CIRCULAR CARBON

RACE IS ON TO FIND SOLUTIONS TO SLOW DOWN GLOBAL WARMING

Spotlight Series

July 2022

FII INSTITUTE
Future Investment Initiative Institute
Impact on Humanity

CIRCULAR CARBON

TO SLOW DOWN GLOBAL WARMING WE NEED TO REMOVE CARBON FROM THE AIR

Numerous methods have been identified, both natural and technological, for extracting carbon dioxide from the atmosphere. Experts are urgently investigating their viability, relative costs and potential trade-offs, synergies and downsides.

THE ISSUE AT STAKE

MODERN HUMAN BEINGS APPEARED ON the planet about 300,000 years ago,[1] but the last 200 years have caused the most damage.[2] Since the start of the Industrial Revolution, more than 2,000 billion tonnes of carbon dioxide have been generated by human activities.[3] We burned wood, then coal and oil, and we stripped huge areas of trees to clear land for farming, disrupting the natural photosynthesis that converts carbon dioxide to oxygen.

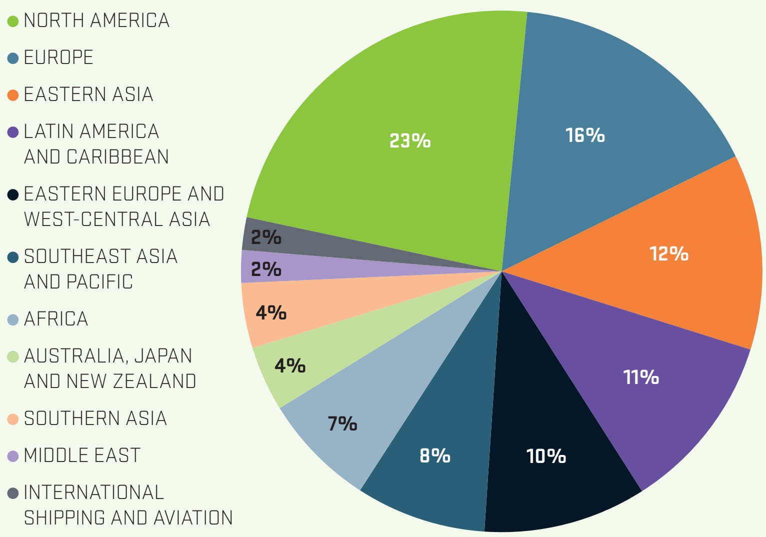
More than a hundred years ago, it was postulated that anthropogenic greenhouse gases could warm up the planet.[3] Now the Intergovernmental Panel on Climate Change (IPPC) has warned us that, to avoid the catastrophic effects of climate change, global temperature rise must be confined to 2°C above pre-industrial levels, or less.[4]

Carbon emissions from energy, industry, agriculture, transport and waste must be reduced. But this won't be enough. The IPPC's latest report states that, in addition, carbon dioxide removal (CDR) is a "key element in scenarios that are likely to limit warming to 2°C or 1.5°C by 2100."[5]

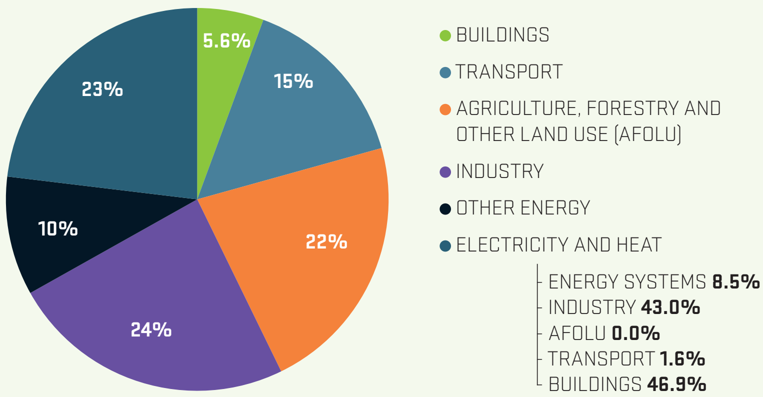
How much carbon dioxide will we need to remove and is this feasible? A report released by the National Academy of Sciences, Engineering, and Medicine (NASEM) concludes that to meet climate goals will require removing 10 $GtCO_2$ per year from the air up to mid-century, and a further 20 $GtCO_2$ per year from 2050 to 2100.[6]

The International Energy Authority (IEA) says that the current pipeline of carbon capture, utilization and storage →

HISTORICAL CUMULATIVE NET ANTHROPOGENIC CO_2 EMISSIONS PER REGION (1850–2019)



GHG EMISSIONS BY SECTOR ($GTCO_2E$)



SOURCE: UN IPPC REPORT, CLIMATE CHANGE 2022, IMPACTS ADAPTION AND VULNERABILITY

COVER: CLIMEWORKS

(CCUS) projects falls well short of the 1.7 Gt of capacity that must be in place by 2030. Capacity must increase at least a hundredfold by 2050, requiring in the order of $1 trillion of investment.[7]

SOLUTIONS COULD MAKE MATTERS WORSE

Arguments are raging over which of the actions listed in tables 1 and 2 has the most potential. Different solutions, applied at scale, come with different social, economic and ecological risks and costs, and a wide range of opinions has been expressed.

UK environmental commentator George Monbiot argues pessimistically of biological sequestration that, even if it were possible to replace chemical-dependent monocultural farming with less damaging regenerative farming, we would not produce enough food worldwide to support the 9.7 billion people expected to be living on the planet by 2050.[8] He fears that country-sized biomass plantations, supporting bioenergy with carbon capture and storage (BECCS), could also lead to mass hunger, because of the loss of agricultural land.[8]

This year's IPCC sixth assessment report on climate change mitigation provides some useful numbers, helping us to evaluate the implications of different forms of CDR. DACCS, the report says, which is currently only at "medium technology readiness," could remove 5–40 GtCO_2 per year at a cost of $100 to $300 per t$CO_2$. The main limitation to deployment, says the report, is the requirement for low-carbon energy.[9]

BECCS, says the IPCC, could remove 0.5–11 GtCO_2 per year for $15–$400 per tCO_2. But, the report adds, "deployment at very large-scale leads to additional land and water use to grow biomass for feedstock and loss of biodiversity." Enhanced weathering, says the report, has the potential to remove 2-4 GtCO_2 per year at a cost of $50–$200 per tCO_2.[10] →

THE GHGs

The four main greenhouse gases are carbon dioxide, methane, nitrous oxide and fluorinated gases. Since CO_2 is the most abundant greenhouse gas emitted by human activity, it is used as a benchmark against which emissions of the others are compared. They are converted into the equivalent of the gas, CO_2e, by multiplying the quantity of gas emitted by their global warming potential (GWP). GWP may misrepresent the impact of short-lived GHGs, like methane. A billon tonnes of CO_2 are represented as a gigatonne, 1 gtCO_2.

Carbon can be captured from industrial and power emissions

Table 1. Carbon capture: natural solutions

Forestation	Planting new trees to counterbalance deforestation and increase natural photosynthesis
Habitat restoration	Peatlands and coastal wetlands, for example
Regenerative agriculture	Includes organic and no-dig farming, perennial crops, woodland planting
Biochar	Biomass product applied to soil, where it can sequester carbon for thousands of years
Enhanced terrestrial weathering	Silicate rock spread on land absorbs CO_2 from the atmosphere
Ocean fertilization	Nutrients applied to the ocean, encouraging algae growth to increase photosynthesis

PHOTO: LUPENGYU/ GETTY IMAGES

Fans for direct air capture at Climeworks' Orca plant

Ocean-based methods have a combined potential to remove 1–100 $GtCO_2$ per year at a cost of \$40–\$500 tCO_2, but "their feasibility is uncertain due to possible side effects on the marine environment." In any case, they are "currently at a low technology readiness level".[11] We can conclude that DACCS (see Table 2) has the most potential to be scaled up and the least adverse environmental impact, but that its high cost is holding it back.[12]

THE MAGIC NUMBER: \$100 PER TONNE

Could that change? DACC specialist Carbon Engineering is currently planning new DACCS plants in Scotland and Texas, each with a capacity of 0.5mt CO_2 per year, with the potential to reach 1mt. Both sites have access to offshore wind energy to power their fans and easy access to geological storage of CO_2. The US site could be operational by 2024. The company estimates a cost of between \$94 and \$232 per tCO_2, once the technology reaches commercial scale.[12]

A cost of \$100 per tCO_2 is reckoned to be the commercial break-even price for DACCS. A study by Arizona State University's Center for Negative Carbon Emissions estimates that the industry will need to grow by a factor of over 300 to reach this cost, maning federal subsidies of up to \$2 billion.[13]

This finding is mirrored by the IPCC. Its sixth assessment report notes that photo- →

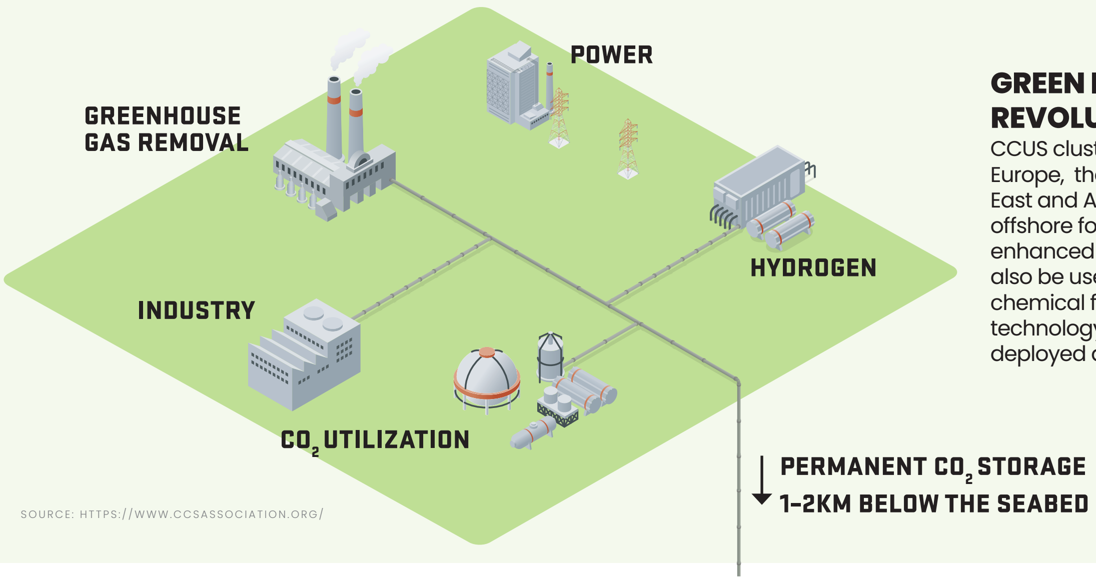
Table 2. Carbon capture: tech solutions

Direct air capture (DAC) sometimes known as direct air carbon capture and storage (DACCS)	Extracts CO_2 from ambient air or point sources for subsurface storage or conversion into other materials
Bioenergy with carbon carbon capture and storage (BECCS)	Burning plants and trees to make power. They absorb carbon dioxide as they grow. The CO_2 released from incineration does not enter the atmosphere
Energy from waste with carbon capture and storage (EfWCCS)	A carbon-negative way of diverting waste from the environment
Pyrolysis	Combustion with low or no oxygen converting waste, including plastic, into combustible gases and liquid fuels. Produces biochar as a residue
Low-carbon concrete	Altering the manufacture or constituents of concrete to lower its embodied carbon
Construction with biomass	Making buildings with wood to reduce the use of steel and concrete

PHOTO: CLIMEWORKS

A CCUS CLUSTER

Multiple industries sharing CO_2 transport and storage infrastructure, enabling these industries to achieve net zero emissions



SOURCE: HTTPS://WWW.CCSASSOCIATION.ORG/

GREEN INDUSTRIAL REVOLUTION

CCUS clusters are being developed in Europe, the US, Asia Pacific, the Middle East and Africa. Captured CO_2 is piped offshore for geological storage or for enhanced oil recovery (EOR). It can also be used to make new plastics, chemical feedstocks or biofuels. The technology is well-proven and can be deployed at scale.

voltaic technology has taken 60 years to reach its current development and scale, producing a competitive wholesale energy price, and says that, for DACCS to contribute to a 1.5°c or 2°C climate charge increase, it will need to mature within 15 years.[14]

A way forward for the economies of the G20 is emerging in the form of industrial CCUS clusters, or networks (see diagram). In this "green industrial revolution" model, carbon is treated a waste product. Clusters combine the components of carbon capture and storage, the production of hydrogen by electrolysis from renewable energy, and processes that convert waste plastic, or carbon, into fuels, products or chemical feedstocks. Geography normally dictates coastal locations, allowing access to offshore wind power and deepwater ports to ship out liquefied hydrogen and natural gas.

Tackling climate change will require the adoption of a number of solutions. But experts agree that technologies like DACCS and BECCS must play a part in any effective scenario to compensate for continuing emissions from hard-to-abate carbon sources, such as agriculture and heavy industry.[15]

It is generally agreed that financial mechanisms, such carbon pricing and globally applied carbon capture credits, will be essential for focusing investment in the areas of the world with optimum conditions for geological disposal. At a government level, we'll need subsidies to drive changes of land use that will keep carbon in the soil and encourage habitat restoration. The measures needed in the first half of this century will require concerted efforts from governments, universities, companies and international bodies. The IPCC has laid excellent groundwork in identifying the cost and potential of different methodologies, but there are still gaps in our understanding of the trade-offs, synergies and possible negative outcomes of the solutions it has identified.

Mineralized carbon dioxide from Climeworks' Orca plant

ILLUSTRATIONS: ROCCOMONTOYA/GETTY IMAGES (2), ANILYANIK/GETTY IMAGES; PHOTO: CLIMEWORKS

CARBON CAPTURE: COMPANIES TO WATCH

The concept of removing carbon from air originated in 1999 with US academic, Klaus Lackner. The following companies show the range of techniques being applied to DAC. This technology will be indispensible for removing carbon from energy generation from gas, biomass and waste, and from hard-to-abate industries. But that won't solve the problem of ambient greenhouses gases. Despite the hype of vanguard companies, DAC is currently far too expensive and energy-intensive to be scalable.

Climeworks is a Swiss company founded in 2009. In 2017, it opened the world's first commercial DAC project in Hinwil, near Zurich. In 2021, with Reykjavik Energy offshoot Carbfix, Climeworks opened the largest DAC facility in the world: the Orca carbon capture plant at the Hellisheidi geothermal power station in Iceland. It captures 4,000 tonnes of CO_2 per year. This is injected into basalt rock, in which it fully mineralizes. EU-funded Project Silverstone will deploy full-scale DAC at Hellisheidi by 2025, aiming to capture and store 85% of the plant's emissions – 34,000 tonnes of CO_2e.

https://climeworks.com https://www.carbfix.com

Carbon Engineering is a Canada-based clean energy company founded in 2009 by Harvard professor David Keith. Part-funded by Bill Gates, it first captured CO_2 from the air in 2015 and produced synthetic fuel in 2017. Its trademarked air-to-fuel technology combines green hydrogen with carbon and water to manufacture petrol, diesel and jet fuel.

With new DACC facilities set to open in the US and Scotland, including geological storage, it has announced plans to capture one million tonnes of CO_2 per year – equivalent to the carbon removal capacity of 40 million trees.

https://carbonengineering.com

LanzaTech is an industrial biotechnology company founded in New Zealand in 2005 by Sean Simpson and headquartered in Chicago. Its technologies are in use in India and China. LanzaTech's process applies microbial gas fermentation to emissions from industries such as steelmaking, chemicals and refineries, as well as from solid waste, producing ethanol, a chemical feedstock for plastics and fuels. LanzaTech's spin-off, LanzaJet, uses Carbon Engineering's green hydrogen and CO_2 process to make jet fuel. Investors include Shell, British Airways and SAS.

https://lanzatech.com

Carbon Collect was formed in partnership with Arizona State University's Dr Klaus Lackner. It is based in Dublin. The company's "mechanical trees" use ambient wind to collect CO_2, a passive approach that removes the need for fans and blowers. It is claimed that the mechanical trees are a thousand times more efficient than natural trees in absorbing CO_2. Assuming a lifetime of 15 years, each tree would capture more than 500 tonnes of CO_2. Wind is abundant, so that's a bonus.

https://mechanicaltrees.com

PHOTO: CLIMEWORKS, CARBON ENGINEERING, LANZATECH, CARBON COOLLECT

PHOTO: CLIMEWORKS

WHAT CAN WE DO?

➲ **Finance:** Carbon pricing mechanisms and international carbon capture credits will be needed to speed up the development of DACCS, BECCS and other technologies, and to encourage their deployment in the optimum areas

➲ **Land use:** Worldwide, agriculture causes almost 25% of carbon loss. The free market won't solve the problem. Land management subsidies will be needed to incentivize biodiversity creation and regenerative agriculture.

➲ **Behavior:** We can help to save the planet by changing our work, transport and energy use – work at home, use public transport and EVs. Diet is important. A plant-rich diet is less carbon-intensive than one relying on meat.

ABOUT FII INSTITUTE

THE FUTURE INVESTMENT INITIATIVE (FII) INSTITUTE is a new global nonprofit foundation with an investment arm and one agenda: Impact on Humanity.

Global, inclusive and committed to Environmental, Social and Governance (ESG) principles, we foster great minds from around the world and turn ideas into real-world solutions in five critical areas: Artificial Intelligence (AI) and Robotics, Education, Healthcare and Sustainability. We are in the right place at the right time: when decision-makers, investors and an engaged generation of youth come together in aspiration, energized and ready for change.

We harness that energy into three pillars: THINK, XCHANGE, ACT. Our THINK pillar empowers the world's brightest minds to identify technological solutions to the most pressing issues facing humanity. Our XCHANGE pillar builds inclusive platforms for international dialogue, knowledge-sharing and partnership. Our ACT pillar curates and invests directly in the technologies of the future to secure sustainable real-world solutions. Join us to own, co-create and actualize a brighter, more sustainable future for humanity. ←

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References

1 National Geographic https://www.nationalgeographic.com/history/article/morocco-early-human-fossils-anthropology-science

2 NASA: The causes of Climate Change https://climate.nasa.gov/causes/

3 NOAA Climate.gov https://www.climate.gov/news-features/climate-qa/which-emits-more-carbon-dioxide-volcanoes-or-human-activities

4-5 UN IPPC report, Climate change 2022, impacts adaption and vulnerability https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf

6 Kleinman Center for energy policy https://kleinmanenergy.upenn.edu/research/publications/the-essential-role-of-negative-emissions-in-getting-to-carbon-neutral/

7 International Energy Authority https://www.iea.org/fuels-and-technologies/carbon-capture-utilisation-and-storage

8 The natural world can help save us from climate catastrophe https://www.theguardian.com/commentisfree/2019/apr/03/natural-world-climate-catastrophe-rewilding

9-11 UN IPPC report, Climate change 2022, impacts adaption and vulnerability https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf

12 MIT Technology review https://www.technologyreview.com/2021/06/24/1027083/what-it-will-take-to-achieve-affordable-carbon-removal/

13 ACS Publications https://pubs.acs.org/doi/abs/10.1021/acs.iecr.0c04839

14 UN IPPC report, Climate change 2022, impacts adaption and vulnerability https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf

15 Frontiers in climate: BECCS and DACCS as Negative Emission Providers in an Intermittent Electricity System: https://www.frontiersin.org/articles/10.3389/fclim.2021.647276/full

Diagram
CCUS clusters
https://www.ccsassociation.org/

Cover shows the Orca plant at the Hellisheidi geothermal power station in Iceland. Run by Clmeworks and Carbfix, it is the largest DACCS facility in the world

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