Q2 2020 | Pulse

Carbon Capture Utilization & Storage

FutureBridge

WHAT'S INSIDE!

What are the major technological developments?

What are the key activities of a CCUS business?

How are the legislation and policy marching ahead in this space?

Which are the latest government funding / investment / public – private partnership schemes?

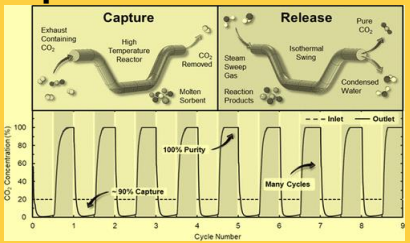
Which start-ups are creating buzz?

ENERGY INDUSTRY INSIDER

FutureBridge

01 Emerging trends

Innovations in carbon capture



FutureBridge Perspective

- **The urgent abatement of CO_2 emissions relies on the development of new, and efficient technologies to capture CO_2 from existing industrial plants; membrane-based CO_2 separation is an attractive carbon capture technology**
- **Thin-film composite membranes are particularly attractive because they provide high gas permeance in comparison with conventional thicker (~50 µm) dense membranes**

Carbon capture: Technology developments

Newcastle University

Dendritic silver self-assembly in molten-carbonate membranes for efficient carbon dioxide capture

29th April 2020

Researchers have developed a self-assembling silver membrane with the highest flux of Ag-supported molten-salt membranes to date (1.25 ml min^{-1} cm^{-2} at 650 °C) and ultrahigh permeability (9.4 × 10−11 mol m^{-1} s−1 Pa^{-1}) for post-combustion CO_2 capture

KAIST

Computational design of a photoresponsive metal-organic framework for post-combustion carbon capture

26th May 2020

Researchers have proposed the photoresponsive metal-organic framework for CO_2 capture; computational simulations indicated that the photochemically induced trans-to-cis transition of the material leads to significant alteration in the CO_2 capacity with adsorption capacity of 89.6 cm^3/g

The Ohio State University

Nanometer-thick supported graphene Oxide membrane for CO_2 capture

10th June 2020

The optimized membranes of graphene oxide showed CO_2 permeance (flux/pressure difference) of 5.7×10^{-8} [mol/(m^2 s·Pa)] (183 GPU) and CO_2/N_2 selectivity of 259 at 57°C in a wet mixture of 20% CO_2 and 80% N_2

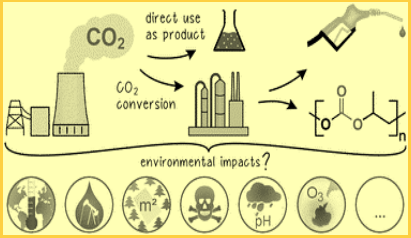
DEVELOPMENTS **Emerging Trends**

Some of the major technological developments in the field of carbon capture in this quarter:

Researchers (Cameron Halliday, et.al.) from Massachusetts Institute of Technology demonstrated the performance of molten alkali metal borates, a new class of materials, at the bench scale, highlighting the ability to operate isothermally at high temperatures through the use of steam as a sweep gas; the ability to capture over 99.9% of incoming CO_2 even at low concentrations or to capture~90% CO_2 under high flow rates and utilize a greater portion of the sorbent capacity

Zhejiang University (Wei Yu, et.al.) has proposed a microencapsulated carbon sorbents that are considered as promising materials for enhanced CO_2 capture owing to their drastically increased gas–liquid contacting area

Innovations in CO_2 conversion & utilization



FutureBridge Perspective

- **Recently, more than twenty reactions involving CO_2 as feedstock have been developed to produce valuable chemicals, such as alcohols, hydrocarbons, esters, and so on**
- **Heterogeneous catalysts (such as carbon-based catalysts, silicas, MOF, etc.) are more desirable for CCU in view of their advantages such as easy product separation, purification and facile catalyst recycle compared with homogeneous catalysts**

CO_2 conversion & utilization (CCU): Technology developments

浙江師範大學 ZHEJIANG NORMAL UNIVERSITY

Achieving the transformation of captured CO_2 to cyclic carbonates

30th April 2020

Work highlights the synthesis of a novel heterogeneous catalyst Bp-POF-Cu and the tandem utilization of captured CO_2 via the catalytic reaction by BpPOF-Cu to synthesis of cyclic carbonate without any CO_2 purification and compression steps

大阪大学 OSAKA UNIVERSITY

Interfacial engineering of PdAg/TiO_2 with a metal-organic framework to promote the hydrogenation of CO_2 to formic acid

8th May 2020

Researchers have developed a modified PdAg/TiO_2 catalyst with an metal-organic framework (ZIF-8) using a facile pretreatment method. The resulting PdAg/TiO_2@ZIF-8 enhanced the selective hydrogenation of CO_2 to produce formic acid even under relatively mild reaction conditions (2.0 MPa, 100°C)

LIÈGE université

A catalytic domino approach toward oxo-alkyl carbonates and polycarbonates from CO_2

3rd June 2020

Researchers have explored the domino reaction between propargylic alcohols, carbon dioxide and various alcohols with the dual objective to prepare oxo-alkylcarbonates with a high yield and selectivity under mild conditions and to extend the process to the synthesis of phosgene-free polycarbonates

DEVELOPMENTS Emerging Trends

Some of the major technological developments in the field of CCU in this quarter:

Researchers (Wenchao Ma, et.al.) from Xiamen University developed a fluorine-modified copper catalyst that exhibits an ultrahigh current density of 1.6 A cm^{-2} with a C_{2+}(mainly ethylene and ethanol) Faradaic efficiency of 80% for electrocatalytic CO_2 reduction in a flow cell

Durham University (L. Jiang, et.al.) has proposed a new study on polyethylene furandicarboxylate produced from industrial CO_2 emissions and non-food-derived biomass to provide an alternative for polyethylene terephthalate for packaging application

Highlights of key business activities (Q2 2020)

key business activities (Q2 2020)	
Kiewit	**April 15, 2020:** Kiewit has signed partnership agreement with Mitsubishi Heavy Industries America and Sargent & Lundy on carbon-capture retrofit plant
inovyn An INEOS company	**May 07, 2020:** Inovyn announced to build power-to-methanol plant with consortium members
LafargeHolcim	**May 20, 2020:** LafargeHolcim has signed a long-term collaboration framework agreement with Solidia Technologies
MAN Energy Solutions	**May 26, 2020:** MAN Energy Solutions won CCUS contract
preem	**May 26, 2020:** Preem CCS launched Sweden's largest CCUS plant
Petrofac	**June 10, 2020:** Petrofac secured contract for Acorn CCS and hydrogen project
AkerSolutions	**June 16, 2020:** Aker Solutions has signed agreement to deliver CO_2 capture plant for Norcem
LAFARGE	**June 24, 2020:** Lafarge, OMV VERBUND and Borealis joined hands for carbon capture and utilization

FutureBridge Analyst Comments:

- *Public and the private sectors are joining hands together on joint execution plans and funding that is focused on ultimate efficacy and long-term impact of CCUS project. The joint partnerships to be major drivers for advancing CCUS technology economy*

Highlights of key legislation and policy activities (Q2 2020)

key legislation and policy (Q2 2020)	
	April 12, 2020: The governor of Virginia (USA) signed the Virginia Clean Economy Act into law
	May 06, 2020: EU, and Switzerland carbon trading link postponed
	May 21, 2020: Australia's federal government released its technology investment roadmap for reducing CO_2 emissions over the next 30 years
	May 21, 2020: UK government draft accord sets path for future UK-EU CO_2 trading
	May 28, 2020: Treasury department, the United States, proposes regulations to govern tax credits for carbon capture and sequestration

FutureBridge Analyst Comments:

- *The proposed regulations around Section 45Q released by the Internal Revenue Service (IRS) is an important development because it would provide guidance as to how the IRS will treat claims for carbon sequestration tax credits based on Section 45Q of the Tax Code*
- *For taxpayers seeking credit for carbon "utilization", the statutory term that includes carbon capture through photosynthetic and chemosynthetic processes and through carbon captured for "commercial markets" , the rules require that the amount of carbon captured and sequestered be demonstrated through a life-cycle carbon analysis meeting ISO 14044:2006 ("Environmental management – Life cycle assessment – Requirements and guidelines") that has either been performed or verified by a qualified third party*

Highlights of key projects – LEILAC project phase II

After promising results from the first phase of the Low Emissions Intensity Lime and Cement (LEILAC) project, HeidelbergCement is starting the further development and scale-up of the LEILAC technology together with the Australian technology company Calix and a European consortium

LEILAC partners

HEIDELBERGCEMENT
TARMAC A CRH COMPANY
CEMEX
Lhoist
calix
TNO innovation for life
PSE
CARBON TRUST
Quantis
SOLVAY asking more from chemistry®
Imperial College London

Highlights of the Project

- In phase II, construction of a demonstration plant that will aim to capture around 20% of a full-scale cement plant's process CO_2 emissions (**100,000 TPA of CO_2**), whereas, in phase I, a CO_2 separation pilot plant with a capacity of **25,000** tonnes per year was constructed at the HeidelbergCement plant in Lixhe, Belgium
- Like its predecessor phase I **(€21 million),** the phase II project is based on Calix's innovative calcination technology and is supported with **€16 million** from the EU research funding programme Horizon 2020
- LEILAC technology **(Direct separation technology, separation of CO_2 with >95% purity)** has potential to reduce significant cost and operating advantages over **competing technologies such as amine CO_2 capture and oxyfuel**
- Commercialisation strategy involves proof of demonstration by **2025**
- Revenue would be generated through **license or royalty arrangements** will be sought from those wishing to use the technology, delivered via engineering and technology partners

United Kingdom Research and Innovation is anticipating that their plan could result in the capturing and storage of around 10% of the UK's carbon dioxide emissions per year by 2040; this can lead the way in the UK's transition to a net zero carbon cluster in the future and would unlock the major local economic benefits by utilising emerging CCS and hydrogen solutions

Government / public – private funds to support CCUS activities

CCUS projects gain funding from UK Research and Innovation

16th April 2020

The consortium of 10 energy and 1 industrial companies secured £1 million funding from UK Research and Innovation to use carbon capture and storage and hydrogen technology to decarbonise energy production and industry in the Humber region of Northern England

Department of Energy (USA) announces $131 million for CCUS technologies

24th April 2020

R&D projects will fall under two areas of interest: 1) Initial engineering design for CO_2 capture from industrial sources; and 2) Engineering-scale testing of transformational post-combustion CO_2 capture technologies through one new funding opportunity announcement (FOA) and the winners of five project selections from a previous FOA

Climeworks AG raised $75 million

2nd June 2020

This is the largest private investment into direct air capture to date. The funding will help to drive forward the Climeworks's scale-up roadmap and expand its carbon dioxide removal capacities

DEVELOPMENTS
Funding & Investment

Apart from Climeworks, Canadian startup Carbon Engineering and U.S. startup Global Thermostat are also looking to scale up direct air capture technology. Like with most technologies at early stages, it's expensive often costing more than $250 per metric ton of carbon dioxide captured

Climeworks offers offset subscriptions to individuals at €1 euro per kilogram of carbon dioxide captured, which works out to about $1,100 per metric ton

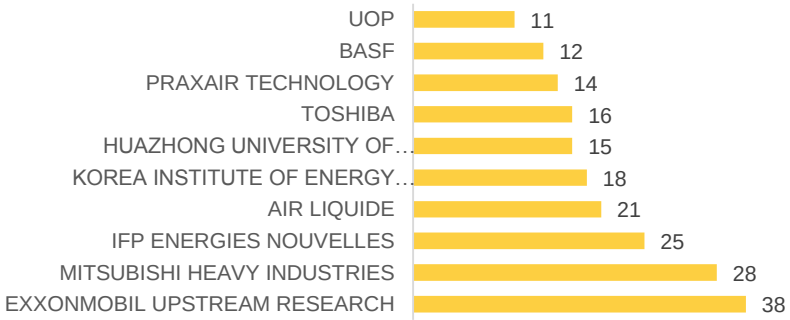
FutureBridge Analyst Comments: Bilateral partnerships and funding will accelerate the demonstration of CCUS technologies; will identify, & reduce and or eliminate general and country-specific technical, regulatory, institutional, financial, economic, environmental, and social barriers to CCUS technology demonstration; and commerclization

02 Quarterly academic review

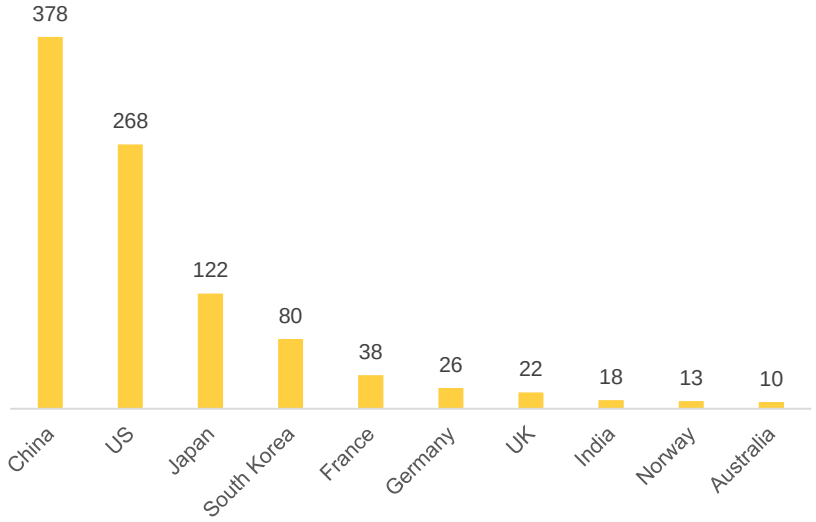
Patenting activity – CCUS

Patenting activity, Q2 2020	
Total number of patents published	932
Number of patents published in Jan	290
Number of patents published in Feb	312
Number of patents published in March	330
Patents Pending (%)	46%
Patents Granted (%)	54%

Top assignees, Q2 2020



Top countries, Q2 2020



Source: Orbit

Academic review – A Robust, scalable platform for the electrochemical conversion of CO_2 to formate: Identifying pathways to higher energy efficiencies

NREL Transforming ENERGY | Argonne NATIONAL LABORATORY | University of Colorado Boulder

Technology description – Electrochemical conversion of CO_2 , published on May 11, 2020

Technology details

Funding

- This research was supported by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office

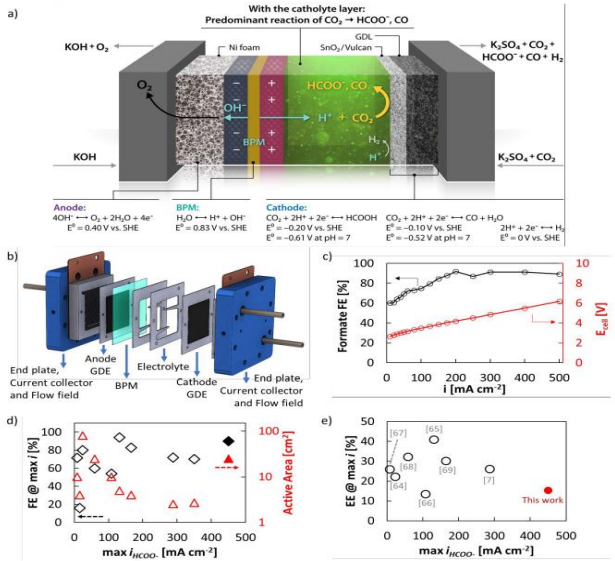


Image: Schematic illustration (a) and cell architecture (b) for a full BPM MEA setup, and the formate FE (c) tested in this cell with Nafion™ or anion-exchange ionomer in the cathode GDE; 0.5 mg cm^{-2} SnO_2 loading was used in all the tests

FutureBridge Perspective

- Research work demonstrated a robust, scalable cell architecture for up to 90% faradaic efficiency for the conversion of CO_2 to formate at 500 mA/cm^2 that was realized at a 25 cm^2 gas diffusion electrode with a carbon-supported SnO_2 electrocatalyst
- A 1.27 mm thick catholyte was used between the bipolar membrane and cathode gas diffusion electrode, which could be further reduced to tens of micrometers upon refinement
- The deconvolution of the potential drop from each individual component/process guides the pathways to higher energy efficiencies of CO_2
- In recent years, remarkable efforts have been made towards the electrochemical reduction of CO_2 into value-added chemicals and fuels, such as carbon monoxide, formic acid/formate, ethylene, ethanol, methane and methanol
- When coupled with renewable energy sources, CO_2 conversion is an attractive approach for utilizing carbon chemical feed stocks while reducing CO_2 emissions and closing the anthropogenic carbon loop

03 Startup highlights

Funding distribution & activities

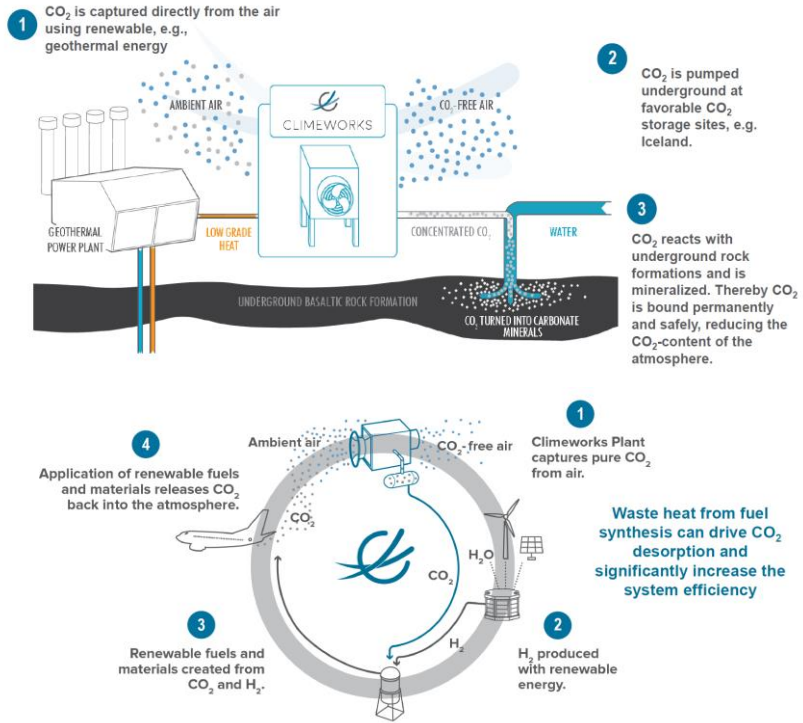
climeworks

USD 75 Mn

1

Carbon Capture

Technology – Direct air capture



FutureBridge Perspective

- On June 2, Climeworks has successfully raised USD 75 million in equity from private investors, which is the largest private investment into direct air capture to date
- Funding will help to drive forward the Climeworks's scale-up roadmap and expand its carbon dioxide removal capacities
- Swiss lender Zuercher Kantonalbank also took part in an earlier funding round and holds a stake in Climeworks
- Climeworks announced that it will use the proceeds to build a new plant with a capacity of about 100,000 tons, and operations could start as early as 2022

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