CO_2 Utilization: The Evolution of the Carbon Economy

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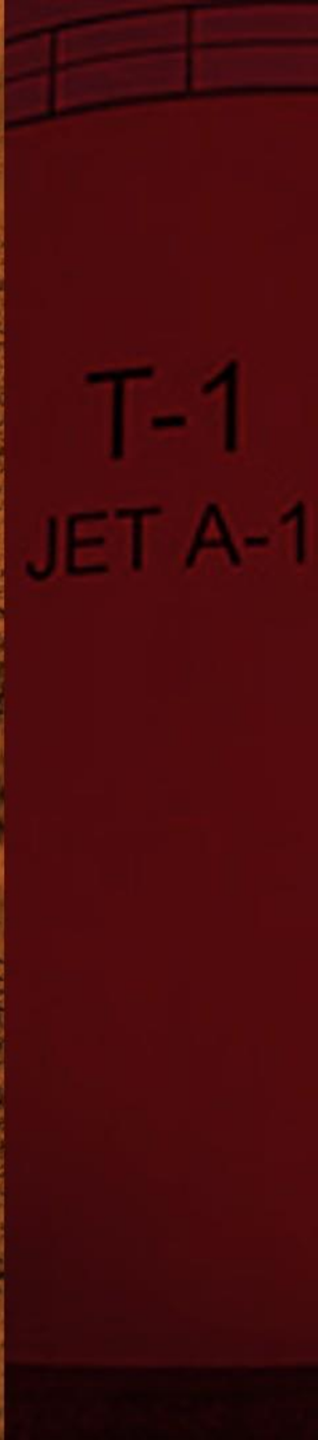


Introduction

While global CO_2 emissions grew steadily in the 21st century, the increase in carbon capture projects positions CO_2 as a valuable product that can be recycled back into the supply chain through CO_2 utilization. This refers to the thermochemical, electrochemical, or biological conversion of CO_2 into a range of value-added products. The global market size for CO_2 utilization is set to reach USD 70 billion by 2030, then increase to USD 550 billion by 2040. CO_2 utilization is emerging as an alternative pathway to subsurface sequestration and presents corporations with an opportunity to create monetizable value from CO_2.

Even in a realized decarbonized economy, global energy and chemicals value chains will still need a steady supply of carbon derivatives as feedstocks or otherwise. But the source of that carbon will increasingly trend toward nonfossil sources, creating opportunities to produce valuable commodity products from CO_2 captured from biomass, industrial emissions, and ambient air. According to the International Energy Agency, plans are already underway for over 20 commercial-scale facilities to capture over 100,000 tonne of CO_2 for conversion to synthetic fuels, chemicals, and building materials.

This e-book explores six key technology categories for CO_2 utilization: **building materials, synthetic fuels, chemicals, polymers, food, and carbon additives**. For each section, it includes a snapshot of the developer landscape, market size and cost tipping point, and a Lux Take on the outlook.

Image source: Neste

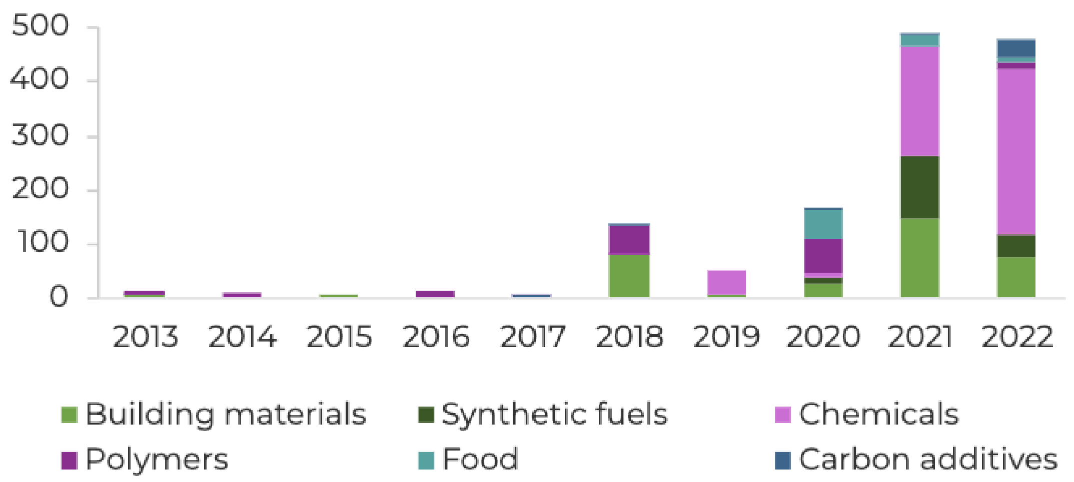
The Investment Landscape

On the investment front, 2021 marked a significant turning point for funding in CO_2 utilization, Until 2018, investments in CO_2 utilization were negligible, and over 90% of investments were limited to building materials and polymers, both of which have low technology barriers and no reliance on hydrogen.

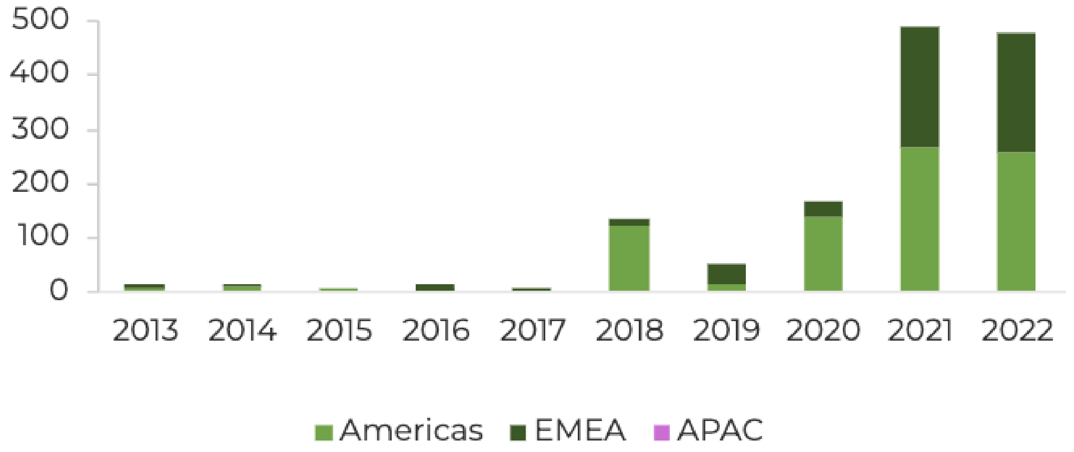
However, the landscape witnessed a 195% surge in funding between 2020 and 2021. The last few years have also seen an increased diversification in technologies and a rise in the number of deals, growing from a mere five annually between 2016 and 2019 to a robust 16 between 2020 and 2022.

Interestingly, while building materials and chemicals are matched in number of funding rounds, CO_2-to-chemicals startups attracted heftier average deals. Some of the larger deals include CO_2 electrolysis companies like Sunfire and Twelve garnered investments of USD 220 million and USD 187 million, respectively. Almost 75% of venture funding is Series B or earlier, signaling that the CO_2 utilization landscape is broadly still in development. Companies are either operating demonstration pilots or gearing up to begin pilots in the next few years.

Investment trends by technology (USD million)



Investment trends by region (USD million)



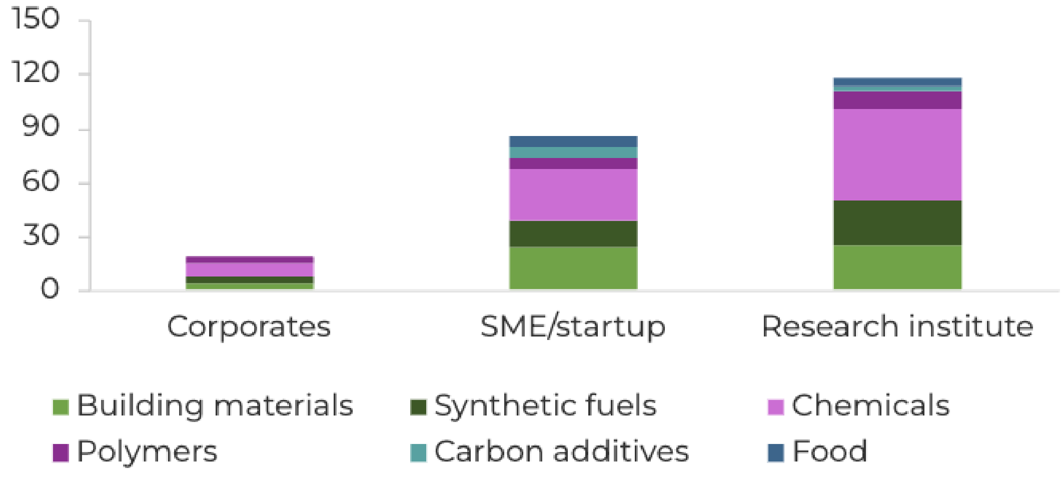
See more at [Investment Trends: CO_2 utilization]

Technology landscape: By entity type and region

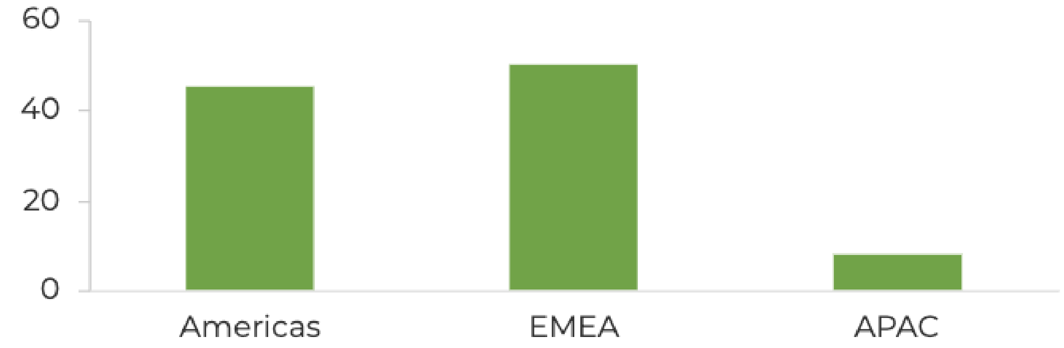
In terms of commercial activity, building materials and chemicals are dominant, comprising about 65% of the entities actively involved in CO_2 utilization. While building materials benefit from fewer technical challenges, allowing for a quicker market entry, the chemicals sector, though more complex, promises a broader spectrum of end products. Geographically, the Americas and EMEA are at the forefront, driven by the pressing need to decarbonize and substantial funding initiatives from bodies like the European Commission and the U.S. Department of Energy. The field also sees significant participation from research institutions, many of which are making strides in areas like electrochemical conversion, co-electrolysis of CO_2 and water, and innovative one-step CO_2 capture and conversion processes.

Policy is also beginning to play a stronger role, For example, the U.S. Inflation Reduction Act of 2022 provides between USD 60 and USD 130 per tonne of CO_2 converted into a value-added product.

Key players in CO_2 utilization (by entity type)

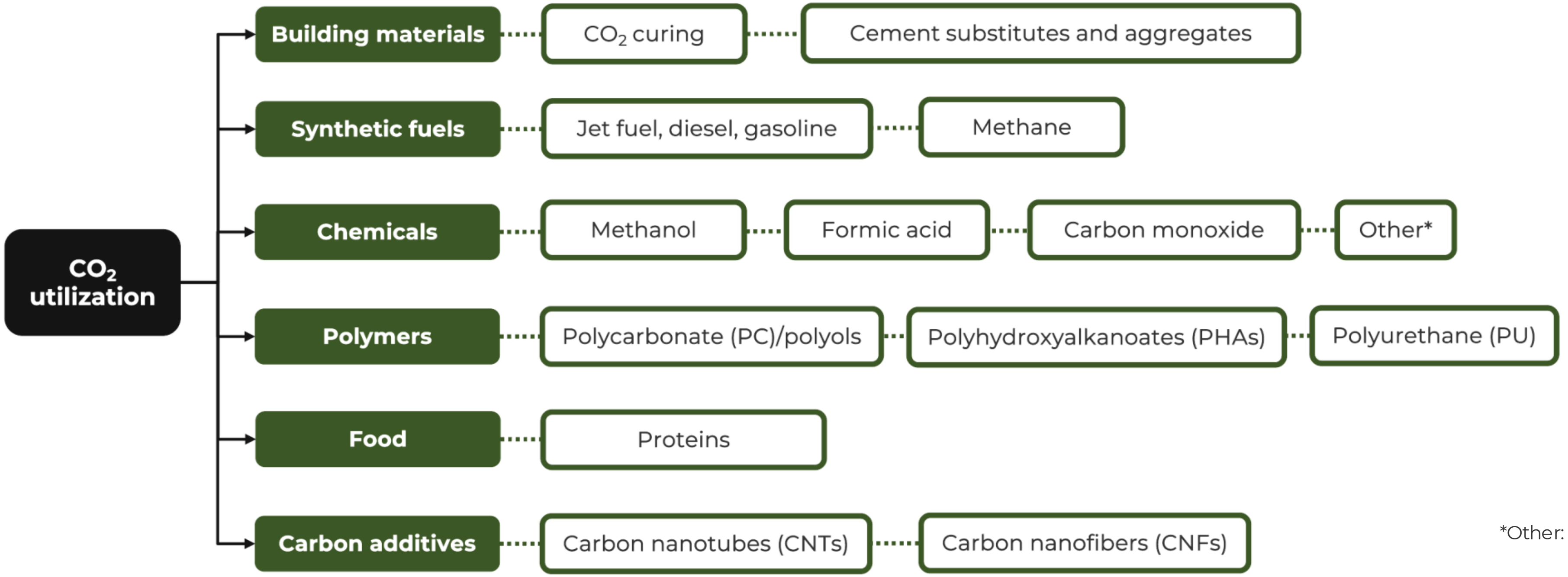


Key players in CO_2 utilization (by region)



See more at Technology Landscape: CO_2 utilization

Lux's CO_2 utilization economy

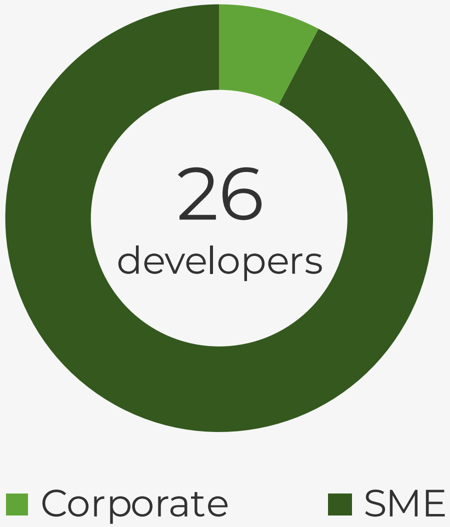


*Other: ethylene, ethylene glycol, monoethylene glycol, butanol, and other C2+ chemicals

- **Building materials:** CO_2 is used to produce aggregates or in curing wet concrete mix.
- **Synthetic fuels:** CO_2 is used to produce hydrocarbon fuels like diesel and methane.
- **Chemicals:** CO_2 is used to produce C1 chemicals like methanol and formic acid.
- **Polymers:** CO_2 is used to produce polymers like PCs or PHAs.
- **Food:** CO_2 is used to produce single-cell proteins for feed applications.
- **Carbon additives:** CO_2 is used to produce carbon materials like CNTs and graphene.

BUILDING MATERIALS

CO_2 can be used to produce aggregates to mix with cement or injected directly into wet concrete for curing



Lux Take

CO_2 emissions are unavoidable in cement production due to the thermal decomposition of limestone. CO_2 utilization provides an avenue for the industry to close its carbon loop. In addition to decarbonization benefits, performance advantages and permanent sequestration can be gained. The conversion pathway is commercially available today, and there is increasing activity with multiple partnerships and projects. Expect continued momentum due to low technology barriers.

What you should do: The technology is a near-term opportunity in CO_2 utilization. While it can decarbonize the concrete industry, it also provides a sizable carbon sink for other industries looking to store their CO_2 emissions. Engage with technology developers in CO_2-based concrete and focus on those that offer performance advantages.

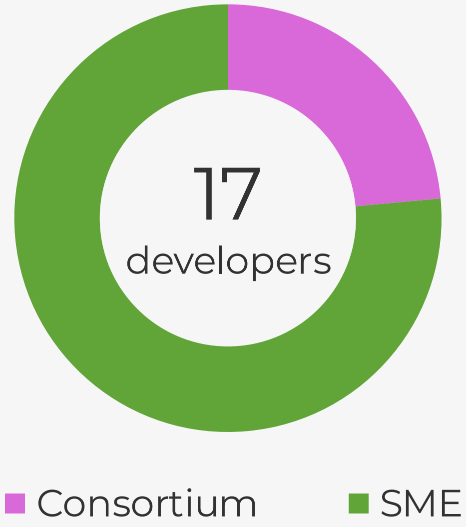
Technology	Aggregates	Curing
Maturity	Scale	Scale
CO_2 consumption* (tonne CO_2/tonne product)	0.087 to 0.44	0.001 to 0.05
Cost tipping point (y)	2031	2027
2050 market size (USD)	337 billion	666 billion

*Uptake levels in materials by weight is 0.1%–5% for curing; for cement substitutes and aggregates, it can be as low as 5% CO_2 or as high as 44% CO_2 for pure carbonates.

CO_2 Utilization

SYNTHETIC FUELS

CO_2 is used for producing both liquid and gaseous hydrocarbon fuels like jet fuel and methane



Lux Take

Synthetic fuels represent one of the largest potential markets for CO_2 utilization, but adoption is and will remain restricted by high costs coupled with the capital-intensive nature of the technology. Production of liquid hydrocarbons like gasoline, kerosene, and jet fuel has more opportunities than methane. Success in synthetic fuels hinges on aviation incorporating low-carbon fuels, which are chemically identical to their fossil counterparts, in their operations.

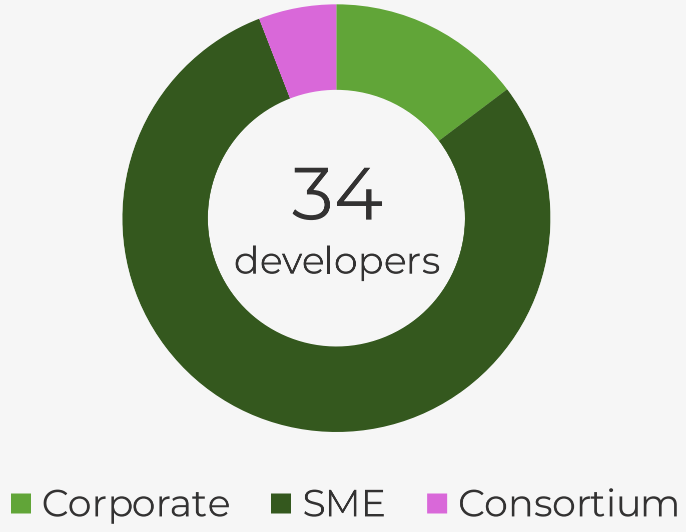
What you should do: Synthetic fuels will not be economically feasible without drastic regulatory support and are a longer-term opportunity in CO_2 utilization. Explore the technology for demonstration projects, more so if you have access to CO_2 and hydrogen from existing operations, but also consider more mature CO_2-utilization platforms and low-carbon fuels for commercial operations.

Technology	Jet fuel	Methane
Maturity	Introduction	Introduction
CO_2 consumption (tonne CO_2/tonne product)	3 to 6	0.8 to 1
Cost tipping point (y)	2042	2038
2050 market size (USD)	1.8 trillion	214 billion

CO_2 Utilization

CHEMICALS

CO_2 is used for producing chemical intermediates like CO, methanol, and formic acid



Lux Take

CO_2 utilization can provide the chemicals industry with an alternative source of essential carbon feedstock on the path to decarbonization. However, CO_2-to-chemicals production is extremely energy intensive and just beginning to see commercialization. Technology viability requires securing cheap renewable energy and green hydrogen, but interim solutions using nonrenewable inputs can bridge the distance to broader adoption in certain regions.

What you should do: Despite high costs, CO_2 utilization should be on the radar for the chemicals industry in addition to first exploring and identifying the limits of more advanced technologies like recycling and biobased feedstocks.

Technology	Methanol	Formic acid
Maturity	Introduction	Development
CO_2 consumption (tonne CO_2/tonne product)	1.28 to 1.50	0.50 to 0.96
Cost tipping point (y)	2036	Cost parity
2050 market size (USD)	183 billion	0.8 billion

CO_2 Utilization

POLYMERS

CO_2 can directly or indirectly be used to make a wide range of polymers, including novel PCs, PUs, and PHAs

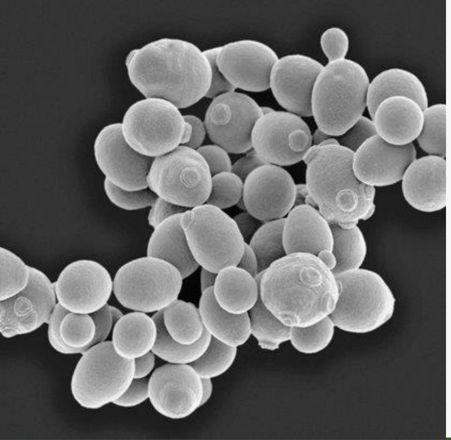
Lux Take

CO_2-to-polymers leverages existing commercial processes and can therefore be a near-term opportunity for the chemicals industry. However, a lot of recent activity has focused on the production of novel polymers with low market maturity. Additionally, the end-use products for such polymers is in consumer markets where biobased materials provide stiff competition. Given the limited addressable market, CO_2-to-polymers will have a minimal impact on carbon abatement.

What you should do: CO_2-to-polymers has a higher maturity than most CO_2-utilization products but should be a low-priority option given its limited scope and competition with biobased materials. Those targeting novel polymer production should prioritize delivering performance benefits relative to incumbents' in the existing commodity market or focus on novel catalyst development.

Technology	**Polyurethane**
Maturity	Scale
CO_2 consumption (tonne CO_2/tonne product)	0.05 to 0.25
Cost tipping point (y)	2028
2050 market size (USD)	191 billion

Note: Some developers target PHAs, but the market is still in its infancy and has historically struggled to gain commercial adoption despite its end-of-life attributes. This market is unlikely to have opportunities and is not included.



CO_2 Utilization

FOOD

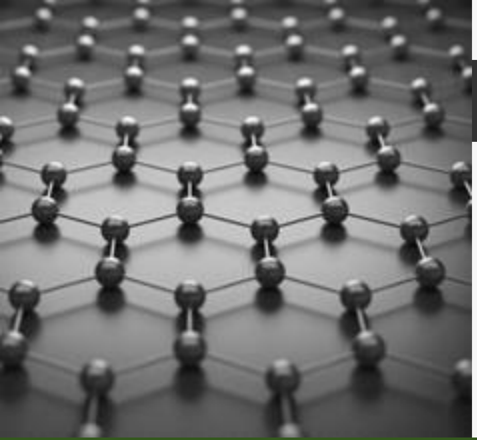
CO_2 is used as a feedstock to produce proteins for feed or food applications

Lux Take

Single-cell protein production has the potential to produce large protein quantities with fewer resources (e.g., land and water) in less time compared with conventional protein sources. Scaled production requires significant investment, and technical challenges abound. Despite this, CO_2-based proteins can capture a large share of the market for alternative proteins.

What you should do: Single-celled protein is at an early stage of development. Those with available CO_2 waste streams should carefully consider capitalizing on the opportunity. Keep tabs on the players advancing pilot-scale production as they are backed by the greatest amount of technical and financial support.

Technology	Food
Maturity	Laboratory
CO_2 consumption (tonne CO_2/tonne product)	0.50 to 0.70
Cost tipping point (y)	2042
2050 market size (USD)	921 billion



CO_2 Utilization

CARBON ADDITIVES

CO_2 is used to produce carbon nanomaterials like CNFs, CNTs, graphene, or other allotropes

Lux Take

Producing carbon additives seems appealing as these technologies can consume and sequester high amounts of CO_2. However, activity in this space is extremely low, and CO_2-based additives will face the same challenges as conventional materials. Any success will depend on strong application development, solid cost reduction, and consistent supply quality — major hurdles that are difficult to overcome.

What you should do: CO_2-based carbon additives will not move the needle for decarbonization given the lack of technological validation at scale and low market penetration expected. Without many viable short- to medium-term opportunities, seek other solutions that offer higher traction with lower barriers to adoption.

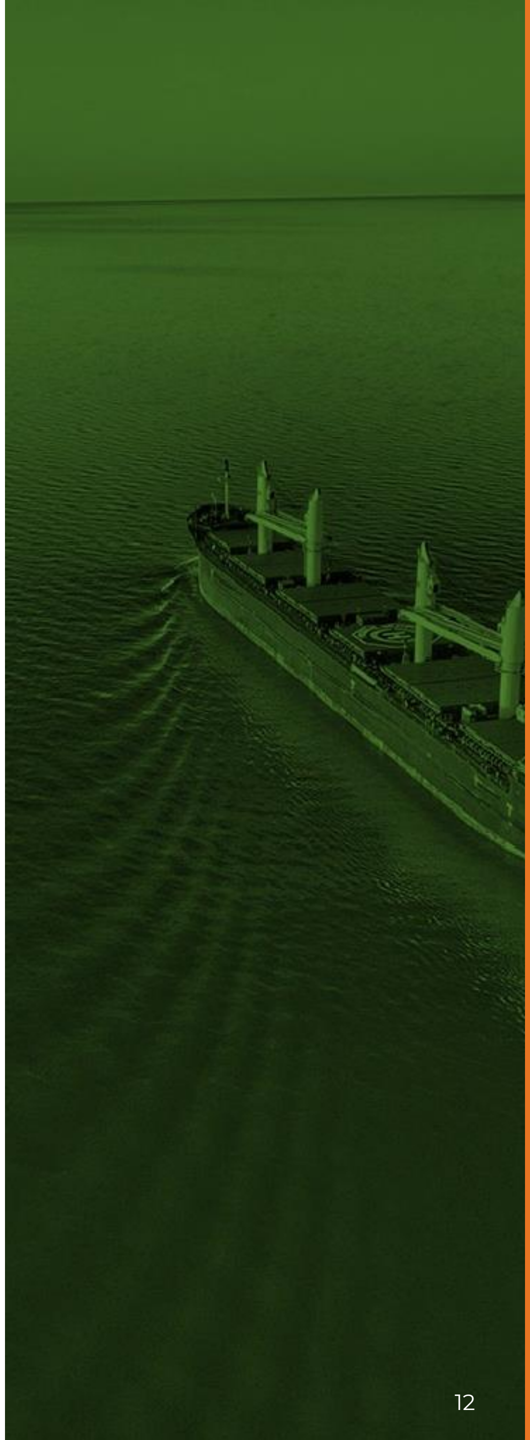
Technology	Carbon black
Maturity	Development
CO_2 consumption (tonne CO_2/tonne product)	3.7 to 4.2
Cost tipping point (y)	2041
2050 market size (USD)	66 billion
CO_2 utilization potential (Gtonne/y)	0.2

CO_2 utilization's growing innovation landscape

Building materials, chemicals, and synthetic fuels show the highest momentum. Accounting for a significant majority of commercial activity across CO_2 utilization, the three categories have seen the highest number of new entrants over the past five years along with notable joint industry efforts. Large-capacity projects for jet fuel and methanol production are led by consortia or technology aggregators that bring together key stakeholders with complementing expertise: carbon capture, electrolyzers, conversion reactors and catalysts, and downstream refining.

Hydrogenation products remain expensive. The overall carbon footprint of the CO_2 utilization product depends on the carbon intensity of its feedstocks; hence, green hydrogen is a necessary process input. This results in higher production costs for end-products like liquid fuels, methane, and methanol. Corporations can optimize their near-term feedstocks to kick-start CO_2 utilization projects (e.g., relying on blue hydrogen while electrolyzer capacity scales), but should remain cognizant of overall life cycle emissions. In contrast, products like building materials, polymers, and formic acid do not rely on hydrogen and therefore have lower production costs.

Growing momentum evident in electrochemical pathways and platform technologies. Several early stage startups are opting for electrochemical CO_2 conversion pathways over catalytic and microbial ones. Novel electrochemical technologies allow direct conversion of CO_2 and water into chemicals that would otherwise be produced by hydrogenation. Platform technologies that show capability in producing a range of chemicals are also in development, and while early stage, they showcase the potential of producing specialty chemicals on demand.



Corporations have the opportunity to build out the energy and chemicals value chains of the future

CO_2 utilization presents opportunities for the chemicals industry to decouple itself from the oil and gas value chain. CO_2 utilization has so far eluded decarbonization of the petrochemical and specialty chemicals industries because of a lack of supporting regulations, resulting in developers of e-methanol projects instead targeting fuels. However, CO_2 utilization has a unique value proposition for the chemicals industry. In addition to a higher margin than fuels, CO_2 utilization provides the chemicals sector with an alternative source of CO_2. As the sector has continued demand for carbon and carbon-derivatives, it will be increasingly pressured to rely on alternative sources of carbon, which include industrially captured CO_2 and products made with industrially captured CO_2. The evolution of the carbon economy in being able to recirculate captured CO_2 in existing production infrastructure therefore offers opportunities for new business models and revenue streams. The chemicals industry already uses methanol and CO feedstocks sourced from the oil and gas value chain — the CO_2 capture and utilization (CCU) pathway allows the chemicals industry to continue its operations without oil and gas reliance.

Regulatory support beyond innovation grants, through direct investment or tax credits, is necessary. The global regulatory landscape currently favors permanent sequestration over CO_2 utilization, but growing commercial activity and technology validation of CO_2 conversion pathways can result in some balance. In addition to growing private sector momentum, regulatory support will be critical for CO_2 utilization products to be cost competitive with their fossil-based counterparts and incentivize corporations to incorporate CCU products in their portfolio.

Key Takeaways

1 **CO_2 utilization is a fast-emerging alternative to permanent sequestration.**

CO_2 utilization fulfills the demand for carbon derivatives in decarbonized energy and chemicals value chains without relying on fossil-based carbon.

2 **Prioritize the product, not the pathway.**

Selecting the best-fit product has a bigger business impact on corporations than the pathway.

3 **Regulatory support is needed to boost market penetration.**

Most CO_2 utilization products are, and will remain, more expensive than their fossil-based counterparts, more so if there is dependence on hydrogen to make them.

About Lux

Our mission is to advise leaders about commercially viable science and technology to enable sustainable innovation. We deliver research and advisory services to inspire, illuminate, and ignite innovative thinking that reshapes and grows businesses. Using quality data derived from primary research, fact-based analysis, and opinions that challenge traditional thinking, our experts focus on finding truly disruptive innovations that are also realistic and make good business sense.

The "Lux Take" is trusted by innovation leaders around the world, many of whom seek our advice directly before placing a bet on a startup or partner — our clients rely on Lux insights to make decisions that generate fantastic business outcomes. We pride ourselves on taking a rigorous, scientific approach to avoid the hype and generate unique perspectives and insights that innovation leaders can't live without.

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