INSIGHT REPORT

AN OVERVIEW OF SUSTAINABLE TRANSPORTATION IN SUPPORT OF REDUCED CARBON EMISSIONS

TAG

CLIMATE SCIENCE

TAG Insights Report: An Overview of the Carbon Capture and Utilization (CCU) Commercial Market

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This TAG Insights Report on *Carbon Capture and Utilization (CCS)* is intended to help companies, managers, practitioners, researchers, investors, and commercial vendors better understand current trends, issues, and market opportunities in this area. A list of representative commercial vendors working in various areas of CCU is included. The five specific areas covered in this report include:

1. Direct Air Capture including Point Source
2. Carbon Removal and Sequestration
3. Carbon Mineralization
4. Enhanced Oil Recovery (EOR)
5. Soil-Based Sequestration

This report is intended for general and unrestricted use, but interested readers are encouraged to connect with the TAG research and advisory team for more information on the private TAG Research as a Service (RaaS) community that covers, discusses, and shares information on these topics in more depth and includes a wider range of startups, vendors, and companies.

TAG Climate Taxonomy

Our advisory work at TAG is guided by our TAG Climate Taxonomy which includes twenty different market categories, with one hundred associated subcategories – all developed consistent with our research into emerging and existing commercial offerings. Subscribers to TAG Research as a Service (RaaS) have access to the more detailed specifics of the taxonomy and the full set of companies working in each area.

The taxonomy is intended to be interpreted as a market guide for commercial (and in some cases, open source) platform, tools, products, and services. The day-to-day tasks of any practitioners focused on sustainability will include many considerations such as dealing with regulators, addressing compliance issues, and keeping up with legislation that will not typically be represented in our taxonomy. We focus here on products and services.

TAG Climate Taxonomy V2.0 – 1Q2024

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Figure 1. TAG Climate Taxonomy

Overview of Carbon Capture and Utilization (CCU)

The following emerging global commercial opportunities for sustainable transportation are covered in this report, including the listing of several viable commercial entities providing solutions on the market today:

- Direct Air Capture (DAC) is a technology that captures carbon dioxide (CO2) directly from the ambient air (as opposed to capturing it from point sources such as power plants). DAC can be combined with point source capture where CO2 is captured directly from industrial or energy-related sources, like power plants or manufacturing facilities, which usually emit large amounts of CO2.

- Carbon removal and sequestration involves removing CO_2 from the atmosphere and storing it in geological formations, oceans, or other reservoirs where it will not re-enter the atmosphere. Sequestration can involve biological processes, like afforestation, or physical processes, such as storing CO_2 in deep underground formations.
- Carbon mineralization is where CO_2 reacts with abundantly available minerals to form solid carbonates. This is a permanent and safe method of storing CO_2, as the carbonates are stable over geological timescales. Carbon mineralization can occur naturally or be engineered to happen more rapidly.
- Enhanced Oil Recovery (EOR) is a method used to increase the amount of crude oil that can be extracted from an oil field. By injecting CO_2 into oil reservoirs, the CO_2 can help to mobilize and push additional oil towards production wells. This process can be part of CCU, as the injected CO_2 is often sourced from industrial emissions, leading to a form of sequestration.
- Soil carbon sequestration involves the process of transferring CO_2 from the atmosphere into the soil through crop residues and other organic solids. This can be enhanced by practices like regenerative farming, no-till farming, cover cropping, and the application of biochar.

Focus Area: Direct Air Capture Including Point Source

Direct Air Capture (DAC) represents a technology suite that isolates carbon dioxide (CO_2) from atmospheric air. The process encompasses ambient air filtration systems where air passes through chemical solutions or solid sorbents that selectively bind CO_2. Two principal mechanisms are employed: liquid systems using hydroxide solutions to capture CO_2, and solid systems where sorbents like amines are coated on porous substrates. Following capture, CO_2 is released from sorbents by raising temperatures or reducing pressure, then collected for utilization or storage.

Point Source Capture (PSC) operates on similar principles but targets CO_2 emissions at their origin, such as flue gases in power plants or other industrial exhausts. Here, the concentration of CO_2 is significantly higher than in ambient air, resulting in different technological requirements and efficiencies. PSC systems often use post-combustion capture with amines or chilled ammonia for CO_2 isolation, pre-combustion capture via gasification and shift reactions, or oxy-fuel combustion where fuel is burned in oxygen instead of air to produce a CO_2-rich exhaust stream.

In the context of sustainability, DAC and PSC contribute to carbon management strategies essential for mitigating climate change. They offer a means to decouple industrial activity from greenhouse gas emissions. The captured CO_2 can be utilized in various industries, creating a closed carbon loop that reduces the need for fossil carbon. Applications include synthetic fuel production, beverage carbonation, enhanced oil recovery, and as a feedstock in the chemical industry, contributing to a circular economy.

The sequestration of captured CO_2 is another pathway towards sustainability. This involves storing CO_2 in geological formations, oceans, or via mineralization, removing it from the atmospheric pool and reducing the net greenhouse effect. DAC, in conjunction with sequestration, can theoretically reduce atmospheric CO_2 concentrations, a critical goal in climate change mitigation.

From a business perspective, DAC and PSC present opportunities. The captured CO_2 can generate revenue streams in markets demanding carbon-neutral or carbon-negative solutions. The technology can also be integrated with renewable energy sources to create more sustainable operations. Moreover, regulatory frameworks like carbon pricing and emissions trading systems can make CO_2 capture financially viable, as emitting industries seek cost-effective methods to comply with regulations.

The scalability of DAC and PSC is a factor in commercial application. While PSC is already implemented on industrial scales, DAC is in earlier stages of commercial deployment. Costs remain a barrier, though advancements in material science and process engineering are expected to drive efficiencies and reduce expenses. Investment in research and development, coupled with supportive policy frameworks, can enhance the commercial viability of these technologies.

Focus Area: Carbon Removal and Sequestration

Carbon Removal and Sequestration encompass methods that extract carbon dioxide (CO_2) from the atmosphere and store it in such a way that it is not immediately re-emitted. This process is critical for addressing the excess greenhouse gases responsible for climate change.

Biological carbon sequestration involves the uptake and storage of CO_2 by plants through photosynthesis. The carbon is stored in plant tissues and soils. Agricultural practices such as reforestation, afforestation, and soil management are typical methods. These practices increase the organic matter in soil, which enhances its capacity to retain carbon.

Physical sequestration includes the capture of CO_2 and its storage in geological formations, commonly referred to as geological sequestration. This involves injecting CO_2 into underground rock formations, including depleted oil and gas fields, deep saline aquifers, and unmineable coal seams. The CO_2 reacts with the minerals in these formations, creating stable compounds that lock the carbon underground.

Ocean sequestration is another form, where CO_2 is directly injected into the deep ocean, where it is hoped to remain for centuries. However, the ecological impacts of this method are a concern and require further study.

Chemical sequestration includes processes such as mineral carbonation, where CO_2 reacts with metal oxides to form carbonates. Industrial carbonation involves the use of industrial residues rich in calcium and magnesium, which can react with CO_2 to form stable carbonates.

These sequestration methods support sustainability by removing CO_2 from the atmosphere, thus helping to mitigate the impacts of climate change. They can also improve soil health, increase agricultural yields, and restore degraded lands.

From a business perspective, carbon sequestration creates opportunities in several sectors. In the energy sector, carbon capture and storage (CCS) can be a revenue-generating environmental service, particularly in regions with carbon pricing mechanisms. Companies can earn carbon credits for sequestering CO_2, which can be sold on carbon markets.

The development of carbon capture and sequestration technologies also opens up new markets for innovation, engineering, and construction services. This includes the manufacturing of equipment for CO_2 capture, transportation infrastructure for CO_2 delivery to storage sites, and the development of monitoring systems to ensure the integrity of the storage sites.

For the agricultural industry, improved carbon sequestration can lead to better soil health and productivity, offering long-term benefits for farmers and the environment. It also presents opportunities for agribusiness to engage in carbon farming initiatives where they can receive incentives for adopting land management practices that sequester carbon.

Overall, carbon removal and sequestration not only provide environmental benefits but also offer a variety of business opportunities across multiple sectors, driven by a growing emphasis on sustainability and the transition to a low-carbon economy.

Focus Area: Carbon Mineralization

Carbon mineralization refers to the process of converting carbon dioxide (CO_2) into carbonates through reactions with naturally occurring minerals. This process can occur both naturally over geological timescales and can be engineered to happen more rapidly as a strategy for carbon sequestration.

In natural settings, carbon mineralization occurs when CO_2 from the atmosphere reacts with silicate and oxide minerals to form solid carbonates. This is a slow process, but it permanently immobilizes CO_2. Engineered carbon mineralization seeks to accelerate this reaction, which involves the exposure of mineral silicates to CO_2 in high-pressure and high-temperature conditions, often with the addition of water to enhance reactivity.

The primary minerals used in carbon mineralization are olivine and serpentine. These are abundant and contain silicate ions that react with CO_2 to form magnesium and calcium carbonates. These stable carbonates can then be stored or used in various applications. Industrial carbon mineralization involves integrating CO_2 emissions sources with suitable mineral feedstocks. The CO_2 can be sourced from power generation, cement production, or other industrial processes. The resulting carbonates can be used as construction materials, thus creating a closed-loop system where the CO_2 byproduct of one process becomes a raw material for another.

Carbon mineralization supports sustainability by providing a permanent and stable method for storing CO_2, helping to mitigate the greenhouse effect and combat climate change. It can convert a greenhouse gas into a range of economically valuable materials, thus incentivizing CO_2 reduction efforts.

From a business perspective, carbon mineralization offers opportunities in several sectors. For the construction industry, the carbonates produced can be used to manufacture building materials like aggregates or cements. This not only helps to reduce the carbon footprint of new construction materials but may also meet regulatory standards for green building practices.

Companies specializing in carbon capture and mineralization technology can benefit from carbon pricing mechanisms, such as carbon credits, trading schemes, and tax incentives. These financial instruments can make carbon mineralization projects more economically viable.

Furthermore, there is potential for the development of new markets for carbonated products, such as carbon-negative cements and aggregates. The technology also holds promise for enhancing oil recovery, as carbonated water can be used in the extraction process, providing additional revenue streams for the energy sector.

Investment in research and development is critical for improving the efficiency of carbon mineralization processes and reducing costs, which will be essential for broader commercial adoption. As such, carbon mineralization is not only pivotal for environmental sustainability but also presents a spectrum of business opportunities that align with global carbon reduction goals.

Focus Area: Enhanced Oil Recovery (EOR)

Enhanced Oil Recovery (EOR) is a set of techniques applied to increase the amount of crude oil that can be extracted from an oil field. Traditional primary and secondary recovery methods typically extract approximately one-third of a reservoir's original oil in place. EOR aims to increase this extraction percentage by changing the physical properties of the oil, the reservoir, or both.

There are three main EOR strategies: thermal recovery, gas injection, and chemical injection. Thermal recovery involves introducing heat to reduce the viscosity of heavy crude oils, facilitating their flow towards production wells. Steam injection is the most common method of thermal EOR, often applied in heavy oil sands.

Gas injection, which can involve the use of inert gases like nitrogen, or miscible gases such as carbon dioxide (CO_2), is employed to either displace oil towards the wellbore or to swell and reduce the oil's viscosity, improving its flow characteristics. CO_2-EOR is particularly significant in the context of carbon capture, utilization, and storage (CCUS). CO_2 for EOR is usually sourced from natural reservoirs or captured from industrial processes.

Chemical injection employs substances such as polymers, surfactants, or alkaline chemicals to improve oil displacement or alter the properties of the oil-water mix in the reservoir, thus aiding oil flow. Polymers increase the viscosity of the injected water, improving the sweep efficiency, while surfactants reduce the surface tension between oil and water, helping to release oil from the rock surfaces.

EOR supports sustainability by maximizing the output from existing oil fields, thereby potentially reducing the need to exploit new resources. When CO_2 is sourced from industrial emissions for gas injection, EOR contributes to CCUS efforts. This process reduces the carbon footprint of the oil produced and provides a bridge towards more sustainable energy practices by integrating renewable energy sources and carbon capture technologies.

From a business perspective, EOR presents opportunities for the oil industry to extend the life of mature fields and enhance the value of their assets. The technology creates new investment avenues and job opportunities, including the need for specialized equipment, materials, and expertise.

The utilization of CO_2 in EOR operations can also create synergies between the energy and industrial sectors, where industries can monetize their CO_2 emissions by selling them for use in EOR. This transaction can be further incentivized by carbon pricing policies, making CO_2-EOR economically attractive.

EOR technologies require significant investment in research and development to optimize recovery rates and minimize costs and environmental impacts. The integration of advanced monitoring and control technologies, such as 4D seismic imaging and smart wells equipped with sensors, has improved the efficiency and effectiveness of EOR operations. These advancements present opportunities for service companies and equipment manufacturers within the oil and gas sector.

To summarize, EOR not only extends the economic life of oil reservoirs but also contributes to the broader energy sustainability goals through the potential sequestration of CO_2 and the improved efficiency of resource utilization.

Focus Area: Soil-Based Sequestration

Soil-based sequestration refers to the process of storing carbon dioxide (CO_2) in the soil organic carbon (SOC) pool. It is a biological process that involves the absorption of CO_2 by plants through photosynthesis and the subsequent transfer of carbon to the soil through plant residues and root biomass. The carbon in the soil is either sequestered as part of the stable organic matter or respired back to the atmosphere as CO_2 by soil organisms.

The potential of soil to sequester carbon depends on factors such as climate, land management practices, and the type of soil. Soil management practices that can enhance carbon sequestration include conservation tillage or no-till farming, which reduces soil disturbance; cover cropping, where crops are grown for the protection and enrichment of the soil rather than for harvest; the use of organic amendments like compost; and crop rotation, which can improve soil structure and health.

Soil-based sequestration plays a role in sustainability as it enhances soil quality, improves crop yield, and reduces the atmospheric concentration of CO_2. Improved soil quality also leads to better water retention, reducing the need for irrigation and the risk of nutrient runoff into waterways. By increasing the organic matter in soils, soil-based sequestration also contributes to biodiversity, both above and below ground.

From a business perspective, soil-based sequestration can open up new revenue streams for farmers and land managers through carbon markets. Participants can earn carbon credits by adopting land management practices that are verified to sequester carbon. These credits can then be sold to individuals or companies looking to offset their carbon emissions.

The agriculture sector can benefit from soil-based sequestration as healthy soils are more productive and resilient to stresses such as drought and disease. This can lead to reduced input costs and higher profitability. Companies that develop and market soil amendments, such as biochar, can also find opportunities in this space.

In addition, the technology sector can capitalize on the need for precise monitoring and verification of soil carbon levels. This includes the development of sensors, data management systems, and platforms for carbon credit trading.

Investment in research and development is crucial for optimizing the methods for soil-based sequestration and understanding its long-term potential and limitations. Policy incentives and the development of standardized measurement and verification protocols are essential for the expansion of soil-based carbon markets.

Overall, soil-based sequestration presents an opportunity to align agricultural practices with climate change mitigation efforts while also offering economic benefits and business opportunities within the agricultural and environmental sectors.

Companies and Contributions

The companies listed below emerged as part of our research at TAG Climate. Our goal in listing these fine firms is to provide a starting point for buyers, advocates, stakeholders, and researchers trying to make sense of the commercial landscape for carbon capture and utilization (CCU) as a means for driving toward a more sustainable energy future.

Direct Air Capture including Point Source Vendors

1. Carbon Clean Solutions - Carbon Clean develops carbon capture solutions which reduce the costs and environmental impacts of carbon capture compared to conventional technologies.
2. Carbon Engineering Ltd. - Carbon Engineering develops technology that captures CO_2 directly from air, and a second technology that synthesizes it into clean, affordable transportation fuels.
3. Climeworks AG - Manufactures and operates direct air capture machines that remove carbon dioxide from the atmosphere.
4. Global Thermostat - Global Thermostat is working to commercialize its solutions for capturing and removing CO2 directly from the atmosphere to address climate change and power the growing circular carbon economy.
5. Newlight Technologies - Uses captured carbon dioxide to produce biodegradable plastics and materials.
6. Prometheus Fuels - Prometheus Fuels aims to replace all oil and gas with zero net-carbon fuels made from the existing CO2 in the air. Prometheus uses a combination of direct air capture and a membrane that eliminates the need for distillation to capture carbon dioxide, and all their technology is powered by renewable electricity.
7. Saipem - Provides technology for capturing carbon dioxide directly from industrial sources.
8. Skytree - Innovates in air capture technology to extract excess carbon dioxide from the environment.

Carbon Removal and Sequestration Vendors

1. Aker Solutions ASA - Delivers carbon capture, utilization, and storage solutions to combat climate change.
2. BP p.l.c. - Focuses on developing carbon capture usage and storage technology to reduce greenhouse gas emissions.
3. Chevron Corporation - Engages in carbon storage technology development and related projects.
4. Eni S.p.A. - Pursues carbon capture and sequestration as part of its strategy for decarbonization.
5. Equinor ASA - Develops large-scale carbon storage projects on the Norwegian continental shelf.
6. ExxonMobil Corporation - Invests in proprietary technologies and research for carbon capture and storage.
7. NRG Energy, Inc. - Engages in carbon capture and sequestration projects at its power generation facilities.
8. Occidental Petroleum Corporation - Implements carbon sequestration in its oil and gas operations to enhance oil recovery and reduce emissions.
9. Royal Dutch Shell plc - Invests in carbon capture and sequestration technologies and projects worldwide.
10. TotalEnergies SE - Operates various carbon capture and storage projects to offset carbon dioxide emissions.

Carbon Mineralization Vendors

1. Blue Planet Systems Corporation - Creates carbonate rocks from CO2 as a replacement for natural aggregate in concrete.
2. Calix Limited - Offers technology to capture CO2 emissions and convert them into useful materials.
3. Carbicrete - Produces a concrete alternative that captures more CO2 than it emits during production.
4. CarbonCure Technologies Inc. - Develops technology that injects captured CO2 into concrete to reduce its carbon footprint.
5. Carbon8 Systems - Uses CO2 to treat various industrial residues, turning them into carbonate products.
6. Fortera, Inc. - Develops innovative materials that reduce the carbon footprint of cement and concrete.
7. Mineral Carbonation International - Focuses on locking away CO2 in solid materials through mineral carbonation technology.
8. Solidia Technologies, Inc. - Provides solutions for manufacturing building materials with a lower carbon footprint.

Enhanced Oil Recovery (EOR) Vendors

1. Canvas Energy- Engages in CO2 EOR to extend the life of oil fields and increase oil production.
2. Exxon Mobile – Denbury (part of Exxon Mobile) specializes in carbon dioxide enhanced oil recovery and carbon capture, utilization, and storage operations.
3. Flogistix, LP - Offers CO2 compression and transportation solutions for enhanced oil recovery projects.
4. Halliburton - Provides a variety of services and solutions for enhanced oil recovery techniques including CO2 injection.
5. Kinder Morgan, Inc. - Manages CO2 pipelines for use in enhanced oil recovery operations across the United States.
6. Linde - Provides industrial gases, including CO2 for enhanced oil recovery operations.
7. Saipem - Develops technology aimed at improving the efficiency of CO2 capture for use in enhanced oil recovery.
8. SLB- Supplies technology, integrated project management, and information solutions for EOR processes.

Soil-Based Sequestration Vendors

1. Agreena - Offers a carbon certification program for farmers implementing sustainable practices that increase soil carbon.
2. Cool Planet - Develops biocarbon products that enhance soil health and increase carbon storage in agricultural lands.
3. Indigo Agriculture, Inc. - Utilizes microbial and digital technologies to enhance soil health and promote carbon sequestration.

4. Loam Bio - Specializes in developing soil microbiome solutions to enhance carbon sequestration in agricultural lands.
5. MycoWorks - Develops fungal mycelium products that contribute to soil health and carbon sequestration.
6. Pivot Bio - Focuses on microbial technology to improve crop yields and facilitate carbon sequestration in soil.
7. Regen Network - Operates a platform for verifying and incentivizing soil carbon sequestration practices.
8. Soil Health Institute - Works on advancing soil health practices to increase organic carbon sequestration.
9. SoilCQuest - Engages in research to develop soil carbon sequestration methods for agricultural resilience and climate mitigation.
10. Terra Genesis International - Provides regenerative agriculture solutions that focus on increasing soil carbon sequestration.

About TAG

TAG is a trusted next generation research and advisory company that utilizes an AI-powered SaaS platform to deliver on-demand insights, guidance, and recommendations in cybersecurity, artificial intelligence, and sustainability to enterprise teams, government agencies, and commercial vendors.