Implementing CO_2 capture and utilization at scale and speed:

The path to achieving its potential

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Implementing CO_2 capture and utilization at scale and speed: The path to achieving its potential

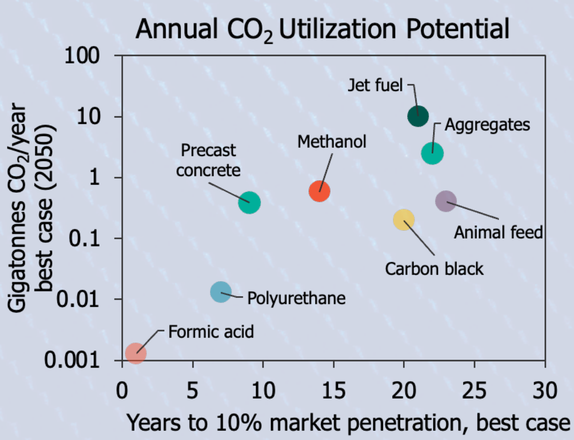
CO_2 capture and utilization (CCU) is an essential tool in the global carbon management toolkit.[1] CCU can contribute to gigaton-scale removal of CO_2 from the atmosphere and can serve as a source of carbon for many essential products made with carbon. It is important to understand, however, that effectively using CCU to help meet our climate goals means that we need to build an entirely new industry coupling carbon capture with carbon utilization.

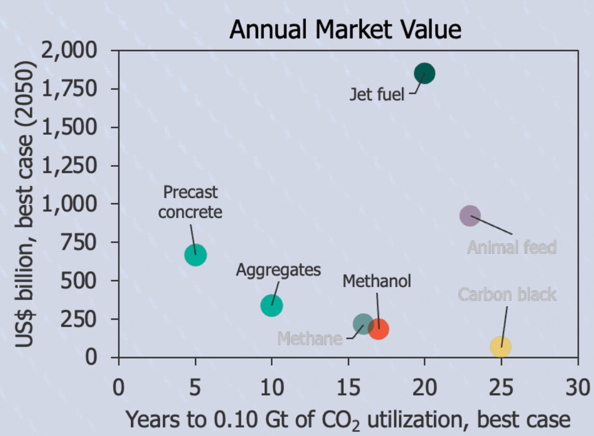
Speed to build an end-to-end CCU industry is imperative.

Maturation of CO_2 utilization technologies since 2016[2, 3]

The promise and potential of CCU has increased since our last projection in 2016.

- Some technologies are ready for large-scale deployment now
- Large-scale deployment is feasible in time for 2050 net-zero commitments
- At only 10% market share, CCU could permanently remove over a gigaton of atmospheric CO_2 annually, and, as a carbon feedstock for the circular economy, could replace even more new fossil carbon
- Revenue projections exceed $1 trillion before 2040





Four products are identified as key targets to pursue for highest climate impact and greatest revenue potential: aggregates, precast concrete, jet fuel, and methanol.

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[1] https://www.ipcc.ch/report/ar6/wg3/

[2] *Global Roadmap for Implementing CO_2 Utilization:* https://hdl.handle.net/2027.42/150624

[3] We conducted this study with research and analysis assistance by Lux Research, Inc. to assess progress in CCU technologies since 2016 and to project growth and investment needs until 2050. This overview presents key findings and recommendations and a link to detailed background documentation for download. Data and analysis presented in the graphs prepared for the Global CO_2 Initiative at the University of Michigan by Lux Research.

Types of carbon dioxide utilization: Track 1 and Track 2

When considering CO_2 capture as part of overall carbon management strategies, it is important to identify what is done with the captured CO_2. How long will the CO_2 be removed from the environment — either in a product (carbon capture and utilization or CCU) or underground (carbon capture and sequestration or CCS)? For CCU, the introduction of Track 1 and Track 2 designations clearly categorizes products based on the duration of CO_2 removal.

Track 1 CCU products

- remove CO_2 for at least 100 years, if not permanently, making Track 1 products functionally equivalent to storing CO_2 underground via CCS

Examples: concrete, aggregates

Benefits:

- CO_2 removal, consistent with negative emissions technologies
- option to generate certifiable, quantitative carbon offsets
- likely to be less costly than CCS, and will generate additional value from useful products

Track 2 CCU products

- Use or decomposition of the product leading to the release CO_2 back into the atmosphere in less than 100 years. This CO_2 can be harvested again to make products, consistent with a circular use of carbon.

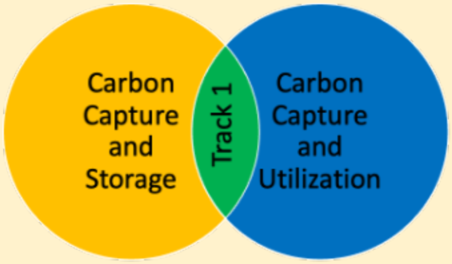
Examples: fuel, tires, clothes

Benefits

- potentially carbon-neutral carbon-based products
- promotes a net-zero, fossil-free carbon economy

The emerging CO_2 utilization industry was assessed, and new projections were developed for the magnitude and deployment rates of various product categories, following the Track 1 and 2 designations.

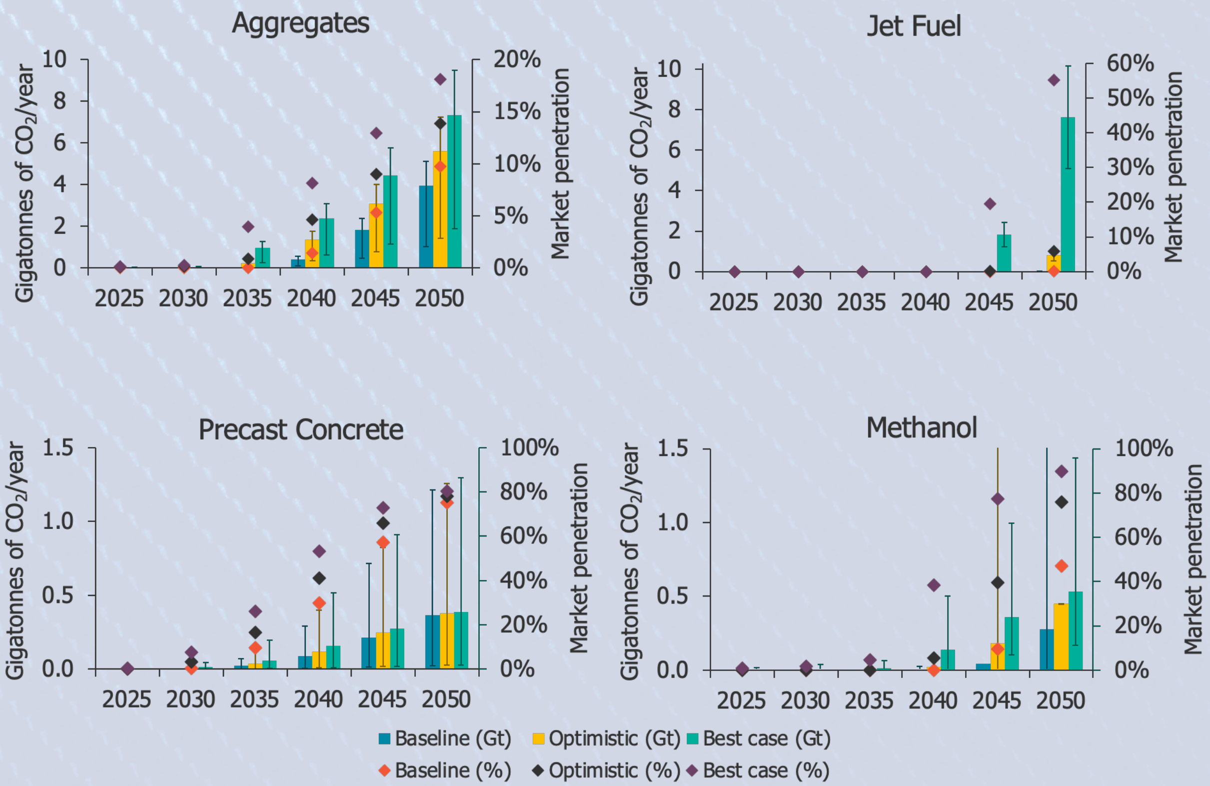
Using the Track 1 and 2 designations for CCU products provides clear guidance for decision makers. CCS and CCU are complementary, with Track 1 CCU products bridging between them, while Track 2 CCU products support a fossil-free circular carbon economy.



Which products and technologies are the most promising?

The new projections show that the long-term potential for CO_2 utilization is larger than estimated in 2016.[4]

- Construction materials are the most promising Track 1 products
- Jet fuel and methanol are the most promising Track 2 products
- The difference in “baseline” and “best case” in the graphs below reflects the fact that cost and other factors influence speed and extent of deployment
- Product-specific variability leads to a range for the CO_2 use projections, depending on the CO_2 contents of the final product, e.g., CO_2 use in aggregate production can range from 0.087 - 0.44 tCO_2/tonne of aggregates *



* The range of projections based on product composition is shown as error bars.

> Precast concrete, aggregates, jet fuel, and methanol are the most promising CCU products. Deployment rates, CO_2 use, and revenue[5] will strongly depend on local policies, existing industry landscape, and energy and raw material availability, e.g., minerals, hydrogen, etc. Integrated and co-located CO_2 capture and utilization is advised for efficiency and reduced CO_2 transportation needs.

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[4] *Global Roadmap for Implementing CO_2 Utilization:* https://hdl.handle.net/2027.42/150624

[5] Read the full report for details on revenue

What are key levers to accelerate deployment?

Significant deployment requires development of cost-effective technologies and markets ready to accept CCU products.

Track 1

- **Aggregates** production will most strongly benefit from adding retrofit carbonation systems as well as regulations that cap quarrying activity. The use of industrial and municipal waste feedstocks that can be carbonated reduces landfilling and associated costs. Carbon credits are not expected to be a significant factor in this product category.

- **Precast concrete** production will most markedly benefit from customer demand, including procurement requirements, supported by the superior performance of the carbonated materials. Close integration with local CO_2 sources could lower the cost of operation. Carbon credits, while not required for deployment, would help accelerate the adoption of the technology.

Track 2

- **Jet fuel** production is most sensitive to the cost of zero-carbon hydrogen and electricity. The cost of production facilities could be reduced via strategic industry alliances and large-scale facilities that accelerate the development of next generation plants. Airline net-zero commitments will create demand leading to accelerated acceptability of higher cost fuels. Specialty use cases, e.g. related to national security, are expected to be competitive at current costs.

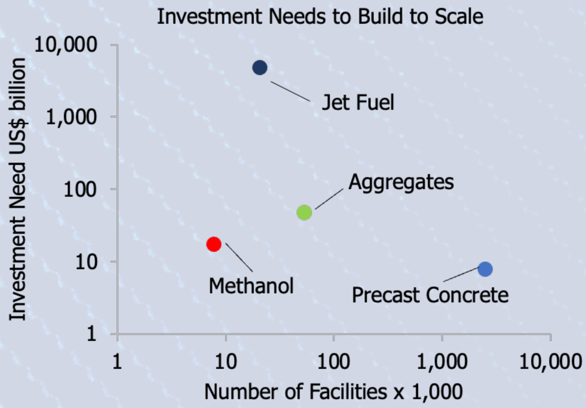
- **Methanol** production is most influenced by the cost of zero-carbon hydrogen and electricity. The cost of production facilities could be reduced via strategic industry alliances and large-scale facilities that accelerate the development of next generation plants. Increasing demand for non-fossil chemicals will likely help reduce the product price.

Specific actions are needed to accelerate deployment of each product category to enter large established commodity markets. Sensitivities to operational expenditures will favor locations where energy and raw materials are available at lower cost.

Number of required production facilities and investment needs

To meet full market demand with a CO_2-product requires a very large number of new or modified existing production facilities.

- Associated cumulative investment needs range from billions to trillions of US$ before 2050
- Track 1 material production will be highly localized, as is currently the case with incumbent materials, and therefore integration with local CO_2 capture, such as direct air or ocean capture, creates opportunities that require little to no transportation infrastructure

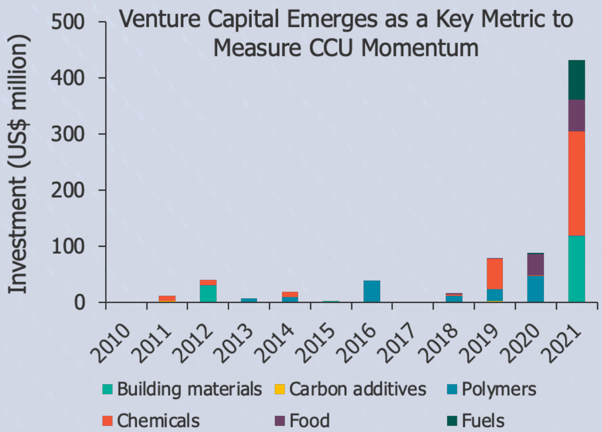


- Track 2 materials can also benefit from a more localized production approach, such as for jet fuel production at or near airports, and methanol production at industry hubs with similar feedstock needs

> The large number and scale of production facilities allows coupling and integration with localized CO_2 capture.

Venture capital is increasing but much more investment is needed

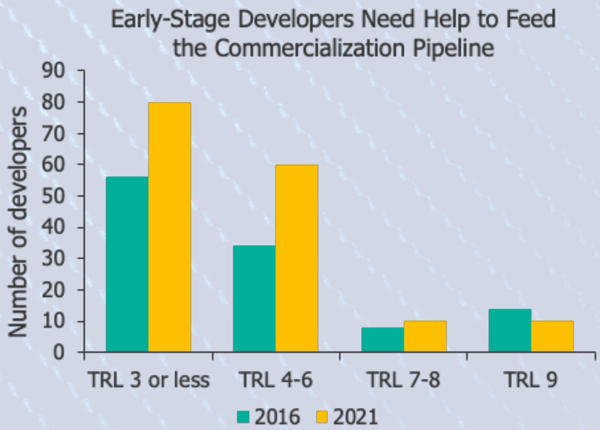
Prior to 2021, the investment community had been cautious about the slowly emerging CCU market, with technologies deemed too immature and not cost-competitive. However, the clear recognition of the urgency in acting to address climate change, improvements in technology, an increasing number of developers, and policy signals have changed the outlook. As the result, investments in CCU technologies began to rise rapidly in 2021.



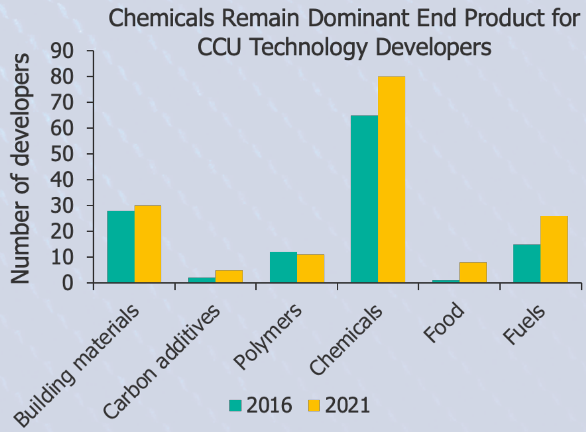
> The sharp increase in Venture Capital funding in 2021 signals that the investment community has noticed the increasing maturity of this area. However, investments still fall far short of what is needed to build this new industry.

Research & development pipeline

Relative to 2016, more inventions are migrating into the startup space and the pipeline is filled with early-stage developers. However, the number of developers at a higher maturity level has essentially stagnated, indicating the need for more research and development support to accelerate the transition to market readiness.



Interest in developing technologies that use CO_2 for chemicals, fuels, and food production (i.e., Track 2) has increased since 2016. The number of developers for building materials (i.e., Track 1) has stagnated.



Many new CCU technologies are in the pipeline, but development is lagging. Most of the technologies are for products with a shorter CO_2 sequestration duration, i.e., Track 2. Larger climate impact could be achieved with a stronger engagement for Track 1.

What can key stakeholders do?

Technology developers:

- Coordinate and drive the certification of CCU construction materials
- Pursue capturing and utilizing CO_2 in the same technology or in an integrated fashion through co-location
- Use standardized life cycle assessments to guide development and to demonstrate the value and social impact of CCU products

Private Sector:

- Connect with emerging zero-carbon hydrogen production and zero-carbon energy conversion systems
- Organize industry associations to develop value and supply chains, and commercial facilities
- Develop and operate industrial capture and utilization clusters for shared learning through public-private partnerships
- Use transparent, standardized life cycle and techno-economic assessments that include societal considerations
- Transition to captured CO_2 as a carbon feedstock

Government:

- Implement incentives to produce and purchase CCU products
- Engage with community stakeholders to ensure transparency, maximum benefits / minimum burdens, and acceptance of CCU installations
- Provide sustained financial and policy support for research, demonstration, and scaling of technologies
- Provide support for public-private partnerships
- Prioritize co-location of capture and utilization facilities as early deployment options
- Invest in supporting infrastructure (CO_2 capture, transportation, zero-carbon electricity, and hydrogen)
- Support infrastructure investment with loans or tax incentives
- Initiate the labeling and/or certification of Track 1 and 2 products
- Assess the climate impact of an economy-wide deployment of Track 1 and 2 products
- Encourage international collaborations

Conclusions

CCU has key advantages relative to CCS: it provides a less expensive method to stabilize and even reduce CO_2 concentrations in the atmosphere and oceans; it provides a means to create valuable carbon-based products, and it can be instrumental in fostering a circular carbon economy.

To ensure its effectiveness, CCU must be rapidly scaled to a global industrial level while being thoughtfully planned and consistently evaluated to minimize unintended consequences.

CCU is not a silver bullet that can single-handedly counter the climate change; however, **it is an essential element of the solution set, and is ready to be deployed now**!

This study was prepared by the Global CO_2 Initiative with research and analysis assistance by Lux Research, Inc.

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For in-depth information, we invite you to download and read the detailed report (https://dx.doi.org/10.7302/5825).

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