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OGCI
OIL AND GAS CLIMATE INITIATIVE

EXECUTIVE SUMMARY

Carbon capture and utilization as a decarbonization lever

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The Oil and Gas Climate Initiative (OGCI) is working with industry, governments and other investors to scale up carbon capture, utilization and storage (CCUS), in particular through the development of CCUS hubs.

Carbon capture and utilization (CCU) specifically could be a lever for decarbonization because it captures carbon dioxide (CO_2) emissions from industries and reuses/recycles the carbon for a different purpose, thus enabling a more circular economy. Estimates of the size of the CO_2 utilization market in the future vary widely from between 10%-33% of total captured carbon.

Today, most utilized CO_2 is channelled into either enhanced oil recovery (EOR) or urea production, with a market size estimated at ~250 million tonnes per annum (Mtpa) of CO_2.

There are several utilization technologies across key pathways that may develop and increase the utilization of CO_2 to ~430-840 Mtpa by 2040. This compares with the need for CO_2 emission reductions in the gigatons per annum scale, suggesting that although utilization may have a part to play in decarbonization, it will likely be relatively small compared to CO_2 storage. However, each CCUS hub is unique and it is likely CCU may have a more significant role in some hubs.

This study only covers conversion pathways, not direct uses of CO_2 (such as EOR) and focuses on those with global impact potential. It looks at four promising CO_2 utilization pathways through to 2040, their CO_2 utilisation potential and key barriers:

- **Construction aggregates** make up the largest potential market by far in terms of CO_2 volume (estimated at ~0.5Gt CO_2 per year), but low product value makes it challenging to compete with low-cost conventional aggregates.

- **CO_2-cured concrete** is a small market in terms of overall CO_2 required (estimated at 40-70 Mtpa CO_2 per year), but the technology is nearly ready for scaling. The economics can be challenging, given high capex requirements for a low-value product.

- **E-fuels:**
  - **E-kerosene** is a medium-sized market (estimated at 50-150 Mtpa CO_2 per year) and technology is nearly ready for scaling. However, overall cost is expected to stay well above conventional and other bio-based kerosene prices without significant regulatory incentives; the scarcity of biogenic CO_2 and the cost of direct air capture (DAC) could be a limiting factor.
  - **E-methanol** is a medium-sized market (estimated at 130-280 Mtpa CO_2 per year) and technology is nearly ready for scaling. However, given that high energy requirements drive the bulk of production cost, the business case is likely to be negative without financial incentives or sufficient low-cost hydrogen (H_2); scarcity of biogenic CO_2 and the cost of DAC could also be a limiting factor.

There are some earlier stage CO_2 uses in the chemical sector to monitor (e.g., green methanol to olefins (MTO), dimethyl ether, and formic acid) and some developing uses (e.g., polymers) that could become small to medium-sized markets. Interesting markets that are gaining traction also include leveraging CO_2 to create proteins for animal feed and producing ethanol using CO_2-based microbes.

There are still common technical hurdles to many of the synthesis pathways: high energy use, expensive inputs (e.g. CO_2 feedstock, green H_2), and commercial grade catalysts – all of which will require time and investments to solve.

Four key factors to realize the market potential of many of these utilization pathways include the cost and availability of CO_2 capture, the source of CO_2 (i.e., biogenic versus fossil CO_2), the cost of transporting CO_2, and the availability of low-cost renewable energy.

Climate impact

A layer of complexity in the business model of CCU is developing either product carbon footprints (PCF) that measure the greenhouse gas (GHG) emissions impact of a specific product/service or lifecycle assessments (LCA) that measure the broader environmental impact beyond GHG.

PCF and LCA consider the direct impact either from cradle-to-gate or cradle-to-grave depending on the assessment required. They can provide customers and markets with the information to assign a premium against versus the alternative products' PCF and LCA evaluations.

While there are several methodologies available, this report uses a simplified approach to LCA looking at only the carbon impact through a side-by-side comparison of the key process steps that differ between the CO_2-derived process and conventional process.

Overall climate impact can be categorized into carbon removals (i.e., increasing a theoretical global CO_2 budget), reductions (i.e., slows down use of a theoretical CO_2 budget), or avoidance (i.e., neutral impact on a theoretical CO_2 budget). The impact varies considerably based on source of CO_2 and whether CO_2 is re-emitted at the end of product's life. This paper leverages academic studies and reports that use different approaches to lay out the range of expected CO_2 impact. There is considerable variance due to lack of consistent approaches used today and differences between regions and technologies.

Rules around carbon accounting in both the voluntary and regulatory schemes are still evolving. The way in which climate benefits can be realized from CO_2 utilization may change over time and vary by region. For example, in the EU, fossil CO_2 can be used for synfuels until 2040, after which only DAC or biogenic sources will be recognized. In the absence of clear rules, CO_2 derived products could run the risk of being perceived as greenwashing by end customers if they do not lead to CO_2 removal and reduction (i.e., are only a CO_2 avoidance).

The ranges of potential carbon impact for the four key CO_2-derived products are as follows:

- **CO_2-based construction aggregates** are estimated to reduce the CO_2 emitted from a ton of aggregate by 12 to 48 kg. Compared to the conventional product with an average emissions of 3 kg per ton, the CO_2-based aggregates have -9 to -45 kg emissions (i.e., negative emissions) per ton. Given that the carbon is sequestered permanently in the construction aggregate, there is typically a net climate benefit.
- **CO_2-cured concrete's** abatement potential is highly dependent on the raw material mix as well as energy volume and intensity for carbonation in the range of 0-413 kg CO_2 per ton (-100% to +5% vs. conventional product). However, given that the CO_2 that is utilized is mineralized into concrete permanently, utilization can be considered equivalent to storage in terms of permeance as long as the process emissions of utilization are not worse than that of the conventional product.
- **E-fuels: E-kerosene's** CO_2 abatement potential can be up to 98% (synfuels) in cradle-to-grave studies on sustainable aviation fuel (SAF). **E-methanol's** CO_2 abatement potential ranges between 30% to 87%-98%. High abatement depends on use of /access to abundant biogenic CO_2 (based on the right feedstock and type of generation) or cost-efficient DAC.

Building the business case

Many of the CO_2 utilized products are still relatively new or under development. The regulatory and policy environment of markets is critical to scaling. Regulation today tends to focus on capture and/or storage rather than utilization, where there is still a gap.

However, specific markets such as the US (where there are subsides for utilization technologies) and EU (where there are fuel mandates) are likely to enable further development and scaling of key utilization technologies. Other markets, where CCUS policies are still under development, such as China, India, as well as several Middle Eastern, African and South American countries, should be observed given increasing interest by key players and/or strong fundamentals (e.g., low-cost renewable energy).

The relative unit economics of each key CO_2-derived product today is considerably higher than the conventional product (between 1.5x-5x), and regulatory enablers such as mandates, ETS/carbon pricing, and incentives/subsides will play a big role in scaling:

- **CO_2-based construction aggregates** are currently two to four times more costly than incumbent and requires landfill tax of ~$50-$100 to incentivize using waste streams for construction aggregates instead of putting them in landfills.

- **CO_2-cured concrete** is currently one-and-a-half times to two times as costly than conventional concrete and requires capex to decrease by 50% as well as carbon pricing of $125-$175 to be profitable.
- **E-fuels (E-kerosene and E-methanol)** are currently two to four times more expensive than regular jet fuel and methanol depending on subsidy availability, the cost of hydrogen, and access to biogenic CO_2 or cost-efficient DAC. Existing or new fuel mandates, subsides, carbon pricing and market-based mechanisms could make E-SAF profitable before 2040, whereas e-methanol requires higher carbon prices of $200-$450 to break even.

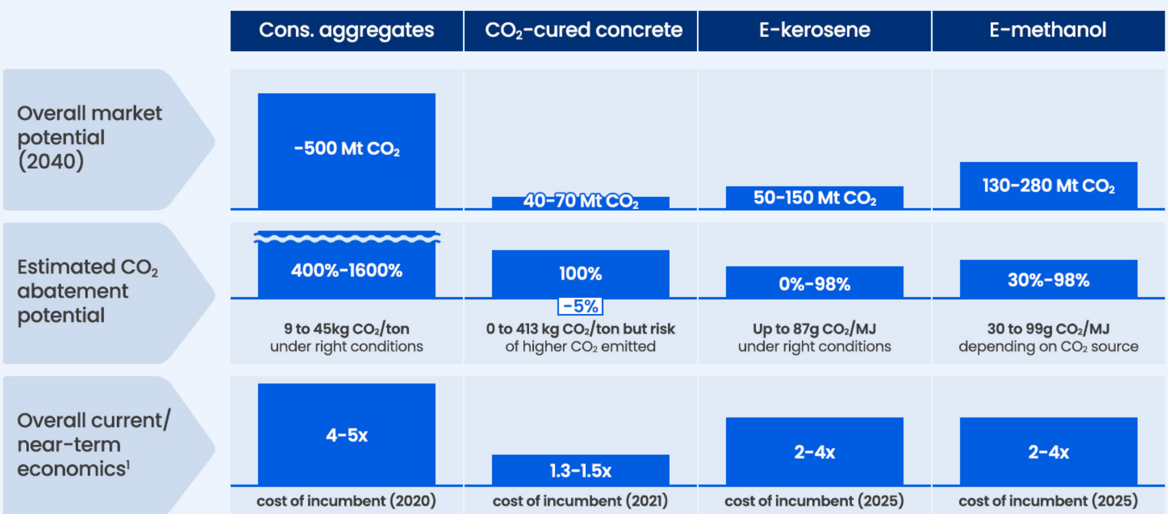
While the economics are not yet favorable, indirect policies such as carbon taxes and emissions trading systems can play a big role in making products economically viable. CO_2 utilization, specifically for synfuels, looks more promising than it did several years ago thanks to significant regulatory and technological developments.

The market for CCU is expected to remain relatively small in the short term, but there is scope for corporates, governments, and other key stakeholders to support research and development (R&D) for the development of technology and to start investing early to build the required markets.

CCU can be a decarbonization lever in the medium- to longer-term, but it is critical that the right set of inputs - the energy mix, green H_2, raw material mix, for example - and technology are leveraged in the processes used to create CO_2-derived products that support climate goals. However, it is important to note that even with the right set of inputs and technology, CCU is unlikely to have the scale to substitute for CO_2 sequestration. This will moderate its part in meeting global decarbonization goals.

EXHIBIT 1

Overview of market potential, CO_2 abatement potential, and estimated economics of four key CCU products



1. Range considers both with and without existing incentives;
Source: Sick. et al CO_2 Utilization and Market Size Projection, GCCA, IEA, Expert Interviews, BCG analysis

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