Tabbre
Research
Report

# The Economics of Direct Air Carbon Capture

**Date:** 20240719
**Version:** 1.0


# Summary

Direct Air Carbon Capture and Storage (DACCS) is an innovative technological approach aimed at mitigating climate change by directly capturing carbon dioxide (CO2) from ambient air and storing it long-term. Utilizing advanced materials such as potassium and calcium hydroxide or polymer resins, DACCS technologies are in various stages of development, ranging from lab-scale prototypes to operational pilot plants. The successful scaling of these technologies is crucial for their broader adoption and effectiveness in reducing atmospheric CO2 levels[1].

Despite the potential of DACCS, its high energy consumption and associated costs present significant challenges that necessitate continued research and development[1].

Economically, the viability of DACCS hinges on reducing costs and establishing robust markets for captured CO2. Initial government subsidies play a pivotal role, but long-term success will require the creation of sustainable business models and market demand driven by corporate investments and commitments. Companies like Swiss Re, Shopify, and Microsoft have already demonstrated support by purchasing carbon credits from verified DAC projects, highlighting the potential for market-driven growth in this sector[2].

Strategies to lower costs include improving the efficiency of sorbent materials and optimizing operational processes, with a target to bring the cost of $CO_2$ capture below the current combined pricing of $250 per ton[2].

The market for DACCS is expanding, with significant investments and advancements expected over the next decade. The technology is projected to play a crucial role in corporate decarbonization strategies, particularly in industries aiming for carbon neutrality[3].

The global DACC market analysis forecasts significant revenue growth and technological innovation, with applications extending to Sustainable Aviation Fuel (SAF) and emissions offsetting in the transportation sector[3].
However, the economic feasibility of DACCS remains a contentious issue due to the high costs of capture and limited existing markets for $CO_2$ utilization[4]. Government initiatives and policy support are essential for accelerating the deployment of DACCS technologies. In the United States, substantial investments are being made through the Bipartisan Infrastructure Law and the Inflation Reduction Act, which enhance tax credits for carbon capture and sequestration projects[5][6].

Private sector commitments, such as those from the Frontier Fund and Bill Gates' Breakthrough Catalyst Fund, further bolster the industry's growth[5].

Nonetheless, ongoing public and private financing, infrastructure development, and regulatory frameworks are necessary to overcome existing barriers and realize the full potential of DACCS[5][2].

# Technology and Mechanism

Direct Air Carbon Capture and Storage (DACCS) involves several sophisticated technologies designed to capture $CO_2$ directly from ambient air and subsequently store it long-term. The following section outlines the main initiatives and technologies involved in DAC processes, their current development stages, and the challenges they face.

## Initiatives and Development Stages

To overcome obstacles related to DAC processes, five main initiatives are suggested: conducting detailed process design, evaluation, and optimization of DAC solutions; exploration of synergies between material and process development; exploration of process potential; technology validation for large-scale deployment; and independent assessment of the performance of existing and emerging DAC technologies[1]. Successful demonstrations at Technology Readiness Level (TRL) 6 or higher are crucial for increasing process fidelity and de-risking technologies. Currently, only a few technologies operate beyond the lab-scale, and moving to pilot and demonstration phases is essential for verifying DAC systems and investigating gaps that can only be addressed at scale[1].

## Material and Process Synergies

The most advanced DAC technologies primarily rely on commercially available materials such as potassium and calcium hydroxide or polymer resins. This approach has helped reduce technical risk and support accelerated pilot and commercial scaling[1]. There are numerous existing materials and millions of hypothetical ones that can be generated in silico for DAC applications. Exploring these materials can help reduce energy consumption or increase CO2 removal efficiency. For example, material properties like specific heat capacity and thermal conductivity directly impact process energy requirements and, consequently, the operational expenditure (OPEX) of the DAC process[1].

## Process Optimization and Validation

Optimizing cycle steps and sequences or sequencing unit operations in a DAC process is essential. Alternative process configurations should be explored, such as alternative regeneration methods for sorbents and solvents, usage of process waste heat through heat integration, or testing alternative bed configurations[1]. Technology validation for large-scale deployment involves studying how to integrate DACCS into local energy systems and existing industrial clusters to benefit from existing infrastructure[1].

## Infrastructure and CO2 Transport

The lack of existing CO2 transport infrastructure is a significant barrier to scaling DACCS. CO2 can be transported via pipelines or shipped to storage sites, necessitating reliable and low-cost transport solutions. The availability of multi-user CO2 pipeline networks is key for reducing CO2 transport costs and facilitating rapid deployment. Examples include the Midwest Carbon Express in the United States and the Delta Corridor connecting parts of Germany and the Netherlands[1].

## Challenges and Future Directions

Despite advances, detailed process designs are still needed for many DAC technologies. Existing process designs often focus narrowly on CO2 capture and release, neglecting other crucial elements for scaling up DACCS. Depending on the CO2 destination, different specifications for the CO2 product stream will be required, often not considered in current process designs[1]. Additionally, experimental or computational measurements of relevant material performance parameters are needed to model and evaluate materials effectively in separation processes[1].

# Economic Aspects

## Subsidies and Market Creation

Although having governments subsidize Direct Air Carbon Capture (DAC) is initially a necessary and helpful activity, long-term businesses must be built to exist outside of government assistance. To increase demand for DAC solutions, companies and organizations stepping forward to continue purchasing carbon from verified projects will create the true market needed to allow DAC to grow. The continued support of corporate leaders in this space, such as exemplified in recent announcements by Swiss Re, Shopify, and Microsoft, is necessary in establishing this demand[2]. This idea can even be expanded for small- and mid-size companies through creating a type of group purchasing organization for these smaller, eco-conscious companies to buy into early-stage carbon removal projects. Broadening the accessibility and momentum of these early agreements will broaden and democratize DAC solutions.

## Cost Reduction Strategies

To significantly reduce the cost of DAC and break the $200/ton CO2 captured price point, below the current combined pricing of $250 from California's Low Carbon Fuel Standard (LCFS) and Federal 45Q tax credits, sorbent material efficiency must be increased. Three key approaches are suggested: (1) reduce the cost of manufacturing materials, (2) increase the cyclic stability (reduce degradation) of materials, and (3) increase the capacity of materials. It is assumed that at the scales necessary for global CO2 level reduction, sorbent manufacturing costs will come down to the same relative level regardless of technology, provided no exotic or rare-earth components are needed[2].

## Operational and Capital Costs

The largest share of the cost for a First-of-a-Kind (FOAK) plant is attributed to capital cost items, with project and process contingencies contributing to 17–39%, depending on the configuration. Direct equipment and installation costs range from 16 to 40%, while owners' costs range from 7 to 14%[1]. Reducing operational costs requires reducing energy use, which is limited by physical boundaries. Achieving significant operational cost reductions requires insights and breakthroughs in material science[1].

## Transportation and Storage

Lack of existing $CO_2$ transport infrastructure is a significant barrier. To enable permanent storage, $CO_2$ can be transported via pipelines or shipped to storage sites, creating the need for reliable and low-cost transport solutions. Examples include the Midwest Carbon Express in the United States and offshore $CO_2$ pipelines connecting Belgium with Norway. Multi-user $CO_2$ pipeline networks are crucial for reducing the cost of $CO_2$ transport and the rapid deployment of DAC solutions[1].

### Research and Development

Further research is needed to better quantify the cost of proposed priority initiatives and their attendant RD&D projects. Simultaneous investments in research, development, deployment, and the buildout of supporting infrastructure are essential. These investments must cover policy, investment, international collaboration, recommendations for the private sector, and stakeholder/community engagement overall[1].

### Scale and Learning

It is expected that upscaling will be crucial for near-future DAC units instead of large-scale roll-outs. Economies of scale lead to lower costs if the plant is larger, although there is limited publicly available data on the performance of demonstration plants[1]. Technologies such as temperature vacuum swing adsorption or KOH with BPMED regeneration are expected to be easily scalable. However, many insights are currently missing and can be extracted from the operation of these plants[1].

## Market and Industry

Direct Air Carbon Capture (DACC) is currently in its nascent stages, facing a variety of challenges. However, it is poised to play a crucial role in corporate decarbonization strategies in the coming decades as the focus on achieving carbon neutrality intensifies across industries[3].

The DACC market is anticipated to witness significant growth opportunities in technological innovation and business model evolution over the next decade and beyond. Key areas for growth include utilizing captured $CO_2$ for Sustainable Aviation Fuel (SAF) and offsetting emissions in the transportation sector[3].

The global DACC market analysis projects revenue forecasts, carbon capture capacity, prominent technologies, regional splits, industry trends, competitive analysis, and growth opportunity identification extending to 2040[3]. The market landscape is a hotbed of innovation, with a competitive environment that includes both start-ups and multinational corporations[3].

One of the major hurdles for DACC is the economic feasibility of the technology, as markets for $CO_2$ are currently limited and do not generate sufficient revenue to offset the high costs of capture[4].
The largest existing market for $CO_2$, enhanced oil recovery (EOR), offers fluctuating revenue dependent on oil prices and has been criticized for perpetuating fossil fuel use[4].

Emerging markets, such as using captured $CO_2$ in synthetic aggregate for concrete, show potential as attractive alternatives[4].

Investment trends indicate a growing interest in regions with abundant clean electricity resources, such as those rich in sunlight, wind, or geothermal energy[7][8].

Significant investments are being made by companies like 1PointFive, a subsidiary of Occidental, which is planning a 500,000-tonnes-per-year DACC plant expected to be operational by mid-2025[7][8].

Tech companies like Microsoft are also entering the market, with deals such as purchasing 500,000 carbon credits over six years[7][8].

Government initiatives are playing a pivotal role in supporting the DACC industry. In the U.S., the Bipartisan Infrastructure Law and the Inflation Reduction Act make substantial investments in direct air capture through funding and enhanced tax credits[5][6]. These include increasing the 45Q tax credits for carbon capture and sequestration, which could make projects economically viable[6].

In 2022, several private sector commitments were announced, such as the Frontier Fund's $925 million in advance market commitments and Bill Gates' Breakthrough Catalyst Fund's $1.5 billion investment in key technologies, including DAC[5].
Despite these efforts, further public and private financing, infrastructure development, and robust regulatory frameworks are necessary to accelerate DACC deployment[5][2].

# Environmental and Social Impact

The deployment of direct air carbon capture and storage (DACCS) technologies carries significant environmental and social implications. Research indicates that direct air capture plants are expected to produce zero or almost zero onsite emissions, which could negatively impact human health or the environment.

However, given that few plants currently exist, comprehensive data for environmental impact assessments is limited [5].

Life-cycle assessments conducted by Climeworks show that their DAC plants have grey emissions that are less than 10% of the captured carbon dioxide when renewable electricity is used, with goals to reduce this figure to 4%[9].

Furthermore, carbon capture technology plays a crucial role in accelerating emissions reductions across various heavily polluting industrial sectors, such as cement, steel, and fertilizer production. These measures support the development of low-emissions fuels and bioenergy with carbon capture and storage (BECCS), a critical component in scenarios to prevent global temperatures from rising more than 2°C above preindustrial levels[6].

Despite these environmental benefits, the implementation of DACCS projects faces potential social challenges. Communities may raise concerns related to the local health and environmental impacts of proposed plants[5].

Therefore, public awareness and education about the benefits and potential challenges of DAC technology are essential for gaining the necessary public support to scale up the technology. Ensuring transparency, inclusiveness, and equity in the development and operation of direct air capture hubs will be critical for the long-term scale-up of this technology[5].

Moreover, the deployment of DACCS must prioritize equity and environmental justice, aligning with initiatives like President Biden’s Justice40, which aims to provide 40% of the benefits of certain federal investments to disadvantaged communities. These technologies not only reduce greenhouse gas emissions but also decrease criteria air pollutants, protect communities from increased cumulative pollution, and create quality, union-friendly jobs across the country[10].

In the fierce debate over carbon capture, it's often overlooked that these technologies can prevent hundreds of millions of tons of climate pollution from reaching the atmosphere annually. Despite criticisms that carbon capture projects, such as mandatory Gulf and Alaska fossil fuel leases, disproportionately harm marginalized communities, proponents argue that it is an essential tool in the broader strategy to achieve 100% carbon-free electricity goals and mitigate climate change effectively[6].

# Challenges and Limitations

Direct Air Carbon Capture (DAC) faces several challenges and limitations that impede its widespread adoption and cost reduction. While government financial support through subsidies and investments in new technologies is crucial, the establishment of infrastructure to standardize downstream assumptions for each technology is equally important. This allows companies to focus on scaling and deploying their solutions rather than expending resources on integrating them into broader systems [2].

# High Energy Consumption and Costs

One of the primary challenges of DAC is its high energy consumption and associated costs. Various DAC configurations, such as '1C: MEA', '1C: Amino acid', and others, do not result in net-negative emissions when tied to current energy supply systems, with the exception of France. This highlights the necessity for large-scale low-carbon electricity and reductions in energy consumption through optimal material selection, process design, and system integration [1].

The gross capture costs for DAC technologies range between USD 60-2750 per tonne of CO2, depending on process and project contingencies[1].

The lowest cost technology, 2A, ranges from USD 60-300 per tonne of CO2 but still shows significant variation due to differences in plant sizes and other factors[1]
.

## Infrastructure and Supply Chain

To facilitate industrial application, frameworks for selecting optimal materials that encompass technical, economic, and environmental performance should be established [1].

There is a critical need for independent research organizations to corroborate company disclosures on DAC performance. Public dissemination of data from publicly funded pilots and demonstrations is essential for knowledge transfer[1].

Furthermore, developing specialized supply chains for DAC-specific materials and equipment is necessary to improve performance and lower costs[1].

## Technological Readiness and Customization

Many DAC technologies are still in the early stages of development. Prototyping technologies that have reached proof of concept in lab environments (TRL 5), piloting beyond lab-scale (TRL 6+), and sustained operation for at least one year are needed [1].

While Climeworks' TVSA technology is the only one to have reached commercial scale (TRL 9), rapid plant buildout across different geographical regions is crucial to spark deployment-led innovation and reduce costs[1].
This expansion requires technology customization and ongoing research and development[1].

### Process Design and Equipment

Harmonizing material and process is vital for efficient DAC operation. A lack of synergy can lead to delays in identifying optimally tailored materials [1].
Fit-for-purpose equipment designed specifically for DAC applications, such as oxy-fuelled or solar calciners and robust heat pumps, can significantly enhance performance[1].

Conducting process intensification studies and independent comparative studies for process designs and equipment are recommended to identify the most efficient and cost-effective solutions[1].

### Investment and Economic Incentives

Current investment in DAC is a fraction of what is needed to drive the technology down the cost curve [11].

Costs are unlikely to drop below $300 to $400 per ton without significant changes. Achieving costs below $200 per ton would require favorable capital costs, supportive infrastructure, accelerated learning, and upfront deployment at scale well before 2050[11].

Governments and corporate buyers could facilitate this by encouraging knowledge sharing across the supply chain in non-competitive areas and focusing investment on two or three promising technologies to accelerate development[11].

### Uncertainty in Cost Projections

Estimating the future costs of DAC technologies is challenging due to the lack of empirical data.

## Future Prospects

The future prospects for Direct Air Carbon Capture (DACC) are promising but hinge on several critical factors. Given the relatively nascent stage of DACC technology, substantial opportunities exist for cost reductions and efficiency improvements.

Historically, the deployment of wind and solar energy technologies has demonstrated the potential for significant cost reductions, a precedent that suggests DACC could follow a similar trajectory, provided there is robust policy support to drive innovation and deployment[12].

## Policy and Investment

The economic downturn caused by the COVID-19 pandemic presents a unique opportunity to boost investment in DACC through economic stimulus packages. Such investments could support a cost-effective pathway to achieving net-zero emissions. Strengthened policy support is essential to accelerate the development and commercialization of DACC technologies[12].

Furthermore, the International Energy Agency (IEA) and other international organizations emphasize the importance of transparency and planning for the anticipated role of Carbon Dioxide Removal (CDR) in net-zero strategies. These strategies should include differentiating between emissions reductions and carbon removals, aligning with scientific recommendations and establishing varied credit categories in carbon markets[13].

## Technological Innovations

Technological advancements are crucial for reducing the operational costs and enhancing the efficiency of DACC. Current DACC technologies primarily utilize commercially available materials, such as potassium hydroxide and polymer resins, to minimize technical risks and accelerate scaling [1].

Research into new materials and optimization of existing ones could further reduce energy consumption and increase CO2 removal efficiency[1].

For instance, improvements in material properties such as specific heat capacity and thermal conductivity can directly impact the energy requirements of the DACC process[1].

## International Cooperation and Scaling

International cooperation is vital for the faster deployment and cost reduction of DACC technologies through shared knowledge and reduced duplication of research efforts. Organizations like the IEA, Mission Innovation CDR Mission, and the Clean Energy Ministerial CCUS Initiative can provide important platforms for collaboration and knowledge sharing [13]. Scaling up DACC units is expected to be crucial for their economic viability. Although there is currently limited publicly available data on the performance of demonstration plants, economies of scale suggest that larger plants will lead to lower costs. Modular technologies, such as temperature vacuum swing adsorption, offer promising scalability options[1].

## Market Dynamics and Private Investment

The DACC industry is anticipated to be a hotbed of innovation, with numerous growth opportunities. Key growth areas include the use of CO2 for Sustainable Aviation Fuels (SAF) and offsetting emissions in the transport industry [3].

The competitive environment encompasses a range of participants, from start-ups to multinational companies, indicating a dynamic and evolving market landscape. Notably, private investors are increasingly supporting DACC projects, motivated by the potential for long-term returns as decarbonization becomes a priority across various industries[3]

# References

[1]: A roadmap for achieving scalable, safe, and low-cost direct air carbon ...
[2]: Inside-Out: Driving Down Direct Air Capture Costs With High-Efficiency ...
[3]: Global Direct Air Carbon Capture Industry Report 2024: - GlobeNewswire
[4]: Direct Air Capture: Definition, Cost, & Considerations | World ...
[5]: Climate tech explained: direct air capture - Financial Times
[6]: Climate tech explained: direct air capture
[7]: Direct Air Capture Measures in U.S. Climate Policy | World Resources ...
[8]: Why the carbon capture subsidies in the climate ... - MIT Technology Review
[9]: Direct air capture technology: innovations in CO, removal - Climeworks
[10]:BIDEN-HARRIS ADMINISTRATION ANNOUNCES $3.7 BILLION TO KICK-START ...
[11]: Shifting the Direct Air Capture Paradigm | BCG - Boston Consulting Group
[12]: Is carbon capture too expensive? – Analysis - IEA
[13]: Direct Air Capture - Energy System - IEA