PitchBook Data, Inc.

John Gabbert Founder, CEO

Nizar Tarhuni Vice President, Institutional Research and Editorial

Paul Condra Head of Emerging Technology Research

Institutional Research Group

Analysis

John MacDonagh
Senior Analyst, Emerging Technology
john.macdonagh@pitchbook.com

pbinstitutionalresearch@pitchbook.com

Publishing

Designed by **Jenna O'Malley**

Published on March 17, 2023

Contents

EMERGING TECH RESEARCH

Carbon Dioxide as a Source of Value

PitchBook is a Morningstar company providing the most comprehensive, most accurate, and hard-to-find data for professionals doing business in the private markets.

Key takeaways

- VC investment into carbon utilization has increased dramatically in the last few years, driven by regulatory and policy incentives, technological advancement, and increasing installation of carbon capture hardware. Carbon utilization provides an alternative to carbon storage.

- Captured carbon can be used as a feedstock to create a broad range of products, including chemicals, fuels, and construction materials, in addition to varied lower-volume applications. Each of these approaches has different requirements, challenges, and decarbonization potential.

- Ultimately, the viability of carbon utilization approaches will vary on a case-by-case basis, depending on factors including energy costs, regulation and policy, consumer and corporate interest in low-carbon products, and the cost of carbon transport and storage in a given location.

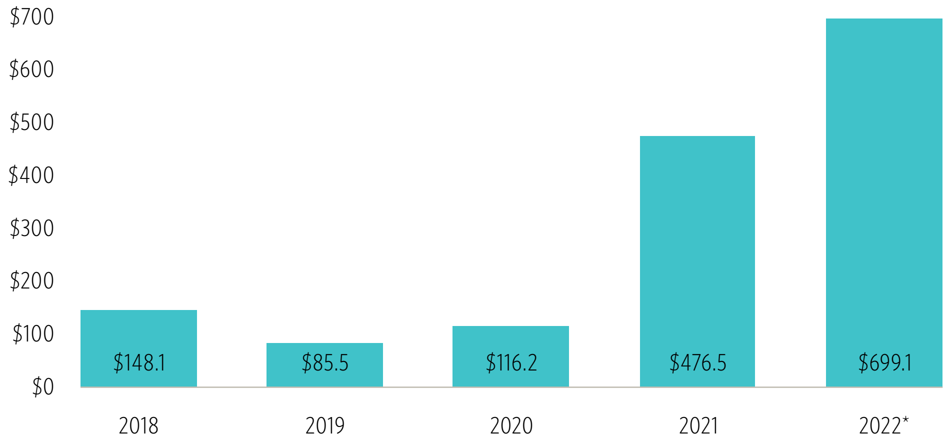
VC activity

VC investment into carbon utilization technologies has increased over the last five years, showing a significant jump from $116.2 million in 2020, to $476.5 million in 2021, and $699.1 million in 2022. The five largest carbon utilization deals in the last five years were to:

- Monolith, which converts natural gas to hydrogen and solid carbon, which is used for industrial applications. Monolith raised $534.0 million over three late-stage VC deals, the largest of which was their $300.0 million Series D in July 2022.
- Twelve, which converts CO_2 to chemicals and fuels, using CO_2 from either point sources or captured directly from the air. Twelve raised $130.0 million in Series B funding in July 2022.
- Prometheus, a CO_2-to-fuels company that also develops the direct-air-capture technology to supply CO_2 to carbon utilization hardware. Prometheus raised $100.0 million in Series B funding in September 2021.

In general, the carbon utilization space contains a wide range of approaches, and companies often offer related services. Carbon capture is the most common—allowing companies to generate their own CO_2 inputs without external providers, or allowing them to offer hardware to handle the entire carbon capture-to-product process.

VC investment in carbon utilization ($M)



Source: PitchBook | Geography: Global
*As of December 31, 2022

"Some of our partners' initiatives can have undesired collateral effects on our own net-zero industries."
—EU Commission proposal for the Green Deal Industrial Plan[2]

Market conditions for climate tech

Global interest in carbon emissions reduction is high, driven partially by a significant uptick in pledges to transition to net-zero emissions. These targets have grown to more than 90% of global GDP,[1] although they vary in their plans of action. Over the last few years, these pledges have increased substantially at the country level, but also from states, cities, and corporations. While pledges vary between different geographies—on their timelines, planned actions, and targets—North America and Europe have progressed particularly rapidly in the last few years.

The EU launched its Emissions Trading System (ETS) back in 2005, and the "cap-and-trade" system—which caps carbon emissions by issuing a set number of carbon allowances and allows them to be traded between participants—continues to reduce the number of carbon allowances issued, applying pressure to decarbonize. Further, the introduction of ETS II allows coverage of additional sectors without forcing them to compete with sectors that have more established decarbonization options.

The US has long been considered to lag Europe in matters of climate change mitigation, but last year saw the signing of the Inflation Reduction Act, which contains a broad suite of federal support for climate technologies. Although it is a little early to see significant effects of the act, its scale is enough to make the US a world leader in climate technologies. To prevent an exodus of climate tech activity to the US and increase European climate tech support, in February 2023, the EU Commission proposed the Green Deal Industrial Plan.

Carbon capture increasing the supply of CO_2 for carbon utilization startups

Many decarbonization initiatives across the world are focused on replacing high-carbon processes with low-carbon alternatives, but alongside this are carbon capture projects, which remove CO_2 from emission sources or directly from the air. Carbon capture technologies have their origins in natural gas processing, but recent interest and engagement in decarbonization—and the regulatory support now available—have pushed carbon capture toward rapid expansion and global commercialization. Further, the technologies behind carbon capture have advanced substantially in the last decade, and continue to do so now, particularly to reduce operating costs associated with the technologies' energy consumption. For more information, see PitchBook's Q3 2022 Analyst Note: Postcombustion Carbon Removal. As of September 2022, the total capacity of carbon capture and storage projects currently in development reached 244 million tons per annum (Mtpa) of CO_2, representing a 44% increase in just 12 months.[3]

1: "Net Zero Stocktake 2022," Net Zero Tracker, Frederic Hans, et al., June 2022.
2: "A Green Deal Industrial Plan for the Net-Zero Age," European Commission, January 2, 2023.
3: "Global Status of CCS 2022," Global CCS Institute, Matt Steyn, et al., 2022.

As companies look to use carbon capture to reduce their overall emissions—or to extend the life of high-carbon physical assets, such as power plants—they're increasingly faced with the challenge of what to do with captured CO_2. To realize carbon reductions, it must be stored or otherwise prevented from reaching the atmosphere. The most basic approach is to permanently store the CO_2, although identifying and establishing a permanent storage site can be costly and time-consuming and can increase the total costs of storage, which also include transportation to the storage site. Transport costs will vary with distance to the site and the available options for transport. Pipeline transport for CO_2 exists in some locations, connecting high volume CO_2 sources with storage sites; this represents the cheapest option, although the initial pipeline construction is expensive, and the pipelines are not flexible once built. Other options such as road and rail can be viable and estimates of transport and storage costs are normally around $10/ton of CO_2 (tCO_2), although the variance is very high, with values ranging from \$4/tCO_2 to \$45/tCO_2.[4]

These costs have boosted interest in ways to use captured CO_2 to generate value while also keeping it out of the atmosphere—although some applications, such as fuel production, do not lock away CO_2 on long timescales. A core benefit of carbon utilization is the potential to eliminate or substantially reduce CO_2 transport costs, as the carbon utilization hardware can be co-located with the carbon capture hardware.

Carbon utilization approaches

As with many areas of climate technology, the definitions of carbon utilization vary. Here, we define carbon utilization as an approach that uses captured carbon as a valuable input in a process, whether it is used to create or improve a product or is used for its physical properties. This is a slightly narrower definition than those that involve the use of CO_2 from dedicated CO_2 sources.

Historically, finding value in CO_2 is a familiar concept, and the bulk of valuable CO_2 was used in two processes:

- **Urea production.** The fertilizer industry accounts for the largest share of CO_2 consumed, where it is used largely for urea production. Ammonia is combined with CO_2 to form urea, but the CO_2 used in this process tends to be generated as a co-product of the ammonia-generating stage, rather than captured from an external source.
- **Enhanced Oil Recovery (EOR)**. This involves pumping CO_2 into oilfields to increase the extraction of oil and extend the lifetime of the oil field. The climate benefits of this are controversial since it's primarily a method to maximize fossil fuel extraction. Further, the CO_2 used for EOR tends to be geologically-sourced CO_2 rather than CO_2 captured from industrial emissions;[5] although, more recently, use of captured carbon has increased.

4: "The Cost of CO_2 Transport and Storage in Global Integrated Assessment Modeling," International Journal of Greenhouse Gas Control, Erin Smith, et al., June 20, 2021.
5: "Enhanced Oil Recovery," US Office of Energy and Carbon Management, n.d., accessed March 9, 2023.

Outside these processes, we've seen rising interest in carbon utilization as a follow-on to carbon capture, either from industrial sources or atmospheric carbon.

Most of the carbon utilization approaches that startups are developing can be divided into three categories:

- **Industrial chemicals.** Converting CO_2 to a wide range of industrial chemicals, including primary chemicals such as methanol and methane, or more complex feedstocks and polymers.
- **Fuels.** Using carbon emissions—plus renewable energy—to form low-carbon analogs to conventional high-carbon fuels, including green natural gas, sustainable aviation fuel, and fuels such as gasoline and diesel.
- **Construction materials.** Incorporating supplementary carbon into construction materials—mainly aggregates and cement.

A key aspect of carbon utilization is the energy requirements of the approach: CO_2 is a low-energy molecule,[6] and turning it into a high energy molecule involves substantial energy consumption. Of the three categories listed above, in general, fuels have the highest energy requirements, followed by chemicals, which vary a lot in their energy requirements. Construction materials have very low energy inputs—if energy is needed for their carbon utilization at all.

The timescales on which carbon is locked away also vary greatly with each category. Carbon-derived fuels release their carbon again during combustion, and construction materials can sequester carbon on timelines that can essentially be considered permanent storage. Chemicals are a diverse category but generally fall somewhere between other approaches.

Carbon-to-chemicals

Carbon to chemical approaches vary greatly in the complexity of their final products. The simpler chemical molecules produced overlap strongly with carbon-to-fuel approaches, as chemicals such as methane, methanol, and formic acid—such as the carbon-to-formic acid approach used by RedoxNRG—can all be readily used as fuels in addition to their use as a chemical feedstock. Toward the more complex product end are polymers, and polycarbonate production, in particular, is an approach that's well suited to carbon utilization. Unlike the smaller chemical products that have dual uses as fuels, polymers tend to be low-energy molecules that don't have the same energy requirements in their production as their smaller counterparts.

6: In other words, it has inherently high stability, hence its persistence in the atmosphere.

Highlighted VC-backed carbon-to-chemicals companies

Econic

- **Founded:** 2011
- **Employees:** 28
- **Total VC raised:** $39.3 million
- **Last financing:** $12.5 million in Series D funding
- **Last financing valuation:** $37.6 million

Econic produces polyols using CO_2 as an input, and these polyols are then used to create various polyurethane products, including foams, coatings, sealants, and adhesives. Based in the UK, Econic's approach uses a proprietary catalyst to react CO_2 with conventionally produced epoxide inputs to form polymer precursors. The technology allows the amount of CO_2 incorporated to vary, such that CO_2 can account for up to 50% of the final product's weight. From a production perspective, their approach allows the final outputs to be altered to meet a range of mechanical needs, including consumer, automotive, and built-environment applications. The hardware required can be retrofit onto existing polymer production assets, simplifying installation and setup challenges.

Monolith

- **Founded:** 2012
- **Employees:** 207
- **Total VC raised:** $625.0 million
- **Last financing:** $300.0 million in Series D funding
- **Last financing valuation:** N/A

Monolith is one of the carbon utilization companies with the highest total VC funding raised, and their $300.0 million series D is the largest deal we've seen in this space. Their approach involves co-production of turquoise hydrogen and carbon black via methane pyrolysis—the process of breaking down materials using heat in the absence of oxygen—using natural gas as the feedstock. This is a somewhat energy-intensive process, and Monolith uses renewable energy for their approach. The carbon black that it produces is an established chemical product with multiple uses, including tire manufacture and creation of inks and pigments—although, the bulk of the carbon black currently consumed is created using high-carbon fossil fuel approaches. The hydrogen that Monolith produces is a core element of its process, and interest in hydrogen as a fuel source has increased in the last 12 months—in part due to the high, volatile prices seen globally for conventional fuels. Further, this hydrogen can be used to decarbonize sectors such as steelmaking, which are otherwise challenging to decarbonize. From a commercial perspective, the effectiveness of Monolith's approach is affected by the cost of the natural gas feedstock and the cost of renewable electricity.

Carbon-to-fuels

While some companies provide a combination of chemical and fuel outputs, there are also dedicated carbon-to-fuel companies.[7] Similar to many of the carbon-to-chemicals approaches, carbon-to-fuel processes have high energy requirements, and most companies use low-carbon energy to match the low-carbon focus of carbon utilization—which can increase operating costs depending on the region in which their operations are based. Ultimately, the final price of most carbon-to-fuels approaches is dependent on the availability of low-cost renewable energy, which continues to increase in capacity and decrease in per-unit cost. Many companies in this space also develop and integrate their own direct-air-capture technology to provide the CO_2 for their processes, which can also add significant energy costs; however, technological advancement in this space continues to reduce the cost-per-ton of CO_2 captured from the air.

Such approaches also tend to focus on transport fuels, particularly the elements of the transport sector that are challenging to electrify, such as aviation and, to a lesser extent, shipping—although CO_2-derived methane and methanol see significant use in stationary applications.

Highlighted VC-backed carbon-to-fuels companies

Prometheus

- **Founded:** 2018
- **Employees:** 28
- **Total VC raised:** $115.8 million
- **Last financing:** $100.0 million in Series B funding
- **Last financing valuation:** $1.5 billion

Prometheus operates its own direct-air-capture hardware to produce both gasoline and aviation fuel. The energy required to power both the carbon capture and carbon utilization stages in its process is generated by dedicated solar and wind installations, and the process involves modular hardware units. Prometheus' technology uses a hydrocarbon electrolyzer that does not require high temperatures and pressures to operate. With more than $100 million in VC funding raised, Prometheus is near the top of carbon utilization startups that have raised the most VC funding; in October 2022, it announced the completion of its commercial-scale cell-and-stack design, which forms the core of its air-to-fuel product. For DAC + carbon-to-fuels companies such as Prometheus, the primary factor that determines the final fuel cost is the cost of the low-carbon energy inputs.

7: Although, in theory, many of these fuels could be used as chemical inputs as well.

Southern Green Gas

- **Founded:** 2009
- **Employees:** 6
- **Total VC raised:** $2.8 million
- **Last financing:** Undisclosed
- **Last financing valuation:** Undisclosed

Southern Green Gas is an Australian company developing solar-powered carbon to methane, methanol, and kerosene technology, although they also engage in carbon sequestration. Currently, construction is under way for the Wallumbilla Renewable Methane Demonstration Project, with methanol and kerosene technologies under development. Their technology is based around modular direct-air-capture hubs located in high-irradiance locations in Australia to provide ample solar power. The solar and carbon capture elements of their technology are critical to Southern Green Gas' process, allowing the avoidance of significant energy costs and allowing the hardware to be deployed in locations with high sunlight rather than being limited to areas adjacent to carbon sources. Their kerosene production is still in development and was only announced in November 2022, following grant funding to develop green aviation fuel.

Carbon Recycling International

- **Founded:** 2006
- **Employees:** 30
- **Total VC raised:** $60.0 million
- **Last financing:** $10.0 million in late-stage VC funding
- **Last financing valuation:** Undisclosed

Based in Iceland, Carbon Recycling International (CRI) has been operating its CO_2-to-methanol process at scale since 2012. CRI states its technology can convert approximately 160,000 thousand tons of CO_2 into methanol each year. Much of this capacity has been added in the last three years. The requirement of carbon-to-fuel approaches for low-cost clean energy is less problematic in Iceland, which has long operated significant hydropower and geothermal electricity generation infrastructure. CRI's methanol production involves combining point-source-captured CO_2 with hydrogen, and two (very similar) pathways are used, differing only in the source of the hydrogen: water electrolysis or a by-product of waste gas. CRI's technology has been implemented in several current projects at European locations, as well as in China, and is stated to be the world's largest CO_2-to-methanol facility.[8]

8: "World's Largest CO_2-to-Methanol Plant Starts Production," Carbon Recycling International, October 26, 2022.

Carbon utilization in construction materials

Global efforts have historically focused on a few specific sectors that were considered easier to decarbonize, hence the early focus on decarbonizing electrical power production. Over time, more aggressive goals have resulted in a push to decarbonize sectors previously not well covered. One such sector is construction, where the global cement industry accounts for approximately 7% of total carbon emissions.[9] Historically, low profit margins associated with cement production have limited decarbonization efforts. However, developments in carbon utilization approaches, together with increased government incentives for low-carbon construction, are providing a means to address the emissions from construction materials. The outlook for global cement consumption is also likely to remain high,[10] since cement is a core component of most new infrastructure.

The challenge of decarbonizing cement is that carbon is emitted at two key points in the process. The first is in the need for process heat—the cement-making process requires heating, which is traditionally supplied through high-carbon fuels. The second source of CO_2 is from a chemical process called "calcination" that is integral to cement production and is more challenging to decarbonize.[11] Overall attempts to decarbonize cement production are varied, and include:

- Replacing high-carbon construction materials with low-carbon alternatives including biological options such as cross-laminated timber or high-strength polymers. These options can be viable in some applications but can't replace cement in all instances, as they have different physical properties and strengths.

- Use of cement formulations that contain lower-carbon supplemental materials, decreasing the high-carbon content of cement.

- Replacement of process heat with heat from clean fuels or renewable energy sources.

- Carbon utilization approaches that incorporate CO_2 into their structure to make a stronger final material. Carbon-cured cement is a key approach for this, involving exposing concrete to CO_2 during the curing phase,[12] where it is absorbed and strengthens the concrete.

Energy requirements are less of a problem for carbon utilization via construction materials in that, usually, CO_2 is converted into low-energy carbonates, reducing the overall energy requirements. Binding carbon into construction aggregates is also possible but is not a common approach, mostly because the margins for aggregate materials are already extremely thin—even compared to cement production.

9: "Global Cement and Concrete Industry Announces Roadmap to Achieve Groundbreaking 'Net Zero' CO_2 Emissions by 2050," Global Cement and Concrete Association, October 12, 2021.
10: "Cement," IEA, September 2022.
11: Calcination is the decomposition of limestone to lime.
12: Concrete is made by combining cement, water, and aggregate materials.

Niche approaches

Alongside the chemicals, fuels, and construction materials approaches, there are several other directions that carbon utilization can take, although these occur at lower volumes than the former categories.

Greenhouse carbon supplementation. This involves adding supplemental CO_2 to greenhouses during peak sunlight hours to increase the rate of plant growth. While not a new concept, historically the CO_2 used was simply generated onsite by gas burners specifically used for this purpose. Using captured CO_2 is a viable alternative, but it does not have the same capacity to scale as other approaches.

Soil enhancement. Adding pulverized silicate rock to soils allows them to capture carbon as it weathers while also improving the quality of the soil. New Jersey-based Eion uses this approach—known as enhanced rock weathering—together with measurement tools to verify carbon sequestration. This approach uses atmospheric carbon to improve soil quality, but is not a viable use case for captured carbon.

Highlighted VC-backed carbon-to-construction-materials companies

CarbonCure

- **Founded:** 2012
- **Employees:** 154
- **Total VC raised:** $11.2 million
- **Last financing:** Undisclosed
- **Last financing valuation:** Undisclosed

CarbonCure develops technology to produce carbon-cured concrete, essentially injecting CO_2 into the concrete mix as it is curing, which then reacts to form solid carbonates throughout the final concrete product. CarbonCure uses this approach to produce pre-cast blocks and structures but also offers hardware that can be installed into concrete mixing vehicles to produce carbon-infused concrete at the point of use. This flexibility is critical for carbon-cured cement to be successful, as it allows carbon-cured cement to be used in standard operations, replacing conventional concrete production. The hardware technology can be retrofit into existing concrete producing hardware, and involves CO_2 storage before injection, a valve system to inject CO_2 into the concrete, and a control box to manage this process.

CarbiCrete

- **Founded:** 2016
- **Employees:** 24
- **Total VC raised:** $28.8 million
- **Last financing:** $23.5 million in Series A funding
- **Last financing valuation:** Undisclosed

CarbiCrete develops a carbon utilization technology that produces carbon-infused concrete. Unlike some carbon-infused concrete approaches, it replaces the cement in concrete altogether, instead using steel slag—a waste product from the steelmaking industry. This has lower carbon emissions than cement, as it does not undergo the same calcination step, although to harden into a high-strength concrete, it requires a CO_2 curing step. This step is carried out in a specialized CO_2 absorption chamber, reaching full strength in 24 hours. CarbiCrete licenses its technology to concrete producers and operates a pilot project that aims to produce 25,000 standard concrete masonry units per day.

Niche approaches, continued

CO_2 as a working fluid. Outside of EOR, CO_2 has potential as a working fluid, for its thermodynamic properties in power generation, possibly replacing water in regions where water is scarce. For this to be viable, though, would require CO_2 to cost less than currently used fluids like water.

Food, beverages, and consumer products. CO_2 is a core ingredient in the beverage industry to carbonated beverages. In addition, captured CO_2 can be used to make other beverages and consumer products. Brooklyn-based Air Company uses this approach, converting captured carbon into fragrances and vodka—although they also develop carbon-to-fuels and chemicals. Air-derived fuels are a growing focus for the company, which was recently awarded $65.0 million by an Air Force Defense Innovation Unit to develop air-to-fuel generation technologies for use on USAF bases.[13]

Overall viability of carbon utilization technologies

There are several reasons companies may implement carbon utilization technologies, including the climate benefits that can make the final products more appealing given the current interest in low-carbon products. Outside the climate benefits, carbon utilization can generate value out of a waste product or improve the physical properties of the final products produced.

Overall, carbon utilization provides an alternative carbon sink to carbon storage options. Depending on the level of federal support available, the emissions reductions on their own could provide enough incentive for carbon utilization approaches to succeed, but it's unclear which approaches hold the most potential. The increasing need to decarbonize some challenging sectors—such as construction materials and transport, for instance—provides additional incentives in those areas. Further, those that provide significant additional benefits from the inclusion of CO_2, such as increased strength or reduced need for additional feedstocks, are at an advantage in that they are less reliant on climate benefits. Avoiding the roughly $10 per ton of operational costs for the transport and storage of CO_2 is also a factor, increasing the financial incentive for companies to install carbon utilization technologies.

13: "The Air Force's Modular Reactor Will Create Jet Fuel Out of Water and Air," Popular Mechanics, Sébastien Roblin, March 3, 2023.