emissions trading scheme such as the European Union’s Emissions Trading System, which tightens the supply of emissions allowances for each sector over time, allows market forces to determine the appropriate carbon price needed to achieve the desired level of total emissions across the scheme. Revenues from carbon markets can be recycled to fund incentives for green industry projects.
- Carbon prices must be high enough to incentivize significant investment in green industry, and this is not yet the case for any global carbon markets.
- Governments putting a price on carbon almost always create additional incentives and protections for industry, to safeguard jobs and certain domestic industries. However, such concessions (for example, free allocation in the EU) can dampen the effect of the carbon price. A well-calibrated carbon price on imported materials could be a more impactful alternative for reducing the risk of carbon leakage and leveling the playing field across producers.
- Some sectors face a double bind wherein a major portion of emissions occur in another stage of their products’ lifecycle, beyond production. To be effective, carbon pricing mechanisms, and adjacent measures, incentives and regulations, should target emissions wherever they occur.

Governments will likely need to offer financial incentives to nascent technologies to improve their economic viability and accelerate commercialization.

- Output-linked incentives such as the US’s 45Q and 45V tax credits are designed to incentivize the uptake of hydrogen and carbon capture and storage. These measures are advantageous because the subsidy paid depends on the realized quantity of hydrogen produced or CO_2 captured, which could have direct emissions benefits on every dollar spent. Some markets are also experimenting with investment-linked, or capex, subsidies, which can be a good alternative, allowing governments to more securely stick to their subsidy budget.
- Governments can offer other types of operational subsidies such as contracts for difference, or even carbon contracts for difference, to support the additional cost of procuring or producing low-carbon technologies and materials. In markets with (or planning to introduce) a carbon pricing mechanism, carbon contracts for difference can effectively do the same thing while reducing the subsidy bill for governments through carbon market revenues in the long run. The SDE++ scheme in the Netherlands has been effective at encouraging the uptake of green hydrogen and CCUS projects.

Policymakers can encourage manufacturers to supply low-emissions materials by supporting the creation of demand for green industrial products, including through public procurement and establishing robust emissions standards.

- Demand from public entities forms a sizeable share of global cement, steel and fertilizer markets, so green public procurement programs can offer a guaranteed buyer for low-emissions materials. Another way that governments can foster demand is through regulatory mandates covering a specific sector – for example, France’s limits on embodied carbon emissions in new buildings – such that they tighten over time to encourage reductions in the carbon intensity of steel and cement used.

- Robust green standards will be the backbone of effective net-zero industrial policy. Clearly defining what 'green' means and progressively tightening the emissions benchmarks will allow producers to strategize for reducing emissions from their manufacturing operations.

Governments can also incentivize – or mandate – companies to lower the carbon footprint of their activities through measures focused on shifting consumption patterns. Circular economy policies can transfer demand from virgin materials to recycled materials, while direct demand reduction mandates can have an immediate impact on emissions.

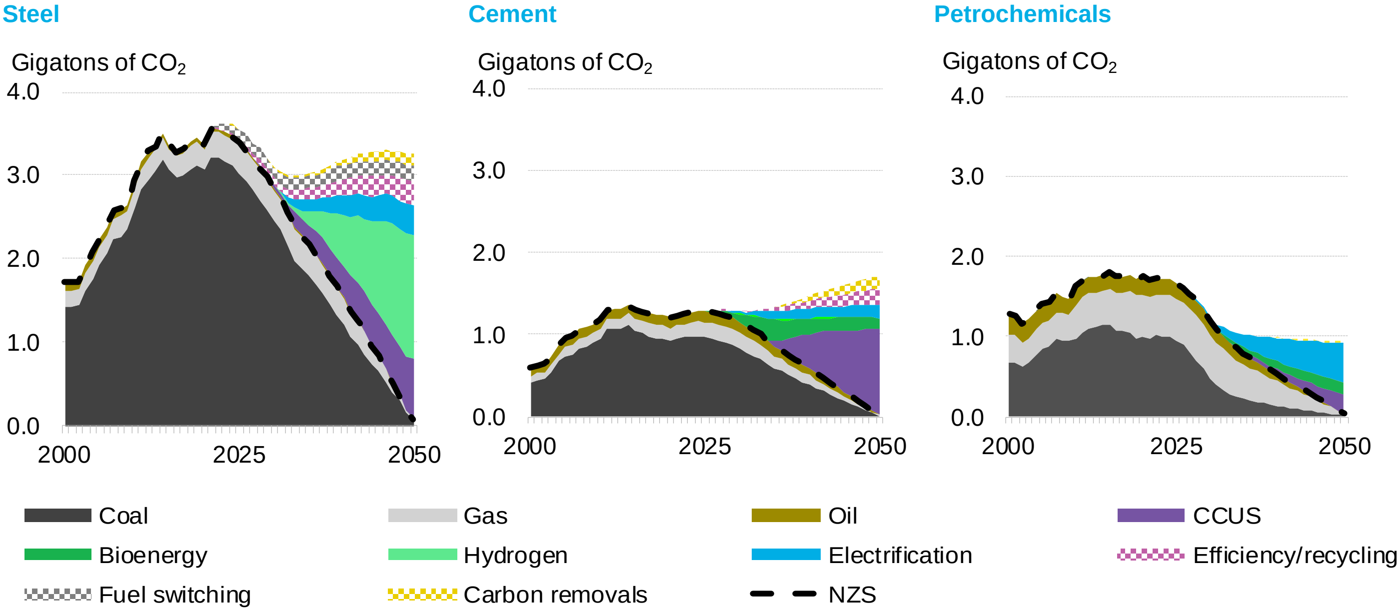
- Some policymakers are tackling agricultural emissions from the application of nitrogen fertilizers by imposing a fertilizer use levy. While reducing demand is important, this type of policy is more functional when paired with measures to ensure emissions from upstream production are also reduced.
- China is implementing a top-down supply-side mandate by restricting the expansion of steel production capacity, unless old production units are swapped for more efficient units. In markets that do not see massive growth in materials demand, governments can explore policies that require manufacturers to swap out old and inefficient plants to build new, greener capacity.
- Extended producer responsibility programs have improved plastic recycling rates in markets such as the Netherlands. The UK's recycled plastic content mandate is forcing many brand owners to increase the share of recycled content in plastic packaging for domestically-produced and imported products, or pay a hefty tax per ton of virgin plastic over the threshold.

Section 2. Scaling up emerging technologies

2.1. The state of play

A range of solutions will be needed to decarbonize heavy industry. Electrification, recycling, hydrogen and carbon capture, utilization and storage (CCUS) are the most important technologies to deliver net-zero steel, cement, fertilizers and petrochemicals – at the lowest cost – by 2050 under BNEF's Net Zero Scenario (Figure 3).

Figure 3: Global end-use sector CO_2 emissions and abatement technologies, based on BNEF's Net Zero Scenario



Source: BloombergNEF New Energy Outlook 2022 (web | terminal).Note: BNEF's Net Zero Scenario (NZS) does not separate fertilizers from petrochemicals. CCUS refers to carbon capture, utilization and storage.

This section outlines the challenges and opportunities in abating emissions in the steel, cement, plastics and fertilizer sectors. It leverages BNEF data and analysis to illustrate the technologies central to least-cost pathways for decarbonizing each sub-sector, such as green hydrogen for steel and carbon capture for cement. It also considers key challenges – which are often multi-faceted and specific to each sector, technology and market – and the status of policy development for the technologies described in this report (Table 2).

Table 2: Overview of decarbonization challenges facing heavy industry by subsector

Sector	Technologies necessary	Policy development level	Key challenges
Steel	Hydrogen, CCUS, Electrification, Efficiency/recycling	Mixed	• The production process requires a reducing agent and extremely high temperatures. • Hydrogen and CCUS are not economically viable today. • Decarbonization requires collaboration across a complex value chain.
Cement	CCUS, Electrification, Efficiency/recycling, Hydrogen	Weak	• The production process requires extremely high temperatures and generates significant direct emissions. • Hydrogen and CCUS are not economically viable today. • Decarbonization requires collaboration across a complex value chain. • Customers are very sensitive to green premiums, and there are few offtake contracts in place today.
Plastics	Electrification, Efficiency/recycling, CCUS, Hydrogen	Mixed	• Requires decarbonization of both the feedstock and the cracking process. • Low-carbon feedstock replacements are not economically viable today. • Most policy interventions to date have focused on recycling plastic bottles composed of polyethylene terephthalate (PET).
Fertilizers	Hydrogen, CCUS, Efficiency/recycling	Very weak	• Requires feedstock and post-application emissions reduction. • It is not economical for most farmers to change or mitigate their fertilizer use. • More than half of the greenhouse gas emissions are released post-application when nitrogen fertilizers degrade on a farm, resulting in highly decentralized externalities.

Technology key: Electrification; Efficiency/recycling; Hydrogen; Carbon capture, utilization and storage

Source: BloombergNEF New Energy Outlook 2022 (web | terminal). Note: Technologies required ordered by most to least important for each sector.

Steel

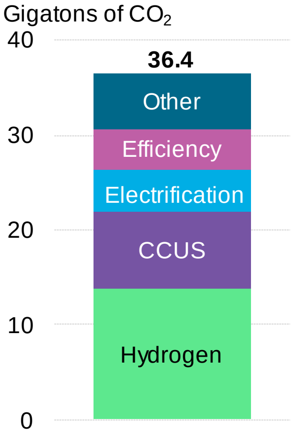
Technologies necessary: Hydrogen CCUS Electrification Efficiency/recycling

Steel is the most widely used metal in the world. It is an essential part of our infrastructure, buildings, vehicles, furniture and packaging. While its emissions per metric ton are lower than those of most other materials, the scale of steel production makes it responsible for 8% of global carbon emissions.[1]

The majority of steel production today – 69% – is fueled primarily by coal, which is used in blast furnaces to convert iron ore into iron, and then in the basic oxygen furnaces that introduce carbon and other additives to turn iron into steel. (This process that pairs blast furnaces with basic oxygen furnaces is known as 'BF-BOF'.) Some 5% of production is fueled by natural gas, which is used in a direct reduction process that is usually combined with an electric arc furnace (DR-EAF). The final 26% of production is secondary, fueled by electricity, which is used to melt scrap steel in electric arc furnaces (EAF) to produce recycled steel.

[1] *BloombergNEF New Energy Outlook 2022* (web | terminal).

Figure 4: Cumulative emissions abatement by technology for steel, 2023-2050



Source: New Energy Outlook 2022. Note: 'Other' includes bioenergy, fuel switching and carbon removals. Efficiency includes recycling. CCUS refers to carbon capture, utilization and storage.

There are four broad levers for decarbonizing steel production (Figure 4), ordered below by their abatement potential:

- **Green hydrogen** (hydrogen produced via electrolysis) can be used to fuel direct reduction in three key ways: hydrogen-ready direct reduction furnaces (H2DR-EAF); using hydrogen in the BF-BOF process as an auxiliary reducing agent (H2-BOF); and simply blending hydrogen into coal- and gas-fired plants without replacing or retrofitting any equipment. The last option is the most feasible today, but H2DR-EAF has the most decarbonization potential. Using hydrogen in blast furnaces can only reduce about 20% of emissions.
- **Carbon capture, utilization and storage** can remove and recover up to 90% of point-source emissions when attached to a power plant or a furnace. This removal rate could increase slightly with technology improvements, especially for high-concentration sources. However, existing steel plants would require significant retrofits, large capex investments, and access to transport and storage infrastructure to incorporate CCUS.
- **Electrification** in primary production requires electrolysis, an early-stage technology that enables the direct production of steel from an iron ore feedstock by using electricity to separate chemical compounds.[2] Steel made this way can avoid almost all the usual process emissions by using electricity as the primary energy input, but it is only likely to become an economically viable solution in the 2040s.
- **Steel recycling** requires scaling the use of electric arc furnaces to produce steel from scrap. It is already a mature technology, but it is not always economical due to the cost of sourcing scrap materials, which come from the waste produced at steel mills, excess steel from automotive and appliance manufacturers, demolished buildings and residential waste. Recycling's emissions impact will be limited by the availability of scrap supply and the carbon footprint of the electricity. Since steel recycling technology is well established, increasing it will primarily require investment in new EAFs and scrap collection and sorting facilities, especially in countries with low EAF capacity and an under-developed recycling supply chain.

Cement

Technologies necessary: CCUS Electrification Efficiency/recycling Hydrogen

Concrete, and the cement used to make it, is the most widely used material on the planet. The scale of its production means it contributes to 3% of global CO_2 emissions.[1] Cement requires very high heat to break down limestone, which is usually produced by burning coal, petroleum coke, waste material or biomass. The heating of limestone, known as calcination, breaks the rock down into lime and CO_2. Cement kilns typically use coal or waste material because they are the cheapest fuels for manufacturers.

The limestone decomposition itself also produces carbon emissions, accounting for more than 50% of the material's total manufacturing emissions. This puts cement in a unique position in industry, as fuel-switching and efficiency gains can only abate up to half of its emissions footprint.

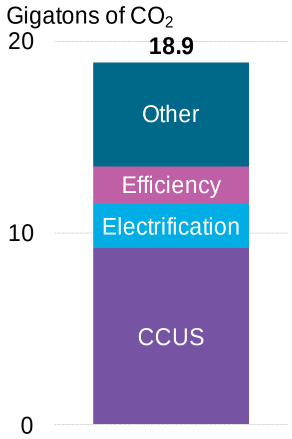
Decarbonizing cement will therefore require CCUS or a change in feedstock composition, or cement could be replaced by another building material. BNEF's Net Zero Scenario relies heavily on CCUS for cement decarbonization, with the technology providing nearly half of total emissions abatement by 2050.

[2] There are broadly two forms of electrolysis: molten oxide electrolysis (MOE), developed by Boston Metal, and solid oxide electrolysis, which ArcelorMittal is investigating.

There are four broad levers for decarbonizing cement (Figure 5), ordered below by their abatement potential:

- **Carbon capture, utilization and storage** systems can be retrofitted onto current cement plants to abate emissions from fuel use and calcination, addressing both combustion and feedstock emissions. CCUS can be paired with traditional fossil-fuel energy or with low-carbon fuels in a cement refinery. Cement itself can also serve as a form of long-term CO_2 storage: the CO_2 reacts with calcium and magnesium compounds during the concrete preparation phase and can even strengthen the material, and the captured CO_2 can be used subsequently in the preparation of concrete.
- **Electrification** is also a potential route to decarbonize some furnaces. Kiln electrification becomes available in the 2030s under BNEF's Net Zero Scenario as new electric furnaces or significant retrofits are required to reach the extremely high temperatures (1400C) needed to produce cement. We expect the use of these furnaces to be limited, however, due to the high cost of power and new furnace designs compared to the fuels currently used and the availability of more viable technologies.
- **Recycling** technologies are available to recover unreacted cement and reuse it, which helps reduce feedstock emissions from virgin limestone, but the process is very expensive. Cement recycling also faces similar challenges as steel when it comes to sourcing sufficient scrap material, resulting in very little cement getting recycled today.
- **Green hydrogen** used as a heating fuel for cement-making would eliminate the heating-related emissions, which account for around 40% of the total. However, its widespread use in the industry is unlikely due to its high costs. Today, hydrogen is only used as a catalyst in kilns to improve combustion efficiency.

Figure 5: Cumulative emissions abatement by technology for cement, 2023-2050



Source: New Energy Outlook 2022. Note: 'Other' includes bioenergy, hydrogen and carbon removals. Efficiency includes recycling. CCUS refers to carbon capture, utilization and storage.

Plastics

Technologies necessary: Electrification, Efficiency/recycling, CCUS, Hydrogen

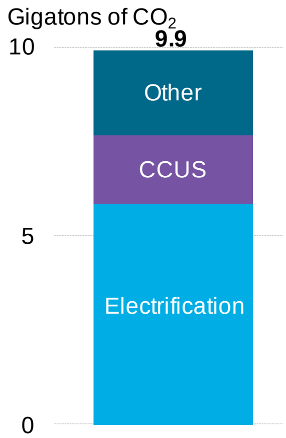
Petrochemicals are the building blocks of countless synthetic materials, additives and reagents, and are an essential component of the industrial supply chain. Most petrochemicals are used in the production of plastics, and demand for plastics is expected to rise as economies grow. Plastics are cheap to make, easy to source and applicable to countless industries. Global demand for high-value chemicals, the subset of petrochemicals that consists of ethylene, propylene and aromatics, represents 5% of industrial CO_2 emissions.[3]

The dominant production route to high-value chemicals is the steam cracking of fossil-based feedstocks such as naphtha, ethane and liquefied petroleum gas. Steam cracking is a highly complex and energy-intensive process with few commercially viable alternatives today. Secondary production of high-value chemicals is also possible through plastic waste pyrolysis (chemical recycling), which yields recycled naphtha for cracking.

The petrochemicals sector mimics cement's double-emissions challenge, as it relies on fossil-based fuels and hydrocarbons both in the feedstock and the production process. It faces a complex path to net zero, requiring electrification, increased recycling, carbon capture and storage and alternative production routes.

[3] International Energy Agency (2022)

Figure 6: Cumulative emissions abatement by technology for petrochemicals, 2023-2050



Source: New Energy Outlook 2022. Note: 'Other' includes bioenergy and carbon removals. CCUS refers to carbon capture, utilization and storage.

There are four broad levers for decarbonizing plastics (Figure 6), ordered below by their abatement potential:

- **Electrified crackers** use clean power to meet process heat demand instead of fossil-fuel combustion, allowing production without any combustion emissions from the steam cracking process. Currently, the petrochemicals industry is working on two alternative electrification routes, e-furnaces and rotodynamic reactors. If the power is from renewable sources, there are no direct or energy-related process emissions in an electrified steam cracker. However, to make the entire production process net zero, feedstock production emissions would need to be abated through a combination of CCUS, bio-naphtha and offsets.
- **Recycled waste plastics** can be processed 'mechanically' or 'chemically' to convert waste polymers back into chemical feedstocks. Mechanical recycling requires waste plastics to be sorted and cleaned before reprocessing, which is resource-intensive. Chemical recycling does not require the same level of precision in the sorting of waste, as contaminants and additives can be removed in the process of breaking waste polymers down into reprocessed feedstock.
- **Carbon capture, utilization and storage** can be used in several areas of the petrochemicals value chain: during the feedstock production process, in the steam cracking process, or in the propane dehydrogenation process.
- **Green hydrogen** can be used as a drop-in fuel to meet energy demand in steam crackers, although it is likely to be out-competed by electrification and CCUS in the near-term because of the operating expenditures of running a hydrogen-fired furnace.

Fertilizers

Technologies necessary: Hydrogen Efficiency/recycling CCUS

Nitrogen fertilizers also face the double-bind emissions conundrum: their production emits both carbon dioxide and nitrous oxide, and the fertilizers continue to emit nitrous oxide as they break down post-application. Ammonium-nitrate, the most widely used fertilizer type, is made by mixing ammonia with nitric acid. Ammonia production emits roughly 1.8% of annual global CO_2 emissions; in 2022, that share equated to 439 million tons of CO_2 equivalent (CO_2e). Some 90% of these emissions come from the gray hydrogen production used to make ammonia, according to the Royal Society, and about 98% of ammonia is currently produced using natural gas (72%) or coal (26%) as the fuel and feedstock.[4]

Ammonia production accounts for 39% of all lifecycle emissions for fertilizers, while on-farm emissions that stem from chemical reactions post-application (on-farm and escaped) are responsible for 59% of total emissions (Table 3).[5]

There are three broad levers to decarbonize the production of nitrogen fertilizers, ordered by their abatement potential:

- **Green hydrogen** is required to decarbonize ammonia production. Gray hydrogen is currently the intermediary product when manufacturing nitrogen fertilizers, but it can be directly replaced by green hydrogen (hydrogen produced via electrolysis) to create **green ammonia.**

[4] The Royal Society (2022). Ammonia: zero-carbon fertiliser fuel and energy storage.

[5] Menegat, S., Ledo, A. & Tirado, R. 'Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture,' *Scientific Reports*, 2022.

However, green hydrogen cannot be used for potassium and phosphorus production where alternative feedstocks are not viable.

- **Carbon capture, utilization and storage** can be paired with natural gas refineries to create blue ammonia. However, this can only capture up to 90% of production emissions, making green hydrogen and green ammonia the preferred decarbonization route.
- **Agricultural efficiency improvements** can help reduce fertilizer demand and in turn eliminate emissions from fertilizer production. Reducing demand is also one of the most promising ways to decrease post-application emissions. There are several measures that can make fertilizers more effective, such as choosing certain crops, rotating crops and applying controlled-release inhibitors.[6] Controlled-release inhibitors help reduce the amount of fertilizer required by enhancing their efficiency. Catch crops can help 'catch' excess nutrients, and cover crops can reduce nutrient loss between crop rotations

Table 3: Breakdown of fertilizer value chain emissions

Point of emission	Emissions (%)
Fertilizer production	39
On-farm	42
Escaped	17
Transport and application	2

Source: BloombergNEF; Menegat, S., Ledo, A. & Tirado, R., 2022.
Note: 'Escaped' refers to emissions from denitrification and volatilization. In both processes fertilizers chemically break down and emit harmful gasses.

What about carbon removals?

Direct air capture (DAC) and bioenergy with carbon capture and storage (BECCS) are not addressed in this report. We have excluded these technologies because we attempt to minimize the use of carbon removals in the Net Zero Scenario in BNEF's New Energy Outlook, particularly in the near term. We focus on technologies that have potential to decarbonize major industrial sectors at the point of emission, rather than technologies to remove CO_2 from the atmosphere afterwards.

2.2. Scale of investment

Some 97% of all investments in the energy transition in 2022 went to relatively mature clean energy technologies, such as renewable energy projects, electrified transport, clean heating in homes and energy storage. Investments in industrial decarbonization have remained much lower due to the high costs and nascent status of the required technologies, as well as the lack of policy support to overcome these challenges.

Policy intervention enabled solar, wind and other mature renewable technologies to scale up and become cost-competitive through public subsidies and private investments. Now, industrial sectors require financial resources, including public subsidies, to help emerging technologies mature and become economically competitive in the near term with the status quo.

[6] BloombergNEF. *Fertilizer Primer: Plant Nutrition Without the Emissions* (web | terminal)

Figure 7: Global annual investment in the clean energy transition by sector

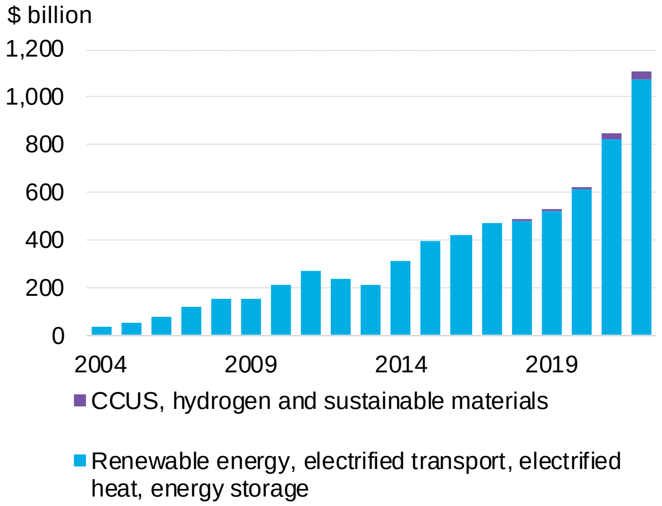
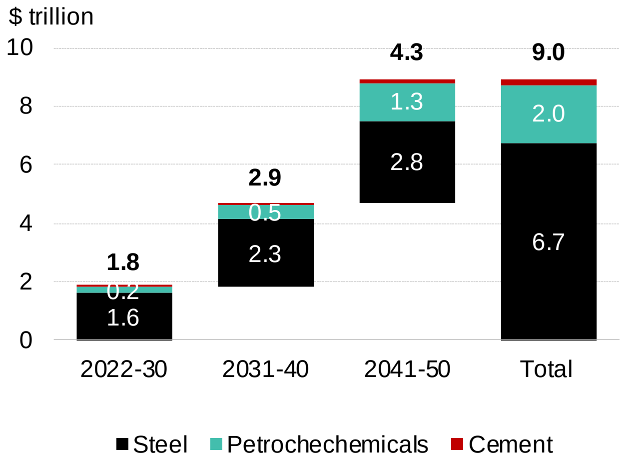


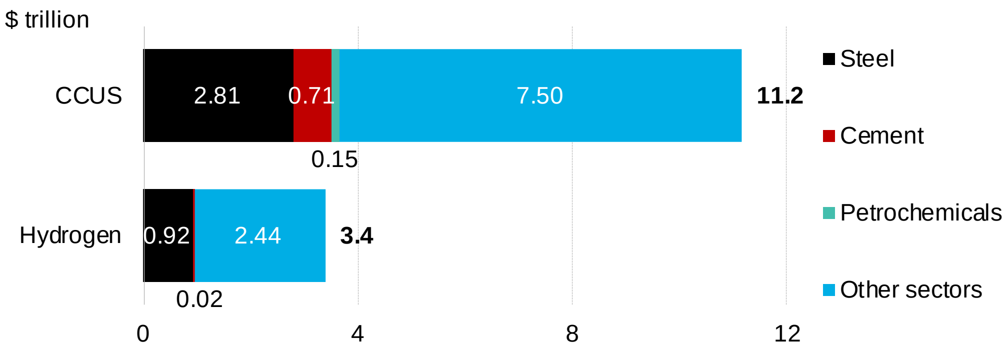
Figure 8: Global investment in sustainable materials by sector, based on BNEF's Net Zero Scenario



Source: BloombergNEF. Note: Investment in sustainable materials refers to recycling and efficiency and excludes investments in CCUS and hydrogen. CCUS refers to carbon capture, utilization and storage.

Investments in CCUS, hydrogen and sustainable materials[7] accounted for less than 3% of annual investments in the energy transition in 2022 (Figure 7). To get on track for net zero, the share of total investment in CCUS, hydrogen and sustainable materials must quadruple, which would equate to a cumulative investment of $24.2 trillion by 2050 (Figure 8, Figure 9). Of this, $12.6 trillion goes to steel, cement and petrochemicals, with the largest share required for steel.

Figure 9: Cumulative hydrogen and CCUS investments required by 2050, by sector, BNEF's Net Zero Scenario



Source: New Energy Outlook 2022 (web | terminal). Note: CCUS refers to carbon capture, utilization and storage. 'Other sectors' includes power.

CCUS requires a much bigger investment than hydrogen: some $11.2 trillion by 2050, inclusive of the power sector, compared to $3.4 trillion. While cement is the sector most reliant on CCUS to decarbonize, the steel sector will actually require the largest CCUS investment due to its size.

[7] 'Sustainable materials' refers to recycling, efficiency and the production of bioplastics.

Hydrogen is a much smaller slice of the pie at $3.4 trillion, with almost all industry-related hydrogen investment going to decarbonize steel.

Related BNEF insights:

For more on these sectors and their decarbonization routes, see:

Decarbonizing Steel: Technologies and Costs (web | terminal)

Cementing Lower Emissions with Carbon Capture and Storage (web | terminal)

Tech Radar: Low-Carbon Cement (web | terminal)

Decarbonizing Petrochemicals: Technologies and Costs (web | terminal)

Ammonia Market Primer: The Struggle to Go Green (web | terminal)

Fertilizer Primer: Plant Nutrition Without the Emissions (web | terminal)

For more on the investment trends, see *Energy Transition Investment Trends* (web | terminal).

See Appendix A for definitions on each technology and Appendix B for details on our policy rating methodology.

Section 3. Policy solutions

Table 4: Comparison of select policy solutions available for industry decarbonization

Policy type	Mechanism	Effectiveness	Scalability	Feasibility	Example
3.1. Cross-cutting solutions	Carbon tax	5*	5	3	Not applicable
	Compliance emissions-trading system	5*	5	3	EU Emissions Trading System
3.2. Incentives (carrots)	Targeted output-linked tax credits	4	3	3	US 45Q tax credit
	Targeted investment-linked tax credits	3	3	2	Canada's CCUS credit
	Targeted demand-side tax credit	4	3	3	Colorado's hydrogen credit
	Supply-side carbon contract for difference	4	3	2	Netherlands SDE++ scheme
	Demand-side carbon contract for difference	4	3	2	Germany's CCfD
3.3. Regulations (sticks)	Green public procurement mandate	4	4	3	Buy Clean California
	Life-cycle emissions mandate	5	3	3	France's RE2020
	Expedited permitting	2	3	5	Seattle's Priority Green Expedited
	Consumption mandate	5	3	1	EU's hydrogen consumption mandate
	Production capacity and swap mandates	5	2	1	China's steel production cap strategy
3.4. Demand-reduction solutions	Farm levy	3	2	2	New Zealand agriculture carbon tax
	Payments for ecosystem services	3	2	2	Japan's direct payments
3.5. Circular economy solutions	Extended producer responsibility	2	4	3	Netherlands extended producer responsibility
	Recycled content mandate	4	3	2	UK recycled content mandate

*Source: BloombergNEF. *Note: The effectiveness of a carbon tax or market is determined by the share of an industrial plant's emissions covered, the CO2 price and concessions like free allocations granted to companies. See Appendix B for our rating methodology.*

Many of the required decarbonization solutions for industry are currently expensive and not often available on a commercial scale. To date, however, policymakers have offered industrial decarbonization far less support than other sectors, such as renewable power and electrified transport, have received. Solar, wind and electric vehicles are all increasingly economically competitive with traditional fuels and internal-combustion engines, but it took decades of government support – in the form of subsidies and other policy levers – to arrive at this point.

Governments can choose several different policy design pathways (Table 1). Some choose technology-specific policies, while others introduce measures targeted at one or more sectors or activities. They can hand out incentives to attract new investors ('carrot's) or progressively raise emissions penalties on consumers or companies ('sticks'). Some policies can be designed to apply across multiple sectors and/or promote new solutions.

Governments must lean on a diverse combination of mechanisms to scale emerging solutions in industrial sectors. This section assesses the most promising policy solutions that are being considered and implemented today to accelerate industry decarbonization. It also provides a review of the potential impact and limitations of each measure type.

3.1. Cross-cutting solutions

Cross-cutting solutions are policy mechanisms that do not fit into the other, better-defined buckets of incentives and regulations. They also include mechanisms that can be applied across several sectors and technologies. In this section, we look at two such mechanisms: carbon taxes and compliance carbon markets. Both of these have been applied to the sectors considered in this report, but to varying and often limited degrees (Table 5).

These mechanisms receive high scores for their effectiveness and scalability, as they have a history of robust impact in other sectors and are easily ramped up (Table 6). They do, however, score lower in feasibility. This is because carbon pricing is often difficult to design and implement in a new market. We highlight and explain the European Union's Emission Trading System as a successful example of carbon pricing.

Table 5: Analysis of cross-cutting policy solutions available for industrial decarbonization

Policy intervention	Steel	Cement	Plastics	Fertilizers
Cross-cutting solutions Carbon pricing mechanisms to reduce emissions	● (Applied in this sector)	● (Applied in this sector)	● (Varying application)	● (Varying application)
Intervention status	● Applied in this sector	● Varying application	● Lacks uptake in this sector	

Source: BloombergNEF

Table 6: Select cross-cutting policy solutions available for industrial decarbonization

Mechanism	Effectiveness	Scalability	Feasibility	Example in this section
Carbon tax	5*	5	3	Not applicable
Compliance emissions-trading system	5*	5	3	EU Emissions Trading System

*Source: BloombergNEF. *Note: The effectiveness of a carbon tax or market is determined by the share of an industrial plant's emissions covered, the CO2 price and concessions like free allocations granted to companies. See Appendix B for our rating methodology.*

Carbon pricing

Governments can put a price on carbon emissions in two main ways: market-based mechanisms such as emissions-trading systems, or fixed-price systems like taxes. Today there are over 60 carbon-pricing schemes around the world, but these vary greatly in terms of price and industries covered. Carbon pricing is a flexible policy mechanism, applicable to a wide variety of sectors and technologies (Table 7, Table 8).

Compliance carbon markets

Compliance markets can either use an absolute cap or an emissions-intensity cap to regulate emissions. The more common, and more stringent, type of compliance carbon market is the former, known as a cap-and-trade scheme. In this case, the cap is the total number of allowances that a government supplies to the market and defines the maximum emissions for the covered sectors during a specific time period. This approach guarantees a certain emissions-reduction trajectory, increasing certainty for investors and participants in the market.[8]

'Permits' or 'allowances' are created up to the cap, and some may be distributed to compliance entities as 'free allocation'. For some sectors, putting a price on emissions could create a risk of carbon leakage, which occurs when companies move production to markets with lower or zero carbon costs. Governments typically aim to prevent carbon leakage through free allocation, tax-free allowances and exemptions, which are common in the early stages of carbon markets as participants get used to the new regime. However, such concessions can limit the effectiveness of the carbon market, so it is important for allowances to be phased out according to a clear implementation timeline.

Table 7: Carbon tax snapshot

Supply	Demand
✓	✓
Neutral	**Targeted**
✓	

Source: BloombergNEF. Note: Supply refers to low-carbon technology producers. Demand refers to industrial end-users. A carbon tax is technology-neutral because it does not require particular decarbonization technologies in the sectors covered.

Carbon tax

A carbon tax requires companies and individuals to pay a fixed price per unit of emissions. It is considered a regulation (stick) and may be applied to the supply, retail, import or use of fossil fuels. The tax rate may vary by fuel or sector. In addition, some policies allow the use of carbon offsets from projects to remove or avoid emissions.

The choice between a cap-and-trade scheme and a tax

For policymakers, the choice between a carbon tax and a cap-and-trade scheme is mainly a choice between a guaranteed price and a defined emissions reduction pathway. A tax does not guarantee a particular decrease in emissions, but it does provide certainty about price per unit of emissions. This is crucial for ensuring that a carbon price will alter behavior, and it enables taxpayers to plan investments. However, setting the tax rate is difficult: if it is too low, companies and households will continue polluting and simply pay the tax; if too high, costs could rise higher than necessary to reduce emissions.

Case study: European Union Emissions Trading System (EU ETS)

Overview: The EU ETS is a regional emissions trading system that covers around 40% of the bloc's emissions from the power, industry and commercial aviation sectors. As of 2023, it remains the largest compliance carbon market in the world in terms of traded value, and it has driven gradual cross-sector emissions reductions, with the largest reductions occurring in the power sector (Figure 10).

[8] BNEF's Carbon Knowledge Hub (web)

How it works: With the exception of free allocations, emissions allowances come to the market via auctions, where emitters can purchase them. Revenues generated by the scheme have risen steadily, in part due to the gradual phase-out of allowances that are freely allocated. Member states were previously required to use at least 50% of auction revenues for climate-related purposes. From 2013 to 2019, they exceeded this target, spending 78% of the carbon market revenues on climate- and energy-related activities.[9] Recent reforms have increased this percentage to 100% of the revenues.[10] The auction system helps provide EU members with the necessary resources to implement their decarbonization plans.

Figure 10: Emissions covered in the EU ETS by sector

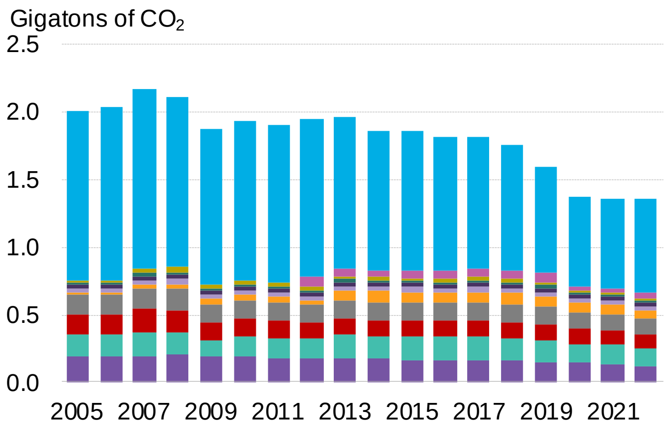
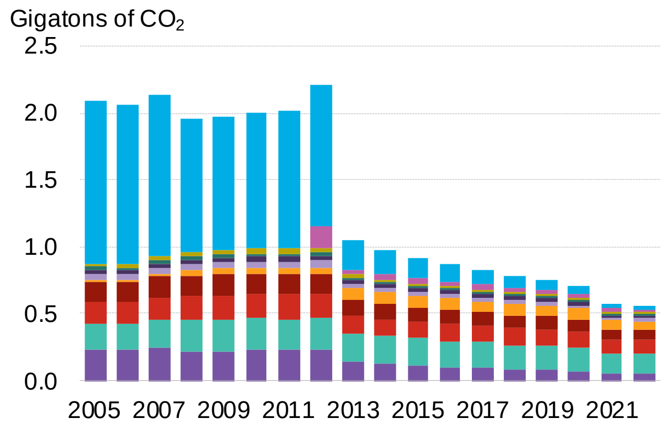


Figure 11: Free allocation under the EU ETS by sector



Industrial heat · Metals · Cement · Refining · Other · Pulp and paper · Lime · Glass · Ceramics · Aviation · Power

Source: European Union Transaction Log, BloombergNEF.

Member states will be required to invest 100% of their carbon allowance revenues on climate action.

In the early years of the EU ETS, free allocations were distributed to protect domestic manufacturing, the fear being that a full carbon price could drive industrial companies to shift production to markets without carbon prices, a phenomenon known as 'carbon leakage'. This effectively shifts greenhouse-gas release to other geographies without additional carbon costs and could make domestic manufacturing more expensive for the country covered by the carbon price. As a result, some governments with carbon markets are evaluating placing a carbon price on imported goods, to level the playing field for domestic manufacturers.

The EU first started phasing out free allocations for the power sector in 2012, but allocations for industrial sectors have remained relatively stable (Figure 11). This is set to change starting in 2026, when the volume of free permits will shrink for select sectors covered under the EU's carbon border adjustment mechanism (CBAM), which began the transitional phase in October 2023. Once the CBAM begins in earnest in 2026, it will tax certain imports from countries outside of the EU, based on the average weekly carbon price imposed within the EU ETS. Under the plan, imports of iron and steel, aluminum, cement, fertilizer, hydrogen and electricity into the bloc will be subject to the EU's carbon price based on their embedded CO_2.[11] As such, free allocations received by domestic industrials within those sectors will be phased out entirely by 2034. This aims to level the playing field between producers operating within the EU ETS and outside of it.

[9] European Commission

[10] Report From the Commission to the European Parliament and the Council

[11] Imports from Norway, Liechtenstein, Iceland and Switzerland are not included in CBAM.

BNEF take: While the EU ETS has reduced power sector emissions, it has had a limited impact on the uptake of low-carbon technologies in industrial sectors. This is because emissions-intensive sectors such as steel and cement have effectively been exempt from paying the carbon price due to the high levels of free allocation. Low-carbon alternatives have also remained prohibitively expensive since industrial players had little or no economic driver to decarbonize

The European Commission's modeling expects CBAM to be effective at reducing emissions, but its ultimate impact remains uncertain. By fully exposing industrial producers to carbon pricing and giving domestic industries access to incentives funded by carbon revenues, the mechanism could spur companies to decarbonize faster than other markets. Steelmakers in the EU, for example, are decarbonizing faster than their global peers and could find themselves filling a competitive global niche if robust demand for green steel picks up.

Table 8: Emissions trading system snapshot

Supply	Demand
✓	✓
Neutral	**Targeted**
✓	

Source: BloombergNEF. Note: Supply refers to low-carbon technology producers. Demand refers to industrial end-users. An emissions trading system is technology-neutral because it does not require particular decarbonization technologies in the sectors covered.

Implementing compliance carbon markets in emerging markets

Emerging markets and developing economies will need to build the capabilities and systems to measure, report and verify (MRV) emissions reductions before a compliance carbon market can be implemented. These systems ensure accounting processes are robust and emissions reductions are real. As such, policymakers may then opt to use this infrastructure to construct a voluntary carbon market framework, which will then encourage companies to introduce their own MRV systems and become familiar with carbon trading. This can facilitate the transition to a compliance market at a later stage. This approach is being used in several emerging economies including India.

Related BNEF insights:

EU ETS Compliance Database 2005-2025 (web | terminal)

World's First Carbon Tariff Is Now a Thing (web | terminal)

'Protectionist' Carbon Border Tariff Won't Rescue EU Steel (web | terminal)

EU ETS Market Outlook 2H 2023: Cleared for the Ascent (web | terminal)

3.2. Incentives (carrots)

Financial and fiscal incentives, or what are often referred to as 'carrots', can be used to promote the uptake of clean technologies, either on the supply side (to accelerate deployment of an emerging technology like CCUS), or on the demand side (to subsidize the procurement cost for buyers). Either way, when designed effectively, carrots enable a technology to mature and eventually compete in the market without these incentives.

Three major incentive mechanisms to support industry decarbonization projects are being explored by governments today: direct grants and preferential-rate loans, tax credits linked to investments or output, and carbon contracts for difference. These mechanisms have a history of applications in the steel and cement sectors, but lack uptake in plastics and fertilizer (Table 9).

In our analysis, two of the most effective incentives for industrial decarbonization are output-linked tax credits, which subsidize the operational costs of low-carbon technology projects, and demand-side targeted credits, which subsidize the cost of procurement. Both of these mechanisms receive high scores for their effectiveness. Investment-linked tax credits, which subsidize the capital expenditure cost, are slightly less effective, since manufactures become fully responsible for their operations after building the projects. To distinguish between the mechanism designs, we evaluate the output-linked, supply-side 45Q credit in the US; the investment-linked, supply-side credit in Canada; and the demand-side credit in Colorado.

We also dive into carbon contracts for difference (CCfDs), which can be applied on both the supply and demand sides. These receive high scores for their effectiveness but lower scores for their scalability. CCfDs are slightly less feasible to implement than targeted tax credits, due to the complexity of designing the precise top-ups that manufacturers or companies should receive for producing or procuring low-carbon technologies (Table 10).

Table 9: Analysis of incentives available for industrial decarbonization

Policy intervention	Steel	Cement	Plastics	Fertilizers
Incentives Subsidies, grants, tax credits to support low-emission technology	● (green)	● (green)	● (yellow)	● (yellow)
Intervention status	● Applied in this sector	● Varying application	● Lacks uptake in this sector	

Source: BloombergNEF

Table 10: Select incentives available for industrial decarbonization

Mechanism	Effectiveness	Scalability	Feasibility	Example
Targeted output-linked tax credits	4	3	3	US 45Q tax credit
Targeted investment-linked tax credits	3	3	2	Canada's CCUS credit
Targeted demand-side tax credit	4	3	3	Colorado's hydrogen credit
Supply-side carbon contract for difference	4	3	2	Netherlands SDE++ scheme
Demand-side carbon contract for difference	4	3	2	Germany's CCfD

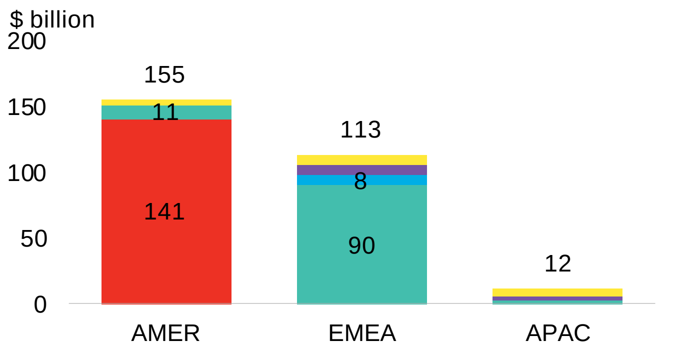
Source: BloombergNEF. See Appendix B for our rating methodology.

Grants and loans

Grants and preferential-rate loans are two types of incentives commonly used by governments to support the adoption of new technologies. While they are typically targeted at a specific technology, they can also be implemented in a technology-neutral way. They are always awarded to specific projects or companies, sometimes through a competitive process.

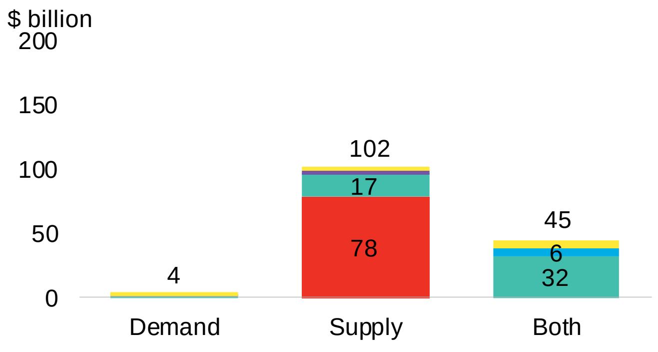
The European Commission approved €4.6 billion ($4.9 billion) in government funds to support a number of hydrogen-based steelmaking projects in Germany, Belgium and France, of which at least €2.9 billion is in the form of direct grants. Globally, about $102 billion has been promised by governments in grants for low-carbon hydrogen (Figure 12). However, there are drawbacks to deploying grants, which are often one-off lump sums, restrictive in what they cover, and conditional in how they can be applied. This can reduce both their effectiveness and companies' ability to use such grants to scale low-carbon operations.

Figure 12: Hydrogen subsidy mechanism used by region



*Source: BloombergNEF's Hydrogen Subsidy Tracker (last updated August 14, 2023). Note: This chart **includes** funding available for blue hydrogen via CCUS subsidies. R&D stands for research and development. AMER refers to the Americas; APAC refers to Asia-Pacific; EMEA refers to Europe, the Middle East and Africa.*

Figure 13: Targeted support for hydrogen by demand and supply



*Source: BloombergNEF's Hydrogen Subsidy Tracker (last updated August 14, 2023). Note: This chart **excludes** funding for blue hydrogen projects. R&D stands for research and development.*

Targeted tax credits

$141 billion in tax credits will be deployed for blue and green hydrogen projects.

Tax credits are becoming a more common incentive, principally in North America, to support investments into hydrogen and CCUS. Tax credits work by reducing the amount of income that is subject to tax. The US has implemented a recurring, output-linked payment mechanism under the Inflation Reduction Act (IRA) to deliver these incentives. Canada, on the other hand, has chosen a one-off capital-investment-linked tax credit to spur its CCUS industry. The case studies below explain the subsidy disbursement models.

Globally, BNEF estimates that $141 billion is available to hydrogen projects in the form of tax credits, inclusive of blue and green hydrogen production (Figure 12). Of this, the majority is from the US production tax credits: BNEF has estimated $120 billion could flow to eligible CCUS and hydrogen projects in the country through the 45Q and 45V tax credits. Some 40% of the total amount we estimate will be spent on hydrogen tax credits, or $55 billion, is estimated to flow to blue hydrogen projects via the 45Q CCUS tax credit from the IRA. Globally, two-thirds of funding for green hydrogen exclusively targets the supply side (Figure 13).

Targeted versus neutral policy design

Incentives targeted to a specific technology are often needed in the early stages of deploying new technologies, when the economics do not work. They can also make it easier for governments to meet broader goals, like building a local supply chain in a certain sector. While technology-specific incentives can encourage producers to manufacture or deploy a selected technology to take advantage of the incentive, they also risk 'picking winners' among the technology solutions, potentially leading to suboptimal outcomes.

A technology-neutral policy, on the other hand, could drive companies to compete against each other to provide least-cost solutions that maximize emissions reductions. In this approach, the market chooses the technologies with the most potential in the energy transition. However, this transition can take longer, as companies hedge risks by investing in many solutions before picking the one that they want to scale, and technologies that are cheaper today may win out over more nascent and expensive ones that have the potential for greater scale and cost reductions in the long run. Governments also subsidize several solutions in this case, slowing down the transition.

Case study: US output-linked tax credit for CCUS

Overview: In 2022, with the passage of the IRA, the US government significantly increased the incentives available to CCUS and hydrogen projects. This included enhancing the 45Q tax credit, which was first introduced as part of the Energy Improvement and Extension Act of 2008, to support CCUS investments. This type of mechanism applies to the supply side and focuses on the deployment of a specific technology (Table 11).

Table 11: Output-linked supply-side credit snapshot

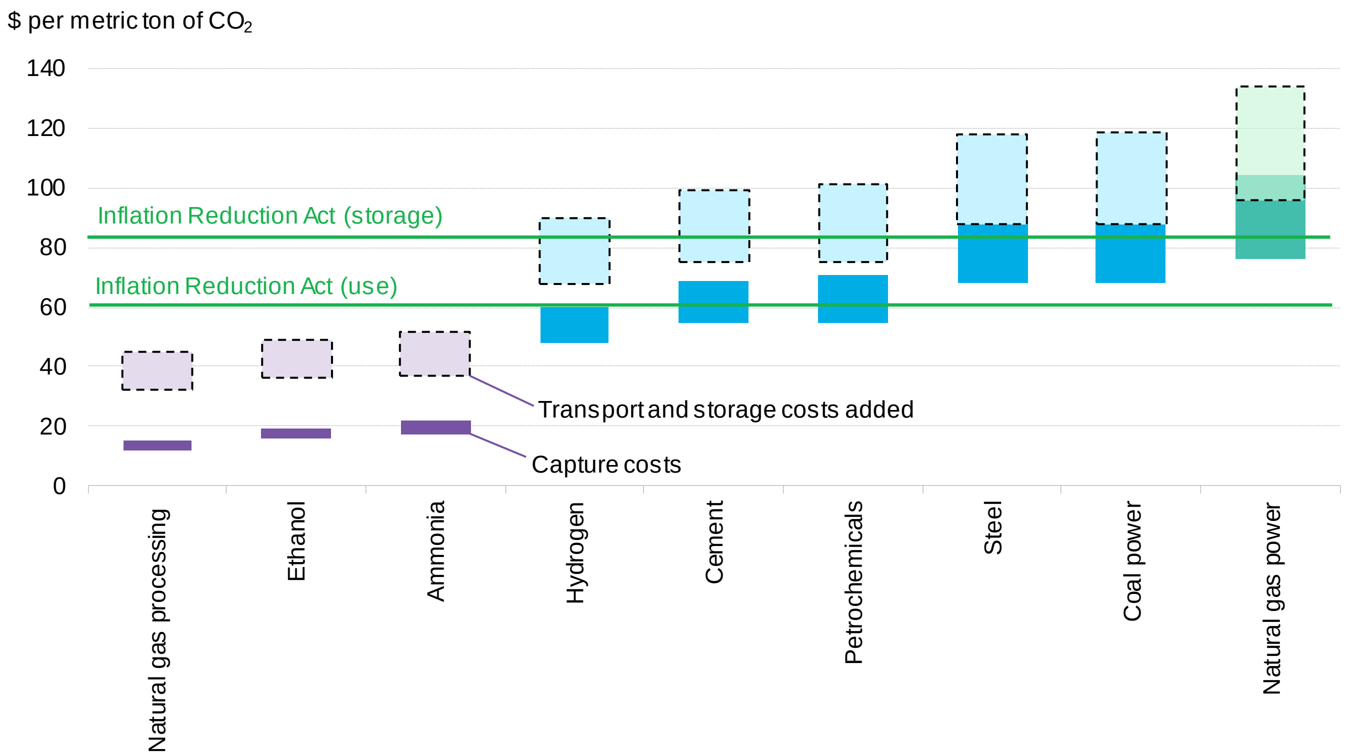
Supply	Demand
✓	
Neutral	**Targeted**
	✓

Source: BloombergNEF. Note: Supply refers to low-carbon technology producers. Output-linked credits for CCUS projects are considered targeted because they only apply to CCUS.

How it works: Point-source CCUS projects that begin construction by 2032 will receive a tax credit of up to $85 per ton of CO_2 for the first 12 years if the captured CO_2 is stored permanently, and up to $60 per ton of CO_2 if it is utilized for any other applications (Figure 14). DAC projects receive an even higher credit of $180 per ton of CO_2 stored and $130 per ton of CO_2 utilized, reflecting the far higher capture costs. A similar output-linked incentive is also available for hydrogen production projects, which promises up to $3 per kilogram of clean hydrogen produced over 10 years.

BNEF take: The US's approach of recurring payments is spurring the development of new CCUS capacity. The current tax credit could make carbon capture viable for industries such as blue hydrogen (ie, hydrogen produced using fossil fuels with the emissions captured), cement, petrochemicals and even some steel plants by allowing them to offset a large portion of their operational costs. Both high-concentration and industrial applications could recover a significant portion of their costs of capture through the 45Q production tax credit. Ammonia producers could fully cover their costs with the credit, making this incentive especially beneficial for blue ammonia in fertilizer production.

Figure 14: Nth-of-a-kind carbon capture cost with the US Inflation Reduction Act credit



Source: Great Plains Institute, BloombergNEF. Note: Hydrogen in this context refers to blue hydrogen only, not green hydrogen via electrolysis.

Some 85 million metric tons of annual capture capacity has been announced in the US since 2022.

The credit provides a simple and accessible way of ensuring revenue certainty for a CCUS project and significantly reduces project risks. This is already driving a rise in CCUS project activity, with 34 commercial projects (85 million metric tons of annual capture capacity) announced since 2022.[12] The scheme has also garnered international interest, with companies entering the US market to tap into these benefits. Ammonia producers could fully cover their costs with the credit, making this incentive especially beneficial for blue ammonia in fertilizers.

The scheme, however, does not cover all the costs of carbon capture, transport and storage for every sector, and there are not credits explicitly offered to companies building the transport and storage infrastructure in the value chain. Because the credit is a flat rate, widespread CCUS uptake in cement, petrochemicals and steel, for example, will require additional incentives, as they have higher operational costs than other sectors.

Case study: Canada's investment-linked credit for CCUS

Overview: In 2022, Canada introduced an investment-linked tax credit aimed at reducing the capex costs of new CCUS projects. The incentive is a one-off tax credit that the investor can claim against its tax liabilities. Like the output-linked credit, this mechanism applies to the supply side and targets a specific technology (Table 12).

[12] BNEF's CCUS Project Database (web). Note: This was last updated on October 26, 2023.

Table 12: Investment-linked supply-side credit snapshot

Supply	Demand
✓	
Neutral	**Targeted**
	✓

Source: BloombergNEF. Note: Supply refers to CCUS producers. Investment-linked credits for CCUS projects are considered targeted because the credit only applies to CCUS.

How it works: DAC projects can receive a tax credit worth up to 60% of the value of the equipment investment, while other CCUS projects can receive a 50% credit for capital invested. Canada also offers a 37.5% credit for capital investment in transportation, storage and use of CO_2 over 2022-2030. In 2031, credit values will reduce by half to incentivize faster action and account for much higher carbon prices by 2030. The scheme explicitly excludes projects that use CO_2 for enhanced oil recovery from claiming these incentives.

The tax credit may lower capture costs for industrial sources like cement, steel, petrochemicals and coal by 25-35%, and direct air capture costs by up to 35%. The Canadian government hopes that pairing the credit with a carbon price, which is expected to reach $75 per ton of CO_2 by 2025 and $130 per ton of CO_2 by 2030, will spur demand, as the credit would make it cheaper to build CCUS than to pay the carbon price.

BNEF take: By pairing the capex-based subsidy with a carbon price, Canada is taking a balanced approach of overlapping incentives and regulations. While this subsidy is technically less generous than the US's tax credits, a program based on capex helps governments keep tighter control of their subsidy budget. Additionally, since the investment credit is a percentage of capex, it accounts for the very different costs of carbon capture systems across various sector applications. In contrast, the 45Q credit is an absolute value, and therefore proportionately smaller for cement and steel producers.

Furthermore, the market has been bearish on investing in infrastructure due lack of demand certainly for CO_2 transport and storage. This policy helps mitigate this risk by offering credits to companies building the transport and storage infrastructure, which is also essential in the value-chain to scale up and bridge the supply gap for CCUS deployment by industries.

Investment-linked vs output-linked incentives

Countries considering subsidy types should weigh both output- and investment-linked credit designs and decide which is more feasible and appropriate for their needs. This should be based on the unique capex and opex costs in their countries, the dominant sectors requiring the low-carbon technology and the existing subsidies that could influence costs. Targeted, technology-specific subsidies could fail if the technology lacks scalability or becomes obsolete.

Case study: Colorado's demand-side hydrogen credit

Table 13: Demand-side hydrogen credit snapshot

Supply	Demand
	✓
Neutral	**Targeted**
	✓

Source: BloombergNEF. Note: Demand refers to demand for hydrogen from industrial sectors. Hydrogen credits are considered targeted because it only applies to hydrogen.

Overview: The US state of Colorado passed a pioneering tax credit for the use of clean hydrogen on May 9, 2023. The $1-per-kilogram subsidy targets hydrogen consumption at the state level, complementing the IRA tax credits for hydrogen production at the federal level. This type of mechanism targets a specific technology, like the two examples above, but instead of incentivizing production, it spurs demand for hydrogen from industrial-end users (Table 13).

How it works: Colorado's tax credit rewards low-carbon hydrogen consumed in industry, heavy-duty trucking and aviation. The subsidy is linked to the emissions intensity of the hydrogen used. A kilogram of hydrogen produced with a lifecycle emissions intensity below 0.45 kilograms of CO_2 equivalent can receive a $1 hydrogen tax credit, while a kilogram of hydrogen with emissions of 0.45–1.5 kilograms of CO_2 qualifies for a $0.33 subsidy until 2032.

BNEF take: Colorado's credit is a rare example of a demand-side consumption incentive (Figure 13), which will help activate a domestic marketplace for hydrogen. In tandem with the IRA's 45V credits for producers, the credit rewards hydrogen consumers in the state that procure lower-carbon fuels. Subsidies and tax credits are most effective at spurring the development and use of an emerging technology when targeted from both the demand and the supply side.

Contracts for difference

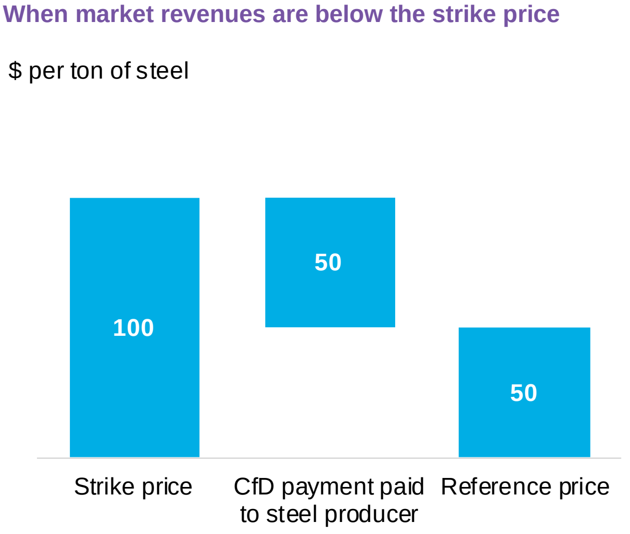
Contracts for difference (CfDs) – whether based on production or based on carbon emissions avoided – are being explored and deployed in several countries, mostly in Europe. CfDs are technology-neutral subsidy instruments, usually awarded via competitive auction, to support the adoption of low-carbon solutions. They have already had proven success in de-risking investment in clean power projects.

CfDs increase the uptake of low-carbon technologies that are not yet competitive with the status quo.

On the supply side, these mechanisms incentivize low-carbon technology/fuel producers to deploy solutions that are not yet competitive with fossil-fuel-based alternatives. When implemented on the demand side, these mechanisms can be used to incentivize emitters to decarbonize by procuring low-carbon fuels/technologies. These measures could be adapted to all industrial sectors and any low-emissions technologies that are procured.

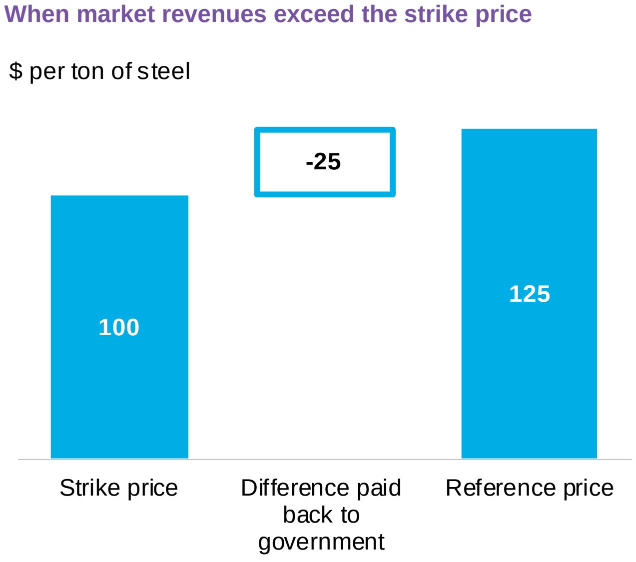
CfDs are structured using a 'strike price' (such as the cost of production to achieve a defined return) and a 'reference price' (typically based on the market price of status-quo production). When the strike price of a low-carbon fuel, such as green hydrogen, or low-emissions material, such as green steel or cement, exceeds the reference price, the government compensates the producer for the revenue difference so that they always receive the strike price. This guarantees the investment returns for the producer and reduces the risk in switching to low-emissions technologies.

Figure 15: Illustrative two-way contract for difference for green steel production



Source: BloombergNEF

Figure 16: Illustrative two-way contract for difference for green steel production



Source: BloombergNEF

This incentive can be applied on both the supply and demand side. For instance, on the demand side, the government pays the steel producer the premium required to produce green steel (Figure 15). If the clean alternative becomes cheaper than the status quo, the steel producer may need to pay back the government or they may retain the 'upside', depending on the scheme's design (Figure 16).

Carbon contracts for difference

Table 14: CCfD snapshot

Supply	Demand
✓	✓
Neutral	**Targeted**
✓	

Source: BloombergNEF. Note: Supply refers to producers of low-carbon technologies. Demand refers to demand for low-carbon materials from industrial sectors. Carbon contracts for difference (CCfDs) are technology-neutral because they do not require the use of specific decarbonization technologies in the sectors covered.

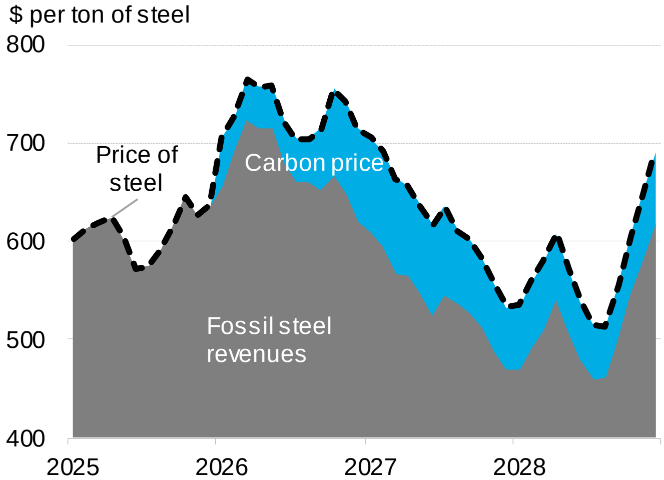
Carbon contracts for difference, or CCfDs, operate similarly to CfDs and can be implemented to incentivize either the production or use of a low-carbon product. In this case, however, the carbon price is accounted for in the top-up payment (Table 14). The strike price of a CCfD is based on the carbon price required to cover the additional costs of producing or procuring a green industrial product (Figure 17).

In a supply-side CCfD scheme, the government subsidizes the additional cost of manufacturing the low-carbon product if the carbon price is too low and, as a result, the strike price is not met by market revenues. In a demand-side CCfD scheme, the government pays out the difference when the strike price needed to procure the low-carbon product, such as green hydrogen, is not covered by market revenues.

CCfDs provide a predictable revenue stream to industrial players, de-risking long-term decarbonization investments. For example, we can compare the revenues of a hypothetical traditional fossil-fuel steel plant (Figure 17) and a hypothetical green steel plant with a two-way CCfD (Figure 18), both operating in a carbon market. While the fossil steel producer is increasingly exposed to rising carbon prices, the green steel plant receives top-up payments when the price of steel is insufficient to meet its CCfD strike price. The government can use carbon market revenues, paid by the fossil steel producer, to supplement the subsidy top-up payments to the green steel producer.

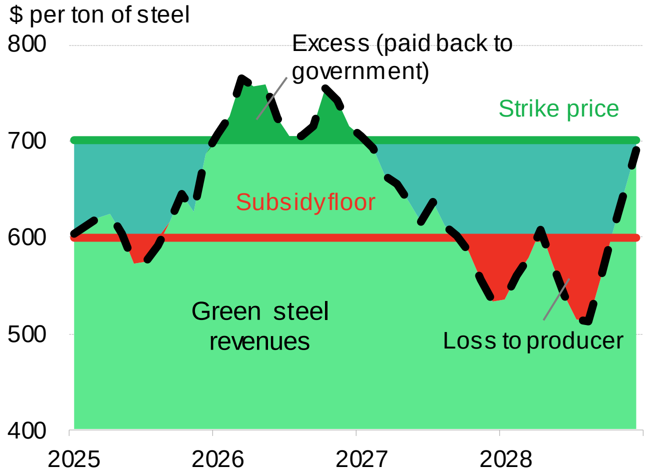
CCfDs reduce the burden on governments by only subsidizing the price difference that allows a company to turn a profit and give governments a way to efficiently use revenues from a carbon market. As with traditional CfDs, the government can set a floor to subsidy payments if the market price falls below a certain threshold and claw back excess revenues if market prices exceed the CCfD strike price.

Figure 17: Illustrative monthly revenues and carbon price payments for a fossil steel plant



Source: BloombergNEF. Note: Market prices and costs are estimated to illustrate the policy mechanism. The price of carbon is accounted for in the price of steel, passing on the cost to the consumer.

Figure 18: Illustrative monthly revenues for a green steel plant with a carbon contract for difference



Source: BloombergNEF. Note: Market prices and costs are estimated to illustrate the policy mechanism. The price of carbon is accounted for in the price of green steel and therefore the revenues.

Case study: The Netherlands' supply-side CCfD

The carbon price is incorporated into the CCfD top-up payment design.

Overview: The Sustainable Energy Transition Scheme (SDE++) in the Netherlands is an example of a supply-side CCfD scheme. The government publishes their auction calendar ahead of time (and adheres to the schedule), allowing companies to arrange the timing of their application and work the subsidy amount into their long-term planning.

The subsidy amount, known in this case as the 'correction amount' is calibrated annually to account for the producers' true subsidy entitlement if a payment below or above the strike price, known as the 'application amount', has occurred.

How it works: The SDE scheme began in 2008 and was particularly influential in incentivizing new wind and solar installations. SDE++, introduced in 2020, offers producers an operational subsidy for renewable technologies in electricity, heat, gas and low-carbon heat, and low-carbon production technologies. Beyond renewable power projects, a range of technologies are now eligible under the scheme, including carbon capture and storage projects, electrolyzers and heat pumps.

Subsidy applicants are chosen based on the emissions intensity of their technology, also referred to as their subsidy intensity (€ per ton of CO_2 reduced or captured). The subsidy amount is calculated by subtracting the base energy price (reference price) from the application amount (strike price). The maximum subsidy cannot exceed this amount multiplied by the CO_2 reduction. The subsidy duration ranges from 12 to 15 years, and subsidy recipients are required to continue tracking and reporting their emissions via industrial net metering after receiving the subsidy.

Projects totaling 686,000 metric tons of annual carbon capture capacity have been awarded since 2021.

BNEF take: The SDE scheme has contributed to renewables deployment, increasing solar's share of domestic electricity generation in 2022 to 15% and wind's share to 18% – up from 0.18% and 5% in 2012 respectively.[13] Additionally, the Netherlands has phased out oil almost entirely from its power sector and decreased reliance on gas from 58% of grid capacity in 2005 to 39% in 2021.

Since the expansion of the policy to SDE++, the government has awarded CCfDs to CCUS projects with an annual capacity of 686,000 metric tons of annual CO_2 abatement potential and hydrogen projects with 76.6 gigawatt-hours (GWh) of annual production capacity.[14]

The Netherlands Enterprise Agency (RVO) explicitly states that technologies with a subsidy intensity higher than €300 ($319) per ton of CO_2 are incompatible with a cost-effective energy transition, thereby capping SDE++ auctions at this level to ensure a more cost-effective path for decarbonization. This illustrates a policy mechanism that is technology-neutral and avoids 'picking winners'.

Case study: Germany's two-way demand-side CCfD

Overview: Germany's CCfD program is a two-way demand-side scheme that aims to support the procurement of hydrogen for steel, cement and other industrial materials. The first auction is planned for the last quarter of 2023.

How it works: Industrial producers assess the subsidy amount they require, by comparing their status quo operations to their potential zero-carbon operations. Industrial producers then submit a bid to the government for their required subsidy payment. Like the Netherlands' SDE++, projects

[13] BloombergNEF *Climatescope 2022* (web **|** terminal)

[14] Netherlands Enterprise Agency (RVO)

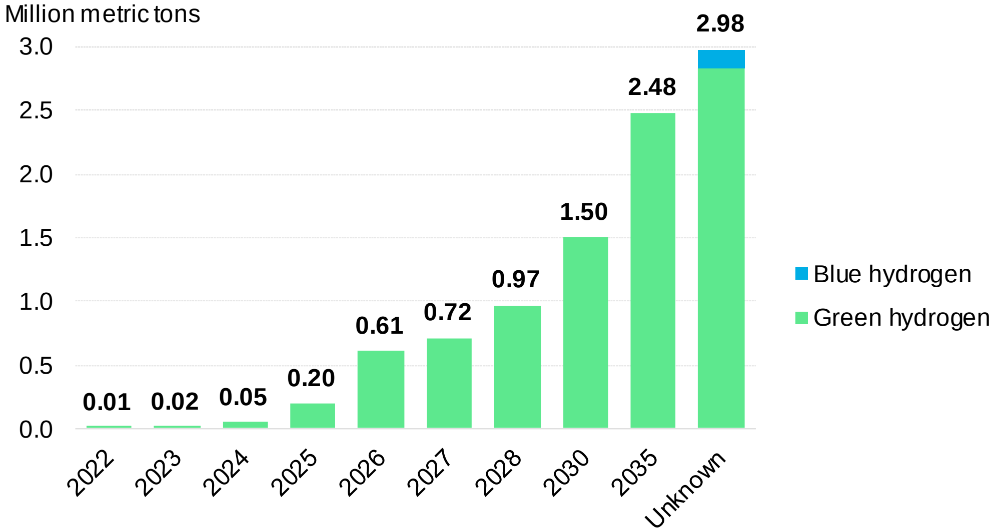
CCfDs complement the EU ETS, reducing the risk of clean technology offtake agreements for producers and buyers.

with the lowest costs per avoided ton of carbon take priority. Subsidy payments are expected to run for up to 15 years. In years where the carbon price is higher than the CCfD strike price, the payment difference is owed back to the government.

BNEF take: Following the example of the Netherlands' program, Germany is implementing CCfDs at a much larger scale. This is especially important since the carbon price under the EU ETS is still not high enough to drive investment in clean industrial products. The volatility and uncertainty of the EU carbon price has made it difficult for market players to hedge their risk and invest in greening their operations. CCfDs can complement carbon pricing by adding a direct incentive for industry to invest in clean production or offtake.

Germany's planned CCfD program, alongside other measures like its proposed auctions for hydrogen-ready power plants, has led to a surge in hydrogen project announcements. BNEF has tracked 1.5 million metric tons of announcements from hydrogen projects planned by 2030, up from just 0.02 million tons in 2023 (Figure 19).

Figure 19: Announced cumulative annual hydrogen production volume in Germany by production type and expected commissioning year



Source: BloombergNEF. Note: Green hydrogen is produced using electrolyzers powered by renewable electricity. Blue hydrogen is produced thermochemically from fossil fuels paired with CCUS. The final year shown in this chart includes projects with an unknown commissioning year. Data are cumulative.

Related BNEF insights

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NetZero Pathfinders Policy Monthly: Materials and Industry (web | terminal)

Smart Policy to Drive Clean Hydrogen Uptake (web | terminal)

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US Hydrogen Demand Boosted by Landmark Colorado Tax Credit (web | terminal)

Germany's New Hydrogen Demand Ambitions are Overstretched (web | terminal)

3.3. Regulations (sticks)

Regulatory measures can be used to impose a legal obligation for organizations to adhere to certain standards or behaviors, which can complement incentives. 'Sticks' include regulations that require compliance with certain rules, such as bans, mandates and taxes. For instance, mandates could require industrial end-users to satisfy certain emissions performance standards or packaging producers to incorporate recycled content into their products.

Mandates are less common than targeted subsidies for new technologies, as it is easier for governments to create regulations for mature sectors/technologies. One reason is that demand-side consumption mandates work better for more mature – and more cost-effective – technologies, such as biofuels, which are already at the commercial stage. However, that does not mean that mandates or taxes in industrial sectors cannot indirectly incentivize emerging technologies. In fact, regulatory measures can create demand for new technologies and unlock business models by placing the onus of compliance on all market participants. Regulatory measures for industrial decarbonization are already being applied for steel and cement, but lack uptake for plastics and fertilizers (Table 15).

This section highlights examples of potentially effective industrial sector mandates, including California's Buy Clean Initiative and France's RE2020, both of which demonstrate potential to reduce emissions. The former sets emissions standards for public procurement, and the latter establishes embodied emissions standards for all construction materials used in new buildings. Other examples in this section include the EU's hydrogen consumption mandate and China's steel production cap.

Production and consumption mandates can be challenging to implement and scale due to potential backlash from industrial players. Possible supply shortages on the capped material and green premiums on the mandated low-carbon technologies are two of the risks connected to this kind of policy mechanism. Expedited permitting for green projects, on the other hand, is highly feasible – but not as effective for reducing emissions or scaling technologies (Table 16).

Table 15: Analysis of regulations available for industrial decarbonization

Policy intervention	Steel	Cement	Plastics	Fertilizers
Regulations Agreements, standards and mandates for green procurement	● (Varying application)	● (Varying application)	● (Varying application)	● (Lacks uptake in this sector)
Intervention status	● Applied in this sector	● Varying application	● Lacks uptake in this sector	

Source: BloombergNEF

Table 16: Select regulations available for industrial decarbonization

Mechanism	Effectiveness	Scalability	Feasibility	Example
Green public procurement mandate	4	4	3	Buy Clean California

Life-cycle emissions mandate	5	3	3	France's RE 2020
Expedited permitting	2	3	5	Seattle's Priority Green Expedited
Consumption mandate	5	3	1	EU's hydrogen consumption mandate
Production capacity and swap mandates	5	2	1	China's steel production cap strategy

Source: BloombergNEF. See Appendix B for our rating methodology.

Green procurement agreements and consumption mandates

Low-carbon procurement targets, agreements and mandates can help to scale demand for green products while remaining technology-neutral (Table 17). By legally requiring industrial end users – whether public or private – to comply with certain emissions standards, such measures can level the playing field for higher-priced net-zero materials.

Public procurement accounts for 25% of global steel demand.

Governments are often sizable purchasers of materials such as cement and steel. In fact, public procurement accounts for 25% of global steel demand. Some governments, notably the US, have recently initiated green public procurement programs for their own purchases. Others are imposing green product purchasing mandates on the private sector, particularly real estate. Some policies set a specific carbon footprint threshold per ton of procured material, while others set overall emissions limits, for example on new buildings. The former is a more direct route to driving investment in green steel or cement. The latter leaves open an array of decarbonization pathways – including material substitution and material use reduction – some of which may not directly help green cement or steel growth.

To set an effective procurement mandate, clear standards defining what qualifies as 'green' are needed. If these procurement programs are implemented without a guaranteed price premium for green materials, they will work as a stick that puts the additional cost on the shoulders of the offtakers. Alternatively, governments can offer incentives other than cash premiums for compliance, such as fast-tracked planning permission for greener buildings.

The Industrial Deep Decarbonization Initiative (IDDI)[15], announced at the COP26 summit in 2021, is the most detailed policy framework for successful green procurement policies. It is a coalition of public and private organizations, led by the UK and India, with the shared goal of increasing demand for low-carbon materials. The IDDI is working to determine consistent minimum emissions standards for steel and cement. Additional commitments include defining a standard reporting framework and evaluation process, deploying a certification process for producers to communicate their low-carbon commitment to material buyers, and creating a global 2050 outlook for decarbonizing the steel and cement industries. IDDI participating countries account for 9% of global demand for finished steel products. Within the IDDI, the governments of the UK, India, Germany and Canada have agreed to purchase low-carbon industrial materials where they are available.

Green standards are the critical backbone for regulating and incentivizing low-carbon materials.

The need for green standards

Regulations and subsidies for green hydrogen mean very little unless there are robust rules defining what is 'green'. The EU has, for example, released a rulebook on what is and is not

[15] Industrial Deep Decarbonization Initiative

green hydrogen. Its criteria include emission thresholds, an additionality of renewables rule to avoid diverting current capacity, hourly matching of demand and supply and geographic constraints on renewables procurement.

Similar efforts are much needed on the demand side, particularly for steel and cement, to define what can be sold and marketed as 'green'. Ill-defined standards could mean that companies that are no more sustainable than the status quo reap the benefits of subsidies. It could also mean decreased investor interest in prioritizing green products.

Case study: Buy Clean California

Table 17: Public green procurement mandate snapshot

Supply	Demand
	✓
Neutral	**Targeted**
✓	

Source: BloombergNEF. Note: Demand refers to demand for the materials from the government. While it targets specific material, green procurement mandates are considered technology-neutral because they do not require particular decarbonization technologies in the sectors covered.

Overview: At the state level in the US, California implemented the Buy Clean California Act (BCCA) in 2017. This is a green procurement mandate that limits the maximum life-cycle emissions for steel, glass, concrete and insulation, based on the global warming potential (GWP) of each material.[16]

Figure 20: Buy Clean California Act global warming potential limit and average emissions intensity per metric ton of steel in the United States

Source: Steel Manufacturers Association 2022, California government. Note: Global warming potential (GWP) refers to the warming potential over 100 years, expressed in kilograms CO_2 per ton of steel. The GWP threshold in this chart applies to fabricated hot-rolled structural steel sections. BF-BOF refers to blast furnace-basic oxygen furnace. EAF refers to electric arc furnace. Average emissions intensity is calculated from both scope 1 and 2 emissions.

How it works: The BCCA requires any bids for publicly funded infrastructure project to include data on environmental metrics and comply with the GWP limits. The standards are updated regularly to consider improvements in industrial processes. For steel, the BCCA limits the warming impact from the purchase of one ton of steel to less than what is caused by the equivalent of 1,080 kilograms of CO_2 over 100 years (Figure 20), with plans to tighten these limits over time.

[16] GWP refers to the total greenhouse gas warming impact, in terms of CO_2 equivalence, over a certain time period

California plans make GWP limits for 'green' steel production more stringent over time.

BNEF take: California's GWP limits are currently set below the US emissions intensity average for traditionally produced hot-rolled structural steel (BF-BOF), but well above the average for steel produced in an electric arc furnace (EAF). Some 70% of steel in the US is already produced via EAF, meaning it falls below the threshold. As a result, the policy supports domestically produced EAF steel and decreases demand for BF-BOF or imported steel that does not comply with the threshold.

The GWP limit is not yet low enough to require investment in new net-zero carbon steel capacity, as there is sufficient EAF-produced steel to meet the demand covered by the Buy Clean Act. However, the California government plans to tighten the GWP limits over time, which could in turn increase investment in primary green steel production, as the regulation becomes harder to achieve with simpler recycling or efficiency measures.

Another option for policymakers is to combine the regulation with an incentive. For example governments could institute a two-tiered system, with the first threshold being a mandatory emissions standard, and the second, more ambitious threshold being an optional target with an extra bonus for companies that reach it.

Table 18: Embodied emissions standards snapshot

Supply	Demand
	✓
Neutral	**Targeted**
✓	

Source: BloombergNEF. Note: Demand refers to demand for construction materials from building developers. Emissions standards are typically technology-neutral because they apply to all materials, and do not require particular technologies.

Case study: France's RE2020

Overview: France is seeking to tackle emissions from buildings with its new RE2020 regulation, which came into effect in January 2022. The regulation aims to reduce carbon emissions from operational energy and construction materials used in new public and private buildings by at least 30% by 2031, compared to 2013 levels.[17] This mechanism targets the demand side, but does not specify which low-carbon technologies can be adopted to meet the thresholds (Table 18).

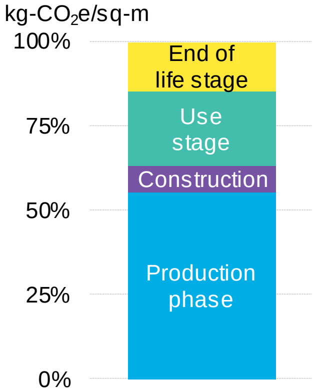
How it works: RE2020 introduces improved mandatory caps for energy demand and consumption, setting a threshold for the total embodied emissions of the construction materials used in new buildings with the limits tightening every three years until 2031.

For single-family homes, the material production and construction-related emissions threshold starts at 640 kilograms of CO_2 per square meter (kg-CO_2/sq-m) in 2022 and drops to 415kg-CO_2/sq-m by 2031. For new apartment buildings, the cap drops gradually from 740kg-CO_2/sq-m in 2022 to 490kg-CO_2/sq-m by 2031 (Figure 22).[18] The policy will first affect new residential buildings and will later apply to offices, schools, hotels and gyms.

[17] Reducing Embodied Carbon In New Buildings: RE2020 In France

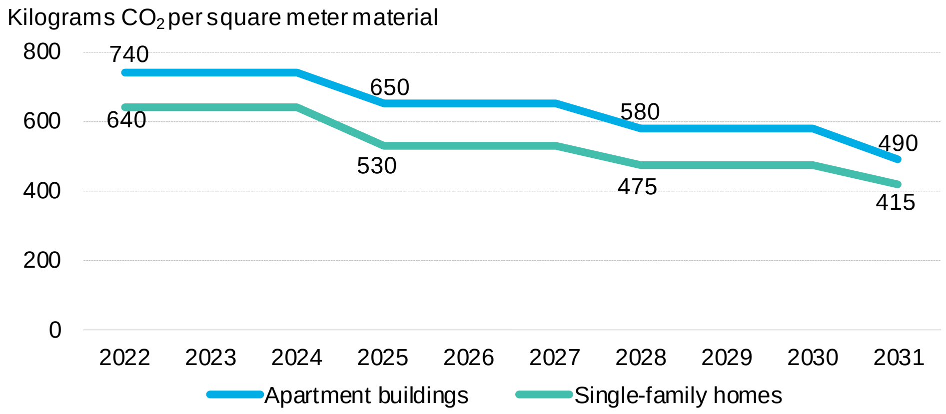
[18] These numbers are calculated using a building lifetime estimate of 50 years

Figure 21: The average embodied emissions of 769 EU buildings in 2022



Source: Ramboll 2022, BloombergNEF. Note: This study is expressed in kilograms of CO_2e per square meter (kg-CO_2/sq-m) over a 50-year building lifetime. This breakdown includes residential and non-residential.

Figure 22: France's RE2020 residential building embodied emissions thresholds for the production and construction-related emissions



Source: BloombergNEF, Ramboll 2022 report, Agora Energy Transition, French government documents. Note: The regulation sets maximum emission thresholds, reduced over time and expressed in kilograms of CO_2 (kg-CO_2) per square meter, over a 50-year building lifetime.

BNEF take: France is one of the few markets to implement a regulation to reduce the embodied emissions of new buildings, inclusive of all building materials. Other governments to date have focused building regulations on operational energy efficiency measures. RE2020 aims to guarantee market demand for green material producers, making the real estate sector carry the burden of the cost premium. This should encourage producers of construction materials to enter the market, which could help increase competition and reduce the green premium for materials buyers. However, this regulation could also qualify as demand reduction (see next section), since it does not specifically mandate the procurement of green materials. To reach the carbon thresholds set, the real estate developer could instead use less of certain carbon-intensive materials.

Furthermore, the average lifecycle embodied emissions of buildings in EU is around 500-600 kg-CO_2e/sq-m, according to a 2022 study, with more than half the emissions in a building's lifecycle coming from the materials-production and construction phases (Figure 21). While the average embodied emissions of buildings in France sit at 634 kg-CO_2e/sq-m for the whole lifecycle of a residential building, the RE2020 thresholds only apply to the production and construction phases. Applying the lifecycle phase breakdowns from Figure 21 to France, the production and construction emissions of the average French residential building are estimated at 399 kg-CO_2e/sq-m, suggesting that the regulation is not yet sufficiently stringent to stimulate the uptake of new low-carbon materials such as steel and cement. However, now that the policy is in place, the government can more easily lower the thresholds, allowing time for companies to invest in low-carbon materials.

Setting carbon thresholds correctly is important. If they are too weak, they will limited material substitution actions rather than incentivizing deep decarbonization; too strong, and the demand for large volumes of net-zero steel and cement could outstrip supply in the short-term, making the targets impossible to meet and causing private sector pushback.

Case study: Seattle's Priority Green Expedited

Table 19: Green expedited permitting snapshot

Supply	Demand
	✓
Neutral	**Targeted**
✓	

Source: BloombergNEF. Note: Demand refers to construction materials from building developers. Green permitting regulations are technology-neutral because they apply to all materials, and do not require particular decarbonization technologies.

Overview: This policy is a voluntary program, not a mandate or regulation. However, it is used here as an additional example of how to incentivize green materials uptake in the real estate sector. In Seattle, building developers experience average approval times of 6.5 months for residential construction permits. Seattle's Priority Green Expedited program offers expedited permits for buildings that aim to meet certain environmental criteria, including energy efficiency, embodied carbon, indoor air quality and resource conservation. This mechanism targets the demand side (buyers of low-carbon material) but is technology-neutral (Table 19).

How it works: Projects must be approved by Seattle's Department of Construction and Inspection Green Team. Applicants are to show proof that they have submitted their project plans for a Green Building Certificate, in addition to fulfilling the city's environmental criteria in the building's plans. If applicants meet all the requirements, then the building plans will be reviewed and approved about 50% faster than status-quo building plans, according to the agency's website. The agency estimates that qualified applicants save three months on average through the life cycle of the permitting approval process.

BNEF take: Rather than offering a green premium or subsidy, Seattle is providing a valuable 'in kind' benefit, that could help project developers save significant amounts of money. Permitting delays can lengthen timelines, increase risk, make it harder for projects to secure financing and potentially lower the return on projects for developers. In most cases, there is little developers can do to affect or expedite the process. Giving developers this option, tied to sustainability criteria, can increase the uptake of low-carbon solutions in new projects, provided the additional cost of meeting the green criteria does not outweigh the cost of the potential permitting project delays.

Policymakers should also ensure that the bodies responsible for permitting approvals are sufficiently staffed. This has been a challenge in some renewable power markets. As with RE2020, the embodied emissions targets must be sufficiently stringent to actually ensure that low-carbon cement and steel must be procured to meet the target. Otherwise, this policy will encourage some low-cost material substitution but no significant industrial decarbonization investments.

Case study: The European Union's hydrogen consumption mandate

Table 20: Demand-side hydrogen consumption mandate snapshot

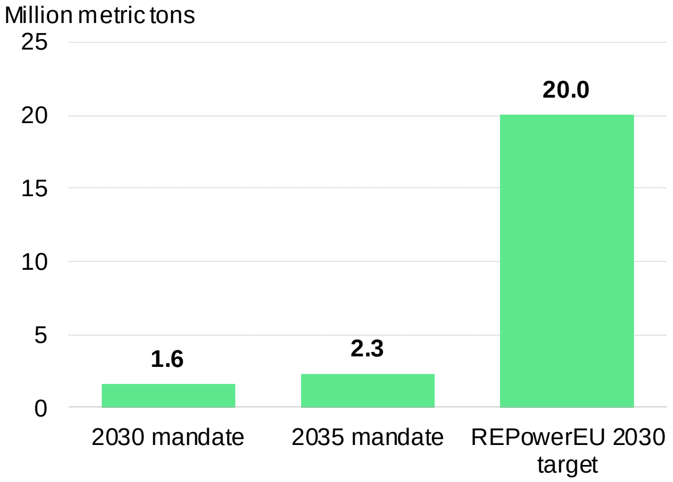
Supply	Demand
	✓
Neutral	**Targeted**
	✓

Source: BloombergNEF. Note: Demand refers to demand for hydrogen from industrial sectors. Hydrogen consumption mandates are considered targeted because they only apply to hydrogen.

Overview: As part of the EU's Renewable Energy Directive, the bloc is introducing a hydrogen consumption mandate for industrial players – 42% of hydrogen procured must be green by 2030, and 60% by 2035. The mandate is considered demand-side since it applies to industrial end-users, and technology-targeted since it specifies green hydrogen (Table 20). EU quotas could create 1.6 million metric tons of hydrogen demand in industry by 2030 and 2.3 million tons by 2035; yet this is only 10% of the EU's 2030 target (Figure 23).

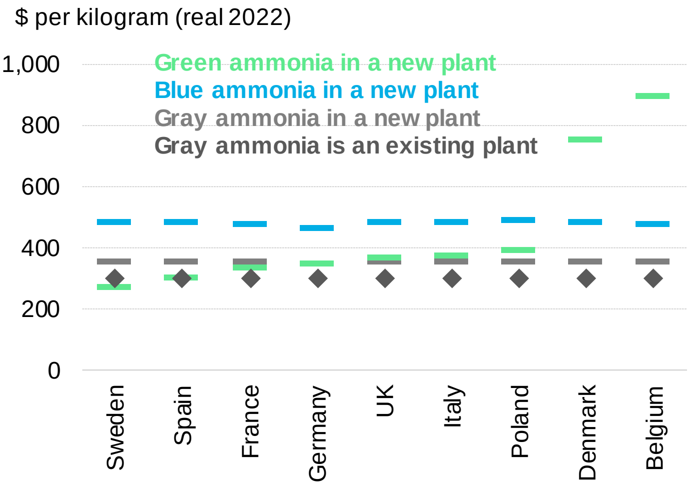
How it works: This mandate targets the traditional consumers of gray hydrogen in industry – ammonia and fertilizer companies, oil refineries and methanol producers. It does not require green hydrogen consumption in sectors that do not already use hydrogen as a feedstock or fuel in their processes.

Figure 23: EU renewable hydrogen quotas for industry in the Renewable Energy Directive versus 2030 EU target for all hydrogen uses



Source: BloombergNEF, European Commission, Fuel Cells and Hydrogen Observatory, Eurostat. Note: Based on 3.9 million metric tons of industrial hydrogen demand (excluding refinery demand) in the EU in 2020.

Figure 24: Marginal cost of green, blue and gray ammonia in select European countries in 2030



Source: BloombergNEF, National Energy Technology Laboratory. Note: Green ammonia refers to ammonia made from hydrogen produced via electrolysis. Blue ammonia refers to ammonia made from hydrogen produced via natural gas paired with CCUS. Gray ammonia is traditional ammonia made from hydrogen produced via natural gas.

BNEF take: The EU's hydrogen consumption mandate could be tangentially useful in improving the economics of demand for hydrogen in new applications – such as shipping, aviation and steel – if the demand from oil refining and chemicals is significant enough to drive down commercial costs of green hydrogen for all. The marginal cost of green hydrogen by 2030 is expected to be lower than gray ammonia in an existing plant or a new plant in Sweden and Spain, and at parity with gray ammonia in a new plant in France and Germany (Figure 24). However, it is unclear if the 1.6-2.3 million tons of demand this policy might stimulate is large enough to bring the whole green hydrogen sector's costs down for all European countries.

Consumption mandates for a new technology can be politically challenging to implement when the technology requires new capital investment for the sector to use it, as is the case with hydrogen and steelmaking. Policy that focuses on existing hydrogen consumers is a good early step to build hydrogen demand.

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EU Hydrogen Quotas Raise Global Demand For Green Molecules (web | terminal)

2H 2023 Hydrogen Market Outlook: The Demand Question (web | terminal)

Table 21: Production cap and capacity swap mandates

Supply	Demand
✓	
Neutral	**Targeted**
✓	

Source: BloombergNEF. Note: Supply refers to material producers such as steel. Production cap and capacity swap mandates are technology-neutral because they do not typically require certain decarbonization technologies for the sectors covered.

Production mandates

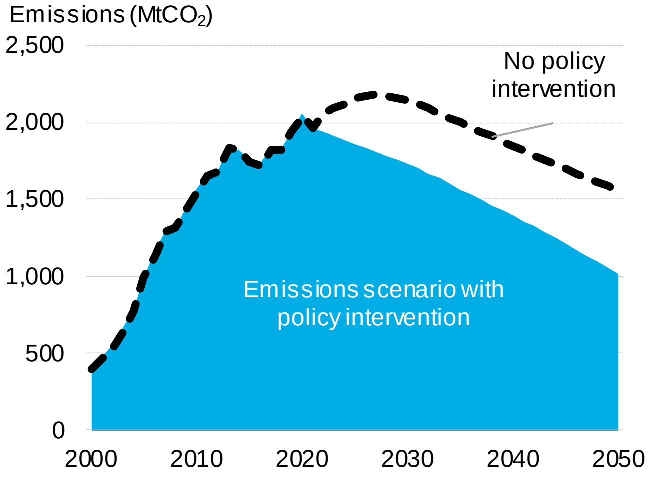
The previous case studies reflected a variety of ways governments can increase the *consumption* of green materials in the public and private sectors through embodied emissions thresholds and consumption mandates. Some governments are also – or instead – looking to mandate that the *producers* of materials reduce their emissions. In this section, we highlight policies in China that cap production output or allow capacity swaps from inefficient production processes to more efficient ones in the steel sector. Production caps and capacity swap mandates apply to the supply side and are technology-neutral (Table 21).

Case study: China's steel production cap and capacity swap mandate

Overview: The steel sector is the second-largest emitter in China. It accounted for 18% of the country's carbon emissions in 2021, or roughly two billion tons of CO_2 equivalent. Globally, China represents 53% of steel production and 65% of steel emissions.

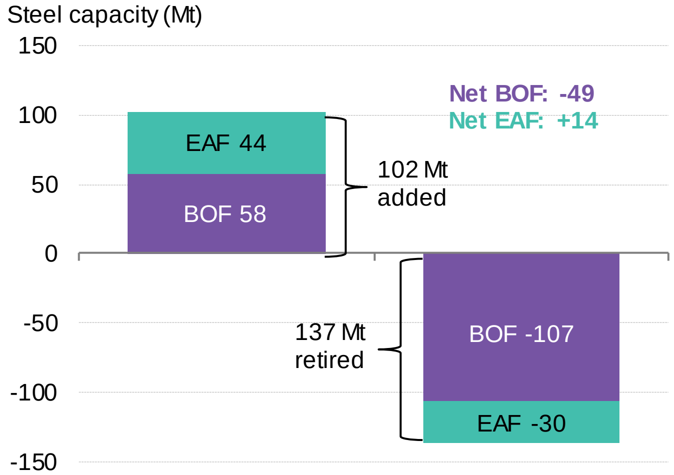
China initiated a campaign of supply-side reforms in its steel sector in 2016, including production cap and capacity swap mandates, to curb the expansion of steel production capacity and output. This policy was initiated to reduce the overcapacity in China's steel sector but has evolved to become a crucial policy for reducing the sector's emissions. China has implemented similar capacity swapping and output curb measures for cement and aluminum, as well.

Figure 25: BNEF estimate of China's steel sector emissions, historical and projected



Source: BloombergNEF; Chinese government; World Steel Association; Shangguan, et al., Climate Change and decarbonization development of Steel Industry, 2021. Note: The emissions scenario with policy intervention couples the effect of the electric arc furnace (EAF) target and mandate, in addition to the output curb. MtCO2 is million metric tons of carbon dioxide.

Figure 26: Steel capacity swaps to be commissioned by 2025



Source: Capacity swapping announcements from provincial government websites, company announcements, BloombergNEF. Note: BOF is basic oxygen furnace or converter. EAF is electric arc furnace. Data include only announcements made from June 2021 until August 22, 2022. The total amount excludes plans without completion dates. Mt is million metric tons.

How it works: In its Action Plan for Carbon Emissions Peaking Before 2030, China strictly prohibits any production capacity increase in the steel sector, and it started enforcing production limits in 2021 to cap crude steel output below the peak levels of 2020. The output limits were initially imposed only in the winter, to reduce air pollution, but are now imposed year-round and could help reduce steel capacity and emissions through 2030.

China is capping crude steel production below the 2020 peak.

However, companies are allowed to build new steel production units if they retire old, inefficient plants. Under this scheme, companies must ensure they are retiring at least 25% more capacity than the new capacity they aim to build. In regions with stricter pollution controls, companies would have to retire 50% more capacity than they are adding. If companies replace old plants with EAF or DRI-EAF plants, then they would only need to retire the same capacity that they plan to add, which will incentive companies to invest in more efficient plants.

China has phased out 150 million tons of steel production capacity over five years.

BNEF take: These measures mandate that companies transition away from their older, less efficient plants when investing in new, more efficient, production capacity. Combined, the supply-side reforms resulted in 150 million tons of net steel production capacity retiring over 2015-2020. BNEF estimates that the steel output likely peaked in 2020, and consequently, emissions from the sector are also likely to have peaked in 2020 (Figure 25). The capacity swapping measure, which only officially entered effect in May 2021, is estimated to lead to a net increase of 14 million tons of EAF production capacity coming online, and 49 million tons of BOF production capacity retiring, based on capacity swapping announcements from companies (Figure 26).

However, the measure could unexpectedly discourage the rollout of decarbonization technologies. Companies that recently built new capacity are finding it challenging to secure additional capacity quota for piloting low-emissions projects, such as hydrogen-based direct reduction plants. Under the current swapping mandate, building a hydrogen project would still require the retirement of an old plant – and companies have little incentive to knock down newly invested blast furnaces simply to test out a still costly new production route. This conundrum requires policymakers to rethink how to reconcile curbing overcapacity and accelerating decarbonization.

Related BNEF insights

What China's Emissions Peaking Plan Means for Steel (web | terminal)

China's Steel Reforms to Enter New, Greener Era in 2022 (web | terminal)

3.4. Demand-reduction solutions

Demand-reduction policies are measures that reduce primary demand for virgin materials. They can come in the form of incentives or regulations. France's RE2020 and Seattle's Priority Green Expedited policies are both examples of measures that can help reduce demand and affect changes in consumption patterns.

Rather than influencing the uptake of a specific green material, demand-reduction policies cut emissions by reducing material consumption, or by improving the efficiency of manufacturing. This policy intervention is generally applied at a sector- or product-level, rather than for a specific technology, and there are examples of applications in the steel and fertilizer sectors, but these measures lack uptake for cement and plastics (Table 22).

In this section, we analyze a farm-level tax on fertilizers and payments for ecosystem services. Both of these mechanisms could be effective for reducing emissions, but they are neither highly scalable nor feasible. The farm levy from New Zealand, for example, seeks to reduce fertilizer demand by taxing farmers on their fertilizer use, a challenging ask in markets where fertilizer-use subsidies have been commonplace. Payments for ecosystem services, or direct payments for incorporating certain regenerative practices, could be more effective, but they are challenging to scale and enforce, leading to limited impact (Table 23)

Table 22: Analysis of demand-reduction solutions available for industrial decarbonization

Policy intervention	Steel	Cement	Plastics	Fertilizers
Demand-reduction solutions Taxes, fees and incentives that reduce material demand	Applied in this sector (green)	Lacks uptake in this sector (yellow)	Lacks uptake in this sector (yellow)	Applied in this sector (green)
Intervention status	Applied in this sector (green) / Varying application (teal) / Lacks uptake in this sector (yellow)			

Source: BloombergNEF

Table 23: Select demand-reduction solutions available for industrial decarbonization

Mechanism	Effectiveness	Scalability	Feasibility	Example
Farm levy	3	2	2	New Zealand agriculture carbon tax
Payments for ecosystem services	3	2	2	Japan's direct payments

Source: BloombergNEF. See Appendix B for our rating methodology.

Table 24: Farm levy snapshot

Supply	Demand
	✓
Neutral	**Targeted**
✓	

Source: BloombergNEF. Note: Demand refers to farmer demand for fertilizers. It's technology-neutral because it doesn't apply to a certain decarbonization method for fertilizers.

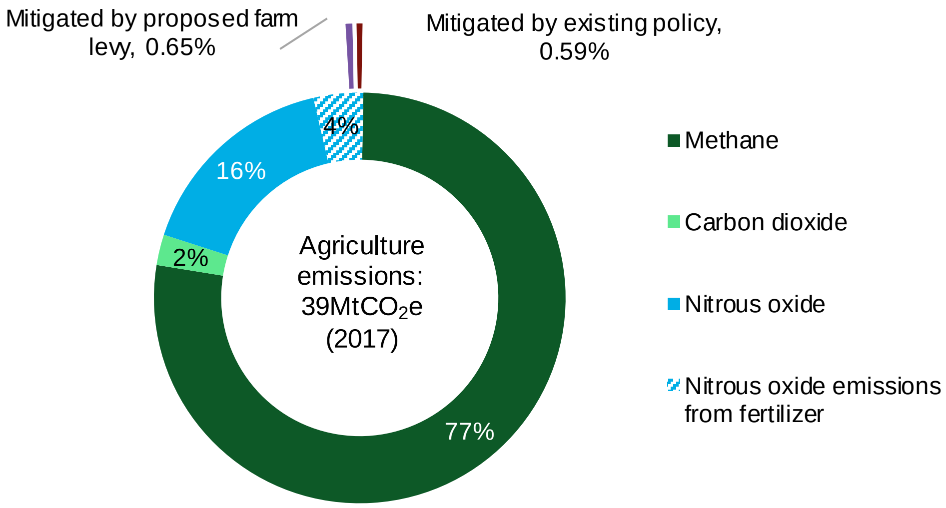
Case study: New Zealand's proposed carbon tax

Overview: The agriculture sector accounts for nearly half of New Zealand's greenhouse gas emissions, and post-application emissions from synthetic nitrogen fertilizers account for 4% of New Zealand's agricultural emissions. National policymakers are considering introducing an agricultural emissions pricing system to reduce demand for synthetic fertilizers, with options including adding the sector to the nation's existing carbon market or creating a new national farm emissions levy. The farm levy targets the demand side of reducing fertilizer use, which in this case is usually farmers, but does not incentivize particular technologies for replacing fertilizers, making it technology-neutral (Table 24).

How it works: New Zealand's proposed farm emissions levy aims to reduce fertilizer use through a charge of NZ$13.80 ($8.07) per kilogram of CO_2 equivalent (CO_2e) for farmers using over 40 metric tons of synthetic nitrogen per year, or those with over 50 dairy cattle. It seeks to cover all farms that emit over 200 tons of CO_2e annually, which would capture 96% of domestic agricultural greenhouse gas emissions, excluding upstream emissions.

Farmers can reduce their tax liability by reducing their fertilizer use, leading to reduced emissions at the farm level. The government also identifies measures, such as increasing the use of controlled-release fertilizers and using urease and nitrification inhibitors, to reduce post-application emissions.

Figure 27: New Zealand's annual agriculture emissions breakdown and nitrous oxide mitigation potential from policy intervention



Source: BloombergNEF, New Zealand Government, He Waka Eke Noa. Note: Emissions breakdown does not include fertilizer production. 'Existing policy' refers to expected agriculture emissions reductions under New Zealand's Emissions Trading Scheme and freshwater regulation. MtCO2e is million metric tons of carbon dioxide equivalent.

Farmers reduce their tax liability by decreasing fertilizers use, thereby cutting emissions.

BNEF take: The proposed levy will have only a small impact on post-application emissions. It could reduce the nation's agricultural emissions by about 0.65% between 2017 and 2030, while other existing policies should enable an additional 0.6% reduction (Figure 27), according to He Waka Eke Noa.[19]

Demand-reduction policies should be paired with upstream interventions

Carbon taxes on farms can help to reduce agricultural emissions by lowering demand for synthetic fertilizers and improving the efficiency of fertilizer use. Additionally, revenues from demand-reduction policies can be re-invested into efficiency and decarbonization measures on farms. Without such measures, even the full decarbonization of global fertilizer supply would not address post-application emissions from the fertilizer industry.

Carbon taxes on farms could also encourage the use of green ammonia in fertilizer production with appropriate accompanying measures. Many countries are net importers of fertilizer, and could consider both encouraging fertilizer demand reductions alongside supporting the offtake of green fertilizers.

[19] He Waka Eke Noa Recommendations for pricing agricultural emissions

Case study: Japan's direct payments for environmentally friendly agriculture

Table 25: Direct payments snapshot

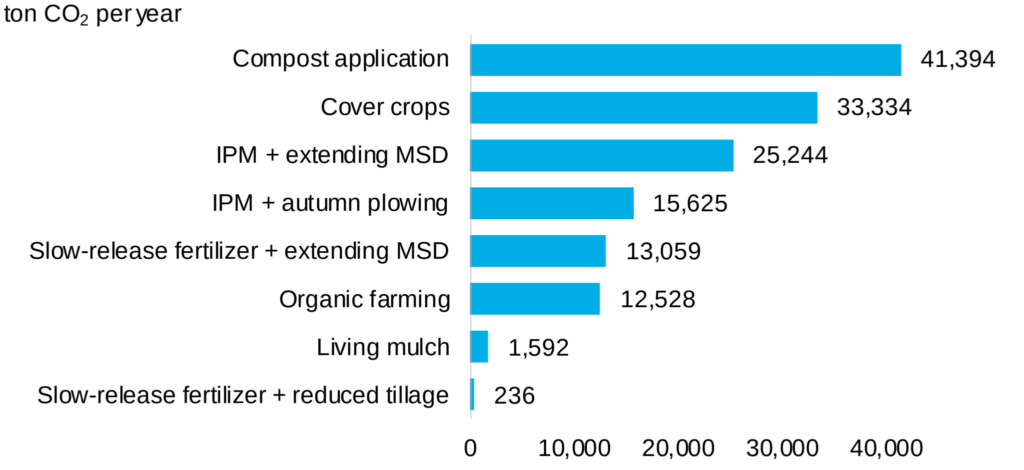
Supply	Demand
	✓
Neutral	**Targeted**
✓	

Source: BloombergNEF. Note: Demand refers to farmer demand for fertilizers. It's technology-neutral because it doesn't apply to a certain decarbonization method for fertilizers.

Overview: Since 2015, Japan has experimented with direct payments to farmers for implementing regenerative agriculture practices. Regenerative agriculture is a non-traditional approach to farming with an emphasis on conservation. Direct payments apply to the demand side of fertilizers (farmers) and do not specify a certain decarbonization for fertilizers (Table 25).

How it works: Farmers in Japan can receive direct payments if they halve the use of chemical fertilizers and pesticides and reduce greenhouse gas emissions or mitigate biodiversity loss. Producers receive 120,000 yen ($859) per hectare for implementing organic farming and 60,000 yen for planting cover crops.

Figure 28: Greenhouse gas emissions reduction via Japan's direct payments for environmentally-friendly agriculture



Source: Japan Ministry of Agriculture, Forestry and Fisheries (MAFF), BloombergNEF. Note: MAFF surveyed effects of activities eligible for direct payments for environmentally friendly agriculture for the prevention of global warming and preservation of biodiversity. In August 2019, MAFF published the final evaluation of the direct payments system that was implemented from 2015 to 2019. IPM refers to integrated pest management. MSD refers to midseason drainage. Autumn plowing in paddy fields has been shown to promote rice straw decomposition and reduce methane emissions.

Japan's direct payments have reduced CO_2 emissions by 143,000 tons per year.

BNEF take: Japan's direct payments for environmentally friendly practices – particularly applying compost and cover crops – have been effective at reducing emissions. The program led to the avoidance of 143,000 metric tons of greenhouse gas emissions per year (Figure 28).

Direct payments to farmers, often to subsidize the cost of procuring fertilizer, are common in some countries as a way to support the production of food. However, this leads to monocultures and the overuse of agrochemicals and natural resources, leading to environmental harm. Japan's program uses the same mechanism in a way to encourage farmers to reduce the use of chemical fertilizers and incorporate other beneficial practices.

Direct payments for demand reduction could be applied in other sectors that buy carbon-intense products, however, it could be less politically palatable, while in agriculture, direct payments as part of food security measures are commonplace.

Direct subsidies in agriculture top $635 billion annually, driving the over-use of fertilizer, excess emissions and biodiversity loss.

Phasing out harmful subsidies

Subsidies available to emissions-intensive sectors such as oil and gas and fertilizers have helped make their products artificially cheap. The World Bank estimates that direct subsidies in agriculture top $635 billion annually, driving over-use of fertilizer, excess emissions and biodiversity loss.[20] Phasing out these subsidies could be as impactful as offering new incentives in reducing the demand for these materials. However, governments must exercise caution, as phasing out fertilizer subsidies could drive up food prices for consumers.

3.5. Circular economy solutions

Circular economy policies involve measures targeting the whole lifecycle of products, aiming to reuse and recycle products for as long as possible. Such measures, which can come in the form of incentives or regulations, are most common for packaging materials such as glass, plastics and paper, and look to increase recycling and improve end-of-life treatment of waste.

Policies geared toward developing or support a circular economy can drive the production of sustainable materials in industry. In the plastics and cement sector, tightening recycled content standards could help reduce the demand for primary materials and thereby emissions. For example, in the steel sector, producing crude steel through EAF using scrap is a low-emissions pathway compared to BF-BOF. Circular economy solutions have been applied to the steel and plastic sectors, but they lack uptake for cement and are not technically applicable for fertilizers because they cannot be recycled (Table 26).

This section profiles extended producer responsibility (EPR) in the Netherlands and recycled content mandates in the UK. EPR schemes are a policy that assign responsibility to manufacturers, importers and distributors for the life cycle of their products, shifting end-of-life costs away from municipalities and consumers. While they are highly scalable, they are difficult for governments to implement, which can limit their effectiveness. On the other hand, mandates on producers to include more recycled content in their materials are highly effective but less scalable, and considerable brand-owner opposition makes them difficult to implement.

Table 26: Analysis of circular economy solutions available for industrial decarbonization

Policy intervention	Steel	Cement	Plastics	Fertilizers
Circular economy solutions Measures to promote recycling that reduces primary materials production	Varying application (teal)	Lacks uptake in this sector (yellow)	Applied in this sector (green)	Not applicable (grey)
Intervention status	● Applied in this sector	● Varying application	● Lacks uptake in this sector	● Not applicable

Source: BloombergNEF

[20] Richard Damania, Esteban Balseca, Charlotte de Fontaubert, Charlotte, et al., 'Detox Development: Repurposing Environmentally Harmful Subsidies,' *World Bank*, 2023.

Table 27: Select circular economy solutions available for industrial decarbonization

Mechanism	Effectiveness	Scalability	Feasibility	Example
Extended producer responsibility	2	4	3	Netherlands extended producer responsibility
Recycled content mandate	4	3	2	UK recycled content mandate

Source: BloombergNEF. See Appendix B for our rating methodology.

Case study: Netherland's extended producer responsibility

Increased producer fees correlate with higher recycling rates.

Overview: Extended producer responsibility (EPR) mechanisms are scalable circular economy policy instruments. They are based on the 'polluter pays' principle and aim to hold manufacturers, importers and distributors accountable for the entire lifecycle of their products, shifting end-of-life costs away from the public sector. Assigning producer responsibility can reduce waste at source, promote environmentally friendly product design, and support the achievement of public recycling and materials management targets.

How it works: In an EPR scheme, producers, distributors and importers are held logistically and financially responsible for the end-of-life treatment of their packaging. To simplify this process, industry players will usually create a packaging recovery organization, or a PRO. In a PRO, producers collectively share the burden of the EPR obligation and recycling targets, accounting for their portion of the financial obligation based on their products' market share of the industry. A PRO must be registered as a separate non-governmental organization that manages the end-of-life of the products, verifies data and reporting and communicates with the governing body.

Figure 29: Plastic recycling rates in the EU and the Netherlands

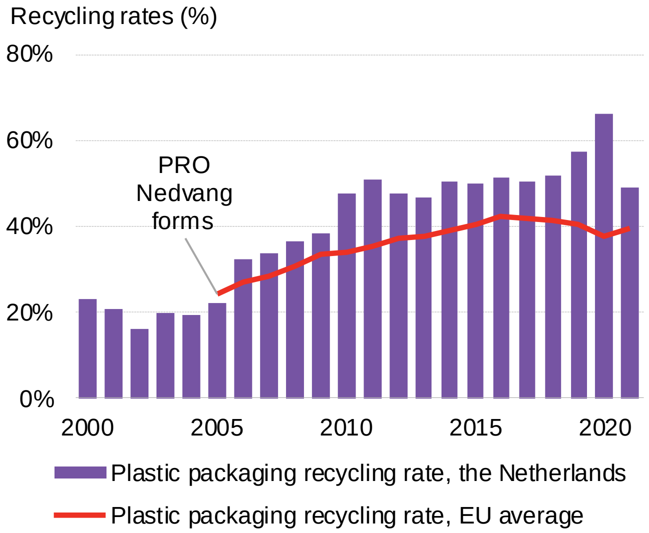
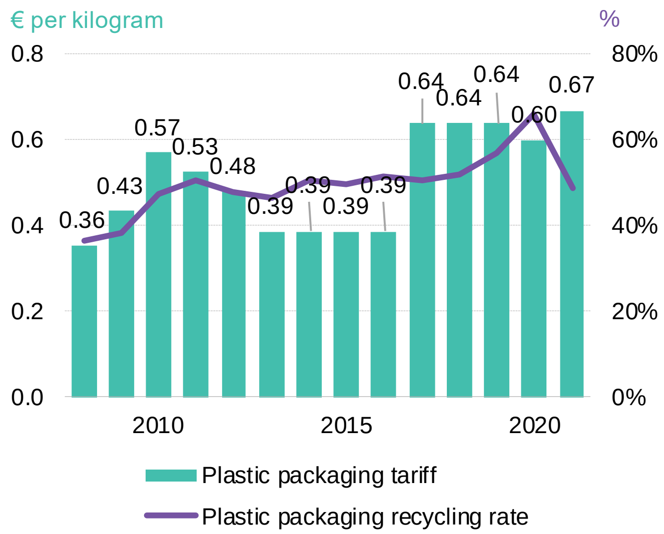


Figure 30: The Netherlands' plastic recycling rate and packaging tariff



Source: BloombergNEF, EuroStat. Note: Recycling rates dipped in 2021 due to the Covid-19 pandemic, but they are expected to recover with increased producer fees. PRO refers to packaging recovery organization.

Table 28: Extended producer responsibility snapshot

Supply	Demand
✓	
Neutral	**Targeted**
✓	

Source: BloombergNEF. Note: Supply refers to brand-owner production of plastic products. Extended producer responsibility regulations are technology-neutral because they do not require the use of specific technologies to comply with the regulation.

In its EPR scheme, the Netherlands operates a packaging recovery organization (PRO), known as Nedvang, which has helped the country surpass the EU's 2030 recycling targets of 55% for plastic packaging and 70% for all other packaging. The country's plastic packaging recycling rate rose from 22% to 33% in 2006, when Nedvang was founded. Since then, its plastic packaging recycling rate has doubled over 2008-2020, to 66% (Figure 29).

The Netherlands' producer fees and recycling rates have ebbed and flowed over the years but have largely done so in tandem. Plastic packaging rates dropped a dramatic 17% between 2020 and 2021, due to the pandemic (Figure 30). Following this decline, Nedvang increased plastic packaging fees to €1.05 ($1.06) per kilogram in 2023 in order to drive recycling rates back up

BNEF take: EPR schemes can increase the amount of plastic waste that is collected and recycled by enforcing compliance among producers. This increases the supply of recyclable materials, making it easier for companies to source recycled feedstock for new packaging.

Increased adoption of EPR schemes at the national and even subnational level could drive more brand owners to commit to recycled-content targets as the availability of recycled material increases. While currently applied mostly to packaging, the concept of an EPR scheme could be used in other sectors. For instance, the steel sector – which needs large volumes of scrap steel in order to decarbonize production – could benefit from a program that taxes waste in order to fund sorting and recycling.

Circular economy policy is multi-faceted

Successful EPR schemes are accompanied by the following policies and practices:

- Investment in comprehensive waste and recycling management infrastructure.
- Minimum collection and recycling rates, and recycled content targets for brand owners.
- A gradual increase in the fee paid to the PRO for products, to ensure coverage of the full cost of collection services.
- New landfill fees to gradually eliminate landfill of recyclables, and/or landfill bans.

Table 29: Recycled-content mandate snapshot

Supply	Demand
	✓
Neutral	**Targeted**
	✓

Source: BloombergNEF. Note: Demand refers to brand-owner demand for virgin plastics. Recycled content mandates are technology-targeted because they stimulate demand for recycled plastics.

Case study: The UK's recycled content mandate in packaging

Overview: Recycled content mandates are the most rigorous form of circular economy policy, usually implemented after other measures, like EPR schemes, have already been implemented. These measures require that certain products contain a specified amount of recycled materials. The UK is enforcing a tax on any plastic packaging that does not meet the standard.

How it works: Under the UK's Plastic Packaging Tax, any plastic packaging manufactured or sold in the UK that does not contain at least 30% recycled plastic will be charged £200 ($260) per ton over the threshold. This tax generated £276 million ($336 million) over the 2022-23 fiscal year.[21] Recycled content mandates increase demand for recycled materials, and thus scrap material, which helps stimulate waste collection and recycling capacity.

BNEF take: Recycled content mandates can be particularly effective in encouraging circularity, as they mobilize the entire supply chain. Packaging producers are required to source recycled material, generating demand and increasing prices for secondary materials. Higher prices incentivize waste managers to increase collection, and spur sorters and recyclers to improve their technology to generate a higher-quality recycled material.

[21] HM Revenue & Customs

However, there can be challenges with scrap availability, especially if there are not supply-side measures to complement the mandate. Ideally mandates are accompanied by an EPR scheme or another supply-side instrument to improve the amount of waste collected. Financial penalties for non-compliance with the mandate can also be invested in recycling infrastructure to bolster the supply chain.

Related BNEF insights

EU's New Packaging Plan Could Accelerate Reuse, Recycling (web | terminal)

Circular Economy for Plastics: Market Intervention Needed (web | terminal)

G-20 Zero-Carbon Policy Scoreboard 2023 (web | terminal)

Appendix A. Glossary of terms

Table 30: Terms and definitions

Category	Term	Definition
Ammonia	Ammonium nitrate	A nitrogen fertilizer produced from ammonia mixed with nitric acid.
	Blue ammonia	Ammonia produced with blue hydrogen instead of gray hydrogen.
	Gray ammonia	A colorless gas with the chemical formula NH_3 made by combining nitrogen from the air and gray hydrogen at high temperature and pressure. It is mostly used as an input to produce nitrogen fertilizers.
	Green ammonia	Ammonia produced with green hydrogen instead of gray hydrogen.
Hydrogen	Blue hydrogen	Hydrogen produced from fossil-fuel feedstocks paired with carbon capture and storage.
	Gray hydrogen	Hydrogen produced from fossil-fuel feedstocks without carbon capture and storage. Today, it is used for its chemical properties, mainly in oil refining and the production of ammonia (NH3) and methanol (CH3OH).
	Green hydrogen	Hydrogen produced via electrolysis (splitting) of water by renewable electricity.
Market terms	Supply side	Refers to the producers of low-carbon technologies and fuels.
	Demand side	Refers to the buyers of industrial products and material producers who procure low-carbon technologies and fuels.

Source: BloombergNEF

Appendix B. Policy mechanism evaluation methodology

Table 31: Policy rating criteria

Score	Effectiveness	Scalability	Feasibility
1	Mechanism has had seemingly no impact on scaling the low-carbon technology or reducing emissions in the sector at hand, and is unlikely to have an impact if implemented in the future.	Mechanism likely cannot be scaled across a sector/technology or a variety or sectors/technologies.	Mechanism likely cannot be implemented and enforced and will likely not be accepted. It is not politically palatable.
2	Mechanism seems to have had a minor impact on scaling the low-carbon technology or reducing emissions in the sector at hand.	Mechanism is challenging to scale across a sector/technology or a variety or sectors/technologies.	Mechanism is challenging to implement and enforce. Acceptability is low.
3	Mechanism has had, or at least begun to have, a noticeable effect on scaling the low-carbon technology or reducing emissions in the sector at hand.	Mechanism could be scaled to encompass a share of a sector/technology or several sectors/technologies.	Mechanism could be accepted, implemented and enforced in a variety of markets, but it could face opposition.
4	Mechanism has had a noticeable effect on scaling the technology at hand or reducing emissions in the sector at hand.	Mechanism could likely be scaled to encompass a share of a sector/technology or several sectors/technologies.	Mechanism could likely be accepted, implemented and enforced in a wide variety of markets.
5	Mechanism has shown a history of impact on the sector or technology at hand, and is projected to incite future impacts.	Mechanism has shown a history of scaling to encompass a large share of a sector/technology or a large variety of sectors/technologies.	Mechanism has been accepted, implemented and enforced in a wide variety of markets. It is largely politically palatable.

Source: BloombergNEF

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