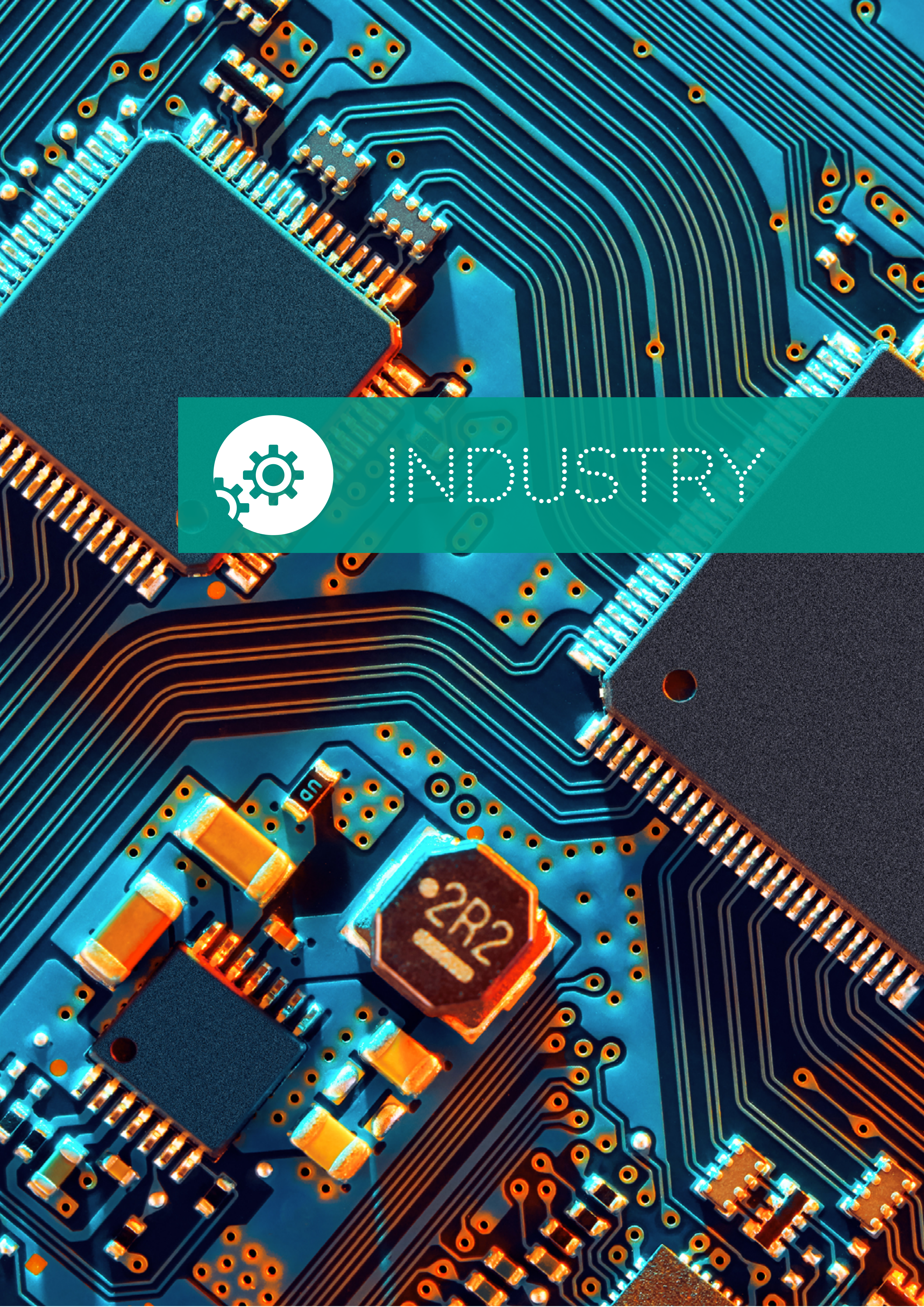

INDUSTRY

Nº 5 Hydrogen, CCS... disruptive technologies remain marginal and dependent on fossil fuels

- Global CO_2 emissions from industry rose slightly between 2015 and 2022, driven mainly by energy combustion.
- Long ignored, CO_2 capture and storage is once again mobilizing investors – especially oil companies, who are extending the life of depleting wells. Installed and developing capture potential remains very low.
- Despite growing political and financial investment since the post-pandemic recovery plans, "green" hydrogen production processes and its decarbonized uses are still limited, and depend on the availability of a decarbonized electricity mix.
- The quest for industrial sovereignty over metals strategic to the transition is defining the contours of a new geopolitical map of raw materials between industrialized countries, China who dominates the value chains, and emerging countries rich in natural resources (Indonesia, DRC, Bolivia...).

KEY FIGURES

Industrial emissions concentrated in a few heavy industries

- **+1% direct emissions from industry** from 2015-2022; steel (+5%), chemicals (+1%) and cement (+11%) represent 71% of the sector's emissions (IEA, 2023a).

Green hydrogen still a long way from its own decarbonization

- **95 Mt hydrogen (H_2) produced** in 2022; <1% of low-carbon origin, and 0.04% from renewable electricity (IEA, 2022).
- **40.8%** of production is employed in oil refining; the remainder is used to produce methanol, ammonia and direct reduced iron ore. 0.04% is devoted to low-carbon uses (transport, storage, decarbonization of industry, etc.) (*ibid.*).
- **25 States** had adopted a hydrogen strategy in 2021, compared to 3 in 2019: the pandemic marked a turning point in investments (*ibid.*).

Carbon capture and storage driven by the petroleum sector

- **42.6 million tonnes per annum (Mtpa)** was the capacity for carbon capture in 2022 (+44% since 2015), *i.e.* the equivalent of Sweden's emissions, and 0.1% of global emissions (Global CCS Institute, 2022).
- **20/30 CCS sites** financed by enhanced oil recovery (*ibid.*).
- **1 single industrial site** equipped with CCS: a cement plant in the United Arab Emirates (*ibid.*).

Metals strategic to the transition become increasingly critical

- Lithium (+539%), cobalt (+124%), nickel (+118%), rare earths (+160%), copper (+60%)... **inflation** is impacting all transition metals (IMF, 2023).
- 74% of cobalt is extracted in the DRC, 68% of rare earths in China, 49% of nickel in Indonesia, 47% of lithium in Australia; 24% of copper in Chile. China controls 57% of refining for these metals (IEA, 2023b).
- **14% of energy needs** of the mining industry covered by renewable energy (REN21, 2023).

FURTHER READING

TRENDS

- CCUS reaches a turning point (2021)
- Boosted by the recovery, the "hydrogen economy" gains credibility (2021)
- "Yes, in my backyard!" Under pressure, international competition for strategic minerals required for the energy transition intensifies (2021)
- Carbon-free steel: a miracle solution and massive investment alloy (2020)

CASE STUDIES

ALSACE • Towards a Made-in-Europe production of low-carbon lithium with the EuGeLi project (2022)

NORWAY • The Longship Project: CCS to decarbonise heavy industries (2021)

TOKYO • Hydrogen fuels the flame of the Tokyo Olympics (2021)

CHILE • An emerging key actor in the renewable energy arena (2019)

TRENDS
INDUSTRIES

The promise of disruptive technologies for decarbonizing industry

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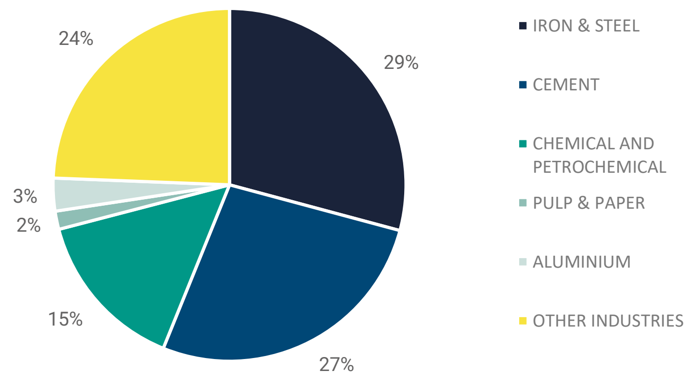
ANTOINE GILLOD • Director of the Global Observatory of Climate Action, Climate Chance

For industries, attaining carbon neutrality involves deep decarbonization of production processes sometimes already at their thermodynamic limit – a tall order for some heavy industries, like cement, steel and chemicals, whose core activity involves unavoidable high-emitting industrial processes. After years of teething troubles, two technologies have found new impetus from governments and investors to respond to the challenge: hydrogen, and carbon capture and storage. At the same time, increased competition between States to access strategic minerals for the transition of industries puts mining companies at the centre of the geopolitical arena.

FIGURE 1

GLOBAL CO_2 EMISSIONS FROM COMBUSTION IN INDUSTRY, 2022

Source: International Energy Agency, 2023



From 2015 to 2022, direct emissions from industry (**FIGURE 1**), which make up 25% of global emissions, rose by 1%, with variable trajectories depending on the country (**FIGURE 2**).[a] **Seventy-one percent of industrial emissions come from just three sectors: steel (+5% from 2015 to 2022), chemicals-petrochemicals (+1%), and cement (+11%).**[1] These processes emit high quantities of CO_2 and the quantity of heat required means electrification is difficult, making emissions

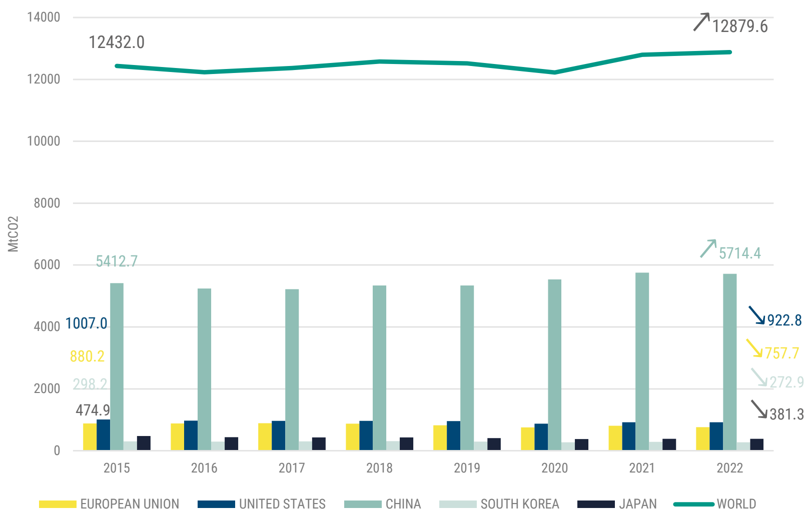
a Unless indicated otherwise, the data used come from the Enerdata "Global CO_2 and Energy" database.

from these heavy industries particularly hard to abate.[2] Since 2015, two "disruptive technologies" have boosted the hopes of states and industrials of getting closer to decarbonizing these sectors: "green hydrogen" and carbon capture and storage (CCS). Although still in their early stages, these two new technology fronts, which are industries in themselves, have received increasing political and financial support since 2015. In parallel, the affirmation of new industrial ambitions for sectors in transition (electric vehicles, renewable technologies, storage batteries, etc.) is reshuffling the cards of mining geopolitics. In this new game, the stakes are shifting for the decarbonization of the mining industry.

FIGURE 2

EVOLUTION OF CO_2 EMISSIONS FROM INDUSTRIES IN MAJOR ECONOMIES SINCE THE PARIS AGREEMENT (2015-2022)

Source: Climate Chance, based on data from Enerdata



Before it can contribute to decarbonization, hydrogen needs to undergo its own transition

Low capacities strongly dependent on carbon-intensive production processes and end-uses

In 2021, the global production of hydrogen amounted to 94 million tonnes (MtH_2), which is a 5% increase compared to 2019, as reported by the International Energy Agency (IEA).[3] Hydrogen production processes are high emitters, generating 900 $MtCO_2$ per year.[4] **99% of hydrogen is qualified as "grey", which means it results from steam-methane reforming of fossil fuels or from coal gasification. Less than 1% of hydrogen production is currently "low carbon" (FIGURE 3)**, mostly resulting from the same fossil processes, but at sites equipped with carbon capture and storage (CCS) technology: otherwise known as "blue" hydrogen. Hydrogen produced by the electrolysis of water only makes up 0.04% of production, despite a 200% rise from 2015 to 2021. With a production capacity of 0.09 Mtpa, "green" hydrogen produced by electrolysis using renewable energy was still anecdotal in 2022.[5] North America is home to the vast majority of operating capacities for producing low-carbon hydrogen (90%), while China has the biggest installed electrolysis capacities (300 MW), ahead of Europe (190 MW), out of a total 700 MW. To reach carbon neutrality in 2050 will require 200 GW of electrolysis before 2030.[6]

Today's hydrogen applications also rely heavily on carbon, with 40.8% of current hydrogen production (40 MtH_2) employed in oil refining. Among its industrial uses (54 MtH_2), 65% of hydrogen is employed to produce ammonia, used in fertilizers (+4% from 2018 to 2021), 25% for methanol to produce solvents and acetic acid (+17% from 2018 to 2021), and 10% to produce direct reduced iron ore for the steel industry (+11% from 2018 to 2021) (**FIGURE 4**). To date, low-carbon applications like decarbonizing transport, producing "zero-carbon" steel, heating buildings, and storing electricity produced from intermittent renewable energy sources remain very rare (0.04%, according to the IEA).

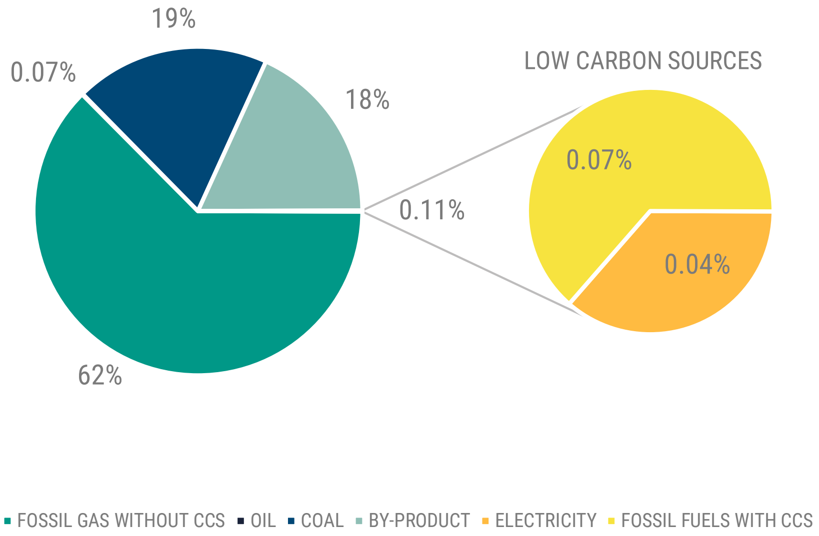
Accelerated, but fledgling investments

The latest review produced by the Hydrogen Council lists 1,040 hydrogen-related projects announced in the world, for a total investment of $320 billion by 2030. Two-thirds of these projects aim to increase production capacities, including 38 Mtpa of low-carbon (green and blue) hydrogen, 60% of it located in Europe and the United States – the remainder target infrastructure and prospection projects. To date, only 2.1 Mtpa of low-carbon hydrogen has received a final investment decision, of which 1 Mtpa comes from renewable energies. Seventy percent of these low-carbon projects are located in the United States, driven by the demand for ammonia and refining. 230 GW of electrolysis capacities have been announced, of which 40% in Europe, but only 9 GW have so far received a final investment decision. Production of "green" hydrogen is therefore in its very early stages.

FIGURE 3

GLOBAL HYDROGEN PRODUCTION BY TECHNOLOGY, 2021

Source: International Energy Agency, 2022



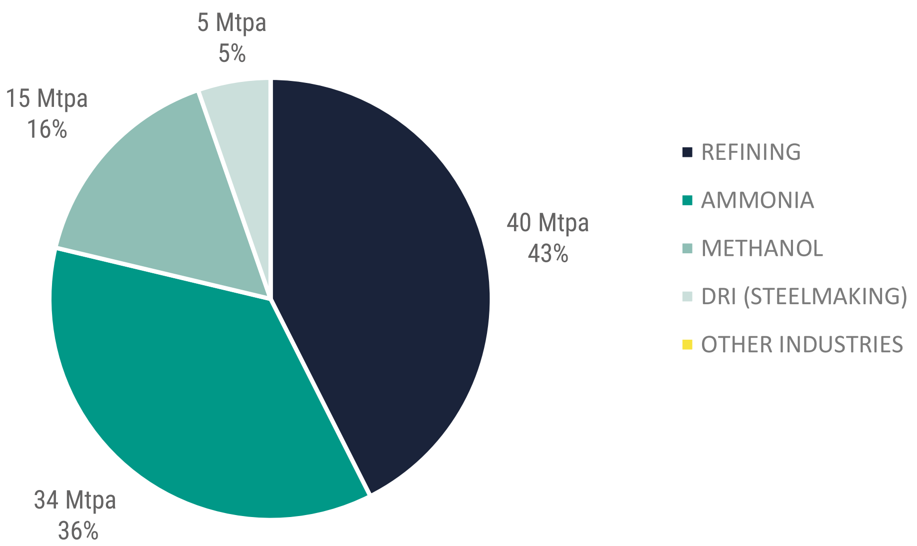
2020 marked a real turning point for the industry: low-carbon hydrogen took centre stage in post-lockdown announcements for public and private investments. In 2019, only three states had adopted strategies to develop hydrogen production with an aim of decarbonization. By 2021, the number had risen to 25, plus the EU, following the adoption of post-pandemic recovery plans, according to the IEA in its *Global Hydrogen Review*. The EU adopted a strategy in 2020, and is investing €10 billion in hydrogen through its *Important Project of Common European Interest* (IPCEI) plan, with a reference level of 3.38 $kgCO_2e/kgH_2$ for so-called "renewable" hydrogen. In the United States, the Biden-Harris administration has earmarked $9.5 billion for hydrogen in the Infrastructure Investment and Jobs Act, targeting carbon intensity of 4 $kgCO_2e/kgH_2$, along with tax credits in the Inflation Reduction Act. Japan, which was the first country to adopt a national hydrogen strategy in 2017, set new production targets in 2023, and intends to invest $107 billion in the sector over fifteen years.[7] In May 2022, six African countries – Egypt, Kenya, Mauritania, Morocco, Namibia, and South Africa – launched the African Green Hydrogen Alliance with the goal of making the continent a key player in green hydrogen production.[8]

These public investments are accompanied by strong mobilization from industrials. In Saudi Arabia, the biggest hydrogen production site in the world, scheduled for 2026, attracted $8.6 billion of multi-party investments in 2023.[9] Oil and gas companies play a major investment role by acting to reconvert existing structures. For example, the European Hydrogen Backbone initiative, launched in 2022 by twelve European gas supply network operators, aims to create an immense network to transport hydrogen throughout Europe, two-thirds of it based on converting the existing gas network. In the United Kingdom, the Zero Carbon Humber project led by Equinor, British Steel and a dozen other partners, intends to convert the gas network in the Humber Estuary to transport hydrogen, while capturing CO_2 from the hydrogen production and storing it in the North Sea.

FIGURE 4

HYDROGEN END-USES REMAIN CARBON-INTENSIVE

Source: International Energy Agency, 2022



Low-carbon applications still marginal

Several low-carbon hydrogen applications compete with each other and attract different investors depending on the local situation. While Japan and Germany are focusing on reducing emissions from transport, the EU's priority is heavy industry.[10] In China, the world's biggest producer of both solar energy and steel, green hydrogen opens opportunities for storing intermittent energy and reducing carbon emissions from heavy industry.

In 2020, 80% of the hydrogen required to produce 185 Mt of ammonia came from natural gas, and the rest from coal.[11] Large fertilizer manufacturers, like Fertiberia and Yara, are now investing in producing ammonia from green hydrogen, in partnership with energy providers like Iberdrola and Engie.[12,13] For methanol, the Dalian Institute of Chemical Physics in China is working on a project to combine green hydrogen production with CCS.[14]

In the steelmaking industry, green hydrogen provides a low-carbon solution for producing heat and in the transformation phase of iron ore ("reduction"), which mostly employs coke. However, 71.5% of the global production of primary steel is still carried out in coal-fired blast furnaces,[15] as well as in 57% of steelworks planned in 2023.[16] Yet in blast-furnaces, total substitution of carbon monoxide with hydrogen is not feasible.[17] In 2016, the energy supplier Vattenfall got together with the steelmakers Swedish Steel (SSAB), and the mining company Luossavaara-Kiirunavaara Aktiebolag (LKAB) to launch the Hydrogen Breakthrough Initiative (*Hybrit*). The project's aim is to manufacture steel by replacing coal with hydrogen and pig iron with direct reduced iron (DRI), produced from green hydrogen.[18] The "Carbon2Value" initiative led by ArcelorMittal combines DRI production via hydrogen with CCS in order to reduce site emissions. In Dunkerque, France, in partnership with the French Agency for Ecological Transition (ADEME) and the French Institute of Petroleum (IFPen), the group is setting up a pilot project based on these methods.[19]

Despite growing investments, the development of carbon capture remains uncertain

Unprecedented investment boom

Carbon capture and storage (CCS) technology has also attracted increased interest since 2017. The term covers different technology families that aim to capture CO_2 from industrial emissions or from electric power stations operating on fossil fuels, and either transport it to a storage point for permanent sequestration in a deep geological layer, or reuse it.

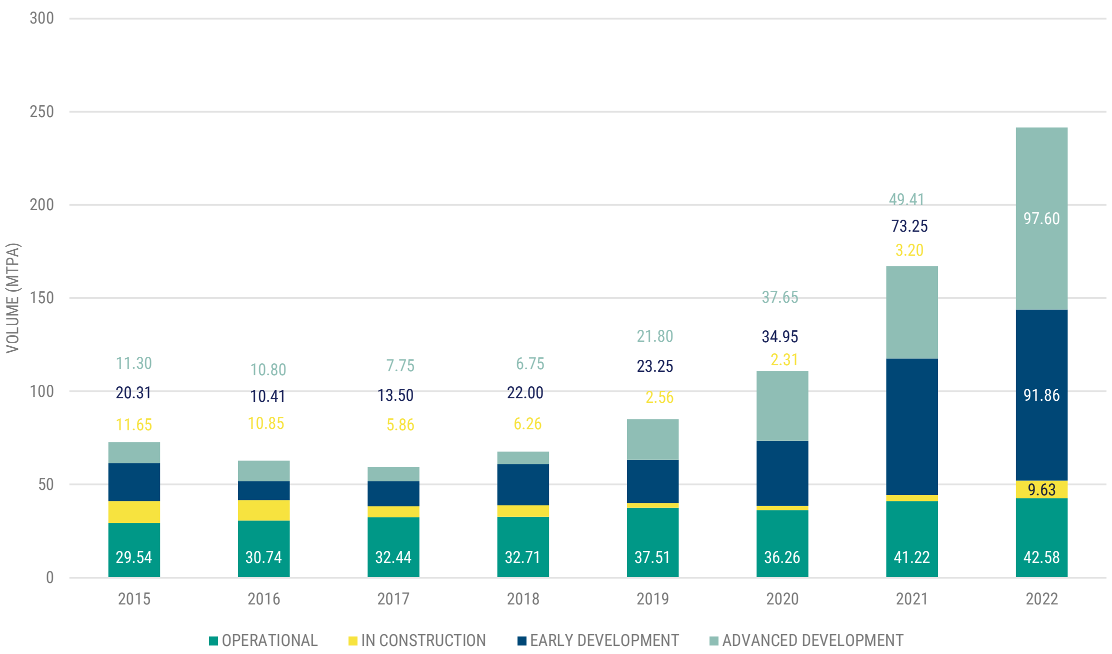
Global investments in CCS amounted to $6.4 billion in 2022 – 45% in the United States – which is almost six times more than in 2019.[20] In September 2022, 30 sites were operating in the world, with a total capture capacity of 42.6 million tonnes of CO_2 per year (Mtpa), compared to 29.54 Mtpa in 2015. This represents an average capture capacity of 1.4 Mtpa.

Current capture capacities are therefore currently more or less equal to Sweden's emissions, or 0.1% of global emissions. Currently, 164 projects are being developed, of which 11 are under construction, and 78 are at an advanced stage of development, representing a capture potential of 244 Mtpa (0.65% of global emissions). From 2015 to 2022, the number of projects in the early development phase multiplied by 3.5, and advanced phase projects by 7.6 (**FIGURE 5**). Another 61 new projects were announced in 2022.[21]

FIGURE 5

PIPELINES OF COMMERCIAL FACILITIES SINCE 2010 BY CAPTURE CAPACITY (MTPA)

Source: Global CCS Institute, 2022



CCS driven by the oil and gas sector

The CCS sector also turns out to be highly dependent on fossil industries. **Historically, most CCS projects have been funded by Enhanced Oil Recovery (EOR): 20 of the 30 sites in operation store their carbon in oil wells to extend their lifecycle**, thus reducing CCS's real contribution to global mitigation efforts. Fourteen of these sites are natural gas processing facilities, five produce ethanol and methanol, one is a refinery, and one is a petrochemical site operated by Sinopec, the Chinese national petroleum company. Operational projects are concentrated in the United States and Canada (18), which are big oil producers. In Europe, 73 projects are currently being developed, mostly in countries possessing hydrocarbon resources and a strong industrial fabric: the United Kingdom, the Netherlands and Norway.

Thus, 85% of CCS project partners are companies from the fossil energy sector.[22] In 2020, CCS was the third "low-carbon" expenditure item for big oil companies,[23] which are equipped with the infrastructure required to transport carbon by pipeline and are interested in extending the lifecycle of wells. In the United Kingdom, the "Net-Zero Teesside" project, which aims to capture and store 2 $MtCO_2$/year emitted by a gas plant in saltmarshes in the North Sea, is funded by the Oil and gas Climate Investment consortium (30% of the world's petroleum) and supported by the British government. In Canada, the "Alberta Carbon Trunk Line" (ACTL) project will reinject part of the CO_2 captured from a fertilizer factory and an oil sand refinery into oil wells in order to extend their operational duration.[24]

Capturing emissions from heavy industry still a long way off

To date, only one CCS installation is in place at the exit of an industrial site: Abu Dhabi CCS captures 90% (0.8 Mtpa) of CO_2 from a steelworks in Mussafah in the United Arab Emirates and injects it into oil fields 43 km away.[25] The deployment of CCS is however attractive for the cement industry, where the concentration of CO_2 emissions makes them easier to capture.[26] In Norway, the Longship project aims to capture 44% of the 900,000 tCO_2 emitted annually by the Norcem Brevik cement plant and then store it in a permanent reservoir via Northern Lights infrastructures, a storage and transportation project with an annual capacity of 1.5 $MtCO_2$ in its first phase, financed to the tune of €680 million by Equinor, Shell and TotalEnergies.[27] In France, the scattered locations of cement plants and their distance from storage sites hinder the wide-scale adoption of this technique.[28]

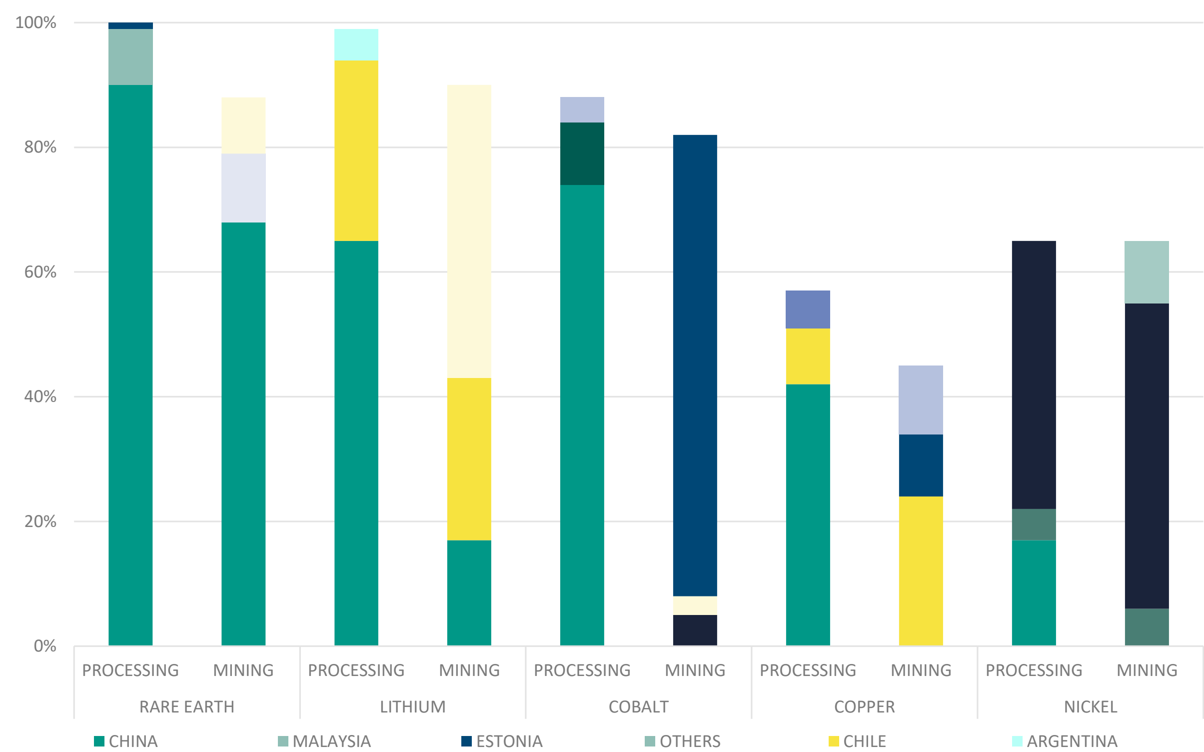
Other applications are still in demonstration or development phases. Today, only one direct air capture (DAC) site exists, called ORCA, located in Iceland. Opened in 2021 by the Swiss company Climeworks, the installation has the lowest capacity of all CCS technologies (0.004 Mtpa). The site takes advantage of a geothermal source for its electricity supply, and the CO_2 is stored in a special reservoir. Climeworks raised $650 million in April 2022 to develop new installations.[29] In addition, no bioenergy with carbon capture and storage (BECCS) sites are in operation in the world; however, the former Drax coal-fired power station (United Kingdom), which has converted to biomass, is due to inaugurate the largest BECCS project (8 Mtpa) in the world in 2027. Lastly, despite the complementary nature of the two technologies, only two blue hydrogen production (with CCS) sites are in place in the world, operated by Shell in Canada since 2015 (geological storage) and Air Products & Chemicals Inc. in Texas since 2013 (EOR).

Despite a gradual shift towards CO_2 storage in deep saline formations in the United States and in the North Sea, storage in oil wells is set to expand in Australia, Southeast Asia and the United Kingdom. For example, the British government has announced that, as well as granting new licences to exploit oil and gas fields, it will be supporting two new CCS projects. These include the Viking project (transport and storage), owned 40% by BP, which will reuse pipelines to carry captured CO_2 to depleting fields in the North Sea.[30]

FIGURE 6

SHARE OF TOP THREE COUNTRIES IN TERMS OF EXTRACTION AND PROCESSING OF SELECTED MINERALS, 2022

Source: International Energy Agency, 2022



Sectors undergoing a transition put pressure on strategic mineral resources

The electrification of end-uses is intensifying the global economy's demand for mineral ores

The global final consumption of electricity, one of the main drivers of decarbonization, rose by 38% from 2010 to 2022. The electrification of end-uses, combined with a greater share of renewable energy in the electricity mix, means the transition depends on global issues of strategic metal supplies.[31] In the last decade, the metal intensity of new electricity production capacities rose by 50%. For the same level of power, a wind turbine requires nine times more metal than a gas power station, and an electric car six times more than a thermal combustion vehicle. The IEA estimates that metal production will need to be multiplied by six by 2040 in a scenario of carbon neutrality by 2050.[32]

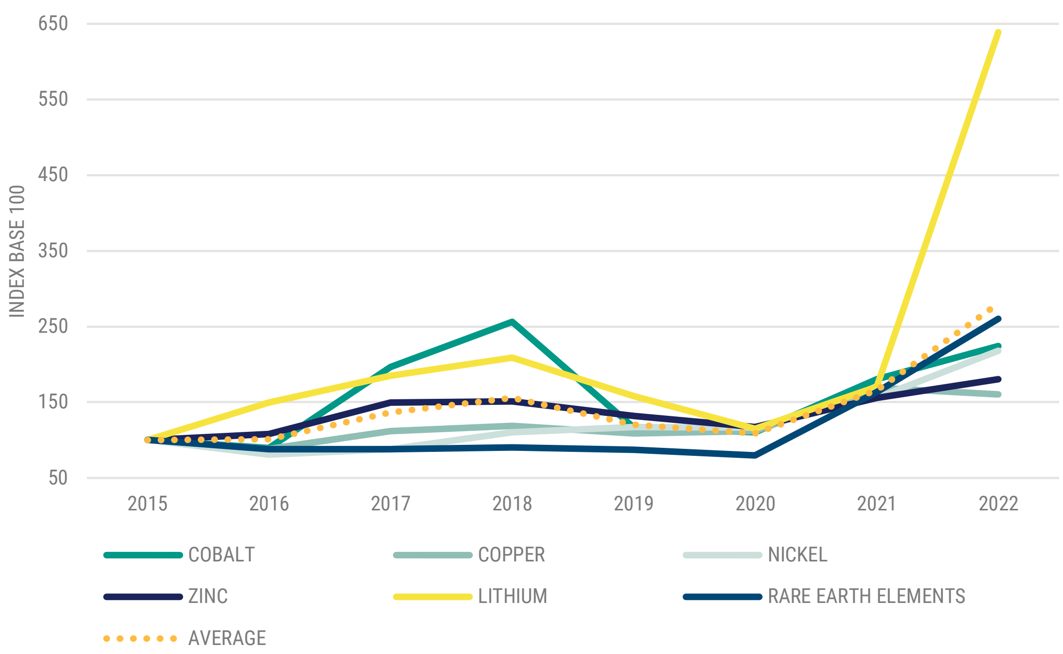
Although they are abundant in the earth's crust, many of these metals are considered to be "critical" by states due to the risks associated with their supply (geographic availability, concentration of extraction and production, political stability in producer countries, etc.), and the importance of metal for economies. Cobalt, copper, nickel, lithium and rare earths, which are the key components of the major transition technologies (batteries, wind turbines, etc.), are the focus of particular attention.[33]

Concentration is an issue for extraction, and in particular refining (**FIGURE 6**). Currently, the Democratic Republic of the Congo (DRC) extracts 74% of cobalt, Indonesia 49% of nickel, Australia 47% of lithium, Chile 24% of copper, and China 68% of rare earths. China is almost unavoidable in refining steps, of which it controls 90% for rare earths, 65% for lithium, 74% for cobalt, and 42% for copper; Indonesia operates 42% of nickel refining.[34] Given this concentration, the growth in demand observed in several sectors in transition (**CF. "ELECTRICITY" AND "TRANSPORT" TRENDS**) has generated high price inflation. From 2015 to 2022, the price of lithium increased by 539%. Over the same period, cobalt (+124%), nickel (118%), rare earths (160%) and copper (60%) also saw rocketing inflation (**FIGURE 7**). The phenomenon impacts industrial industries strategic to the transition, especially electric batteries, whose price is strongly dependent on the price of these metals.

FIGURE 7

EVOLUTION OF PRICE INDEX OF SELECTED MINERALS, 2015-2022

Source: Climate Chance based on data from IMF Primary Commodity Price System



From mines to factories, states seek to gain control and sovereignty

The acceleration of some transition sectors coupled with increasing geopolitical tensions has seen access to strategic metals revive economic nationalism. On the one side, industrialized states dependent on imports are attempting to secure their supplies, via joint ventures, free trade agreements, supply contracts, and by opening mines on their own territories.[35] The EU Critical Raw Materials Act and the US Executive Order 14017 on America's Supply Chains are responses to this objective.[36,37] On the other side, emerging countries with abundant mineral resources are setting up industrialization strategies to substitute exportation, and tightening the global supply of minerals in order take advantage of their raw materials resources to integrate value chains and increase added value. The Chilean president Gabriel Boric has announced his intention to increase state control of national lithium. In April 2022, Mexico had already created Litio para México, a state-run company to nationalize its resources.[38] In 2021, the leading Korean battery company, LG Energy Solution (LGES), signed a memorandum of agreement with four public Indonesian companies to form the Indonesian Battery Corporation, and create a national nickel industry.[39]

The opening of new mines comes up against opposition from civil society in countries that sometimes turned the page on their mining history years ago, or due to environmental concerns. In Serbia, strong popular opposition forced the government to cancel the biggest lithium mining project in Europe in the Jadar Valley.[40] In Portugal, against a backdrop of natural heritage protection, local movements frequently gather and demonstrate against the government's ambition to open mining concessions to exploit lithium in the region.[41] In Indonesia, increasing numbers of activists have been arrested since the revision of the mining law in 2020: in 2021, 53 people were pursued on criminal charges after opposing mining projects.[42]

In response to environmental concerns, companies are innovating to reduce the environmental disturbances caused by mining activities. The "Zero Carbon Lithium" project deployed in Germany by the Australian company Vulcan with support from the automobile maker Stellantis, and the project "European Geothermal Lithium Brine" (EuGeLi) driven by the French mining company Eramet in partnership with Electricité de Strasbourg, both aim at extracting lithium from geothermal brine to reduce carbon emissions, water consumption, and the cost of open-air mines or evaporation tanks generally used in the sector.[43]

For the most part, companies in the mining sector are aware of their strategic role in supplying the raw materials needed for the low-carbon technology transition. Their transition plans tend to follow three strategic axes. The first involves totally or progressively disinvesting carbon-intensive energy: AngloAmerican has exited from the coal mining business in South Africa,[44] while the petroleum branch of BHP has merged with Woodside Petroleum.[45] The second is to reduce the carbon intensity of their extraction activities and the entire supply chain: only 14% of the energy needs of the mining industry were covered by renewable sources in 2021, despite being the most electrified heavy industry (44%).[46] Lastly, companies are trying to focus their efforts on exploiting metal mines that supply low-carbon markets and thus contribute downstream to the energy and technology transition in the transformation of raw materials into finished or semi-finished products. This positioning takes the form of numerous mergers and acquisitions,[47] along with joint ventures aimed at innovation in hard-to-abate industries. In this last area, Rio Tinto and Alcoa for example formed a joint venture in 2018, Elysis, to develop a process to produce aluminium without emitting CO_2 – BMW has already placed an order to supply its production lines from 2024.[48]

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