Hard to Abate Sectors & Emissions II

The Road to Decarbonization

Citi GPS: Global Perspectives & Solutions
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HARD TO ABATE SECTORS AND EMISSIONS II

The road to decarbonization

Energy transition investment has soared in recent years – from US$212 billion in 2013 to more than $1.7 trillion in 2023.

Most of that investment has been in electrified transport and clean electricity. This should be celebrated. But we also need to acknowledge the need to boost investment in other technologies and sectors.

Hard-to-abate sectors such as steel, cement, aluminum, shipping, and aviation are today responsible for more than one-third of energy-related greenhouse gas emissions when allocating emissions to different sectors.

Many of these sectors are expected to grow over the coming years. In fact, if no action is taken, emissions from these sectors could increase by more than 50% by mid-century[1]. In many countries hard-to-abate sectors are responsible for a large part of overall emissions.

For example, 36% of China's emissions are attributed to industrial processes, whilst in the US the figure is estimated at nearly 23% of all greenhouse gas emissions. Countries won't reach their net-zero commitments unless these sectors are decarbonized.

In our previous report on hard-to-abate sectors just 3 years ago, we discussed the solutions available to decarbonize and their associated costs. The cost premiums were high for many of these sectors, and it was difficult to see how they could reduce emissions in the near-term. Many, including us, thought that decarbonization in these sectors would really start to take off in the 2030's. We were wrong.

Spurred by government support, legislation, and a push from clients such as auto manufacturers and cargo owners that want to reduce their scope 3 emissions, we are now seeing that decarbonization in these sectors has started. We wrote this report to acknowledge that progress. But it's clear too that more needs to be done.

So where are these sectors now? What is happening with the scale up of new fuels and technologies? What are the bottlenecks? And how are we going to finance this transition?

To answer these questions, we provide:

- A detailed analysis on the progress in solutions needed to reduce emissions from these sectors
- An analysis on where the aviation, shipping, steel, aluminum, and cement sectors are in their journey to become net-zero. What is pushing these sectors, and have they started investing in ways to reduce their emissions?
- A discussion on ways to finance this transition. How are corporates financing their transition and what is needed?

[1] Citi GPS (2021), Hard-to-abate sector and emissions, The Toughest Nuts to Crack for a Net Zero Future.

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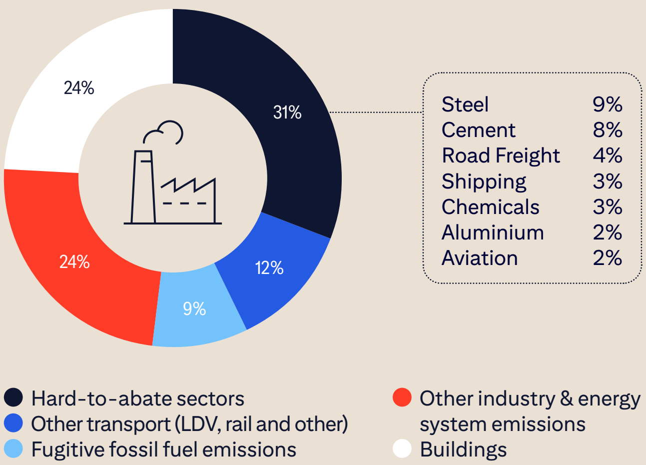
Hard to Abate Sectors & Emissions II

Why does it matter?

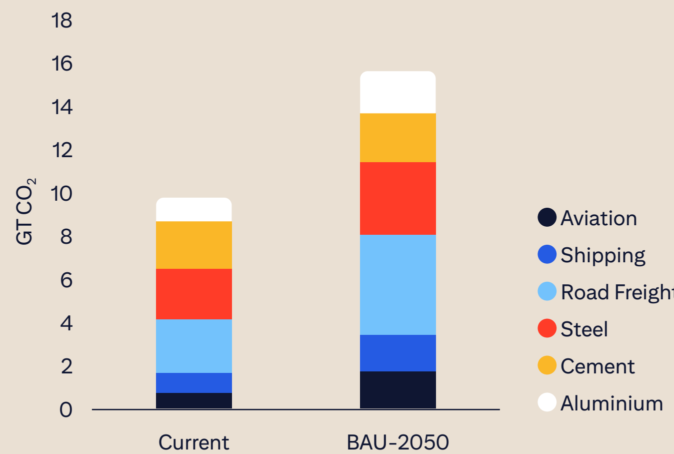
Hard to abate sectors are currently responsible for 1/3 of energy related emissions. If no levers are deployed to reduce these emissions, these are expected to increase by more than 50%.

Hard-to-abate sectors are responsible for 1/3 of energy-related greenhouse gas emissions



Source: Citi GPS, Mission Possible

Emissions from hard-to-abate sectors will grow by more than 50% under a BAU scenario



Source: Citi GPS, BNEF

Note: This does not include the chemical industry

Supply side solutions

Ways to reduce emissions from hard-to-abate sectors can be divided into 4 buckets – (1) renewables and nuclear, (2) clean hydrogen, (3) CCUS and (4) biomass. There has been substantial progress over the last few years.

Renewables & Nuclear

- Commitment by countries to triple renewables
- Nuclear – 80 small modular reactors (SMRs) are being developed
- The promise of floating nuclear power plants

Clean Hydrogen

- 477 hydrogen projects to come online by 2030
- Cumulative production of 44.6MT/H2 by 2030
- 1.4 billion tonnes of synthetic fuels
- Cumulative investment ~$200 billion

CCUS

- Over 350 projects in development
- Over 420 million tonnes of CO2 captured by 2035

Biomass

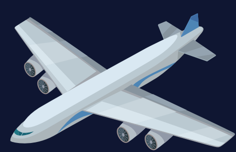
- Renewable fuel capacity to increase from 6.9 billion gallons to just under 21 billion gallons by 2030

Sector specifics

Spurred by regulations, government support and a push from clients we are seeing many sectors start to decarbonize.

Shipping

44 Green Corridors Initiated. Low carbon fuels ships on order- 229 methanol ships, 346 battery/ hybrid operated, 11 ammonia ships, 7 nuclear, 22 hydrogen and 19 biofuels



Aviation

A cumulative total of 6.7 billion gallons of SAF has been announced up to 2030- 5.4% of current global jet fuel demand

Steel

66 green steel projects could be operational in 2024, increasing to 202 by 2030

Aluminium

50 innovative projects that are contributing or else plan to contribute to a reduction in emissions

Cement

53 CCUS plants that the cement industry is investing in. Increase from 2.2 $MtCO_2$ to 80 $MtCO_2$ in 2030 of emissions captured

Financing the transition

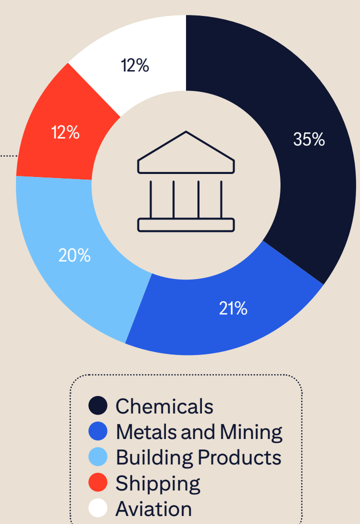
Trillions are needed every year to finance the transition. Most of the funding is done on corporate balance sheet, however we need to move to more project finance projects.

Types of finance structure

1. **Corporate Balance sheet** – cash rich companies are funding projects themselves or are lending against their balance sheet – $80 billion of green bonds were issued for hard-abate sectors over 5 years (see chart).

2. **Project Finance** – Funding of long-term infrastructure, industrial projects and public services using non-recourse or limited recourse financial structure.

3. **Other financing structures** – raising equity, carbon credits and government grants/tax credits. Companies are stacking these revenues.



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Contents

Introduction	7
Section 1: Solutions	8
Section 2: Sectors	27
Industrial Sector	44
Financing: How do we scale up the finance needed?	65
Conclusion	73

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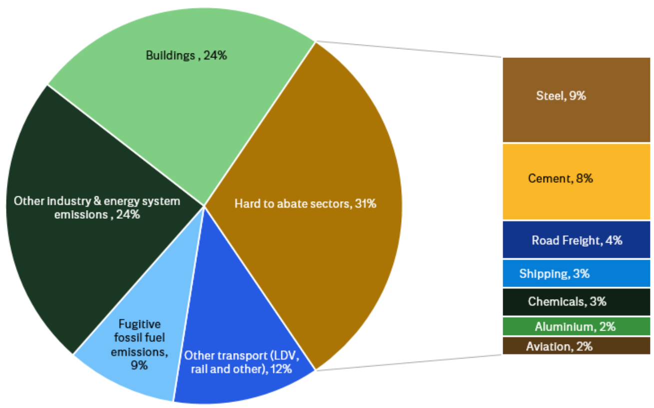
Introduction

It's been a long time coming, but the decarbonization of hard to abate sectors is happening.

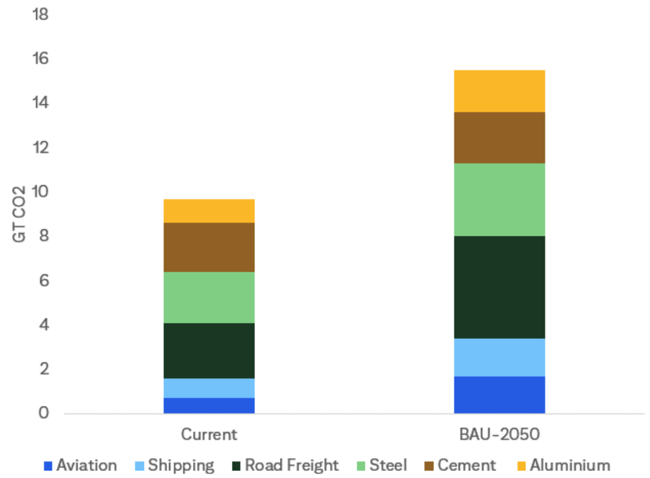
Investment in technologies and new fuels are expected to increase significantly over the next few years. Government support has been instrumental in helping to scale up some of these technologies.

Figure 1. Hard-to-abate sectors are responsible for one-third of energy-related greenhouse gas emissions



Source: Citi GPS, Mission Possible

Figure 2. Emissions from hard-to-abate sectors will grow by more than 50% under a BAU scenario



Source: Citi GPS, BNEF

Note: This does not include chemicals

Sectors are being pushed by legislation and carbon taxes which will become costly over the next few years. Clients are also asking for this change. Companies with strong net-zero commitments are looking to work with others that have similar ambitions.

Many companies are now willing to pay the cost premium for green products and services.

This is especially noticeable for the steel industry in which some European automakers have committed to buy green steel, and in the maritime industry, in which cargo owners are tendering for green shipping to help create a market.

The task (and ambition) is huge. We need to deploy trillions of dollars to scale up solutions and to decarbonize these sectors.

Currently, most of the financing for many of these projects is done on a corporate balance sheet, with the help of government support. However, the overall funding needed for energy transition is such that corporates will not be able to finance their needs on balance sheet alone and will increasingly need project finance. This is essential especially in emerging and developing economies in which investment is muted.

The progress made over a very short period has been substantial. However, barriers do remain, and we need to negotiate them quickly so as not to stifle the investment being made.

The landscape is changing fast, and we expect more investment, policies, and announcements over the next few years.

Decarbonization has truly started for hard-to-abate sectors on the road to net-zero.

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Section 1: Solutions

There are many ways to decarbonize hard-to-abate sectors. These include improvements in energy efficiency, increasing the recycling and circularity of materials and better designs. But these aren't enough to reach net-zero.

So, we need supply side solutions. These include:

- The use of renewables and nuclear for power and thermal heat generation
- Biomass for transport fuels such as sustainable aviation fuel, green methanol for the maritime sector, and thermal heat for the industrial sector
- Hydrogen as fuel cells or hydrogen engines in shipping or aviation, and to produce hydrogen derivative fuels (synthetic fuels), which also requires captured CO2; like biomass it can also be used to replace fossil fuels for thermal heat generation needed in industry
- The use of carbon capture utilization and storage (CCUS) that captures CO2 either from point stationary sources or through the atmosphere from direct air capture.

Several innovations are being developed, such as novel cements and electrowinning for the steel industry, which we discuss in the next chapter.

The use of carbon credits through the voluntary carbon markets or compliance markets (if allowed) can also help companies reach their net-zero commitment. For example, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is a quasi-compliance carbon market set up to help the aviation sector reduce its emissions using carbon credits. Carbon credits are not included in this report, however, please refer to the GPS report on the Voluntary Carbon Market for additional details.

Choosing among these solutions will come down to cost, scalability, and public support, at least in the short term. The solutions are also connected. For example, green hydrogen needs clean electricity, whilst synthetic fuels which are important for the aviation and maritime sector require clean hydrogen and captured CO2.

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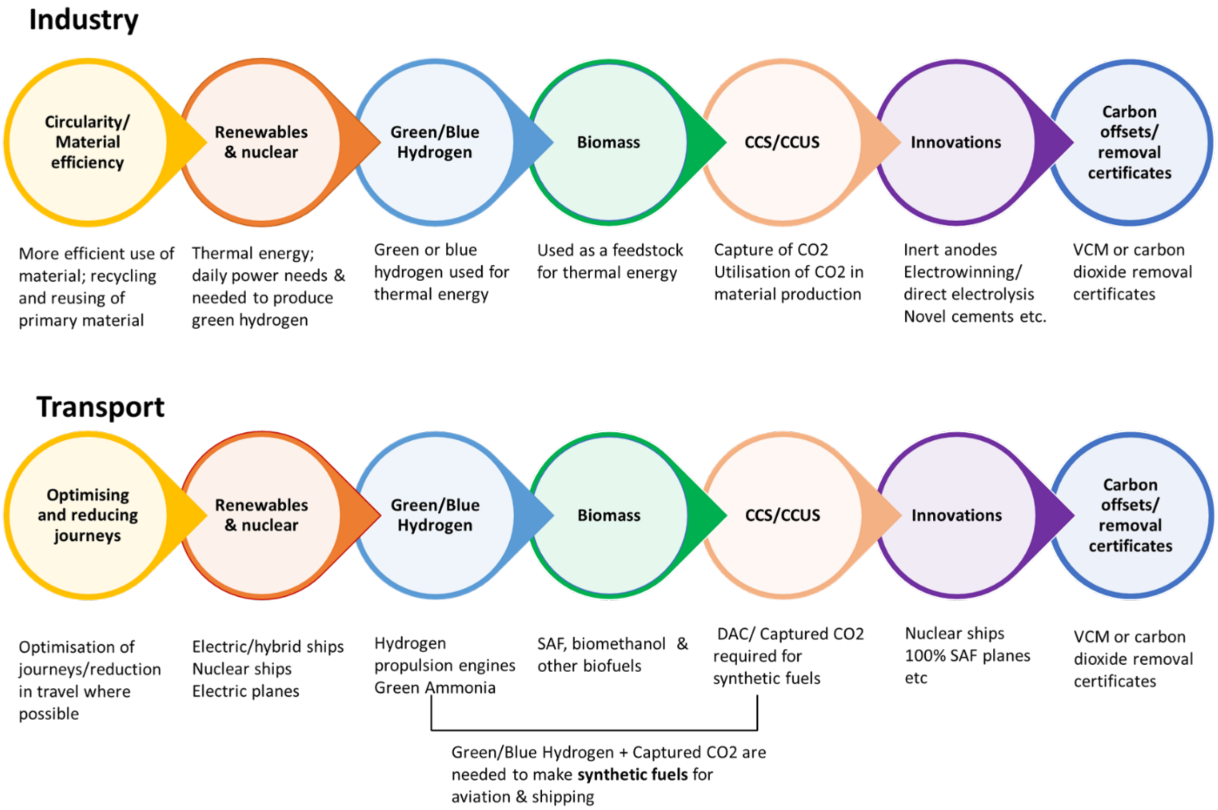
Figure 3. Solutions to decarbonize across industry and transport



Source: Citi GPS

So where are we with these solutions? Are they being scaled up? The answer is yes, but in a very country/region specific way.

Most of the increase we are seeing is due to the plethora of legislation and policies and/or available economic instruments such as grants and tax credits that have been implemented in various countries.

In the next section we discuss some of the progress in these solutions, the policies that are available in various countries, and the barriers and challenges that persist.

Increase in renewables and nuclear

Renewables or nuclear are essential for the hard-to-abate sectors we cover in this report.

As highlighted in the diagram above, clean electricity coupled with electric furnaces and boilers can help generate the thermal heat needed in industry. It can provide daily power needed for aluminum smelters or even power ships. It is also needed to produce green hydrogen.

Currently, we generate approximately 28,000 TWh of electricity per year – 60% of this is from fossil fuels.

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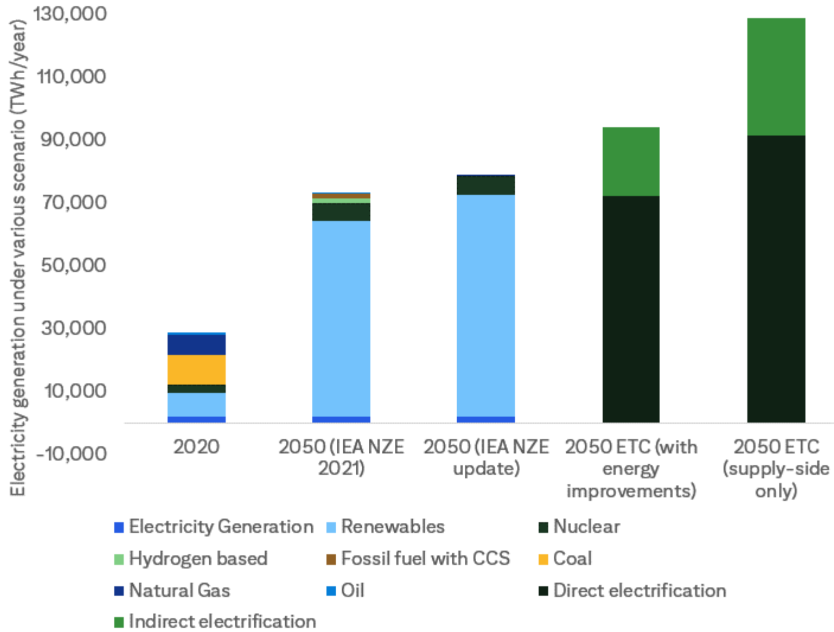
It is estimated that electricity demand will increase by 3-5 times by 2050 depending on which scenario we look at. Figure 4 below compares the IEA's NZE scenario with the Energy Transition Commission (ETC) scenario. These two scenarios have different underlying assumptions and therefore different results. But they both agree that electricity demand for industry is expected to increase substantially.

For example, the IEA states that the share of electricity in total final consumption of the industrial sector increases from 21% in 2020 to 46% in 2050.

The ETC assumes that a large demand for electricity will be needed to produce green hydrogen. They estimate that green hydrogen production would reach 150-300 million tonnes in 2050. This would require 7,000-14,000 TWh of green electricity, which is nearly double the electricity demand in the United States.

This will be difficult to achieve.

Figure 4. Current and future electricity generation under various scenarios



Source: Citi GPS, Energy Transition Commission, IEA
Note: ETC refers to Energy Transition Commission. Indirect electrification refers to electricity used to produce new fuels such as synthetic fuels, production of green hydrogen, green ammonia and extra electricity for hydrogen storage for power flexibility

Update on progress

Renewables have had continuous policy support in more than 130 countries, leading to a significant increase in global capacity and a reduction of costs.

In many countries, renewables are now cheaper than fossil fuel power production.

Over the years, most of the growth in renewables has come from China. In fact, China accounts for almost 60% of new renewable capacity that is expected to become operational globally by 2028.

During COP28, countries committed to tripling renewable power and doubling energy efficiency by 2030. Tripling renewables will not be easy and will require huge

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investment in renewable energy assets estimated at $9.4 trillion between 2023 and 2030[2]. In 2023 investments in renewables reached $622 billion, so to meet this figure we would need to increase annual investment to approximately $1.3 trillion per annum. We also need to boost investment in power grids and in energy storage solutions.

Many countries are however stepping up to this challenge. For example, the US is offering tax credits and other grants, accelerating the investment in clean electricity. Other countries in the EU and the Middle East are using auctions to help grow the market.

Nuclear

In addition to renewables, there is also the promise of new Small Modular Reactors (SMRs), which are smaller and more modular than traditional nuclear plants. Nuclear energy over the years, in many countries except China, has been plagued by negative public perception, high costs, and delays in construction. But this is changing.

Nuclear can play an important part in helping to decarbonize hard-to-abate sectors and scale up clean electricity. SMRs should become operational in this decade and according to the IAEA more than 80 commercial SMR designs are being developed around the world. SMRs do have a lower upfront capital cost per unit of energy produced compared to traditional nuclear plants; however, it is still to be determined whether they are economically viable[3] and government support may be required to help scale them up.

The interesting thing about SMRs is their design, which allows them to be assembled in a factory and transported to a location for installation. It could be possible to repurpose shipyards to construct SMRs and floating nuclear facilities. This may speed up construction and reduce costs.

According to Core Power, 'floating nuclear power plants (FNPPs) are nuclear power plants mounted on, or integrated into, a conveyance other than a marine vessel, to produce energy'. These are not new – there are already a small number of FNPPs that have been deployed using traditional nuclear technology such as Pressurized Water Reactor technologies. However, nuclear technology has also advanced. For example, Molten Salt Reactors (MSRs) are nuclear reactors that use liquid fuel in the form of very hot fluoride or chloride salt, rather than solid fuel used today. This liquid fuel acts as both the fuel and the coolant[4].

FNPPs can be used for different applications including providing clean electricity and heat in remote locations, decarbonizing mining activities and offshore oil and gas operations, providing power to a port, alternative fuel production, floating data centers, water desalination, and grid scale electricity production. If the tech industry starts investing in SMRs and FNPPs to meet their growing demand for electricity for their data centers, this could help scale up SMRs and reduce the costs for hard-to-abate sectors that have tighter margins.

The maritime sector is also debating using nuclear to decarbonize – nuclear is not new to shipping. We discuss this in more detail in the section on shipping.

[2] BNEF, Tripling Global Renewables by 2030, Hard, Fast and Achievable
[3] Jonathan Liou, September 2023, IAEA, What are Small Modular Reactors (SMRs)?
[4] Core Power, Why Maritime Needs New Nuclear

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Challenges and bottlenecks

Several bottlenecks have emerged that are delaying investment in renewables and nuclear:

1. **Increase in costs:** The cost of building renewables and nuclear has risen substantially in many countries on the back of higher rates. This is also affecting the economic attractiveness of auctions for renewables. In fact, some developers have refrained from bidding in auctions due to the uncertainty over whether contracts can account for the current macroenvironment.

2. **Permitting:** The time taken to obtain permits for the installation of renewables is delaying many projects. The IEA estimates that on average the time it takes to obtain necessary permits can range from 1-5 years for solar PV projects, 2-9 years for onshore wind, and 9 years for offshore wind projects. Many governments are trying to solve this. For example, the European Commission issued permitting guidelines in 2022 to set clear permitting timelines and has introduced the Net Zero Act that can help support permitting issues related to important technologies for energy transition including solar and wind.

3. **Grid improvements:** Currently insufficient investment in grid infrastructure is preventing faster expansion of renewables. It is estimated that more than 3,000 GW of renewable generation are in grid queues, and half of these projects are in advanced stages of development. This is a challenge that both advanced and emerging and developing economies are facing. For more information, please refer to Citi's Research report 'Unlocking Gridlock'.

4. Given that renewables have an intermittency problem, there needs to be additional investment in short and long duration energy storage.

5. There is a lack of data and real-world experience in the use of SMRs and questions and concerns on safety, cost, and nuclear waste need to be addressed.

Competition for clean electricity and power will increase substantially over the next decade. Companies today can already make use of green electricity in their operations either through (1) direct on site production, (2) direct purchase straight from the grid of a local energy carrier as part of a long-term Power Purchase Agreement (PPA), and/or (3) virtual coverage by for example entering into a long-term PPA that funds green power from sites into the supply grid in an amount equal to the amount covered.

Hydrogen

Hydrogen has gained some momentum since we wrote the initial hard-to-abate sectors report three years ago, but its current use is still muted to some extent. However, government policies in many countries are changing this.

Clean hydrogen would need to be used to decarbonize already existing uses such as refineries and ammonia production. It also can be used in many other hard-to-abate sectors such as steel, aluminum (refining stage), and in transport through hydrogen propulsion engines or through synthetic fuels which also require captured CO_2.

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There are challenges: hydrogen has a low volumetric energy density, it is difficult to store and move given its highly flammable nature, and it is difficult to transport in its current form.

It also requires a lot of clean electricity if green hydrogen is produced, and it is expensive compared to fossil fuels. Its widespread use amongst new users would also depend on the competition from other available solutions.

Different colors of hydrogen

There are many ways to produce hydrogen cleanly. These include:

1. Using fossil fuels and carbon capture utilization and storage known as blue hydrogen
2. Using electrolysis and renewables known as green hydrogen
3. Using electrolysis and nuclear known as pink hydrogen
4. It can also be produced using biomass through a process called biochemical conversion.

Hydrogen can also be found in its original form. It is a naturally occurring gas generated in specific geological settings. The industry has also given naturally occurring hydrogen a color-- it is now referred to as white hydrogen. Until now most white hydrogen discoveries were made by accident by geologists working in the oil and gas industry or as an unintended consequence of geothermal or water extraction[5]. However, the race is on to find naturally occurring hydrogen which would avoid the use of green electricity and water needed to produce green hydrogen (electrolysis requires a lot of water) and avoid the use of CCUS to produce blue hydrogen. The Geoscientist journal has stated that natural hydrogen explorers are applying for exploration permits in various places. However, currently there is no government support as opposed to what we are seeing happen in the green and blue hydrogen space. White hydrogen however could prove to be a game changer, if found in abundance and if cheap enough to compete with other clean hydrogen production methods and with fossil fuels.

Progress on hydrogen

So, is clean hydrogen being scaled up? The answer is yes, at least on paper, as many announced projects still must reach FID.

Currently, more than 1,600 hydrogen projects are planned, but according to BNEF just 477 projects will come online by 2030, with an annual production estimated at 16 million tonnes of H2 and a cumulative production of 44.6 million tonnes of H2 by 2030.

To put this into some sort of context, currently 100 million tonnes of grey hydrogen is currently used per annum. Cumulative investment in hydrogen is expected to reach just under US$204 billion in the same time-period.

The US is expected to have the most hydrogen projects come online, followed by Europe, China, and the MEA region.

Cumulative investment figures in Europe are expected to be higher than North America as Europe is banking on green hydrogen projects that are more capital-intensive compared to mostly US-based blue hydrogen projects.

[5] Geoscientist, Nature Hydrogen: the new frontier

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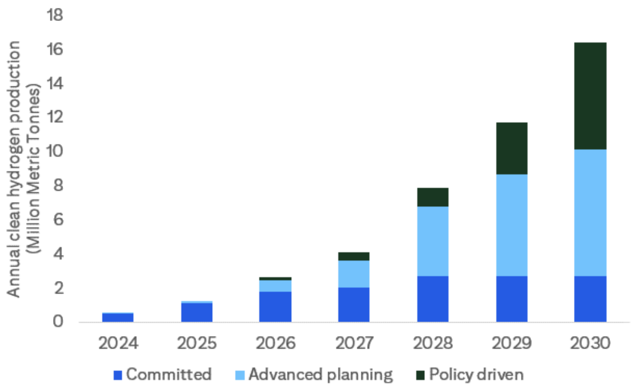
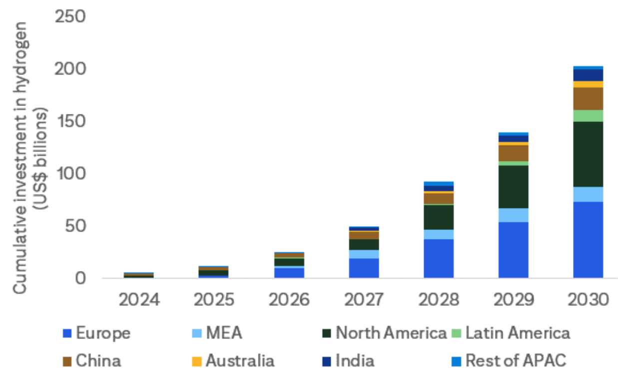
Figure 5. Annual production of clean hydrogen



Source: Citi GPS, BNEF6
*Committed refers to projects that are either operational or have reached FID; Advanced planning are those projects that are showing signs of progress and reached an advanced planning stage; Policy-driven refers additional supply that can come online by 2030 with announced policies and other market drivers.

Figure 6. Cumulative investment in clean hydrogen



Source: Citi GPS, BNEF

Many hydrogen projects expected to come online are policy driven. In recent years a string of regulations and several tax incentives have appeared that are encouraging the development of blue and green hydrogen projects. The map in Figure 7 shows different policies around the world.

The US has the most generous offerings through the Inflation Reduction Act. It has multiple tax credits that can be applied for hydrogen projects, including Tax Credit 45V which can be stacked with Clean Electricity Tax credit relevant for green hydrogen projects. It also has a tax credit for CCUS which can be relevant for blue hydrogen projects.

The Inflation Reduction Act has also spurred other countries to do the same. For example, Australia has just committed to providing a tax credit of AU$2 per kg of hydrogen produced using renewable energy; this is uncapped and will be available for a maximum of 10 years for each eligible project[7].

[6] BNEF (2024), Hydrogen Supply Outlook 2024, A reality check
[7] K&L Gates, Proposed new Australian hydrogen production incentives and support, May **2024**

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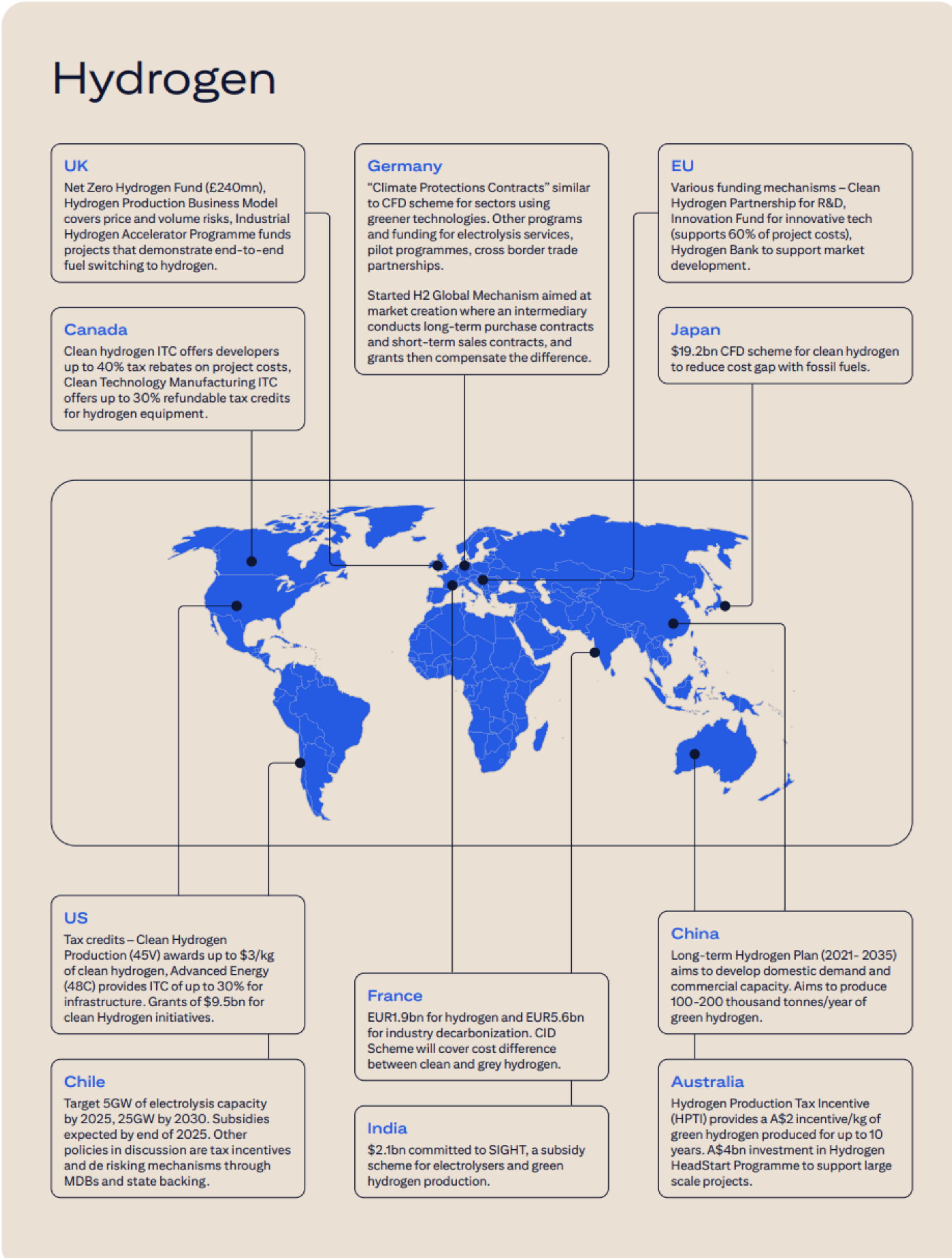
Figure 7. Hydrogen policies in different jurisdictions



Source: Citi GPS

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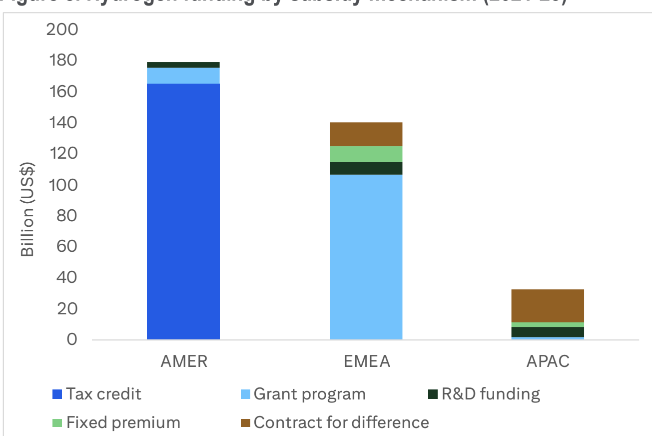
Unlike the US, the EU does not allow state aid, unless it is justified by reasons of general economic development. However, there is some room for government interventions to take place and some countries such as Germany have been successful in their bid to the EU to use state aid to help expand solutions for its industrial sector.

Germany has also launched a Carbon Contracts for Difference (CCFD) to help bridge the gap of costs for certain technologies including hydrogen. It has also introduced its H2 Global Scheme, which is a double auction mechanism targeting both hydrogen producers and end users. Japan is also launching a similar CCFD targeting hydrogen.

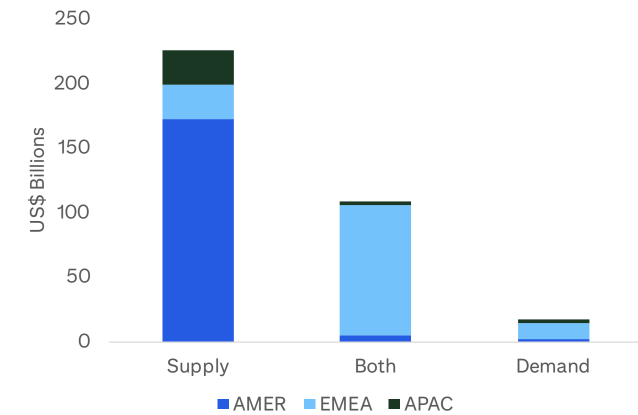
Other schemes in the EU include the Important Projects of Common European Interest (IPCEI) and its Hydrogen Bank which has just awarded €720 million for seven projects even though there is a lot of uncertainty whether any of these projects would reach FID due to the low auction price.

Figure 8. Hydrogen funding by subsidy mechanism (2021-23)



Source: Citi GPS, BNEF

Figure 9. Hydrogen funding by category (2021-23)



Source: Citi GPS, BNEF

According to BNEF, as of November 2023, only 10% of clean hydrogen production capacity planned by 2030 had identified a third party (an offtaker)[8] that has committed to buy a certain amount of clean hydrogen at an agreed price.

Most of the offtakers are current grey hydrogen users such as fertilizers and refineries, with smaller amounts attributed to steel, aviation, and shipping as shown in the next chart. So, there is a mismatch between the supply and demand side that needs to be addressed.

[8] BNEF (2023), Hydrogen Demand: Tiny But Rising

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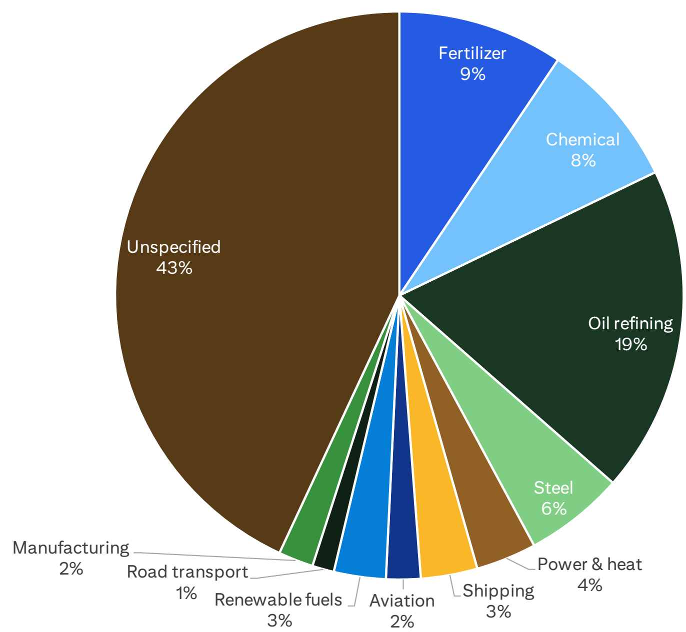
Figure 10. Specified offtakers of hydrogen as of November 2023



Source: Citi GPS, BNEF

Hydrogen derivative fuels

If we look specifically at hydrogen derivative fuels (also known as e-fuels, synthetic fuels or power to liquids) which also require CO2, then the picture is mixed, with some additional capacity being introduced.

These synthetic fuels could be essential to various modes of transport including shipping and aviation. Currently, there are three operational plants: (1) in Chile operated by HIF Global that has a capacity of 150,000 gallons; (2) in Germany operated by Atmosfair which produces 120,000 gallons; and (3) in Texas run by Infinium.

However, many large operations are planned which could come online by 2030 with an estimated production capacity of 1.3 billion gallons. The market consists of start-ups as well as oil companies, but it is expected to grow significantly after the 2030's.

In the EU, regulation is trying to move supply forward. For example, the ReFuelEU Aviation legislation requires refineries to provide 1.2% of the total fuels they supply to EU airports to be synthetic in 2030, increasing to 35% in 2050. However, synthetic fuels are prohibitively expensive estimated at 2-7 times more than conventional jet fuel.

Green ammonia or blue ammonia (produced from natural gas with CCUS) which is also produced from clean hydrogen could be a solution for the maritime sector; however, as we discuss in the section on shipping, there isn't yet one solution that the sector has settled on, and other solutions such as methanol are also being sought.

Currently, there are 185 low-carbon hydrogen projects that have plans to produce green ammonia; however, it is not quite clear whether this is for transportation

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purposes (as hydrogen can be transformed into ammonia just for ease of transportation) or whether part of this would be directed to the shipping industry.

Looking ahead

In summary, hydrogen and hydrogen derivative fuels can play an important part in reducing emissions. Governments such as Germany are banking on this solution for industrial decarbonization.

Clean hydrogen would need to be produced to replace today's use of grey hydrogen estimated at 100 million tonnes today; however, scaling it up significantly for other users such as hard-to-abate sectors is still being debated.

For projects to reach FID, they need to find guaranteed offtakers whether this is for new users such as the steel industry or current grey hydrogen users. There have been some large projects that have been successful and are great examples of how to scale up hydrogen.

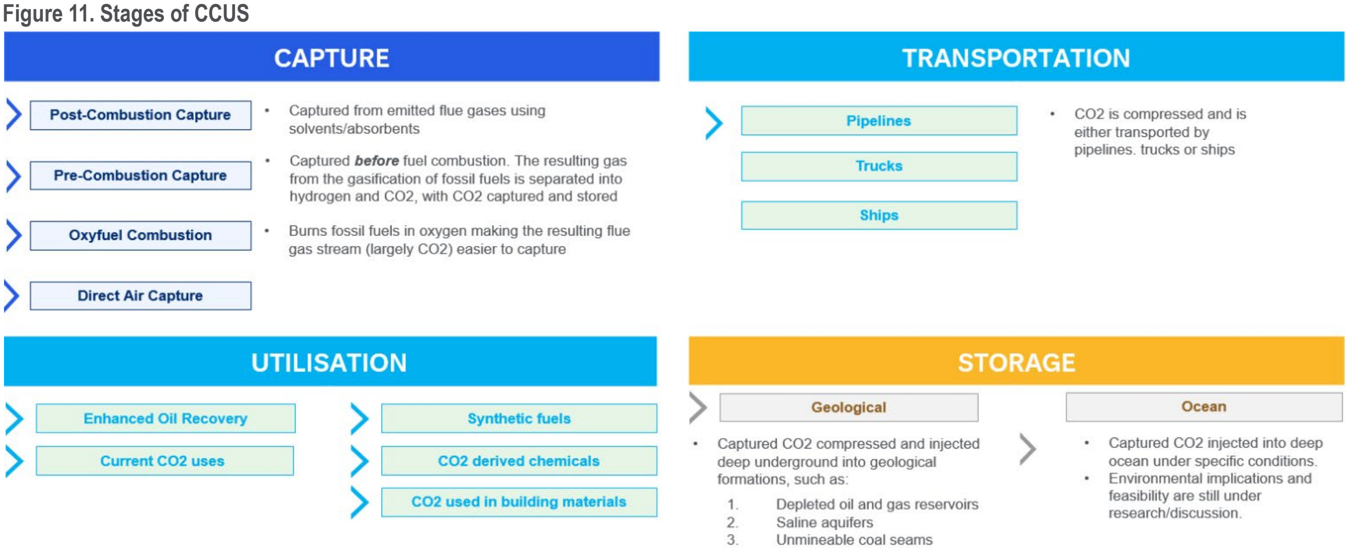
For example, H2Green Steel, which we discuss later in the report, is an excellent project that has been successful in attracting a diverse group of offtakers with some doubling up as equity investors.

Carbon capture utilization and storage

CCUS is a suite of technologies that either prevents CO2 from being released into the atmosphere from the use of fossil fuels or that captures CO2 directly through the atmosphere in the form of direct air capture.

It can be used by all hard-to-abate sectors, either directly capturing CO2 from industrial processes or indirectly by capturing CO2 from the atmosphere.

Figure 11. Stages of CCUS



* Potential of captured CO2 to be used for value-added commercial industrial uses
Source: Citi GPS

Update on progress

According to the Global Status of CCS (2023), 41 CCUS projects are in operation and 351 in development. As of 31 July 2023, the total CO2 capture capacity of CCS

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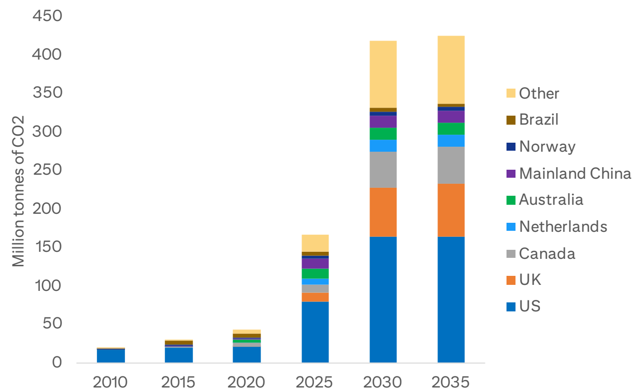
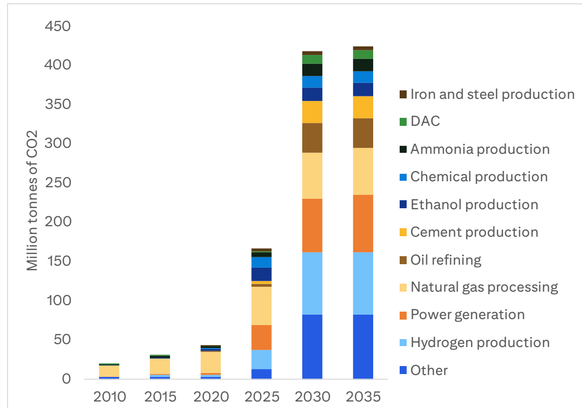
projects in development, construction, and operation was estimated at 361 million metric tonnes of CO2 per annum. BNEF has slightly higher figures with nearly 422 million metric tonnes of CO2 that should come online by 2035 as shown in the figures below.

Figure 12. Proposed carbon capture capacity by country



Source: Citi GPS, BNEF

Figure 13. Carbon capture capacity by sector (cumulative)



Source: Citi GPS, BNEF

Most announcements for CCUS projects are in countries where there are favorable policies such as the US where it is offering tax credits of $80/tonne of CO2 captured for CCS, $60/tonne for CCU, and $180/tonne of CO2 for Direct Air Capture projects.

The UK has targeted incentives and supporting regulation. For example, it has added $20 billion to its budget to support the industry which will be used to assist in the development of four CCUS clusters. It has also awarded licenses for carbon storage that are strategically located to support the storage of CO2 from the announced hubs.

The development of hubs which mostly take place in industrial sites are becoming an important part of scaling up CCUS projects as transportation for CO2 can be shared amongst different players.

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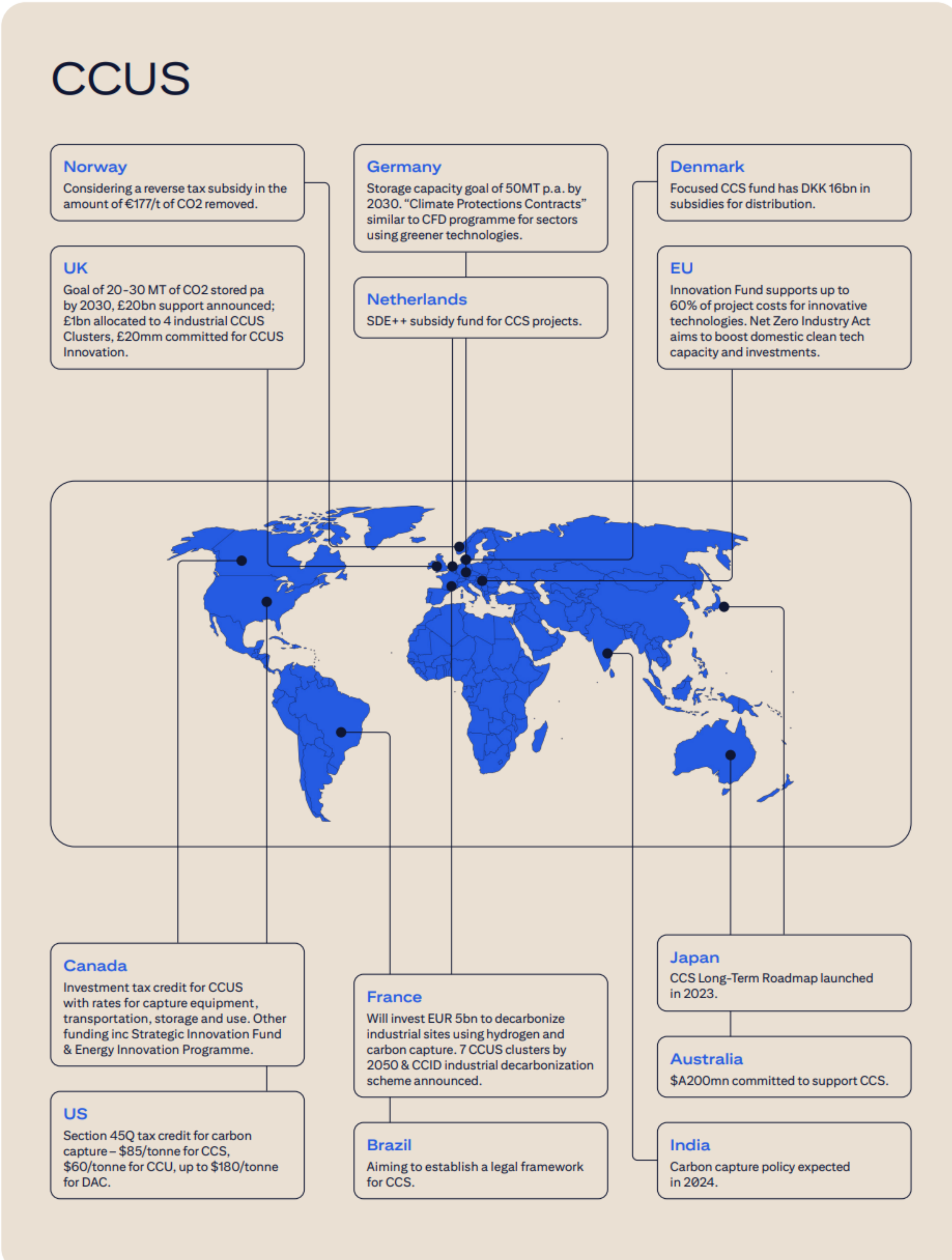
Figure 14. Policies on CCUS in different jurisdictions



Source: Citi GPS

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Norway is particularly well placed to capitalize on CCUS as it has significant geological storage. Its Longship Project aims to be the first ever cross-border, open storage CO2 transport and storage infrastructure network. In fact, a bilateral agreement has been made among Norway, Belgium, Denmark, the Netherlands, and Sweden.

This will enable CO2 captured from industrial sites in these countries to be transported and stored in geological storage sites in the North Sea region in Norway[9]. Ships will be used to transport captured CO2 from these sites.

Liquified CO2 ships are becoming an option for many countries that do not have geological storage available or to help avoid lengthy permitting processes associated with building pipelines which could delay the investment in CCUS.

Many other countries are investing in cross-boundary CO2 transport and storage activities involving the use of transportation of CO2 by ship. For example, Malaysia, Indonesia, Thailand, Brunei, and Timor-Leste are all developing opportunities to receive and store CO2 from other neighboring countries[10].

Transportation networks as well as storage facilities of CO2 need to be built alongside carbon capture plants. If not, this will become a bottleneck for capture projects.

We are already seeing this happen. For example, in the US there is currently more than 167 million tonnes per annum of capacity being announced, but there isn't enough transport capacity (estimated at just under 71 million tonnes pa) or storage capacity (under 100 million tonnes pa).

Carbon utilization

CO_2 that is captured can also be utilized in different products or processes. Currently, approximately 230 million tonnes of CO_2 are used every year in urea manufacturing, the oil and gas industry, metal fabrication, food manufacturing, etc.

In recent years, many companies have developed new products or processes using CO2 which include CO2/hydrogen-derived fuels (discussed in hydrogen section), CO2-derived chemicals and CO2 that is used in building materials.

It is extremely difficult to calculate with any certainty the future market for CO2 - derived services and products. Estimates of CO2 used in such products range from less than 1 GtCO2 to 7GtCO2 per year by 2030[11] which is approximately 2-16% of today's total CO2 emissions.

Even though carbon utilisation can increase the revenue from carbon capture projects, using CO2 in products and services does not necessarily mean it is good for the climate. It depends on several things such as whether CO2 is displacing fossil fuels or energy-intensive chemicals, how much energy is required to convert CO2, and how long the carbon is retained in the product or service.

[9] Government of the Netherlands, Five northern European countries conclude international arrangements on transport and storage of carbon across borders
[10] Global CCUS report 2023
[11] ibid

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Looking ahead

The cost of CCUS is rather steep for some industries, especially for those that do not have high concentrations of CO2 in the flue gas.

Government policies, subsidies, grants, and pricing of CO2 together with regulation are essential to scale up this technology. Cross-border collaborations and a speeding up of permitting can help increase the transport and storage components for CO2. DAC is significantly more expensive (estimated at $600/tonne of CO2) due to the low CO2 concentration in the ambient air.

However, given the potential of using CO2-derived products such as synthetic fuels in aviation and shipping, DAC application at scale is essential.

Biomass

Biomass is complex. Many feedstocks can be used to produce different products that are essential to reducing emissions across all sectors, including hard-to-abate industries.

At its broadest, biomass includes all biological material – plant, soils, and animals. It is basically any organic matter that is available on a renewable basis. It includes agriculture crops, agriculture waste and residues, wood and wood waste, animal waste, municipal waste, and aquatic plants.

Several products are produced from biomass, including liquid fuels, gaseous fuels, and solid biomass as shown in the next chart. The feedstock first needs to be harvested and/or collected, transported to biorefineries (if needed), and converted to different forms. These products can then be used for different applications including power generation, fuels for aviation and shipping, and as a source of heat for industry and in buildings.

Biomass can also be used as a feedstock – to produce furniture and other wood products, to produce fibers in the textile or construction industry, and as a chemical building block to produce plastics, and other chemical feedstocks such as solvents, paints, and pharmaceuticals.

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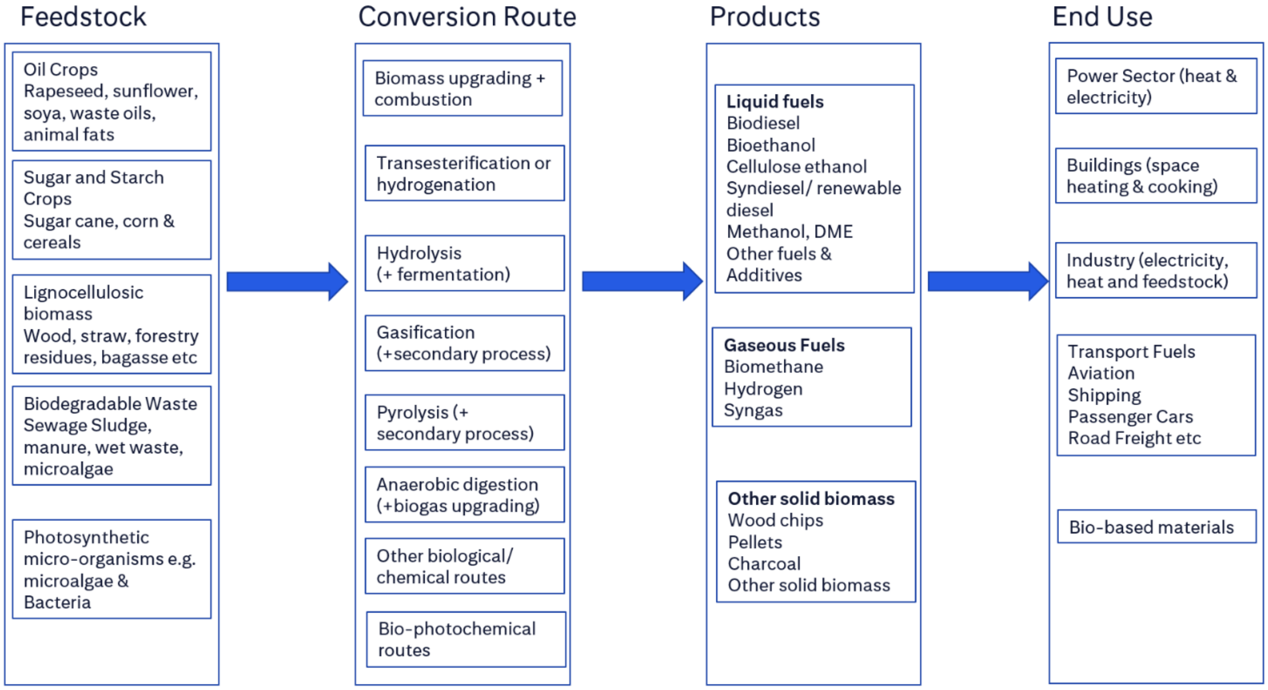
Figure 15. Feedstocks, conversion routes, and products



Source: Citi GPS, adapted from Committee of Climate Change (2018)[12] and updated

Progress on biomass

For the industrial sector, biomass can be used to replace fossil fuels for heat; however, its use will be location specific. For example, some steel plants in Brazil, which have an abundance of biomass, are currently using charcoal in place of fossil fuels. Some sectors such as cement are also using waste to reduce some of their emissions in the near term, whilst waiting for other technologies such as CCUS to scale up.

The growth in biomass for energy use for the hard-to-abate sectors that we cover in this report will come from advanced renewable fuels – in particular sustainable aviation fuel produced from HEFA[13]. There are plenty of policies and legislation that have been introduced to encourage the aviation sector to invest in SAF as described in more detail in the chapter on aviation.

Advanced renewable fuels are already being produced. The current cumulative production was estimated at 6.9 billion gallons in 2023, the majority of which was used in road transport. It is expected that this would increase to just under 21 billion gallons in 2030, with 31% of this produced as sustainable aviation fuel as shown in the figures below.

Most of this would be produced using different biomass feedstocks. As we can see in the next chart, the US has the most commercial projects that should come online over the next few years, with most of these using hydro-processing of liquid biomass due to the synergies with oil refineries and the high costs of other technologies.

[12] Committee on Climate Change (2018), Biomass in a low carbon economy
[13] HEFA (Hydrotreated Esters and Fatty Acids) is a type of biofuel that is made from vegetable and animal oils and fats or waste products such as cooking oil.

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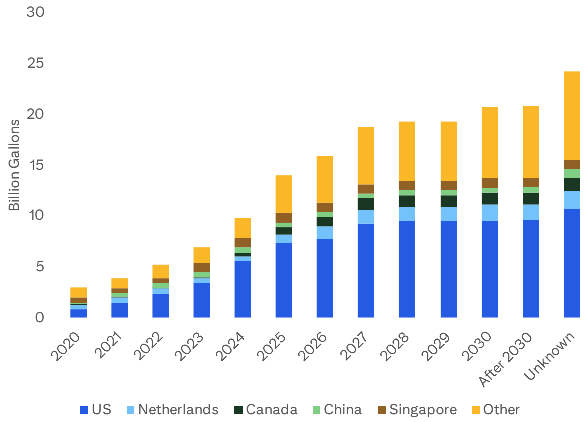
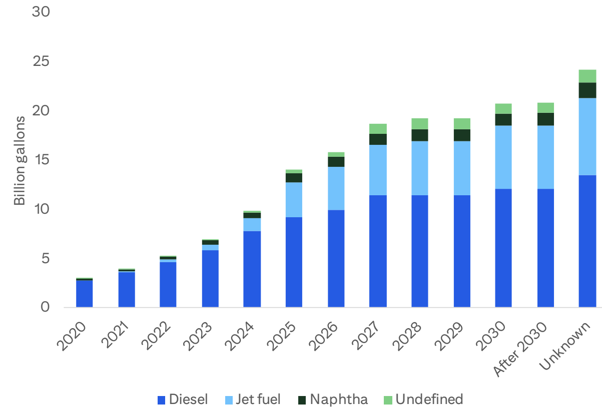
Figure 16. Cumulative renewable fuel by country



Source: Citi GPS, BNEF

Figure 17. Cumulative renewable fuel by product



Source: Citi GPS, BNEF

Challenges – the availability of sustainable feedstocks

Biomass can only contribute to emission reductions if it is sustainably sourced, with low levels of carbon emissions across its supply chain including lifecycle growth, collection, and transformation. And therein lies the problem of biomass use – it is inherently complex to ascertain the sustainability of biomass feedstocks.

However, if done well, using biomass for energy and for materials can result in low or zero emissions, because the carbon released at the point of combustion was previously removed from the atmosphere during the biomass growth.

Calculating how much sustainable biomass is available for energy transition and material use is not easy and differs immensely from one study to the next. For example, the IEA claims that between 130 and 240 EJ of sustainable bioenergy could be available by 2060. To put this number into context, globally we currently consume about 580 EJ of energy, so the IEA states that there could be enough sustainable biomass to meet 40% of today's energy demand.

However, other studies have lower estimates; for example, the Energy Transition Commission estimates sustainable biomass availability at 40-60 EJ per year under their prudent scenario, increasing to 120EJ under their ambitious scenario. Given all this, many argue that the use of biomass should be prioritized for sectors that have no alternative solution to reduce emissions such as the use of feedstock for plastics and to produce sustainable aviation fuel.

We should recognize however that these figures, indeed any estimates of the potential availability of sustainable biomass feedstocks in the future, are highly uncertain. They consider several factors, most notably yields for energy crops, policies promoting sustainable biomass, and investment.

The risk of failing to deliver sustainable feedstocks also increases as the estimates rise. While our biomass future could focus on certain feedstocks, such as agricultural waste and sustainable forestry residues, the most likely outcome is that there will be a mix of different feedstocks used for biomass production.

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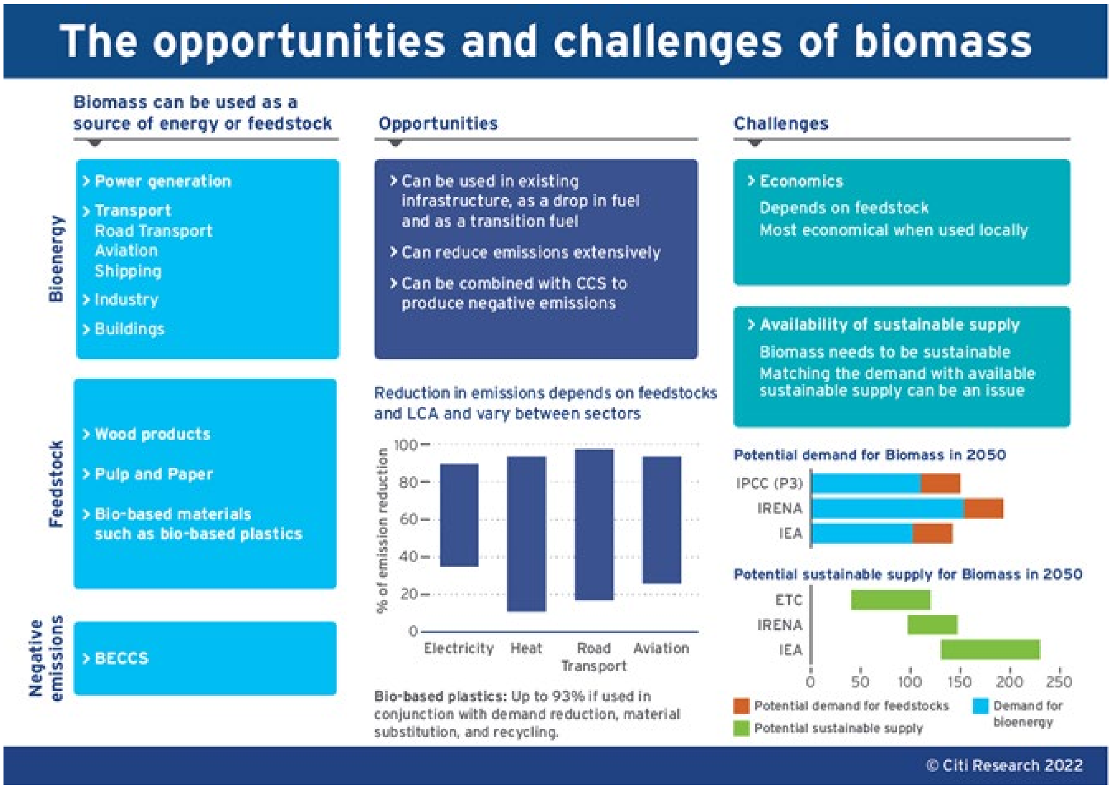
The choices also vary significantly by region. Countries in the Scandinavian region and Canada, for example, offer more opportunities for forestry residues, while countries such as Brazil and the US may continue growing energy crops as they have the right policies and investments in place. It will also be the case that biomass such as renewable diesel or biofuels will play an important part in transition fuels for road transport until other technologies could be scaled up.

Figure 18. Opportunities and challenges



Source: Citi GPS

Europe and the US have different policies and strategies in place on feedstocks. For example, the EU in its Renewable Energy Directive update (RED III) excludes biofuels made from palm oil and have a cap on crop-based biofuels. The RED III regulation also contains measures to protect inappropriate indirect land use changes and using feedstock that would otherwise be used for food production.

In addition to this, the RefuelEU legislation sets particular standards for SAF feedstocks and bans certain feedstocks such as food crops, palm oil, and soy oil and limits the use of SAF generated from feedstocks not included in the RED III Directive.

The U.S .government on the other hand has taken a different approach and allows crops such as corn and soy to be used for SAF if these are produced using climate smart methods such as no tilling, crop cover, etc.

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Looking ahead

Biomass is essential for many hard-to-abate sectors, especially the aviation industry. It can be quite confusing at the global level to determine which feedstocks could be used to produce different products, as many countries have different regulations.

However, to be effective in reducing emissions, biomass must come from sustainable sources, and given that these are limited, biomass should be prioritized for sectors that have no other solution to decarbonize; this includes the aviation sector.

We are seeing an increase in the investment for advanced renewable fuels which are essential for the aviation industry; however, as we discuss in the next section, much more is needed.

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Section 2: Sectors

Are hard-to-abate sectors investing in these solutions?

Whilst the solutions discussed in the previous chapter are costly, we were surprised to see that decarbonization of these sectors has started – at least in some countries.

This is for several reasons:

1. Legislation pushing companies to reduce emissions such as the EU ETS, SAF mandates are being introduced in various countries.

2. The availability of grants, subsidies, and tax credits is also providing incentives; however, the majority is on the supply side.

3. Clients are requesting this. For example, European auto manufacturers have become investors and offtakers of green steel. Cargo owners have set up Zero Emissions Maritime Buyers Alliance (ZEMBA) and are putting together tenders for green shipping.

4. Many commercial banks have set out net-zero commitments, and whilst they will help their clients transition, they will be less inclined to support carbon-intensive investments. Many banks are also signatories to sustainable finance principles such as the Poseidon Principles for the shipping industry, and Sustainable Finance Principles for the aluminum and steel industry.

5. The realization that this is coming, and it's better to be at the forefront than be a laggard.

Whatever the reason, progress is being made since our first hard-to-abate sectors and emissions report. We divide this part of the report into two sections: (1) transport – aviation and shipping; and (2) industry – steel, aluminum, and cement.

Transport: Aviation and Shipping

Transport-related emissions account for approximately 20% of energy-related emissions. Whilst investment for electric vehicles for passenger cars has increased in many countries, investment in decarbonization of other transport modes has been rather muted until recently. This section focuses on the progress of the shipping and aviation sector; more information on road freight is available in our previous report.

Shipping

Shipping carries approximately 80% of global trade by volume and 70% by value[14]. It is responsible for transporting more than 11 billion tonnes of goods per year and involves 2 million seafarers[15]. Shipping is recognized as one of the most efficient forms of commercial transport, although the enormous scale of the industry means it is still responsible for 3% of energy-related GHG emissions and 11% of transport-related emissions.

[14] Gray et al. (2021), Decarbonising ships, planes and trucks: An analysis of suitable low carbon fuels for the maritime, aviation and haulage sectors; Advances in Applied Energy, Vol 1, 23 February 2021

[15] Poseidon Principles, 2023 Annual Disclosure Report, December 2023

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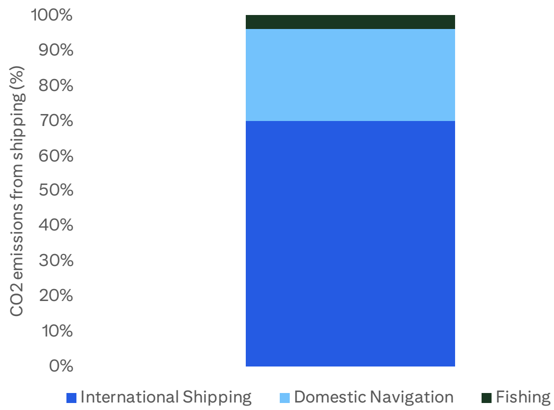
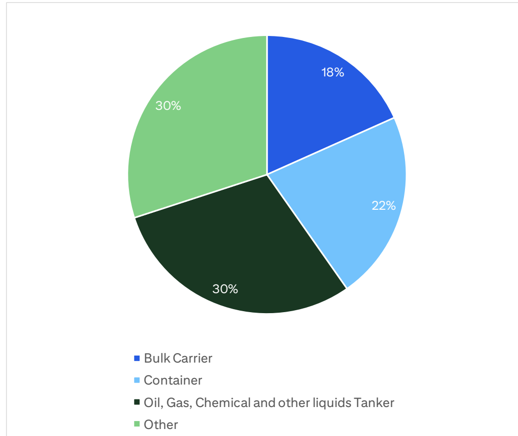
Figure 19. Emissions from shipping



Source: Citi GPS, IMO 2020

Figure 20. Share of CO2 emissions by ship class



Source: Citi GPS, IMO 2020

The shipping industry is only in the very early stages of decarbonization; however, a lot has been done over the last few years. Decarbonizing the shipping industry is complex due to the high cost of available low-carbon options; the development of distribution, storage, and bunkering facilities for low-carbon fuels; and the challenges created by long asset replacement cycles (the average lifetime of vessels is 20+ and longer for some sectors).

The sector can reduce its emissions by improving fleet management and optimizing voyage plans. It could also improve energy efficiency by improving ship design and hull and propulsion efficiency. However, the only way to fully decarbonize this sector is to invest in new technologies and alternative zero emission fuels. These can include:

- Electric engines, which are battery operated or run on fuel cells
- The continued use of combustion engines with drop-in biofuels or LNG –these options do not fully decarbonize the sector but could help reduce emissions in the short term
- The development of new engines that can run on low-carbon fuels such as green ammonia and sustainable methanol or e-methanol
- Using nuclear technologies to power commercial maritime vessels, which could reduce the need to scale up new fuels and bunkering facilities
- The possibility of onboard carbon capture facilities, which is still being debated.

The solutions chosen will vary depending on the type of ship and voyage time (e.g., battery operated ships will only be feasible for short voyages), availability of low-carbon fuel, cost and widespread bunkering facilities.

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Nuclear Power Ships

Nuclear is not a new technology in shipping; however, it has mainly been used on military ships[16]. Recently, the use of nuclear energy as propulsion for merchant ships has been discussed as a way toward decarbonising the maritime sector. Nuclear ship propulsion during operation emits no CO2 or any other particulate emissions such as NOx or SOx.

Several research projects are underway on using nuclear as a way to decarbonise the sector. For example, the American Bureau of Shipping (ABS) has published results of a study done with Herbert Engineering Corporation into the adoption of advanced nuclear reactors onboard a 14,000 TEU containership. The results show that if the container vessel was powered by two Lead-Cooled Fast Reactors, this would be sufficient to power the ship for its entire lifespan. In addition, they found that this would increase the cargo capacity of the ship and its operational speed.

Many advanced discussions are also happening within the sector. For example, H-Line Shipping, Hyundai Merchant Marine, Janggeum Merchant Marine, the Korea Atomic Energy Research Institute, and others have signed an MOU for the development of SMR-powered merchant ships. Japanese shipping giant Imabari Shipbuilding along with a dozen more companies have invested in Core Power to develop a floating nuclear power plant using SMR technology that could also one day be used by the maritime industry[17].

However, regulation, safety concerns, insurance, and liability could be barriers and further work would be needed on this front. There are already some existing IMO regulations on the operation of nuclear ships and the International Convention for the Safety at Sea (SOLAS) also has a number of criteria for the design and operation of nuclear ships. However, these need to be updated to include new nuclear technologies that are coming on to the market.

On the issue of cost, nuclear ships require a large upfront capital cost compared to other options such as low-carbon fuels.

It is not quite clear whether nuclear run ships would materialise on a large scale, but there is growing interest in the maritime sector and their importance in the race to net-zero should not be dismissed[18].

Policy and regulation

The shipping industry is principally regulated by the International Maritime Organization (IMO), which is responsible for the safety of life at sea and protection of the marine environment. The IMO has adopted comprehensive frameworks of detailed technical regulations that govern the shipping industry.

National governments, as members of the IMO, are responsible for ensuring that this legislation is enforced and the ships that are registered under their flags comply.

The IMO over the years has been criticized for not doing enough to reduce emissions across the shipping sector; however, in July 2023, the 2023 IMO Strategy on Reduction of GHG Emissions from ships (Resolution MEPC. 377(80) was adopted.

This resolution called for net-zero emissions from international shipping 'by or around' 2050. It was significantly more ambitious than its initial strategy, which aimed for a 50% reduction in emissions from international shipping in 2050 compared to 2008 levels. The IMO member states also agreed on indicative

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[16] Wang et al. (2023), Using Nuclear Energy for Maritime Decarbonization and Related Environmental Challenges: Existing Regulatory Shortcomings and Improvements, Int J Environ Res Public Health, 2023 Feb; 20(4):2993

[17] IEEE Spectrum, The case for by nuclear cargo ships

[18] Offshore Energy, SHI, KHNP and Seaborg to develop floating nuclear plants, April 24, 2023

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checkpoints for the industry for total annual GHG emissions reductions that included:

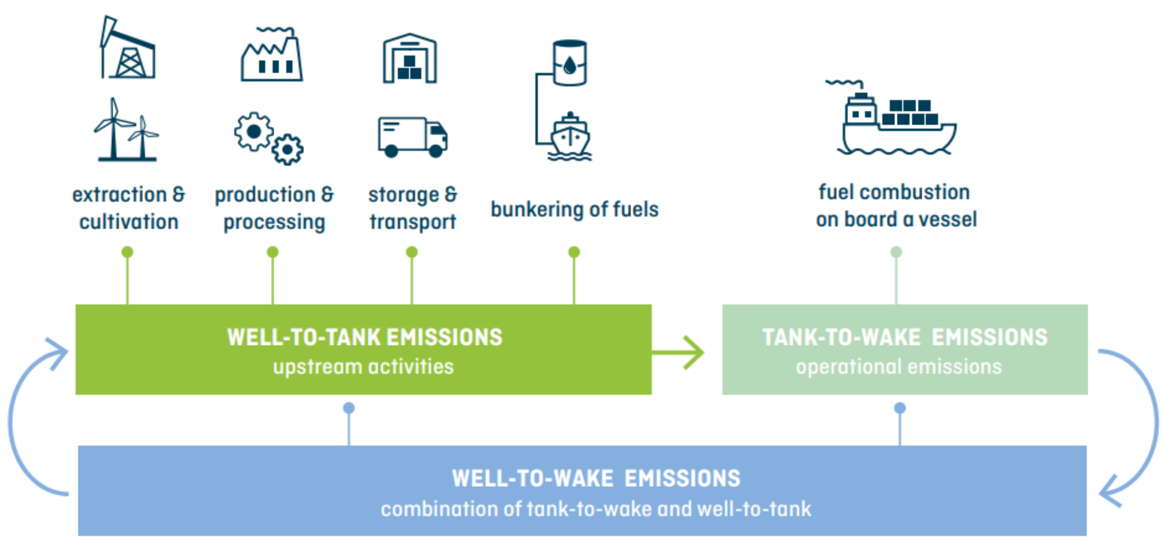
- At least 20% reduction striving for 30%, by 2030 compared to 2008 levels
- At least 70% reduction striving for 80%, by 2040 compared to 2008 levels.

It also called for an ambition for zero or near-zero emissions fuels and technologies to make at least 5%, striving for 10% of energy used by international shipping by 2030.

Another change was the inclusion of all GHG emissions and not just CO2 emissions and that the sector should take into consideration the full lifecycle emissions (well-to-wake emissions).

This could include emissions from upstream activities such as production and processing and operational activities such as fuel combustion on board. The IMO also requires shipping companies to report their Carbon Intensity Requirement (CII) that applies a rating of A-E for vessels above 5,000gt based on grams of CO2 emitted per cargo carrying capacity and nautical mile.

Figure 21. Well-to-wake emissions



Source: Citi GPS, Poseidon Principles

Besides this, for the first time ever the shipping industry has been included in a cap-to-trade system. In 2024, the EU ETS system was extended to maritime transport with compliance obligations due to be gradually phased in. Carbon allowances would need to be purchased for 40% of emissions in 2024, rising to 70% in 2025 and 100% from 2026[19].

It applies to cargo and passenger ships above 5000 GT from 2024 and offshore ships above 5000 GT from 2027. Initially, it will only cover CO2 emissions but will be

[19] BNEF, Shippers Scramble to Go Green as EU Carbon Crackdown Dawns: BNEF

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widened to include methane and nitrous oxide from 2026. General cargo and offshore ships less than 5000 GT would be required to report their emissions and could be included in the ETS system later. Shipping companies would be obliged to purchase allowances to cover:

- 50% of emissions from voyages departing from an EU port to a non-EU port and vice versa
- 100% of emissions from voyages between EU ports
- 100% of emissions from ships docked in an EU port.

To address carbon leakage, the law also specially targets non-EU ports near the EU with a high share of transshipment. The cost of compliance is expected to be significant and according to the DNV's Director of Environment Maritime Erik Nyhus could cost the industry roughly up to €10 billion per annum once fully implemented in 2026[20].

Some companies are passing the ETS cost to cargo owners. For example, Maersk has stated that there would be a standalone charge known as an Emissions surcharge that it would pass on to its clients; however, this surcharge would not be included in its Eco delivery service which currently uses biofuels for its journey.

Figure 22. EU ETS Extension to Maritime Transport

EU ETS Extension to Maritime Transport

Introduction Timeline

	2023	2024	2025	2026	2027	2028+
Ship sizes and types		MRV Review		EST Review		
Cargo / Passenger ships* (5000 + GT)			First surrendering year on 2024 emissions			
Offshore ships (5000 +GT)	–	–				First surrendering year on 2027 emissions
Offshore and general cargo ships (400 – 5000 GT)	–	–			Inclusion in the EU ETS to be considered as part of the ETS review	
Greenhouse Gases						
Carbon Dioxide (CO_2)						
Methane (CH_4) and Nitrous Oxide (N_2O)	–					
Phase-in						
% of emissions to be surrendered as per the EU ETS Directive		40%	70%	100%	100%	100%

*Ships already covered today by the EU MRV regulation — Under MRV Scope — Under MRV and EU ETS Scope

Source: Citi GPS, adapted from the European Commission

In addition, as part of the EU Fit for 55, the EU Council has adopted the FuelEU Maritime Initiative which promotes the use of renewable, low-carbon fuels and clean energy technologies for ships. This will come into force in January 2025.

[20] DNV, Emissions data tracking key to EU ETS and CII cost management

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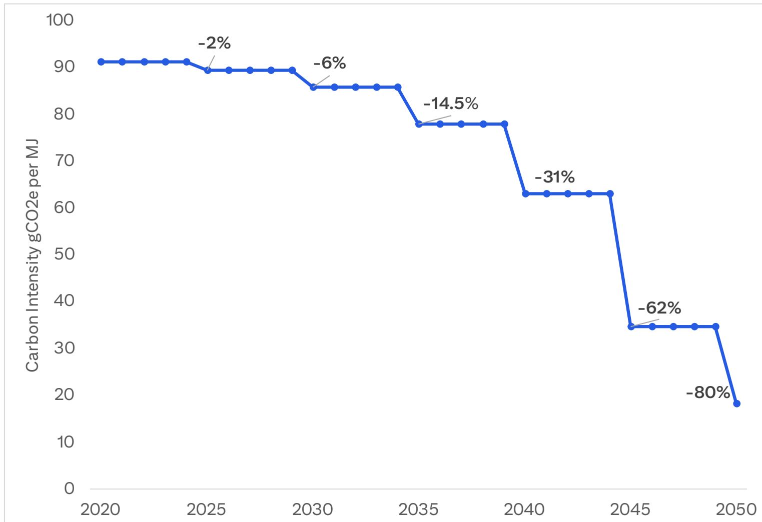
The legislation states that all vessels that are subject to the EU ETS system will also have to comply with a GHG intensity metric relative to a 91.16GCO2e per megajoule of fuel.

These targets as shown below become more stringent in the following years, reaching -62% compared to 2020 levels in 2045. However, the EU has agreed that it would defer to the IMO if it executes against its revised ambition. This would be a relief to the maritime sector as the proposed regulation will be difficult and bureaucratic for shipowners to report against.

Figure 23. FuelEU Maritime targets relative to 2020 level



Source: Citi GPS, BNEF

Other initiatives

It is not only regulation that is encouraging the shipping sector to decarbonize; other initiatives such as the Poseidon Principles, The Sea Cargo Charter, and the Zero Emission Maritime Buyers Alliance (ZEMBA) are also having an impact. We discuss some of these initiatives below:

The Poseidon Principles provide a global framework for integrating climate considerations into the lending decisions to promote the decarbonization of the shipping sector. They were the world's first sector-specific, climate agreement amongst financial institutions.

These principles were spearheaded and developed by global banks including Citi, Societe Generale, and DNB in collaboration with leading maritime companies and supported by the Global Maritime Forum, Rocky Mountain Institute (RMI), and UMAS.

Signatories to the Poseidon Principles include 35 leading banks, jointly representing 80% of global shipping finance. Signatories commit to report each year the climate alignment of their shipping portfolio each year through a climate alignment score.

The **Sea Cargo Charter** is similar in principle to the Poseidon Principles – it provides a global framework for aligning chartering activities within responsible environmental behavior to promote the decarbonization of shipping.

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It is not only banks and chartering activities that are making a difference. Cargo owners that want to reduce their scope 3 emissions have set up the **Zero Emissions Maritime Buyers Alliance (ZEMBA)**. It is a buyers' group within the maritime sector with a 'mission to accelerate commercial deployment of zero-emission shipping solutions.'

ZEMBA aggregates the demand for zero emission shipping with other companies and puts out a tender for zero emissions shipping. Given that the demand is aggregated, this reduces costs and enables early access to net-zero shipping.

The organization has just concluded its first tender for shipping that achieves 90% reduction in GHG on a lifecycle analysis compared with fossil fuels. More than a dozen companies would benefit from this deal, including Amazon, Patagonia, and Nike. The winner of this tender was Hapag-Lloyd that powers ships using waste-based biomethane. ZEMBA signals to the market that there is already demand for zero emission shipping, which is essential to help scale up the low-carbon solutions for the shipping sector.

Update on sector

The shipping sector is at an early stage of decarbonization, but we are seeing some good projects and initiatives that are taking place.

The **Green Corridors Initiative** which was set up in COP26 under the Clydebank Declaration has seen some significant progress. Creating specific trade routes where decarbonization efforts can be scaled up, including setting up regulatory measures, safety regulations, and financial incentives, can speed up the sector's decarbonization efforts.

They could encourage companies to set up joint ventures and collaborate together whilst also encouraging the public sector to support new infrastructure that is needed, such as the distribution of new fuels and bunkering facilities. There are currently 44 green corridors that have been initiated, some more advanced in planning stages than others, and 171 stakeholders are involved including industries, governments, ports, regulators, and others.

A mixture of energy sources will be used in these green corridors, including methanol, ammonia, electricity, advanced biofuels, and others.

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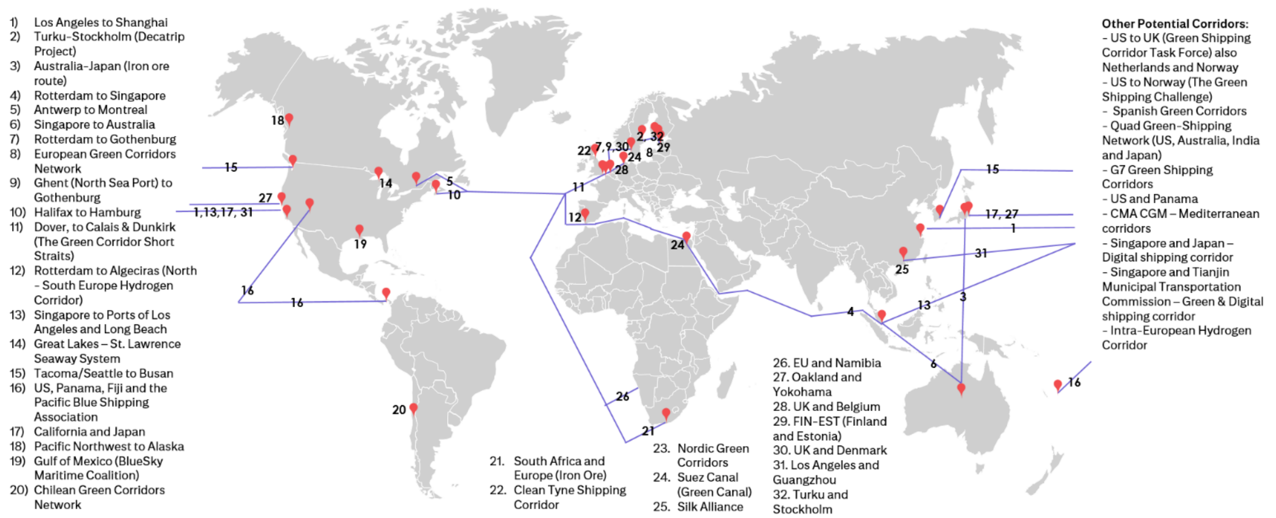
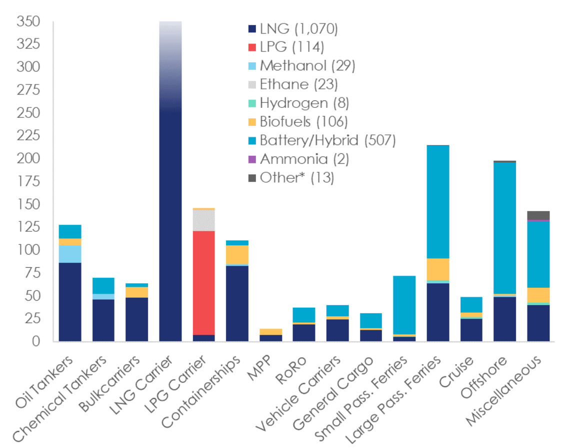
Figure 24. Green Corridors



Source: Citi GPS, Clarkson Research

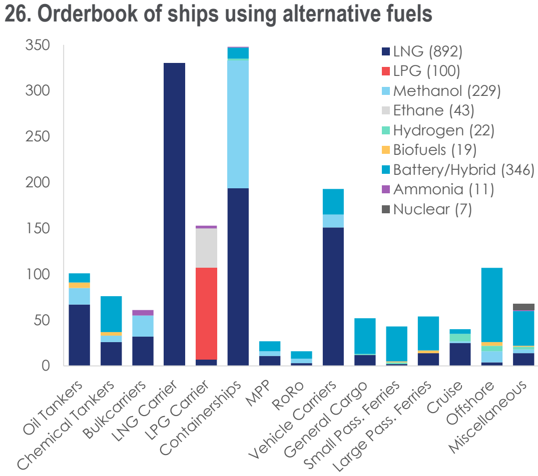
In addition, according to Clarksons Research, 6% of fleet in gross tonnage (GT) is already using alternative fuels as shown in the diagram below. This 6% also includes ships operating on LNG, which is seen as an important transition fuel. 29 ships in operation are already using methanol, whilst 507 are battery/hybrid. There are however a lot more ships on order that will use alternative fuels as shown in the diagram below – more than 200 methanol ships, 346 battery/hybrid operated,11 ammonia ships, and 7 nuclear. The ships on order today will stay in operation at least until 2050. The industry has not yet crowded around one particular solution, and for a while there will be a mix of solutions that the sector will invest in.

Figure 25. Fleet (100+GT) using alternative fuels (6% of fleet GT)



Source: Citi GPS, Clarkson Research

Figure 26. Orderbook of ships using alternative fuels



Source: Citi GPS, Clarkson Research

Looking ahead

The maritime industry has come a long way, but more needs to be done. The IMO's decision to finally commit to net-zero and the inclusion of the maritime sector in the EU ETS system will push the industry further. Uncertainty abounds as to which solution is most feasible over the long term, and this uncertainty could delay the sector to invest in new zero-emission ships.

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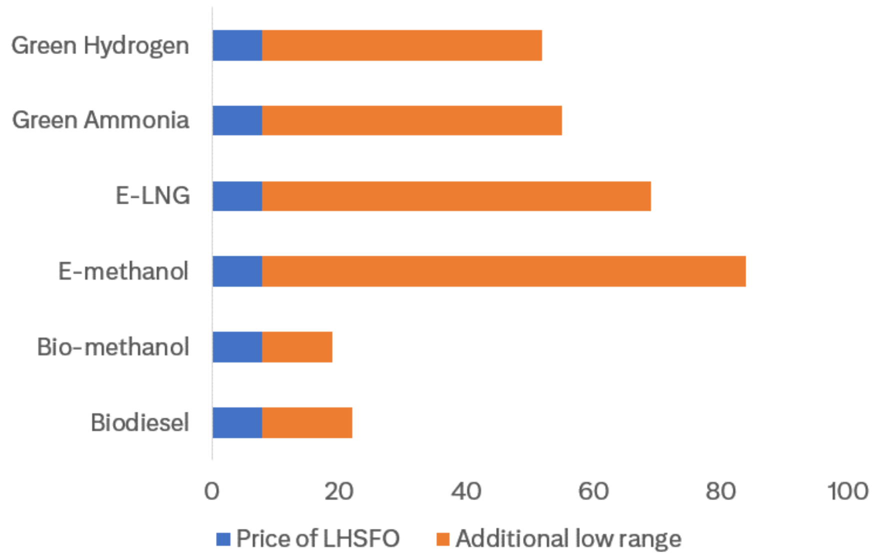
The cost is the most significant barrier (see diagram below), however, what is clear is that cargo owners are willing to pay a premium for green shipping as we have clearly seen from initiatives such as ZEMBA, which include large retail players such as Amazon. A market is being created as we speak. The uncertainty just needs to settle.

Figure 27. Cost premiums for various alternative fuels



Source: Citi GPS, Lloyds Register and UMAS

Aviation

The aviation industry is responsible for 12% of transportation sector's emissions and 2% of energy-related GHG emissions.

The domestic aviation emissions (including airport emissions and emissions from ground service equipment) are covered under countries' net-zero pledges, but international flights that represent 65% of the aviation's CO2 emissions are instead covered by the UN's International Civil Aviation Organisation (ICAO).

ICAO adopted a long-term aspirational goal of net-zero emissions by 2050; this goal reinforces the industry's commitment to reduce emissions as expressed by Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The aim is to address any annual increase in total CO2 emissions from the international civil aviation above 2020 levels and contribute to the industry's commitment to carbon-neutral growth from 2020[21]. However, as we will see from this chapter, over the last few years national governments have also set up policies, strategies, mandates, grants, and tax credits to encourage the aviation industry to decarbonize and to help scale up the solutions needed. Before we discuss this, it is important to take a step back and understand the solutions that the aviation sector has available to reduce emissions.

[21] Citi GPS, Hard-to-abate sector and emissions, the toughest nuts to crack for a net-zero future

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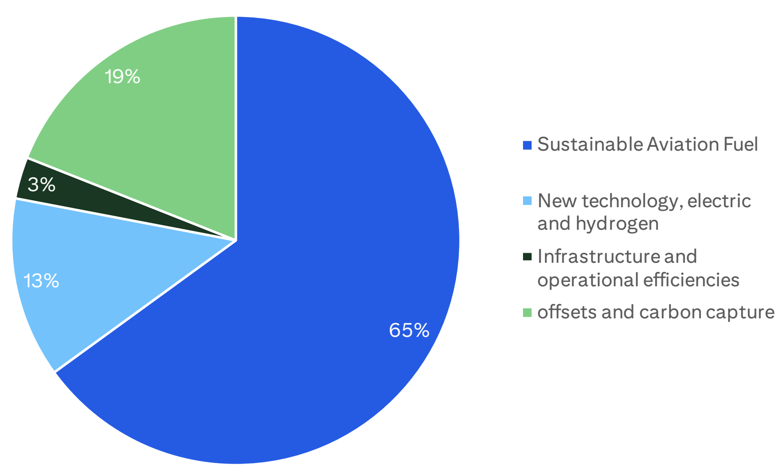
Solutions to decarbonize

The aviation sector's route to net-zero will require the deployment of multiple technologies and tools across the industry, some of which are not yet fully commercialized. These include:

- Aircraft technological improvements such as a reduction in weight, improvements in aerodynamics, and use of systems to improve the efficiency during the operation of the aircraft
- Operational improvements such as structural changes in air traffic management, energy savings at airports, single engine taxi, and reduced taxi times
- Sustainable aviation fuels that can reduce emissions up to 90% depending on feedstock; these could include fuels made from sustainable biomass and also synthetic fuels also known as e-fuels, power to liquid of hydrogen derivative fuels
- New hydrogen or electrical aircraft for short/medium haul flights
- The use of market-based systems such as carbon credits/offsets as stated in CORSIA. We discuss CORSIA in more detail in our previous report on hard-to-abate sectors.

According to International Air Transport Association (IATA), achieving net-zero for the aviation industry would require a combination of the above solutions, with 65% of emission reductions coming from the use of sustainable aviation fuel as shown in the diagram below.

Figure 28. IATA Net-zero Scenario includes a combination of solutions



Source: Citi GPS, IATA

Update on policies and legislation

Over the last few years there have been a plethora of policies, legislation, and strategies that have been introduced in many countries on green aviation. The map below shows some of these policies across various countries, and a detailed description can be found in the appendix.

Several countries have introduced SAF mandates. For example, the Refuel EU Aviation which is part of the EU Fit for 55 Initiative has set up mandates for fuel suppliers to make a minimum share of SAF available to EU airports starting in 2025. The mandates are phased in as follows:

- 2% of SAF in 2025
- 6% of SAF in 2030
- 70% in 2050
- From 2030, 1.2% of fuels are to be synthetic; this increases to 35% in 2050.

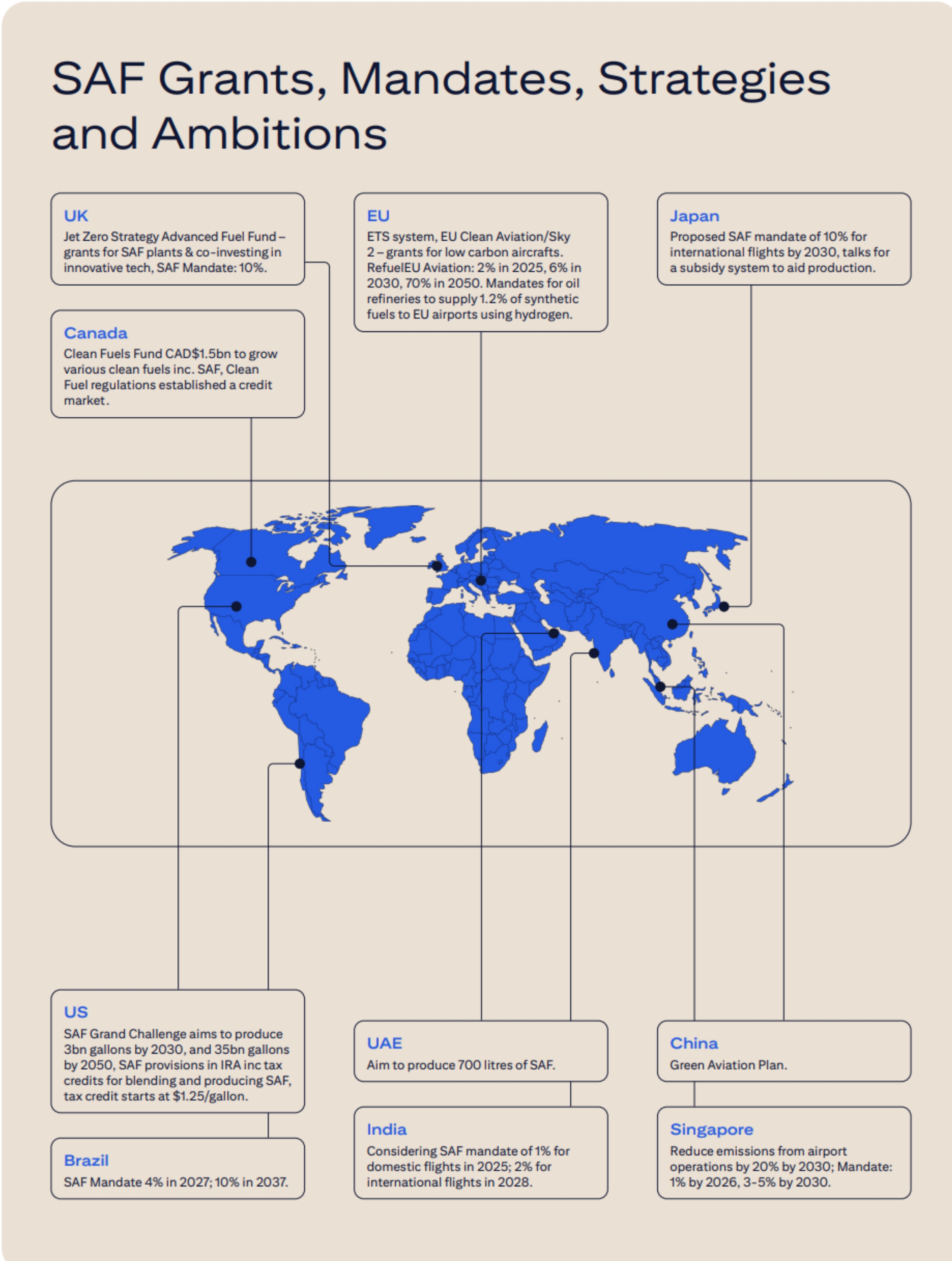
The legislation also requires airports with passenger traffic greater than 800,000 per year or greater than 100,000 tonnes freight per year to facilitate access to SAF. Other countries with mandates for SAF include the UK (10% by 2030), Singapore (3-5% by 2030), and Brazil (10% in 2037).

The EU ETS system has included aviation since 2012; however, this sector has benefitted from free allowances over these years. These will be phased out gradually – reducing to 75% in 2024, 50% in 2025, and 0% from 2026 onwards.

This is applied solely to intra-EU flights and not international flights; however, the EU Commission has stated that this will be extended to all flights unless CORSIA which is under the remit of ICAO is 'positively evaluated'[22].

[22] IATA, EU ETS reform destabilizes international consensus for aviation carbon reduction

Figure 29. Policies on SAF in various countries/regions



Source: Citi GPS

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The US has also introduced its SAF Grand Challenge, aiming to expand SAF production to 3 billion gallons per year and wants to increase this to 35 billion gallons by 2050[23]. To help achieve this, the US government has introduced five years of tax credit support for SAF through the Inflation Reduction Act. In 2023 and 2024, SAF will qualify for a revised blenders tax credit (40B).

Eligible producers can apply to obtain a $1.25 to $1.75 credit for each gallon sold of SAF depending on the percentage of emission reductions compared to conventional jet fuels. To calculate lifecycle analysis of SAF, the US government introduced a model called SAF-GREET which has just been updated and, contrary to the EU, includes certain crops such as corn and soybeans as feedstocks.

They can only be included if these crops are grown using climate smart agriculture practices such as no tilling, the use of cover crops, etc.[24]. From 2025, this tax credit will be replaced by Clean Production Credit (45Z), which is about half of the revised blenders tax credit.

The US government also set aside $244.5 million in grants through the Fueling Aviation Sustainable Transition (FAST) to support projects for SAF production, transportation, blending, and storage. Grants are also available in other countries such as Canada through their Clean Fuels Fund, which supports all clean fuels including SAF. Most of the policies and grants available are in the EU and North America, with very limited policies available in other regions such as APAC and MEA.

In addition, the Pegasus Guidelines have been set up by RMI in cooperation with global leading banks including Citi and in consultation with the aviation industry. These are similar to the Poseidon Principles established for the shipping industry. The aim of the framework is to help banks to independently measure and disclose the climate alignment of their aviation lending portfolio.

Update on progress

Many airline companies have a goal for SAF to make up 10% of their overall jet consumption by 2030. There are, however, some differences across regions. For example, Singapore has set up a lower target of 5% by 2030, whilst freight carriers such as DHL and FedEx aim for 30% by the same date[25].

[23] U.S. Department of Energy et al, SAF Grand Challenge Roadmap, Flight plan for Sustainable Aviation Fuel
[24] U.S. Department of the Treasury, IRS Release Guidance to Drive American Innovation, Cut Aviation Sector Emissions, April 30, 2024
[25] BNEF, 2024, Sustainable Aviation Fuel Outlook, Match 5, 2024

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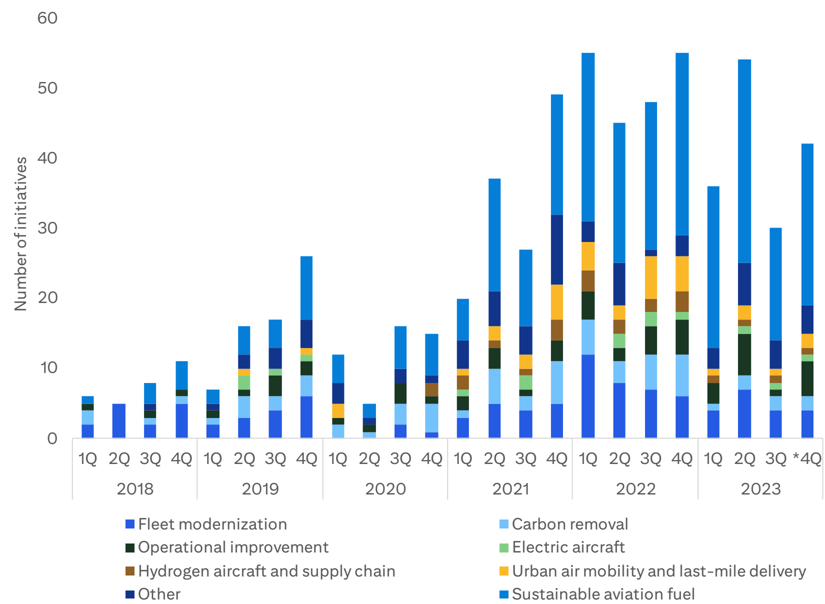
Figure 30. Airline decarbonisation strategy trends



Source: Citi GPS, BNEF

Spurred by regulation and the available grants, we are now seeing the aviation industry scale up investment in SAF to meet their overall commitments. More than 100 agreements between SAF producers or distributors and aircraft operators have been identified since 2019.

Many airlines that are investing in SAF are focusing on the development of alternative SAF methods and not just HEFA such as synthetic fuels or alcohol-to-jet pathways (refer to previous hard-to-abate sectors for a description of different pathways to make SAF). SAF availability at airports is also improving. In 2016 only two airports received ongoing SAF deliveries; this has now increased to 80 airports across the world.

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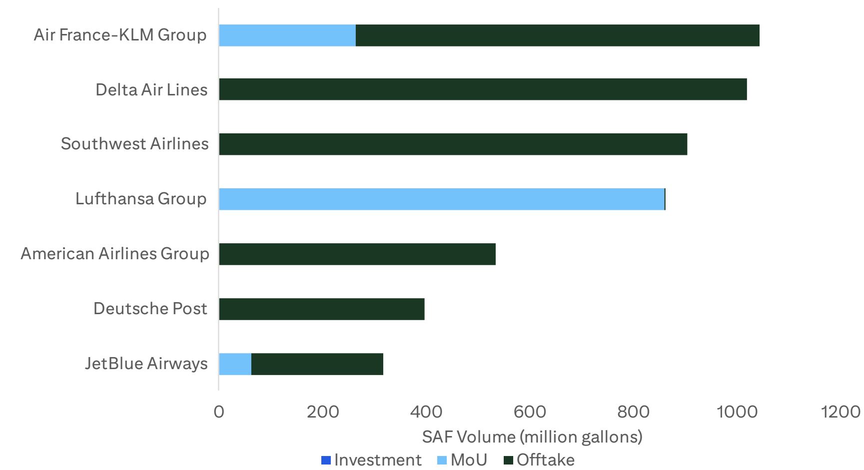
Figure 31. Example of SAF offtakes by airline

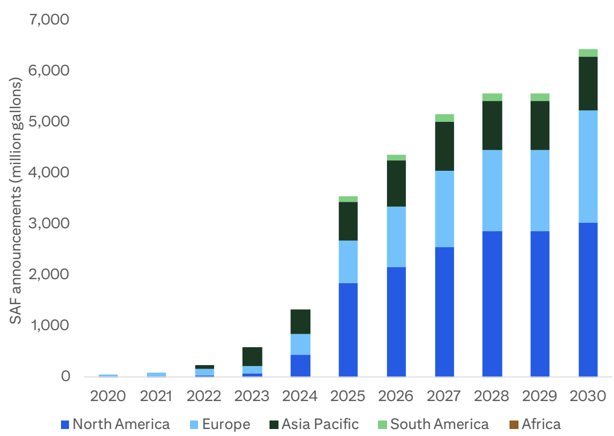


Source: Citi GPS, BNEF

As of March 2024, a cumulative total of 6.7 billion gallons of SAF has been announced up to 2030; this is approximately 5.4% of current global jet fuel demand. This is still very small compared to 105.7 billion US liquid gallons (425 billion litres) of SAF that is needed[26].

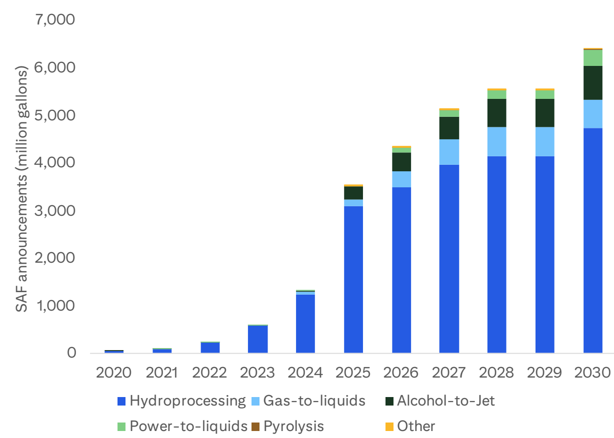
The number of announced projects is changing all the time, and it is unclear how many projects would materialise. The majority of the announced projects are in North America and Europe. The HEFA pathway is still the most dominating source of SAF thanks to the synergy with current refineries; however, other forms of SAF such as those produced from power to liquids and alcohol to jet start to increase from 2025 onwards.

Figure 32. Announcements on SAF by region as of March 2024



Source: Citi GPS, BNEF

Figure 33. Announcements on SAF by feedstock as of March 2024



Source: Citi GPS, BNEF

[26] According to IATA, 450 billion litres (approximately 105 billion gallons) are needed to decarbonize the aviation industry.

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Book and claim system

Due to limited availability of SAF, some airlines are exploring a 'book and claim' system. This is a chain-of-custody model in which the administration record flow does not necessarily connect to the physical flow of the product throughout the supply chain.

This enables airlines and corporates to purchase SAF credits/certificates that represent emission reductions from the use of SAF, without actually fueling their plane with SAF. It allows airlines to buy SAF from the available global pool rather than be limited to the 80 airports that supply the fuel. SAF credits/certificates can also be purchased in advance of the fuel actually being delivered.

For example, Microsoft made a deal with World Energy, a SAF producer, for the displacement of 43.7 million gallons of traditional fuel with low-carbon SAF fuel. It is a 10 year-book and claim system enabling companies like World Energy to have upfront investment to grow and reduce emissions from Microsoft's business travel and supply chain.

The physical production of SAF is tied to certificates, which are independently accredited, tracked, and verified using a digital chain of custody method. Deals like this show that decarbonizing aviation is not only important for airlines but also important for their corporate customers that want to reduce their scope 3 emissions. A similar system is also being developed for the maritime sector.

Other innovations

There are also several types of low-or-zero emissions propulsion airplanes being developed, which can be categorized as battery-electric, hydrogen fuel cell, and hydrogen combustion. For example, Airbus has plans through its ZEROe projects to create airplanes using hybrid hydrogen-electric fuel cells or direct hydrogen combustion.

They plan to enter the market in 2035. There are also start-ups that are entering the market. For example, 15 start-ups have signed some sort of agreement with different customers such as airlines, aircraft lessors, and charter services. These are for small aircrafts with fewer than 100 seats and will be used for short-haul flights of fewer than 1000 km.

Governments are also piling in grants and innovation funds to scale up this innovation. The EU is providing grants for innovations on new aircrafts such as electric powered, hydrogen and efficiency improvements through its Clean Aviation/Clean Sky 2 programs. The US has R&D initiatives such as NASA's CHEETA and the Department of Energy's ASCEND and REECH. China also has a Green Aviation and Manufacturing Development Outline, which lays out targets for zero emission aircraft development.

So, there is substantial movement by many governments to create zero emission propulsion systems, but they will take a while to come onto the market and will most likely be available for short-haul flights. SAF currently remains the most viable option to decarbonize the sector.

Looking ahead

The biggest barrier to decarbonizing the aviation industry is cost. Since airlines do not manufacture the aircraft themselves or produce the fuel they are reliant on, they need others to create technical advances. Currently, SAF must be blended with jet fuel; however, there are new aircrafts being developed that can run on 100% SAF fuels. Virgin Atlantic inaugurated the first-ever 100% SAF flight which flew from London to New York. The majority of SAF today is produced from hydrotreated

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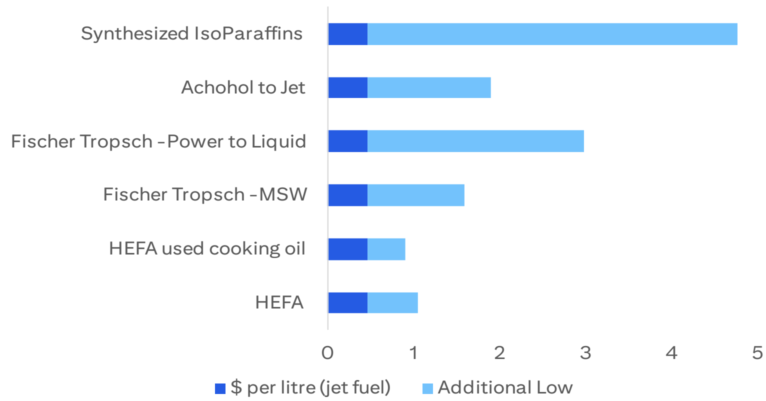
esters and fatty acids (HEFA) which uses vegetable oils, waste oils or fats as feedstocks; however, synthetic fuels also need to be scaled up.

Airlines are investing directly in companies to help them scale up sustainable aviation fuel. Governments are also providing grants and other support to help scale up some of the initiatives, but more needs to be done. The volume of SAF needed is enormous; we need to go from producing 6 billion gallons in 2030 to 105.7 billion US gallons in 2050, which will require significant investment. The cost premiums for SAF are high as shown in the figure below. In the near term, it is more likely that the sector would use carbon credits to reduce their emissions through CORSIA.

Figure 34. Cost Premiums for SAF based on different technologies (lowest prices)



Source: Citi GPS, Pavlenko et al. (2019), EASA EEA & Eurocontrol (2019), van des Smar et al. (2021). Note: Costs refer to the minimum viable selling price that may differ from final sales price which supplies may ask for. These costs are based on proving SAF in the EU, and they will be different in other regions.

The big question is who is going to pay for this transition at least until costs reduce? According to IATA, sustainable measures would add as much as $73 to the cost of a one-way seat on a flight from New York to Paris. To some, this might not seem so much at first, but if you are a family of four you will be feeling the pinch. Charging business passengers the premium could be the best solution, as many corporates are also trying to reduce their scope 3 emissions which includes business travel.

Summary on transport

There are many similarities between the aviation and the maritime sector. For example, they share similar solutions and will compete for these solutions (e.g., synthetic fuels) and they also need to invest in transportation and storage of the low-carbon fuel in ports and in airports, which is not easy. Regulation is pushing these sectors to start investing in solutions.

The major difference, however, is that the maritime sector has clients such as cargo owners that are willing to pay a premium for green shipping, However, in the aviation sector it is not quite clear who this will be – it might be corporates that want to reduce their scope 3 emissions and that could afford to pay this premium. Both sectors have started to decarbonize and scale up solutions; however, there is a lot more that needs to be done. As of now, the aviation sector will only manage to produce SAF to replace 5.4% of current global jet fuel demand in 2030. The problem is not with the demand for SAF. It is significantly scaling up the supply that is the issue.

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Industrial Sector

The industrial sector is currently responsible for approximately 20% of global energy-related CO_2 emissions. While the majority of direct emissions (produced on-site) come from energy production of fossil-fuels, CO_2 emissions can also result from leaks and chemical transformations.

The industrial sector encompasses a wide range of processes and product manufacturing, but some of the most energy and emission-intensive sub-sectors include the production of iron and steel and cement.

According to the IPCC, to limit global warming to 1.5 degree C, it would require the industrial sector to reduce its direct and indirect emissions by 75-90% by 2050.

Some industries that use electricity as their main energy source can easily decarbonise by investing in low-carbon electricity sources such as renewables.

However, there are other sectors whose emissions are harder to abate, mainly because they use fossil fuels as both an energy source and a feedstock, require high temperature industrial heat, or because their emissions result from chemical reactions occurring in industrial processes rather than from the combustion of fossil fuels (process emissions). It is estimated that one-quarter of industrial emissions are process emissions.

As we highlighted in our previous report, there are several potential solutions to reducing CO_2 emissions from these hard-to-abate sectors; these include material and energy efficiency improvements, fuel and feedstock switching such as the use of hydrogen, process innovation, and CCUS.

As we will see in this chapter, decarbonization has started. But many sectors are investing in a diverse set of fuels and technologies and have not yet settled on any one solution. Regulation, subsidies, and the availability of these resources in different countries will ultimately influence the decisions taken by this sector. Before we discuss the progress in these sectors, it is important to look at some of the policies that are pushing the industry.

Regulation and policies

Government policies have been instrumental in pushing the industrial sector to seek out solutions to reduce emissions. Some of these sectors such as the steel industry have extremely tight margins, so government support is essential.

In Europe, it is the ETS system that is encouraging the industry to decarbonize coupled with the availability of grants from EU innovation fund and other economic instruments from individual governments. The ETS system covers energy-intensive industries including oil refineries, steel works, and production of iron, aluminum, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids, and bulk organic chemicals[27].

Over the years, free allocations of allowances have been given to industrial sectors due to the risk of carbon leakage; however, this is set to come to an end. In fact, by 2034 free allocations for energy-intensive industries will be revoked and funds obtained from the EU ETS system will shift toward the EU Innovation Fund. Many

[27] European Commission, Scope of the EU Emissions Trading System

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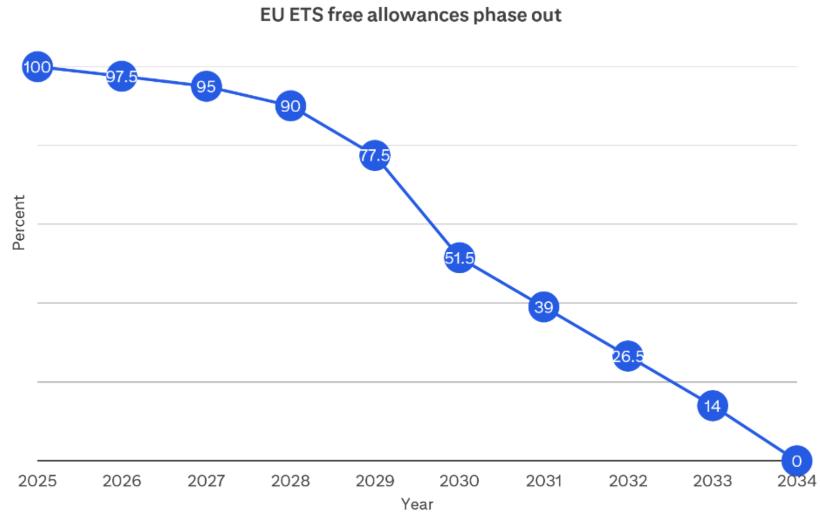
industrial players are already benefitting from grants obtained from the EU Innovation Fund to build new green capacity.

The phase out of these free allocations will occur gradually as shown in diagram below and will align with the introduction of the Carbon Border Adjustment Mechanism (CBAM).

Figure 35. EU ETS free allowances phase out for energy-intensive industries



Source: Citi GPS, International Carbon Action Partnership

Carbon Border Adjustment Mechanism

CBAM is a policy that targets the imports of certain carbon-intensive goods into the EEA, which includes 27 EU member states along with Liechtenstein, Norway, and Iceland; Switzerland has opted out. It is a customs tariff on the emissions content of specific goods.

A three-year transition period began in October 2023, which requires exporters to the EU to calculate and disclose emissions of these goods according to the EU Commission's default values. CBAM itself will gradually start from 2026.

Countries that have similar carbon taxes or cap and trade systems would be able to claim back the difference to what is being charged in the country of origin and to what is being paid in the EU under this system. Exporters would need to purchase a CBAM electronic certificate for each tonne of emissions embedded in these products. They then surrender CBAM certificates – one for each tonne of reported direct emissions tagged to ETS price as calculated on a weekly basis.

It is not yet quite clear what impact CBAM would have on industrial manufacturing outside of the EU borders, whether this would encourage industrial production globally to decarbonize or at least direct cleaner manufacturing to the EU with the more carbon-intensive production exported to other countries outside of the EU borders.

Citi Research has written extensively on this subject where they calculate which countries could be most affected by this piece of legislation and the cost that CBAM would have on the price of different materials. The introduction of CBAM might create some sort of competitive level field for energy-intensive industry in the EU, but according to Citi Research analysts it is not a silver bullet.

Government policy in the US focuses on green public procurement and the availability of grants and tax credits for energy-intensive industries. The 'Invest in America Agenda' includes a green public procurement initiative whose aim is to provide a market for low-carbon materials and other products by prioritizing steel,

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concrete, asphalt, and flat glass with lower emissions for federal procurement and funding processes.

The US government also introduced two tax credits: the Qualifying Advanced Energy Project Tax credit also known as 48C which is a competitive funding opportunity (budget of $10 billion) that supports manufacturers to expand energy projects and the Advanced Manufacturing Production Credit (45X) which is focused on providing incentives on the domestic production of critical materials and includes aluminum production.

Both India and China have also introduced regulation and targets. The Perform, Achieve, Trade (PAT) scheme in India sets energy-saving targets for emission-intensive sectors including aluminum, cement, iron, and the steel industry. It provides certificates based on achievement of these standards, which can be traded through a market-based system.

In China the government has set a goal to produce 15% of its crude steel using the electric arc furnace (EAF) route by 2025, which would cut emissions from the sector by 8.7%[28], and it is also pushing aluminum smelters to move into areas that are rich in hydro resources. These two countries really matter, as the majority of the production and the future demand for materials such as steel and cement will occur in these countries.

So, given this push from several governments, has the industrial sector started its journey to decarbonisation and is it investing in solutions. In the next section, we take a deep dive into three sectors: steel, aluminum, and cement.

Steel

The steel industry is currently responsible for 7% of global emissions and almost 30% of industrial emissions[29]. Steel is an important metal for many industries including building and infrastructure, domestic appliances, automotive, and other transport systems, metal products, and electrical equipment as shown in the diagram below.

[2828] Reuters (2024), China lags in efforts to achieve 2025 green steel goals, analysts say
[29] BNEF, Decarbonising Steel, 2021

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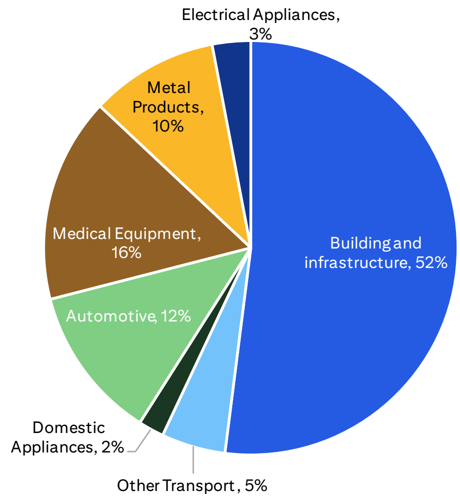
Figure 36. Steel use by sector



Source: Citi GPS, World Steel Organisation

There are two process routes that dominate today's steel manufacturing process. The first is the blast oxygen furnace (BF-BOF) route that uses coal and iron ore to produce steel and represents most of today's primary production (72%). The second is electric steelmaking based on EAF.

In an EAF plant, either steel scrap is used as a feedstock or direct reduced iron (DRI – requires iron ore as a feedstock and is usually produced using natural gas). BF-BOF plants are more carbon-intensive than EAF plants and emit on average 2.1 tonnes of CO2 per tonne of crude steel (CS). EAF are less carbon-intensive and on average EAF using scrap metal emits 0.5 tonnes of CO2 per tonne of CS produced whilst DRI-EAF emits 1.2 tonnes CO2/t CS.

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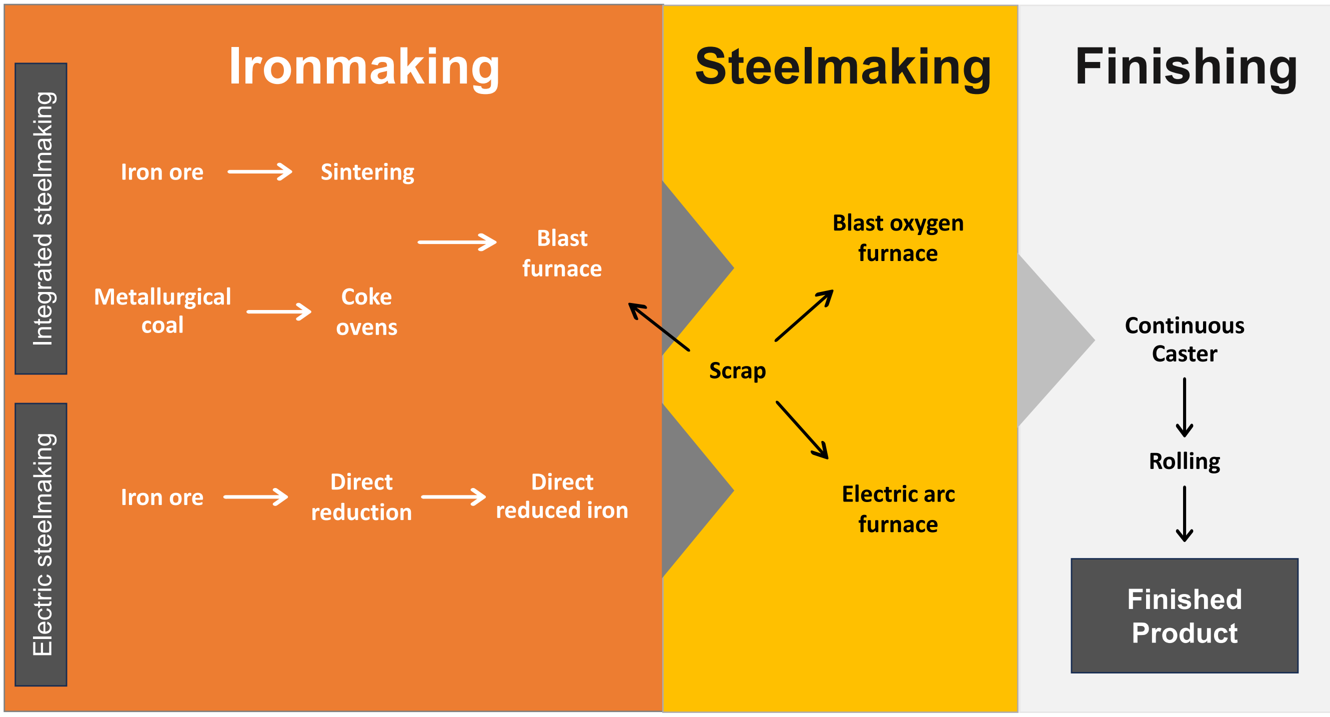
Figure 37. Steel making processes

Major Steelmaking Process Routes.



Source: Citi GPS, Adapted from BHP Steelmaking process routes

The mix of process routes varies among different countries. For example, China which produced 54% of total crude steel in 2022 was mostly reliant on the BF-BOF production route and uses coal as the major source of energy.

On the other hand, places like the Middle East and the US use electric arc furnaces, either using steel scrap as an input or direct reduced iron with natural gas.

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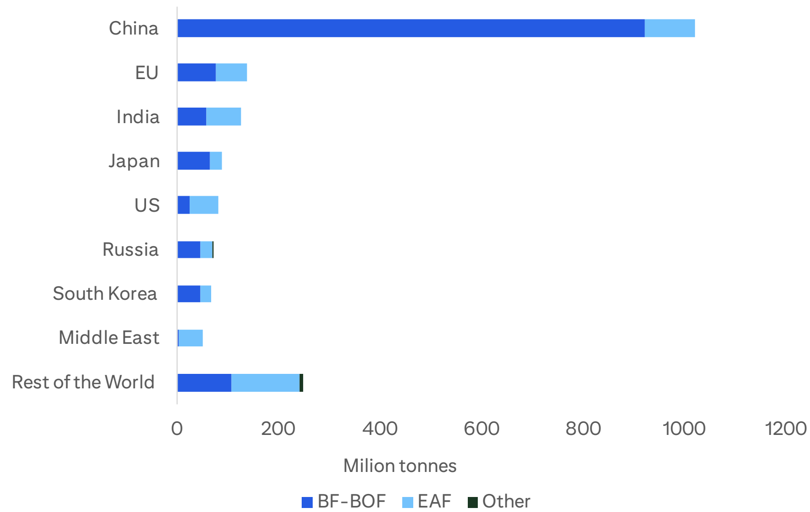
Figure 38. Steel production in various countries/regions by process



Source: Citi GPS, World Steel Association

As we have highlighted in the previous hard-to-abate sector GPS report, the steel industry has several different pathways that it could take to reduce emissions. These include:

- Demand side solutions such as lightweight design, greater reuse of building components, and greater efficiency in building construction
- Energy efficiency improvements
- Increase in the use of recycled steel, which would increase the production of steel using the cleaner EAF route
- The use of biomass or hydrogen to replace fossil fuels used in steel making; this could help decarbonize DR-EAF production, but it won't fully decarbonize the BF-BOF process route
- The use of CCUS especially for BF-BOF plants, which cannot be totally decarbonized by using other resources
- New technologies such as direct electrolysis or electrowinning (refer to box below).

The solutions that will be implemented would differ by country and depend on factors such as the age of existing assets, the competitiveness of various technological solutions, the availability of steel scrap, the availability of good quality iron ore for DR-EAF plants, and the availability of local energy sources. For example, areas that are accessible to low-cost green electricity and natural gas might favor switching to DR-EAF with the intention of using clean hydrogen in the future.

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New Technologies

Molten Oxide Electrolysis is a new technology invented by Massachusetts-based Boston Metal. This new process uses renewable electricity to convert all iron ore grades to high-quality liquid metal. Several steps in steel making are eliminated, such as coke production, iron ore sintering and pelletizing, blast furnace reduction, or basic oxygen furnace refinement. This process consists of an inert anode that is immersed into an electrolyte containing iron ore, and then it is electrified. When the cell heats to 1600oC, the electrons split the bonds in the iron oxide in the ore, producing pure liquid metal. This process does not generate CO2. Unlike EAF-DRI systems, this method can work with low-quality iron ore.

Another start-up company Electra is leveraging proven industrial-scale electrochemical and hydrometallurgical processes to produce emission-free iron. They convert iron ore into iron metal through patented electrochemical process operating at just 60oC and powered by renewables. Similar to MOE, this process can be used with all qualities of iron ore.

Both companies have currently received significant funding and if economical can revolutionise the iron and steel industry. Large steel producers are also investing in new technologies. For example, Siderwin is a project funded from the EU Horizon project that aims to develop an innovative electrochemical process to transform iron oxide into steel metal plates.

Update on sector

Many steel companies have set up net-zero commitments, but they differ per region. For example, European steelmakers have the most ambitious targets due to EU legislation and a direct push from clients such as the European auto manufacturers. Asian steel makers are lagging their European counterparts and have the additional burden of having invested heavily in the production of steel through BF-BOF process, which is more difficult to decarbonize.

There are also fewer government policy initiatives such as grants or funding available in these regions. However, it is expected that the introduction of CBAM would have a material impact on the price of imported steel, reaching an extra €200/tonne of steel[30], in the EU in 2034. This could encourage many companies in Asia to reduce their emissions to avoid paying such a cost.

In the US, most of the steel making is through EAF plants, which is already less carbon-intensive than other regions, and many companies there are refraining from explicitly committing to net-zero.

This does not mean that investment in low-carbon steel will not materialize; tax credits and grants could help spur the production of new fuels that are needed to decarbonize this sector together with the scale up of green electricity. In fact, more than $1 billion was given to steel producers from the US Department of Energy's (DOE) Industrial Demonstration Program for a variety of different technologies including CCUS, hydrogen, and steel recycling. However, projects would require substantial additional investment[31].

As of April 2023, 33% of global crude steel capacity was covered by a net-zero target; this differs by region, with more than 80% covered in the EMEA region.

[30] Citi Research, CBAM primer and how EU producers and importers could save up to €600 million on higher CBAM related costs from 2026

[31] BNEF (2024), Cement, Hydrogen Top Takers from $6 billion US Green Fund

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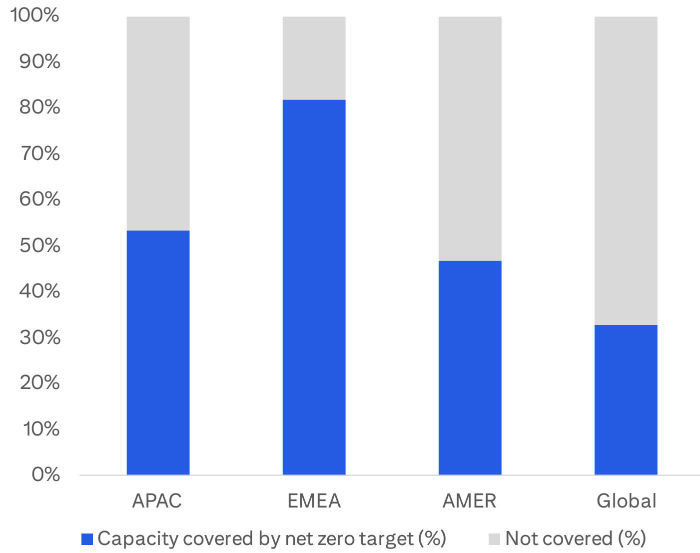
Figure 39. Capacity covered by a net-zero target as of April 2023



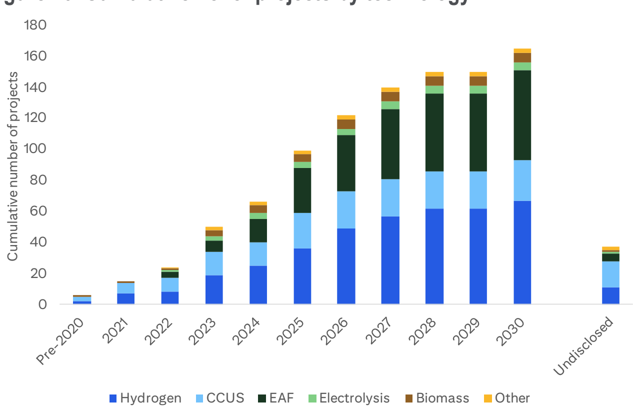
Source: Citi GPS, BNEF

Decarbonisation in the steel industry has started. The Green Steel Tracker tracks the decarbonization efforts of 138 steel companies around the world. They estimate that there are 61 projects that are active and are either online or will be developed soon. They also track 38 prospective projects that have either lost traction, got cancelled, or have evolved into a bigger scale.

BNEF has a slightly higher figure; they state that 66 green steel projects could be operational in 2024, increasing to 202 by 2030 (37 of which do not have a commissioning year). This is continuously changing as more announcements are being made all the time.

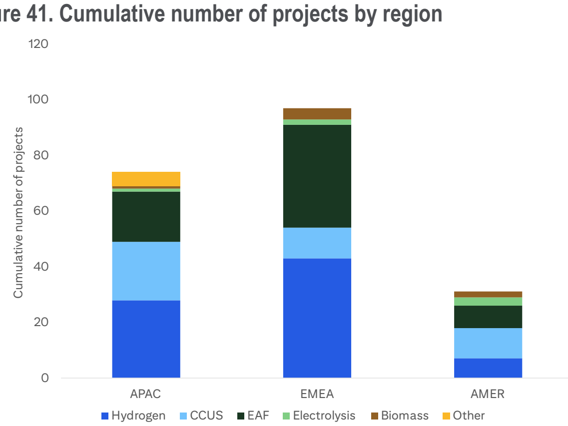
The charts below show the cumulative number of green steel projects by technology and region until 2030. This does not mean that all these projects would reach FID, but it gives a clear indication that the steel industry is investing in low-carbon solutions.

Figure 40. Cumulative no. of projects by technology



Source: Citi GPS, BNEF

Figure 41. Cumulative number of projects by region



Source: Citi GPS, BNEF

The industry is considering different solutions, and many major steel companies have a diversified and balanced approach. Hydrogen and EAF seem to be the ones that are resonating the most with companies especially in EMEA; however, the use of CCUS is also growing in all regions, but the projects are mostly in pilot or feasibility stage.

Large hydrogen steel projects include H2Green Steel, which has secured financing and plans to produce 5 million tonnes of green steel by 2030. HYBRIT is also another project run by SSAB, LKAB, and Vattenfall that is already producing green steel from hydrogen.

Both these projects are in Sweden, as the country is blessed with high-grade iron ore and the availability of hydro resources that are essential for H2DR-EAF plants. Middle East countries such as Oman, Saudi Arabia, and the UAE also have proposed green steel projects; they have the availability of cheap gas for DR-EAF process, which could be adapted to use hydrogen once the technology matures.

However, most low-carbon steel projects are currently relying on public sector support. For example, ArcelorMittal has disclosed that it has managed to secure public financing from a variety of different countries, including Canada, Spain, and Germany. In fact, if you map out the announced green steel projects, they are either based in places where carbon prices and legislation will start to be costly, and/or where there is the availability of grants and other available public sector support.

Many major banks as stated in previous sections have also committed to net-zero and so will not have the appetite to invest/lend money to carbon-intensive projects that could raise the cost of capital for these projects.

The Sustainable Steel Principles is an initiative set up in 2022 with the aim to facilitate the net-zero transition of the steel industry by providing a methodology of banks to measure and report emissions associated with their loan portfolios compared with a net-zero pathway. They are similar to the Poseidon Principles set up for maritime shipping and mentioned earlier in this report. They were developed by five large banks: Citi, ING, Société Générale, Standard Chartered, and UniCredit. Each year, the signatories to the principles report on how their finance portfolio aligns with a net-zero scenario.

Looking ahead

The steel industry's decarbonization is first starting in countries that have policies and/or available public finance to help the sector decarbonize. The push for this sector is also coming from clients.

The cost premium of green steel will only have a small impact on the end product. For example, 0.5% on a passenger car and 1.5% on white goods. It will be higher for buildings estimated at 2.1%[32]. These cost penalties reduce significantly in 2040 54 and 59and 2050. So, it is for this reason that the clients of the steel industry such as auto manufacturers are pushing the industry to decarbonize and some of these companies have already signed agreements to offtake some of the production of green steel.

[32] Mission Possible Partnership, Making Net-Zero Steel Possible, An Industry-backed 1.5oC-aligned transition strategy

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Figure 42. Price difference of consumer goods with steel produced from green hydrogen vs conventional prices

Consumer Goods	2030	2040	2050
Passenger cars	+0.5%	+0.4%	+0.3%
Buildings	+2.1%	+1.9%	+1.4%
White Goods	+1.5%	+1.4%	+1.0%

Source: Mission Possible, Citi GPS

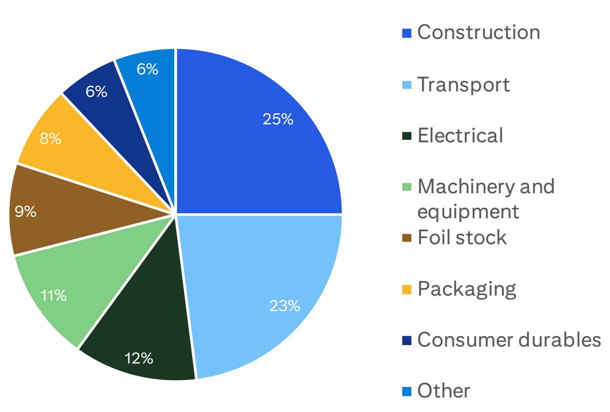
However, the cost to the steel industry itself will be significant – estimated at 15% higher than a BAU scenario (this does not include capital expenditure). This is why many companies are relying on public sector financing to help invest in these solutions. The most difficult to decarbonize is the BF-BOF process, which is the route that is mostly used on a global level. Using recycled steel through an EAF process is the most effective and cheaper option, but the availability of recycled steel could be an issue, and so we are seeing other technologies being adopted with no clear winner yet in place. It will be a balanced approach, but one that will lead to green steel becoming a reality in the long term.

Aluminum

Aluminum is a highly versatile material that can be used for many different applications such as transport, construction, packaging and electrical engineering.

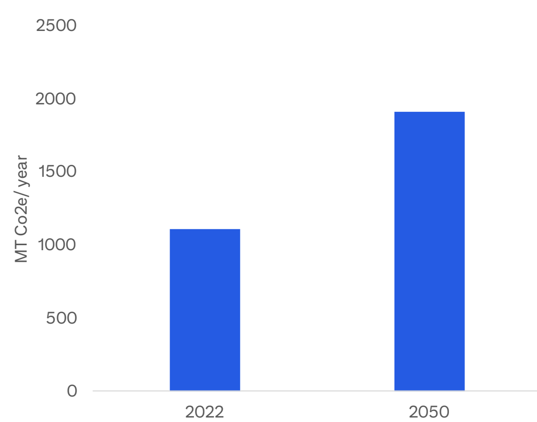
Transport and construction are major end-users with nearly 50% of primary aluminum demand, as shown in the figure below. This material is a key enabler to help reduce emissions in various sectors, as its use is essential in the production of renewable energy, electric cars and others, however its production is energy-intensive. Globally, the sector is responsible for 2% of global emissions. Demand is expected to increase over the years (80% by 2050[33]), and therefore emissions could grow by as much as 72% if no levers are deployed to reduce them.

Figure 43. Global end use of primary aluminum by sector, 2020



Source: Citi GPS, Statista

Figure 44. Emissions for the aluminum sector under a BAU scenario



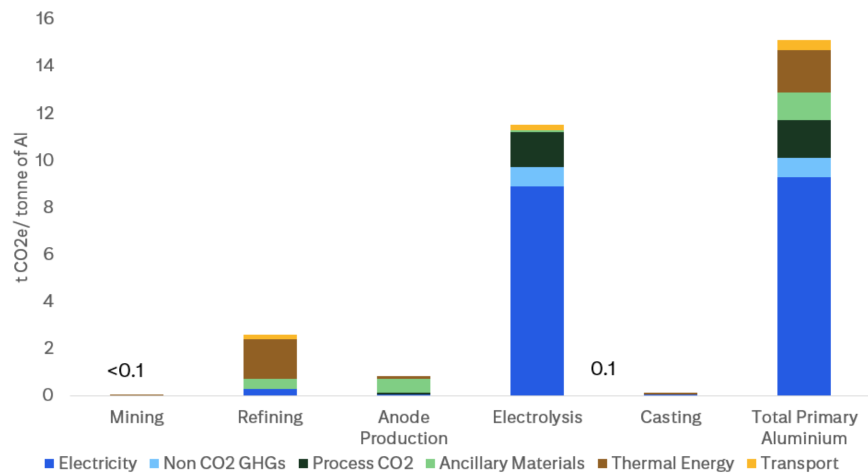
Source: Citi GPS, Mission Possible

[33] Mission Possible, Aluminum

Value chain of aluminum production

There are five main stages in the value chain of aluminum, including (1) mining for bauxite, (2) refining, (3) anode production, (4) smelting, and (5) casting. Aluminum can also be recycled and re-used many times, and therefore its circularity is infinite. This is known as secondary process. Each of these processes requires energy, and the refining and smelting processes are the most energy-intensive, and therefore responsible for most emissions from this sector.

Figure 45. Emissions generated by the production of primary aluminum



Source: Citi GPS, Aluminum International Institute

Bauxite is the most common material in nature from which aluminum is formed. It is extracted through either open-pit mining or underground mining and is mainly found in tropical or sub-tropical regions. Most bauxite is crushed into smaller pieces, washed or filtered before being sent to a refinery for further processing.

There are two processes in refining: digestion and calcination. Refining alumina needs thermal energy, the majority of which is provided by coal. The end-product is a white powder (alumina), which can be transferred to aluminum smelters or used as an input for the chemical industry[34].

[34] European Aluminum (2023), Net Zero by 2050: Science-Based decarbonisation pathways for the European Aluminum Industry, November 2023

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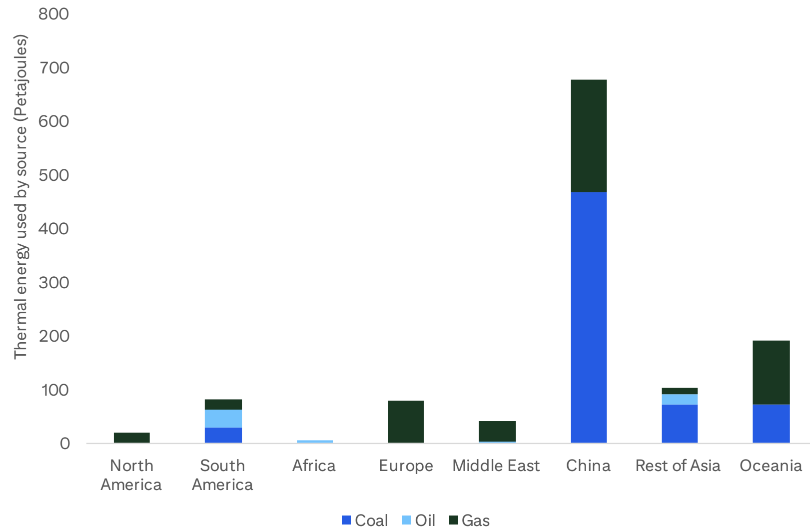
Figure 46. Refining thermal energy consumption by source and by region in 2020 (PJ)



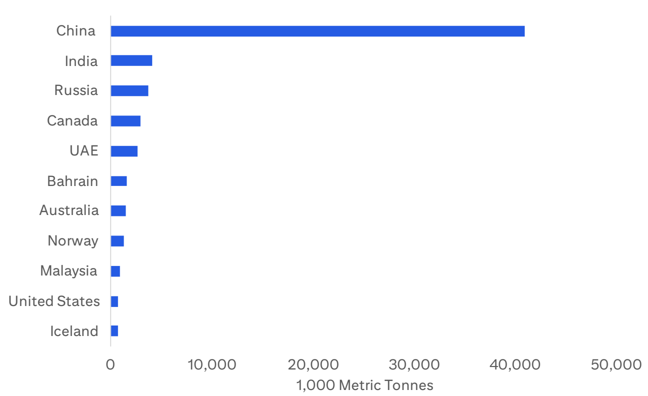
Source: Citi GPS, Mission Possible Partnership

Smelting – Anode production and smelting

Smelting is the process of extracting aluminum from alumina through electrolysis in a carbon lined cell. A constant supply of anodes is needed for electrolysis. Most smelters used prebaked anodes. The smelting process itself needs a constant source of cheap electricity, however given that carbon-anodes are used, this process emits process emissions. This stage is extremely energy-intensive and is responsible for over 70% of greenhouse gas emissions of this sector.

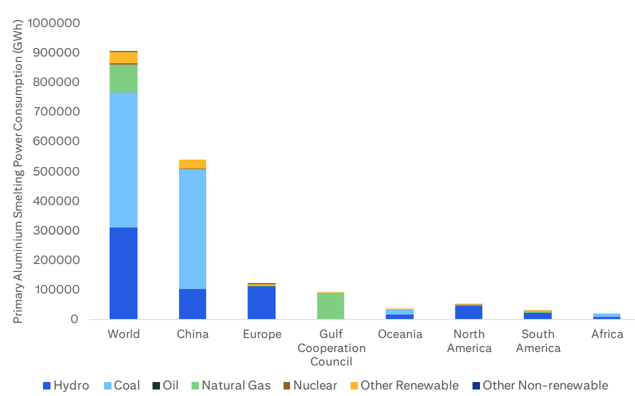
Often smelters are built close to hydropower stations (34% of total smelter production is from electricity source from hydro power), however 50% of smelting production currently uses electricity generated from coal. This differs across regions; for example, in Europe most smelters use hydropower as the main source, in China (where most aluminum is produced) 74% of smelters use electricity generated from coal, whilst in the Gulf nearly all smelters use electricity generated from natural gas. Following this, the aluminum is sent for casting to produce the final goods.

Figure 47. Global smelter aluminum production by leading country, 2023



Source: Citi GPS, Statista

Figure 48. Primary aluminum smelting power consumption by source



Source: Citi GPS, International Aluminum

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Secondary aluminum – recycling

Aluminum is one of the most recycled materials in the world. Recycling cuts emissions by 95% per tonne of aluminum produced. On average, only about 0.5 tonnes of CO2e is emitted per tonne of secondary aluminum, in contrast to approximately 15.1GTCO2e for primary production. From a price perspective, the figures are much the same; it is estimated that secondary aluminum trades at approximately 85% of primary aluminum trading prices[35].

Maximising secondary production would require an increase in volumes of secondary material that comes from a variety of sectors, including transport, construction, packaging, consumer durables, electrical and machinery and equipment. Recycling rates of aluminum are already high. The global recycling efficiency rate (RER), which is used as an indicator to estimate the amount of recycled aluminum produced annually from new and old scrap as a percentage of the total amount of available scrap sources, stands at 76%. Around 75% of the total aluminum produced globally is still found in operation. Increasing recycling figures through an increase in scrap collection would help reduce emissions from this sector, however other decarbonization solutions would also need to be scaled up for this sector to reach net-zero.

Solutions

Many solutions are available that could help reduce emissions across the sector. From a demand perspective, it is important that we reduce losses in product manufacturing processes, and that we design products with more durability and lighter weight to reduce the demand for aluminum. On the supply side we can:

- Increase recycling rates and secondary production – the secondary production still uses energy and emits CO2 emissions, but it is 95% less carbon-intensive when compared to primary aluminum production.
- Use fuel switching for the refinery process – this can be through either electrification using electric boilers or switching to clean hydrogen. Biomass could also be used, although there is heavy competition from other sectors such as aviation and its sources need to be sustainable. Mechanical vapour recompression (MVR) can also be used for the digestion state of the refinery process. An MVR system uses renewable power to drive mechanical vapour compressors to displace thermal energy derived from fossil fuels.
- Substitute carbon anodes for inert anodes – this can reduce process emissions from smelting systems. Several companies have come together and invested in research and development to develop such a system.
- For the smelting process itself, use green electricity or retrofitting with CCUS to help reduce emissions. Smelters require a constant source of electricity, and this is why many are based close to hydropower systems. The intermittency of renewable power generation could be an issue for the smelters.

[35] Mission Possible, Making Net Zero Aluminum Possible, An Industry-backed, 1.5oC-aligned transition strategy.

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Figure 49. Solutions to decarbonize the aluminum sector

	Mining	Refining	Anode Baking	Smelting	Casting
Total Emissions		16%	5%	71%	
Demand side	Better designing of products, light weighting, reduce material losses				
Collection & reusing aluminium scrap	Increase secondary production				
Supply side solutions		1. **Digestion**- Fuel Switching - Electrification, hydrogen, biomass; MVR	Inert Anodes or CCUS	Clean electricity or CCUS	
		2. **Calcination**: Fuel switching- electrification, hydrogen, biomass			

Source: Citi GPS

Update on sector

There is some evidence that the sector has already managed to reduce its emissions whilst increasing production at the same time. The chart below shows primary and secondary aluminum production against total annual greenhouse gas emissions.

In addition to this, the International Aluminum Institute is tracking around 50 innovative projects around the world that are contributing or else plan to contribute to a reduction in emissions. They divide these projects into 3 pathways: electricity decarbonization, direct emission reduction, and recycling and resource efficiency. According to the International Aluminum Institute, 10 of these projects are already in operation. Mission Possible has a higher figure: it estimated that 30 projects are currently operational, whilst 6 have reached FID[36].

These projects include a mix of various technologies including electric boilers for alumina refinery, renewable technologies for smelters, CCS and others. There are several industrial initiatives that are also happening across different countries, such as Elysis in Canada, Norsk Hydro in Norway, and TRIMET and Arctus Aluminum in the European Union. All of these projects reduce emissions significantly.

[36] Mission Possible Partnership

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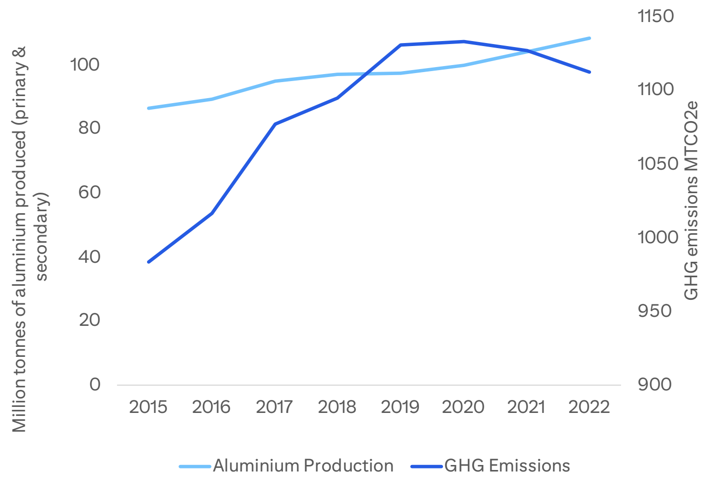
Figure 50. Annual aluminum production vs GHG emissions



Source: Citi GPS, International Aluminum Institute

Elysis

Elysis is a research project to replace carbon anodes with inert anodes, and can be retrofitted with existing smelters and new installations. This will help reduce process emissions from the aluminum smelting and, coupled with renewable energy such as hydropower, the smelting process can easily be decarbonised.

The project is unique as it a collaboration amongst two competing companies, Rio Tinto and Alcoa, which have joined forces and invested together to research carbon-free smelting, and to scale up and commercialise this technology. The company also has investment support from the government of Canada and Quebec in exchange for a 3.5% equity stake, whilst Apple, which will offtake the green aluminum product, has also invested in the project.

In China, a multibillion-dollar push is underway to decarbonize this sector. The government is offering aluminum smelters opportunities for cheap hydropower to encourage them to allocate. The push in China is coming from two directions: 1) the introduction of the CBAM in the EU, which is estimated to increase the cost of aluminum by more than €200/tonne[37] and 2) a push from clients such as mobile phone makers who want to use green aluminum in their products.

In addition to this, similar to the shipping and steel industry, four banks together with RMI and the aluminum industry stakeholders have developed the Sustainable Aluminum Finance Framework, which has a similar remit to the Poseidon Principles and Sustainable Steel Principles.

The Framework sets the scope and boundaries of absolute emission metrics and calculates the carbon intensity and 1.5oC-alignment of aluminum lending portfolios. For the primary and recycling boundaries, the Framework follows a “fixed boundary” approach, where reporting parties collect and report emissions data for all activities

[37] Citi Research, CBAM primer and how EU producers and importers could save up to €600 million on higher CBAM related costs from 2026

within the boundary, irrespective of the activities within their financial or operational control.

Semi-fabrication of aluminum production or activities, including extrusion, rolling, casting or coating (i.e., products that can be used outright or used as inputs for further processing), can be calculated on an optional basis.

Given semi-fabrication transforms primary and recycled aluminum to produce different products, the framework follows a company-based variable reporting boundary, where reporting parties report only on the activities that are both in scope and within their financial or operational control.

Looking ahead

Aluminum is an essential material to produce electric vehicles and renewable energy infrastructure, which all need to scale up in a net-zero world. Its demand should therefore increase over time. While recycling aluminum uses 95% less energy than primary production, the increase in global demand will not be met only by increasing recycled aluminum in the near future.

Hence, it remains a top priority for the aluminum sector to decarbonise the primary production. Decarbonising parts of the aluminum process is harder than others; for example, refining needs thermal heat whilst smelting requires continuous availability of electricity. It is estimated by Wood Mackenzie that at least $6 billion of annual investment in low-carbon aluminum technologies is required out to 2050 to deliver smelter and refiner supply under a 1.5oC scenario.

More importantly, as carbon taxes phase in, the cost curve will shift upwards, which will also imply higher aluminum prices. The implementation of CBAM will impact the primary aluminum market by reducing the carbon intensity of aluminum imports in the EU. Direct and indirect emissions of aluminum smelters currently range from 5 tonnes of CO2e/t of aluminum to 20 tonnes of CO2e/t of aluminum. If CBAM includes only direct emissions, then it is estimated that this will cost more than €200/tonne of primary aluminum in 2034.

The premium costs for decarbonisation for smelting would depend on clean electricity prices, which differ across many countries.

Cement

Cement forms an important part of the economy; it is essential for buildings, for transportation and for other infrastructure. Over 4 billion tonnes of cement are produced each year; approximately 70% of this is produced to make concrete, whilst the rest is used in mortars and plasters[38].

Demand is expected to grow over the years driven by population growth and infrastructure development. Cement and concrete are mostly produced close to their use, due to the bulky nature and low value of the product. China is currently the largest producer of cement, due to large infrastructure developments, although its demand is expected to decrease over the years.

[38] Mission Possible Partnerships (2023), Making Net-Zero Concrete and Cement Possible

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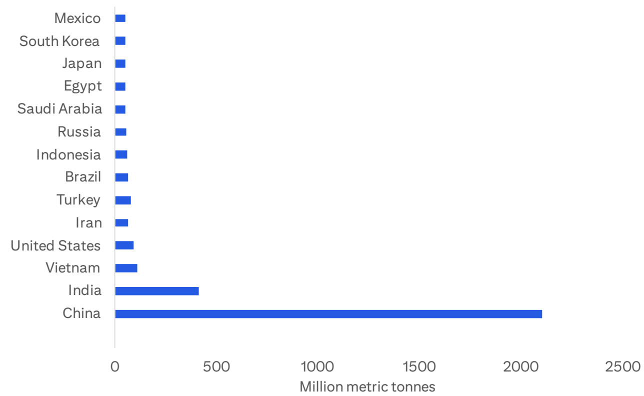
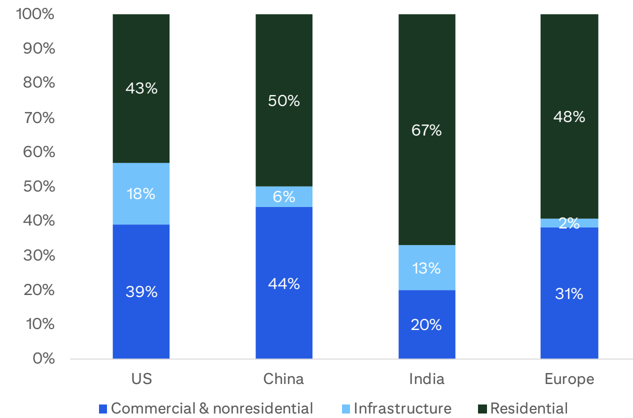
Figure 51. Largest producers of cement



Source: Citi GPS, Statista

Figure 52. Uses of concrete in various countries



Source: Citi GPS, Mission Possible Partnership

The cement industry is energy-intensive and is responsible for approximately 7% of global emissions, the equivalent of India's entire emissions. Forty percent of emissions are produced from the burning of fossil fuels (coal, coke or natural gas) to heat the kiln.[39]

However, 50% of emissions in this sector are linked to the process of producing the clinker[40], a by-product of a chemical reaction, and are known as process emissions. These emissions cannot be reduced simply by changing fuel sources or increasing the efficiency of cement plants.

Value chain of cement and solutions for decarbonization

There are several stages to produce cement and concrete and each stage emits emissions and requires different solutions. These include:

- Extraction, preparation and transportation of raw materials (limestone and clay), which are sources from local quarries – 1% of emissions.
- Clinker production – This is an intermediary product which is produced from the extracted clay and limestone. CO2 is emitted during the calcination of limestone into lime (chemical reaction – process emissions: 53% of emissions) and during the burning of fuels required for calcination and clinkerisation (direct emissions: 35% of emissions).[41]
- Cement production – This is where the clinker is ground to cement and where supplementary cementitious materials (SCMs) such as fly ash, ground granulated blast-furnace slag (GGBs) are added. Emissions are related to electricity use in the mills: 5% of emissions.

[39] "Chaudhury et al. (2023). Low-CO2 emission strategies to achieve net zero target in cement sector. Journal of Cleaner Production, 137466."
[40] "Mission Possible Partnerships (2023), Making Net-Zero Concrete and Cement Possible"
[41] "Mission Possible Partnerships (2023), Making Net-Zero Concrete and Cement Possible"

- Concrete production and application – Concrete is made by mixing cement with aggregates such as sand. This can be done on site, or in bulk at a plant. It is then used in the construction of buildings and infrastructure (5% of emissions).

Cement also absorbs CO2 from the air during its lifetime, this is known as recarbonation and can reduce entire emissions from this sector by up to 10%[42].

Solutions

Clinker production is responsible for 88% of the sector's emissions[43]. The process is extremely carbon-intensive; in fact, it is estimated that for every tonne of clinker produced, nearly one tonne of CO2 is emitted.

Fuel switching such as using hydrogen, and biomass could be effective in reducing thermal related emissions. Using waste is the low-hanging fruit and is a cheap way for the sector to reduce some of its emissions.

Electrifying heat through electric boilers and clean electricity supply can also reduce direct emissions. However, these solutions are only able to reduce direct emissions (35% of total emissions); they are not effective in reducing process emissions.

CCUS can capture both the direct and process emissions from clinker production. The captured CO2 can also be utilized in products that can either improve the performance or replace the cement, or even replace products such as aggregates. Residual emissions will typically remain, as with today's CCUS technologies it is not possible to capture 100% of emissions.

Other solutions include the increased use of supplementary cementitious materials (SCMs) such as fly ash, limestone, ground granulated blast-furnace slag (GGBS) and calcinated clay, which can help reduce the amount of clinker that is needed, thereby reducing both direct and process emissions. For example, calcinated clay mixed with limestone has the potential to reduce process emissions by 40%.

There are many companies offering new ways to either reduce the clinker needed or replace it entirely. For example, Ecocem has developed a technology that makes cement with up to 70% less clinker and uses more SCMs and fillers; 70% of the clinker is replaced and produces 60% less CO2. Carbicrete is another company that replaces cement with steel slag, eliminating a highly polluting substance from the concrete mix and replacing it with industrial waste to make concrete. It also then cures the concrete with CO2 – this is considered a carbon-neutral product.

Even though there has been plenty of research on reducing emissions from clinker production, it has not yet been possible to make the reactive component of cement without emissions. However according to Cambridge Electric Cement, a new startup company associated with the University of Cambridge, this is now possible. They combine a process of using recycled concrete waste to form a cement powder and use this instead of lime-flux in steel recycling. As the steel melts, the flux forms a slag that floats on the liquid steel[44].

[42] Mission Possible Partnership (2023), Making Net-Zero Concrete and Cement Possible
[43] "Mission Possible Partnerships (2023), Making Net-Zero Concrete and Cement Possible"
[44] https://cambridgeelectriccement.com/the-product/

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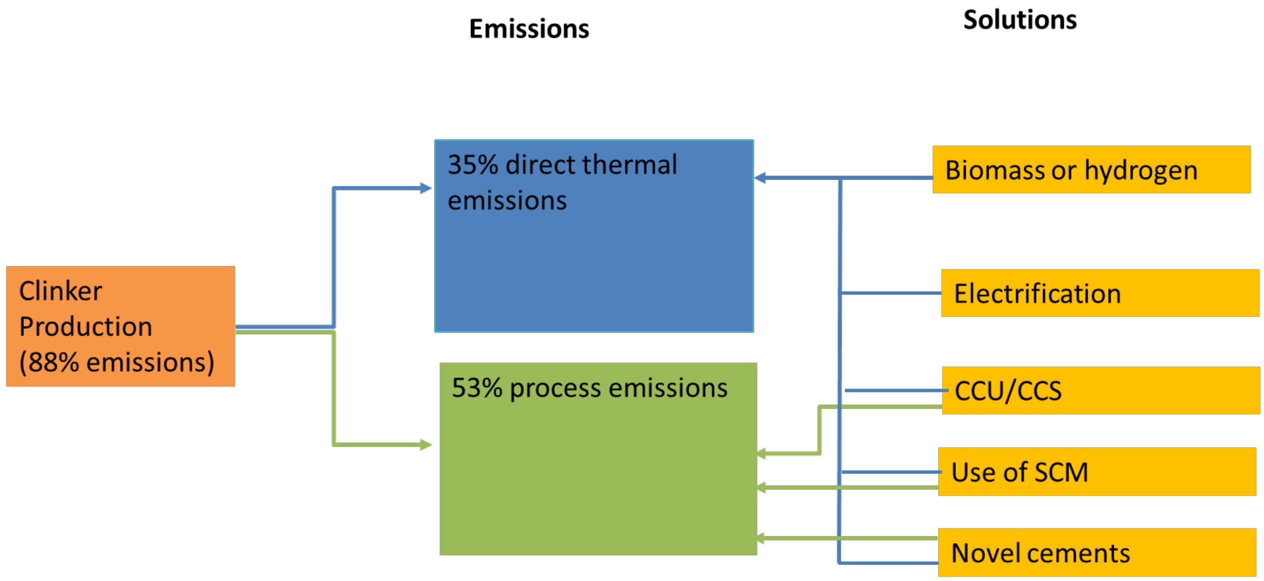
The researchers found that this slag, which is quickly cooled off and ground into a powder, is virtually identical to the clinker. If they manage to scale this technology up and if the economics work, then this could help reach net-zero cement more effectively.

Figure 53. Solutions to reduce emissions from clinker production, which is responsible for 88%



Source: Citi GPS, Mission Possible Partnerships

* Use of SCM, also known as clinker substitution, involves the increased use of supplementary cementitious material to reduce the amount of clinker needed

Update on sector

The industry has started to invest in several solutions to reduce emissions. Much of the progress is happening in the EU as the industry is being pushed by a reduction in free allowances in the ETS system, which will impact European cement makers.

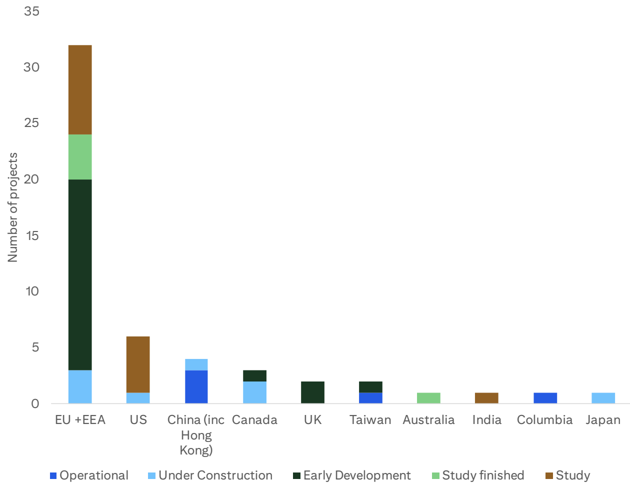
The availability of public support through the EU Innovation Fund is also helping to spur investment. Ephrem Ravi, Head of Building Materials at Citi Research, tracked more than 26 CCUS projects that European cement companies are investing in – 21 of which are based in Europe, with the remaining in North America.

According to the Leadership Group for Industry Transition, there are around 53 CCUS plants globally that the cement industry is investing in. The majority of these are in early development, however 5 are already in operation, whilst 8 are currently being constructed. This is a significant increase – the industry in 2023 was only capturing 2.2 million tonnes of CO2; this is expected to increase to over 80 million tonnes of CO2 in 2030. This is just a fraction of the total emissions of the sector estimated at 1.6 billion tonnes of CO2 in 2022, but it shows the industry is moving at least in certain regions/countries.

The industry is also investing in calcinated clay projects, as shown in the graph below. Many of these projects are also occurring in Africa and South America. Calcinated clay can reduce emissions for up to 40% but they cannot fully decarbonize the sector.[45]

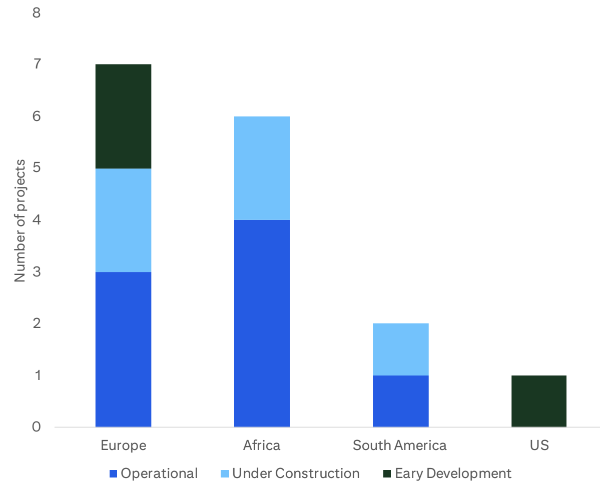
[45] https://www.industrytransition.org/insights/calcined-clay-tracking-decarbonization-cement-

Figure 54. Announcements of carbon capture projects in the cement industry



Source: Citi GPS, The Leadership Group for Industry Transition (LeadIT)

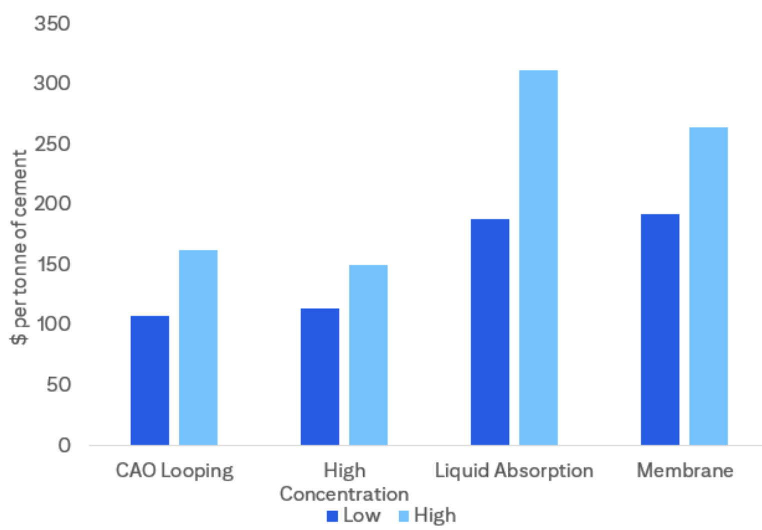
Figure 55. Announcements of calcined clay



Source: Citi GPS, The Leadership Group for Industry Transition (LeadIT)

Cement and lime also form part of the CBAM which would encourage companies that export these products in the EU to reduce emissions. It is estimated that the price of cement under CBAM would increase from €74/tonne in 2023 to €230/tonne of cement in 2034 assuming that the EUA prices would rebound to €100/tonne of CO2. At these prices, the investment in CCUS and other solutions becomes more cost effective.

Figure 56. Cost of CCUS per tonne of cement



Source: Citi GPS, BNEF

industry/#:~:text=Clinker%20production%20requires%20much%20higher,to%20the%20calcination%20of%20limestone.

Looking ahead

Solutions to decarbonize this industry revolve around the reduction of emissions from the production of the clinker, which is responsible for 88% of the sector's emissions.

The cement industry has started investing in solutions such as CCUS to reduce its emissions, although the majority of investment is in Europe. Pushed by EU legislation and the availability of grants, it's the European cement companies that are moving the fastest. Projects in the US are increasing, while in other regions it remains muted. It remains to be seen if CBAM would reduce emissions in other parts of the world, or at least in countries that export cement and lime into Europe. The economics suggest that it would, although most of the cement and concrete are produced close to their use.

Summary of industry

The steel, aluminum and cement industry segments have started marching towards decarbonization. These sectors are being pushed by legislation, the availability of grants and, in the case of steel and aluminum, their clients who are willing to pay a cost premium for green products. The Carbon Border Adjustment Mechanism (CBAM) will be costly for carbon-intensive materials as described in the various sector chapters. This will provide an incentive for companies who export to the EU to reduce their emissions over time and avoid paying this customs duty. It will take time, the cost premiums of solutions are high, and these sectors have rather tight margins, but progress is being made and many companies now have a clear strategy of how to reduce emissions. New technologies are also emerging such as inert anodes for the aluminum sector, direct electrolysis and electrowinning in the steel sector and novel cements which could revolutionize the industry- the economics just need to work and until they do, government support is essential.

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Financing: How do we scale up the finance needed?

In our previous hard-to-abate sectors report, we estimated that the cost of carbon abatement for steel, cement, aviation and shipping is approximately $1.6 trillion per annum for our high scenario (not including aluminum). This figure only looks at abatement costs for these sectors and does not include the capital investment needed in solutions such as hydrogen, CCUS, renewables, nuclear and biomass. The total investment needed to decarbonize these sectors is difficult to calculate as it depends on the decarbonization paths that these sectors adopt over the next few years, however there is no doubt that trillions would be needed.

So how do we scale up these projects and how do we finance them?

Currently most financing for energy transition is happening on balance sheet, but the scale of finance needed means that many more projects need to occur off balance sheet. We are already seeing a few project finance projects materialize, for example, NEOM Green Hydrogen Project, Northvolt and H2Green Steel, but many more are needed if we want to scale up solutions fast.

Corporate finance: Lending on balance sheet

This model involves a single entity that develops the project and finances all the related costs. They may choose to do this through a subsidiary, which would then be included into the corporate's financial accounts.

Large corporates may be cash rich and can fund the transition themselves, or they can use cashflows from other operating activities and use their credit worthiness to raise equity or borrow funds, either using the capital markets through the issuance of sustainable bonds and their equivalent, or directly through commercial institutions through a diverse set of instruments available. Sustainable bonds include green, social, sustainable and sustainable linked and transition bonds, and other thematic bonds such as SDG, blue and orange bonds.

The downside to the above is that they would need to absorb all the liabilities and risks of the project, which could be substantial if the project does not perform well.

Corporates can raise debt at reduced interest rates when compared to other financial tools, such as project finance discussed below, as lenders would have recourse to all of the corporate's assets in the event that the debt is not repaid.

With subsidies and grants being offered in many countries, companies can also make use of these additional funds for their projects. Most of these grants do not cover the full capital, but they can be of real help especially for first-of-a kind projects.

Issuance of sustainable bonds

A total of US$80 billion in sustainable bonds has been issued by the hard-to-abate sector issuers in the past 5 years (since 2019): 2% of the overall sustainable bond market in the same period ($3.7 trillion). The Chemicals sector issuance was the largest, estimated at 35% of the hard-to-abate sector sustainable bond market. This was followed by Building Products (including cement) and Metals & Mining (including aluminum and steel) at ~20% each. The Shipping and Aviation sustainable bond issuance represent 12% each of the hard-to-abate sectors sustainable bond market over the same time-period.

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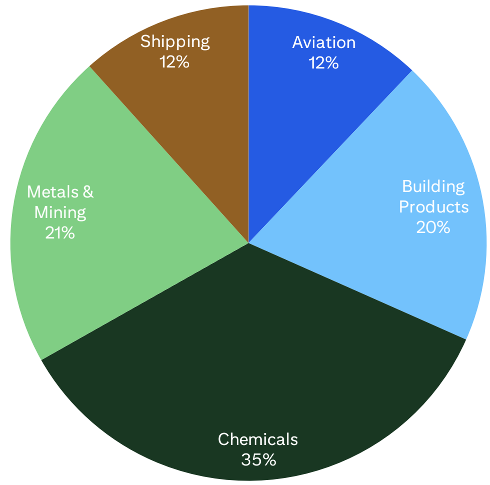
Figure 57. US$80 billion in sustainable bonds issued by hard-to-abate sectors



Source: Citi GPS, Dealogic, Refinitiv

Green bonds remain the most popular for hard-to-abate sector issuers (63% of their sustainable bond issuance), followed by sustainable linked bonds and transition bonds (32%).

It's interesting to note the evolution of the most common categories we've seen in hard-to-abate sector use of proceeds frameworks since 2019: while in 2019 Green Buildings, Clean Transport and Energy Efficiency were the top categories in the frameworks of green bonds issued, since then, Renewable Energy, Energy Efficiency and Pollution Prevention & Control have taken precedence.

This development is presumably due to the gradual firming up of market guidance for decarbonisation / transition pathways for each of these sectors. For example, the CBI Steel Industry criteria was released in 2022 whilst the EU Taxonomy entered into force in 2020 and added new transition sector criteria in 2023. Most companies publish Sustainable Finance Framework to show investors how they plan to use the proceeds from their issuance.

For the Shipping industry, a blue bond label could also be sought. The International Capital Markets Association (ICMA) produced a guidance document on the issuance of blue bonds. It details a number of activities that could fall under a blue bond, including Sustainable Maritime Transport, as shown in the table below.

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Figure 58. Sustainable Marine Transport

Sustainable Marine Transport	
Example Project Outputs	**Example Impact Indicators**
Retrofitting vessels for decarbonization & emissions reduction, energy efficiency, or improved ballast management	Ships with new measures (number) Annual GHG emissions reduced (tCO2e)
Commissioning vessels that utilize alternatives to heavy fuel oil, provide improved fuel efficiency, leverage alternative technologies for low-carbon transport, or present significantly lower emissions profiles	Ships with new measures (number) Annual GHG emissions reduced (tCO2e)
Sustainable vessel deconstruction and recycling (or scrapping)	Shipping companies using responsible ship breaking practices (number) (outcome)
Integration of maritime transportation with marine spatial planning & integrated zone management	Spatial management & operational policies in place to protect marine species
Potential social Co-Benefits	
Percentages of female seafarer recruits and of female seafarers in senior management	Percentage over x%
Exclusions: Vessels fully run on fossil fuels including LNG; Vessels exceeding limit values for SOx and NOx; Companies in violation of IMO Ballast Water Treaty or lacking hull treatments against biofouling; Companies that are not in compliance with IMO and MARPOL Regulations relating to waste disposal at sea, or that are disposing of toxic & quantifiable high levels of any waste into the sea	

Source: Citi GPS, ICMA

Even though corporate financing is efficient and will form a large part of the investment needed, other forms of financing, such as project finance, would also need to be scaled up to meet the significant investment needed in decarbonizing hard-to-abate sectors.

Project finance

Smaller companies that do not have large balance sheets,or have high debt to equity ratios or projects that require significant investment might find project finance more attractive. Project finance is the funding of long-term infrastructure, industrial projects and public services using non-recourse or limited recourse financial structure. The debt and equity raised would be paid back from future cash flows.

Companies would need to find interested investors and a standalone company known as a special purpose vehicle (SPV) would need to be formed. There could be a diverse group of investors from private equity, family offices, sovereign wealth funds, impact investors, pension funds, and also industrial sponsors that may not have an investment role or take an equity stake in the company, but will agree to offtake the product, known as offtakers.

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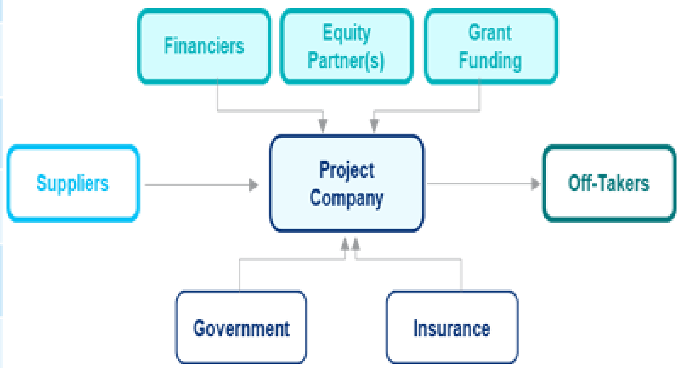
Figure 59. Project Finance- key stages and key risks

Traditional Project Finance

Pre-Financing	Financing Stage	Post-Financing Stage
Seed capital provided and Special Purpose Entity (SPV) created. This entity will serve as the borrower. A feasibility study is completed with risks mitigated where possible.	Contracts signed with remaining partners (additional equity investors, contractors, governments, etc.). Commercial financiers step in.	Project is operational and repayment is made from cash flow of the project company.

Key Risks and Partners

Equity Risk	Quality equity sponsor is imperative to ensure certainty of funds of the equity required to construct the project
Construction Risk	Contractor(s) with a strong track record of timely and on-budget project delivery
Offtake Risk	Long-term offtake agreement with strong counterparty
Political & Regulatory Risk	Solid country governance, track-record of enforceability, and stable regulatory framework
Revenue Risk	Revenue and cashflow certainty is critical for project finance
Technology Risk	Risk mitigation for performance risk for new technologies and potential obsolesce risk



Source: Citi Global Insights, Citi Commercial Bank

Other forms of capital could include government grants ,for example, through the EU Innovation Fund, whilst Export Credit Agencies (ECAs) could provide government-backed guarantees or insurance for loans extended by banks to entities that are buying the goods and/or services from the ECA home country.

ECA financing is particularly attractive when large purchases are made from a selected number of countries. They can help de-risk commercial projects. They can provide debt guarantees and can also be direct lenders. ECAs are used for many different financial structures and not just limited to project finance (see box below).

The debt related to project finance is known as non- or limited-recourse debt. This means that in times of default the lenders can only pursue the collateral and nothing else. For this reason, non- or limited-recourse debt commands high lending rates compared to corporate finance structures described above, which could be compounded even further with any risks of the project which cannot be mitigated.

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Figure 60. Export Credit Agencies

Export Credit Agencies

Export Credit Agencies (ECAs) are government backed and used to mitigate traditional risk for the procurement of goods & services from suppliers in an agency's home country. They provide loan guarantees, insurance, and finance short, medium, and long-term facilities. These agencies provide liquidity for large project finance and through risk mitigation, enable the raise of competitive funding sources. Agencies in different countries have various eligibility criteria; some examples shown below.

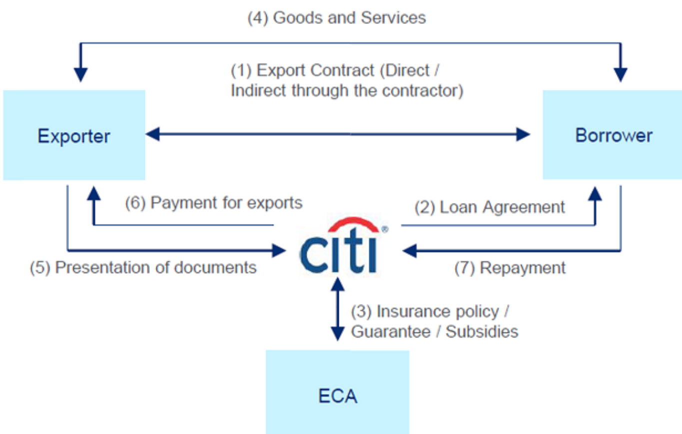
Bpifrance — Bpifrance provides comprehensive insurance and covers ≤ 95% of strategic imports driven by national security.

Euler Hermes — Euler Hermes (through UKF), provides guarantee support for ≤ 90% of imports strategically important to Germany.

Bank of China — Export Import Bank of China serves as a direct lender and provides 100% cover for strategic commodity imports to the nation.

Sace Gruppo CDP — Sace Gruppo CDP insures ≤ 95% of Italian exports from the Push Program and strategic interests abroad.

Typical ECA Funding Structure



Instruments utilized are the following:

- Direct Lending
- Credit Insurance
- Credit Guarantees
- Export Finance

Timeframe: Export Credits can be offered for short-term (up to 2 years), medium term (2 to 5 years), and longer-term (over 5 years).

Sectors Covered: All, heavily in exporting sectors.

Source: Citi Global Insights, Citi Commercial Bank

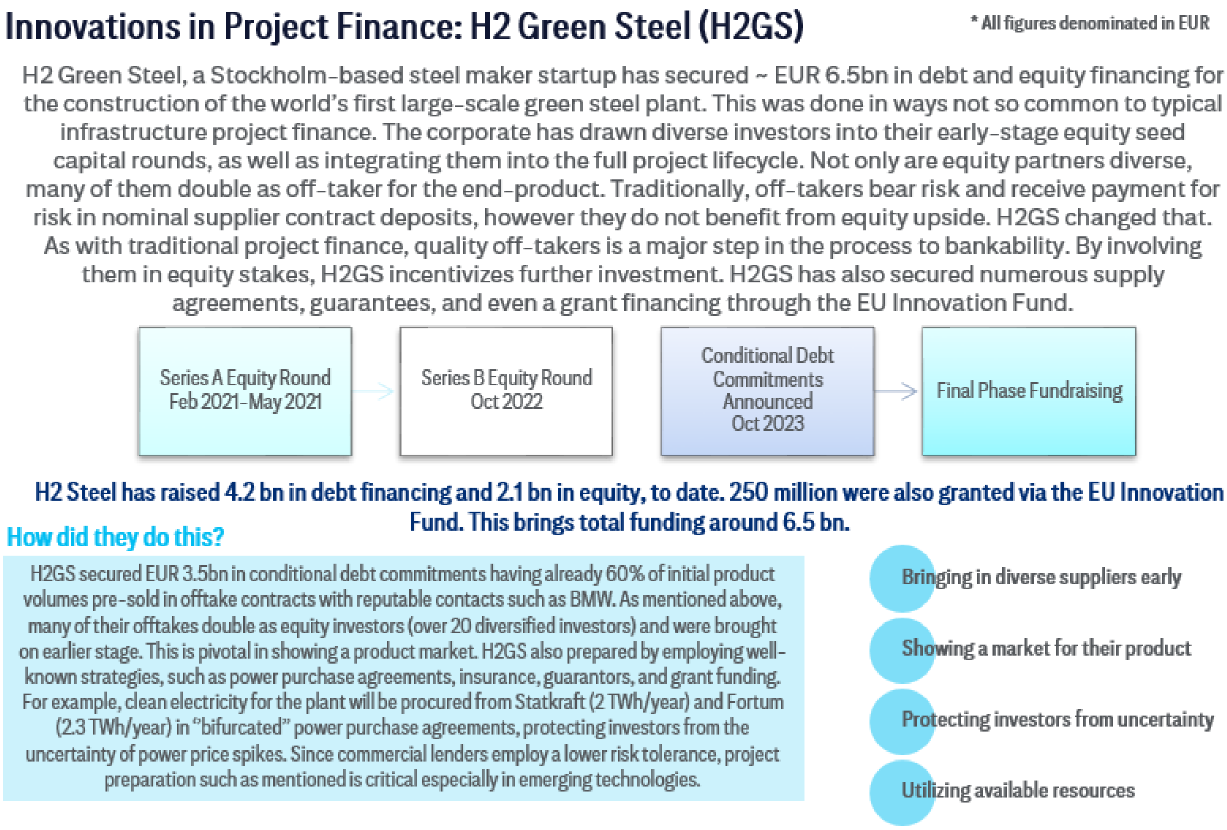
There are several conditions for lending. Banks and other financial institutions would require that the cash flows being generated through the project are enough to service the company's debt. If operating cash flow is too low to cover the debt, then this leads to a funding gap.

Future revenue/cashflows could be an issue for some innovative low carbon projects such as direct air capture (DAC) and CCUS. In some cases, a direct revenue stream could be achieved for these projects by selling the CO2 to companies for it to be re-used in the production of other products. Carbon, as yet, has not been valued as a valuable resource, but its use in the production of chemicals, synthetic fuels, buildings and others will be needed in the future. This means that the demand and price are difficult to set today to support a project financing structure.

In some projects that sell a physical product, such as hydrogen or SAF, this could be abated by securing offtake deals for the product for a certain period. For example, for the NEOM Green Hydrogen project, the offtake of the fuel was secured for 30 years by one of the companies that had a stake in the SPV, reducing offtake risk and guaranteeing a steady revenue stream for the project.

The H2Green Steel project we highlight below also had offtakers come on board, which enabled project financing to be finalized. These offtakers include European car manufacturers such as BMW, as well as Kingspan, Bilstein Group, Marcegaglia and Scania – see box below.

Figure 61. H2Green Steel



Source: Citi Global Insights, H2GreenSteel, Rocky Mountain Institute

Due to the overall funding need for energy transaction, corporates will not be fully able to finance needs on balance sheet and will increasingly need project finance. However, there are some barriers that we need to address, with the main one being that banks are critical for infrastructure investment, but banking regulations are not supportive. Basel III, which was introduced in 2010 (first phase) after the financial crisis, affected the attractiveness of infrastructure investment for the banking sector. The second phase of Basel III, also known as Basel IV or Basel III Endgame, which was due to come into force in 2017 but has been delayed until 2025, makes this even more pronounced. In fact, we are already seeing many banks withdraw or limit their involvement in project finance.

In emerging markets, where much of this investment typically takes place, there are multi-lateral development banks and development finance institutions that are well-seasoned in project finance. Working together with banks and other investors, they can help de-risk many of these projects, making them more attractive business opportunities. However, like commercial banks, the use of these risk defeasance tools is hampered by regulation, including BASEL III interpretations. As a result, it appears there is insufficient collaboration between the public and the private sector in this area.

Joint ventures

Companies can also form joint ventures and invest together in solutions. For example, Alcoa, an aluminum producer, is co-investing alongside Rio Tinto, Apple and the Canadian and Quebec governments in the ELYSIS carbon-free aluminum project. Canada and Quebec are investing $60 million (CAD) for a 3.5% equity stake, with the remaining ownership split between Alcoa and Rio Tinto. This project aims to produce inert anodes in replacement of carbon-anodes used today in Aluminum smelting, this will enable this process if coupled with renewable power to become carbon-neutral.

Other forms of financing – Equity and carbon credits

For companies that are starting on their journey, equity funding from VCs or private equity companies is typically their first stop. For the hard-to-abate sectors, these companies usually provide unique and innovative solutions to help decarbonize this sector.

Unfortunately, climate-tech funding from VCs and private equity in 1Q 2024 fell 35% relative to rolling four-quarter average[46].

Investment through special catalysts such as the Breakthrough Energy Ventures (BEV) could be a good solution for many companies in this space. The aim of BEV is to ‘finance, launch and scale companies that will eliminate greenhouse gas emissions throughout the global economy’.

According to its website, the investment firm has raised more than $2 billion to support 100 companies. Many commercial banks, such as Citi, have put direct capital into this catalyst. Traditionally, investment banks have become involved with equity raising at the IPO stage, although some banks are also helping scale up new innovative solutions through impact funds or advisory, and in some cases direct funding to companies that are more established in their journey.

Other forms of financing besides equity raising, are the use of carbon credits either through the voluntary or compliance markets. Our GPS report on voluntary markets explains how this market works. It also highlights several new players that are entering this market such as new marketplaces and other carbon platforms that connect companies of all sizes with trusted carbon credits.

For example, Frontier is a marketplace that acts on behalf of both buyers and sellers. It has committed to buy an initial $1 billion of permanent carbon removal between 2022 and 2030. Its main aim is to accelerate the development of carbon removal technologies. Buyers decide how much they would like to spend on carbon removals each year, and Frontier aggregates this demand and spend, vets suppliers, and facilitates carbon removal purchases. The supplier then invests in technologies to remove carbon and passes the carbon dioxide removal certificates back to the buyers. Carbon removal certificates are basically certificates showing that a company has invested in a carbon removal project that physically removes 1 metric ton of CO2. This model helps raise finance for carbon removal projects and helps increase the investment in these projects.

DAC companies are also offering the opportunity for companies and even individuals to purchase carbon dioxide removal certificates directly from them. With the availability of government grants and tax credits in the US, many DAC companies are able to stack cashflows from different sources and together with selling equity they are able raise enough financing to build large and expensive projects.

[46] BNEF, Climate-Tech Investment Radar 1Q 2024: Funding Drops 35%

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Financing in emerging and developing economies

Whilst we see financing starting to emerge in the decarbonization of hard-to-abate sectors, it is very regional specific with advanced economies and China moving at a fast pace.

Many advanced economies have the fiscal capacity to help finance the decarbonization in their countries however many emerging and developing economies do not and have other pressing issues such as basic infrastructure, education and poverty.

This is where it is essential for the World Bank, and other DFIs to step in and play an extremely important role in helping to finance projects in these countries and helping them attract and increase private finance into these economies.

Whilst this is beyond the scope of this report, we have previously published a report entitled 'Unlocking climate and development Finance' which provides some highly detailed information on how to create bankable projects in many of these countries, and the importance of various players that are essential in this transition.

What could happen also is that there is a spill-over effect from the decarbonization of hard-to-abate sectors in advanced economies: as technology and new fuels are scaled there, these then become cheaper over time and will be easier to scale up at a global level.

However, in parallel, we believe governments in emerging and developing economies should put together plans to ensure that they capitalize on this new green economy that is emerging, as the opportunities for jobs and for the economy will likely be substantial.

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Conclusion

- Drivers of investment: clear policies, carbon markets, taxes, subsidies, grants, and mandates.
- Scale up demand incentives: most are on the supply side globally and most are in North America and Europe.
- Competition amongst these sectors for certain solutions.
- Decarbonization is happening but needs to be scaled up; clients are also pushing this transition.

Spurred by legislation, the availability of government support and a push from clients who are now willing to pay a premium for green products or services, many sectors have started their journey to reduce emissions.

When we published our initial hard-to-abate sectors GPS report 3 years ago, there was very little happening and we were still debating what solutions were available.

This has changed. Investment has started.

Governments in many advanced economies have stepped up, doing the groundwork that is needed. They are developing strategies, providing government support, and using economic instruments such as Carbon Contracts for Difference, which are all helping to scale up the investment needed. These technologies and new fuels will not be feasible without their interventions, and government support will be need for the foreseeable future until cost premiums are reduced.

There remain some barriers such as the mismatch between supply and demand for solutions, delays in projects due to permitting issues and an increase in costs due to inflation, etc. These need to be solved urgently if many countries want to reach their net-zero commitments.

Currently, most of the financing is done on balance sheet. Over the last 5 years $80 billion of green bonds issuance has come from hard-to-abate sectors. This will likely increase substantially over the next few years.

We have also seen some large project finance structures that have come to fruition, such as H2Green Steel and NEOM. However, due to the overall funding need for energy transaction, corporates will increasingly need project finance. This is also extremely important for developing and emerging countries where raising private capital is rather difficult. The progress in these countries is rather muted, and this needs to change.

There are about 100,000 ships and over 20,000 planes in operation, thousands of steel and cement plants and over 200 aluminum smelters. Many of these have not started their journey to reduce emissions.

However, the good news is that the march to decarbonization has started in these sectors even though it is based mostly in advanced economies. Hopefully there will be spillover effects that will emerge, and that can help reduce emissions in hard-to-abate sectors other countries.

The journey to the decarbonization of hard-to-abate sectors has undoubtedly started.

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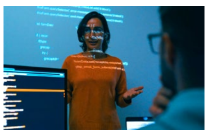

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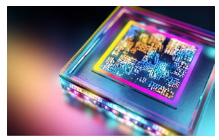

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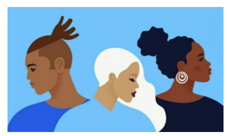

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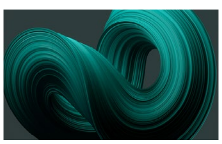

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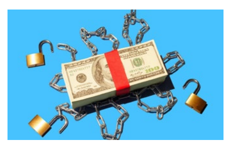

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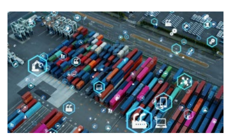

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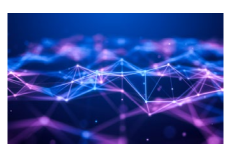

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