Reactive CO_2 Capture:
Process Integration for the New Carbon Economy

Peter Agbo, Sarah Baker, Todd Deutsch, Doug Kauffman, Josh Schaidle

February 18th-19th, 2020

Marriott Denver West, Golden CO

Workshop Goal and Objectives

Goal

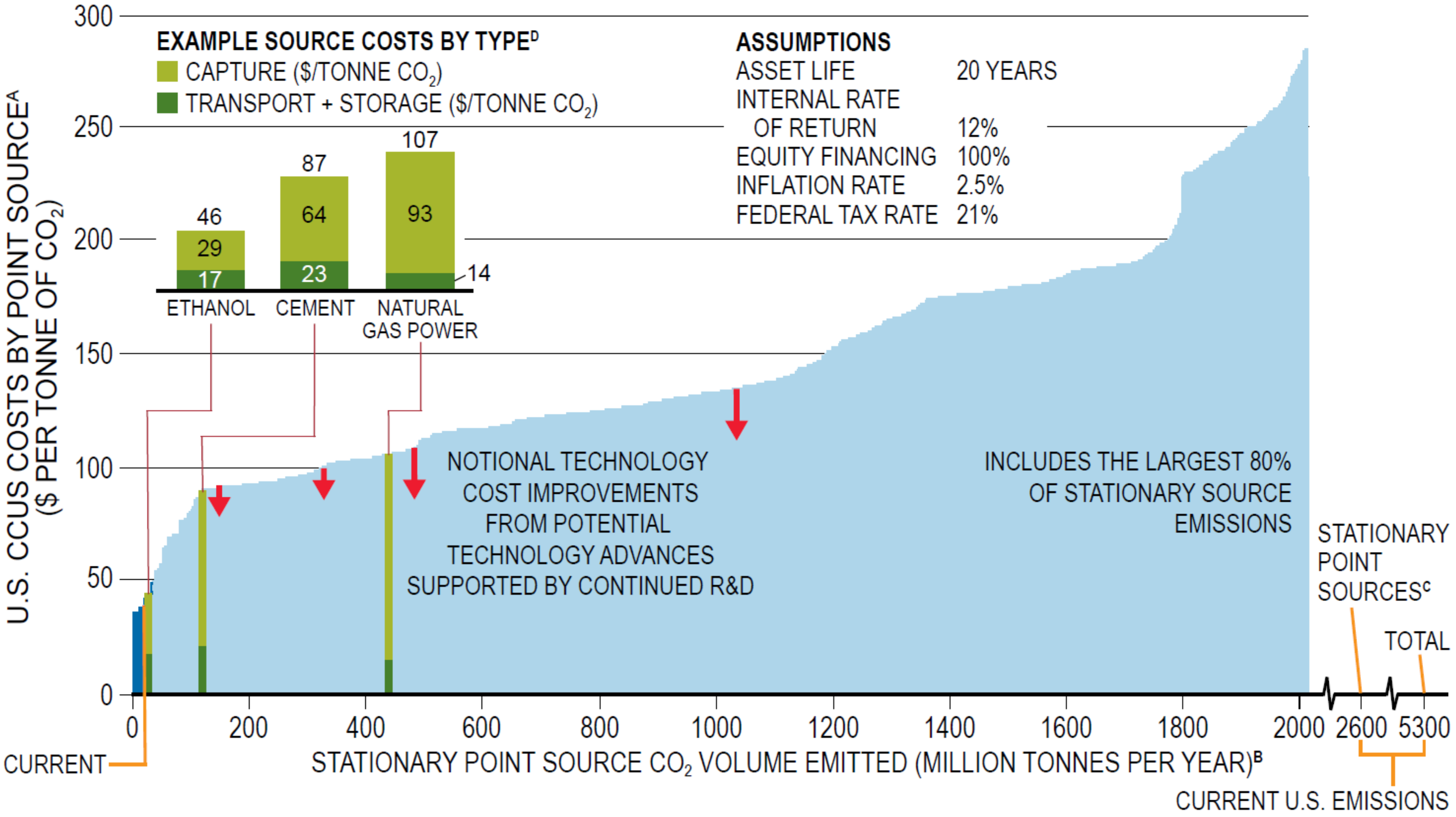
Develop a vision for success for reactive CO_2 capture within the context of a circular carbon economy and define a strategy for achieving that vision

Objectives

- Develop relationships and bridge gaps between CO_2 capture and CO_2 utilization
- Identify major technical challenges, knowledge gaps, and barriers to progress
- Define research needs
- Establish metrics for success

Why Reactive Capture?

Challenge: High Costs of CO_2 Capture, Transport, and Storage



National Petroleum Council, *Meeting the Dual Challenge, A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage*, 2019

Opportunity

Reactive CO_2 capture could offset costs of storage and enable a circular carbon economy while reducing need for CO_2 transport

Definitions and Workshop Scope

Reactive Capture Definition: The coupled process of CO_2 separation from mixed gas streams and conversion to valuable product(s)

Can include:

- Integration of CO_2 separation and conversion in one step (e.g., catalyst-coated membrane)
- Integration of separation and conversion in one unit (e.g., regenerating capture media through CO_2 conversion during recycle)
- Process intensification in the pathway from CO_2 capture to products (e.g., reduced unit ops)

Workshop Scope:

- Must form a valuable product, or mixture of products (e.g., more valuable than CO_2 loaded capture media)
- The product or mixture of products must be in a more reduced state than CO_2 (i.e., conversion of CO_2 must involve transfer of reducing equivalents)
- CO_2 source agnostic (e.g., atmospheric CO_2 and concentrated point sources included)
- Photosynthesis is outside the scope of this workshop

Faradaic Electro-Swing Reactive CO_2 Adsorption

Scientific Approach

- Leverages redox-active species to capture and release CO_2
- CO_2 is captured via the carboxylation of reduced quinones
- CO_2 is released during cell discharge (reversed polarity)
- Cell architecture maximizes the surface area exposed to gas, allowing for ease of stacking of the cells in a parallel passage contactor bed

Significance and Impact

- CO_2 uptake achieved at concentrations as low as 6000 ppm
- CO_2 capacity is independent of the inlet feed concentration
- >90% faradaic efficiency
- Offers an alternative to temperature-swing or pressure-swing adsorption systems
- Opportunity for direct integration with CO_2 conversion

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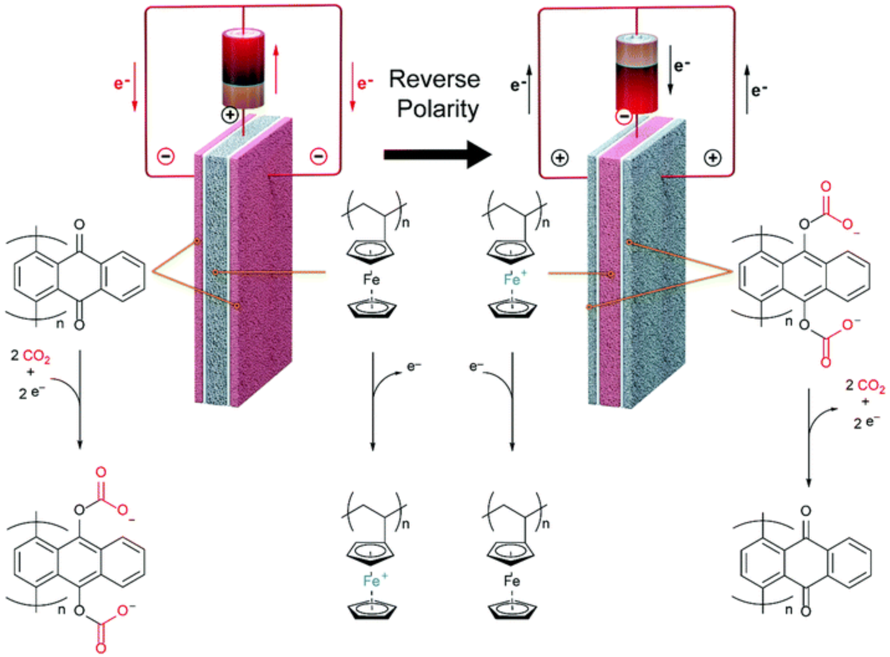
Cite this: *Energy Environ. Sci.*, 2019, 12, 3530

Faradaic electro-swing reactive adsorption for CO_2 capture†

Sahag Voskian and T. Alan Hatton*

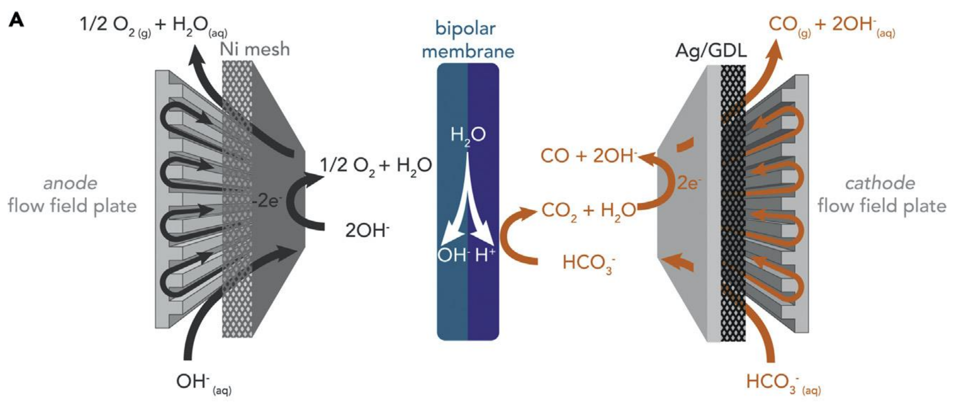


Energy Environ. Sci., 2019, 12, 3530-3547
International Journal of Greenhouse Gas Control 2019, *82*, 48–58

Electrochemical Upgrading of CO_2 Capture Solution

Scientific Approach

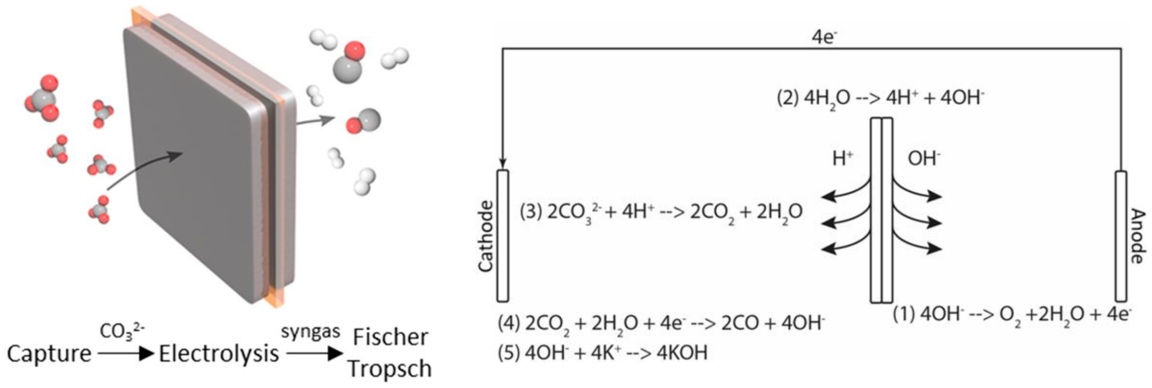
- CO_2 is captured in KOH solution to form (bi)carbonate ions
- Carbonate is fed to the cation conducting side of a bipolar membrane based CO_2 electrolyzer
- Protons supplied by the bipolar membrane generate CO_2 from carbonate
- CO_2 is reduced to CO, at its point of generation from CO_3^{2-}, which also regenerates the hydroxide for further capture
- H_2 is also produced so pure syngas is the cathode product



Joule 3, 1487–1497, June 19, 2019

Significance and Impact

- Combined capture and conversion demonstration at a relevant current density – 150 mA/cm^2
- Energy efficiency ~35%
- Stable operation over 145 hours
- Near 100 % carbon utilization – no need to remove CO_2 from product stream

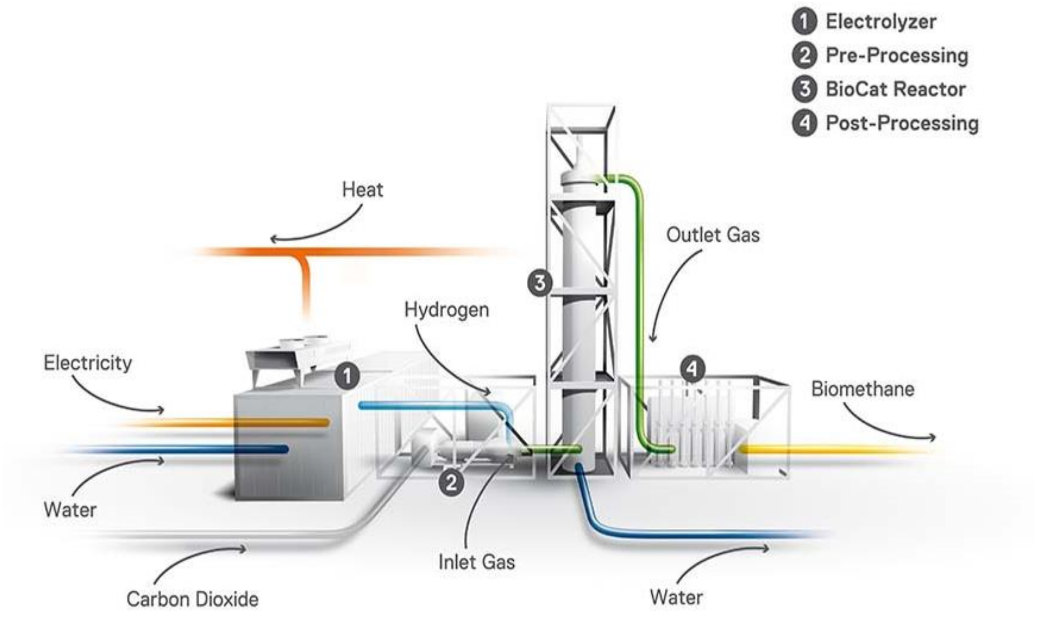


ACS Energy Lett. 2019, 4, 1427−1431

Renewable Methane Production

Scientific Approach

- Utilize excess electricity production for the electrolysis of water to H_2 and O_2
- Optimized strain of methanogenic archaea to perform methanation under industrial conditions
- 125 kW PEM electrolyzer feeds 2.5 kg H_2/h, continuously producing 4.1 scfm CH_4
- 98% carbon efficiency of CO_2 to CH_4
- Post-processing for pipeline quality natural gas



$$4H_2 + CO_2 \xrightarrow{\text{Biocatalyst}} CH_4 + 2H_2O + \text{Heat}$$

Significance and Impact

- Potential long-term storage strategy via conversion of electricity and CO_2 to CH_4
- High efficiency CO_2 capture and conversion strategy
- Demonstrated route to renewable methane
- Large market and NG-grid to absorb curtailed electricity

BioCatProject POWER-TO-GAS VIA BIOLOGICAL CATALYSIS

SoCalGas A Sempra Energy utility

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Electrochaea

CO_2 to Methanol via KOH/Ethylene Glycol

Scientific Approach

- CO_2 is captured in a mixture of KOH and ethylene glycol
- Captured CO_2 is hydrogenated into methanol at mild temperatures using H_2 and a Ru-based catalyst
- Quantitative methanol yields after 20 hours under 70 bar H_2 and 140 °C
- Lower operating temperatures also possible
- Regeneration of capture solvent allows multiple capture/conversion cycles
- Demonstrated potential for direct air reactive capture

Significance and Impact

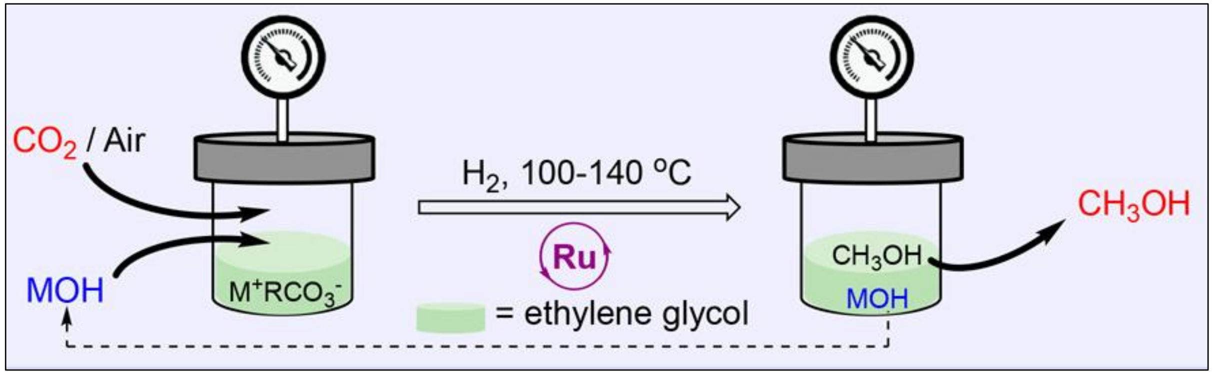
Clear potential for integrating direct air capture with production of a carbon neutral commodity chemical

J|A|C|S
JOURNAL OF THE AMERICAN CHEMICAL SOCIETY
pubs.acs.org/JACS Communication

Hydroxide Based Integrated CO_2 Capture from Air and Conversion to Methanol

Raktim Sen, Alain Goeppert, Sayan Kar, and G. K. Surya Prakash*

Cite This: https://dx.doi.org/10.1021/jacs.9b12711 Read Online



Journal of the American Chemical Society, Article ASAP
DOI: 10.1021/jacs.9b12711

Carbon Nanotubes via Molten Carbonate Electrolyzers

Scientific Approach

- Molten carbonate electrolyzer
- Governing reactions:
    - (1) CO_2 (g) + Li_2O → Li_2CO_3
    - (2) Li_2CO_3 → C (s) + Li_2O + O_2 (g)
    - (Net) CO_2 → C + O_2
- Control carbon nanofiber morphology via current density, electrolyte (Li-K-Na), and electrolytic temperature

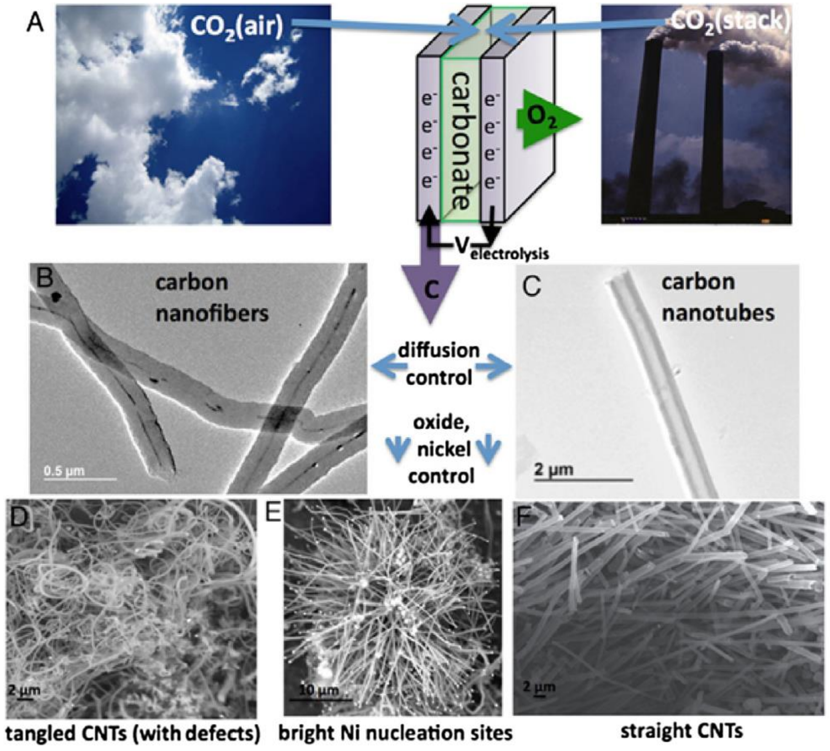
Significance and Impact

- Potential for high coulombic and carbon efficiencies if Li_2CO_3 is not consumed during the reaction and is continuously regenerated from CO_2
- High-value product
- Leverages atmospheric CO_2

NANO LETTERS
Letter
pubs.acs.org/NanoLett

One-Pot Synthesis of Carbon Nanofibers from CO_2

Jiawen Ren,[†] Fang-Fang Li,[†] Jason Lau,[†] Luis González-Urbina,[†] and Stuart Licht*,[†]
[†]Department of Chemistry, The George Washington University, Washington, DC 20052, United States



Nano Lett. 2015, 15, 6142-6148; Energy Conversion and Management 2016, 122, 400-410

Agenda

What does success look like?

February 18th, 2020

1:00pm	Meeting Kick-off
1:15-2:00pm	Bill Tumas (NREL) and Roger Aines (LLNL)
2:05-2:50pm	Sean Simpson (Lanzatech)
2:50-3:20pm	Break
3:20-5:00pm	Panel Discussion • Ian Rowe (Bioenergy Technologies Office • Lynn Brickett (Office of Fossil Energy) • Paul Kenis (University of Illinois) • Todd Wilke (Carbon Engineering) • Bill Tumas (NREL) • Roger Aines (LLNL)
5:00-5:30pm*	Break (Poster presenters set up posters)
5:30-8:00pm	Reception and Poster Session

How do we achieve success?

February 19th, 2020

7:00-8:00am	Breakfast
8:00-8:30am	David Miller (NETL)
8:35-9:05am	David Heldebrant (PNNL)
9:05-9:20am	Break
9:20-9:50am	Etosha Cave (Opus-12)
9:55-10:25am	Matthew Kanan (Stanford University)
10:25-10:45am	Organize into Breakout Sessions
10:45-12:00pm	Breakout Session (5 rooms)
12:00-1:00pm	Lunch
1:00-3:00pm	Breakout Sessions
3:00-3:15pm	Break
3:15-4:00pm	Breakout Session Readouts
4:00-4:15pm	Closing Remarks

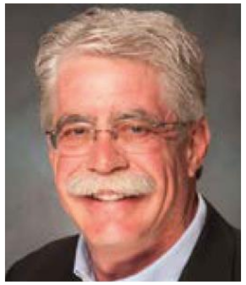
*All moderators please meet in the Golden Ballroom at 5pm today to discuss roles and responsibilities

Ground Rules

- All ideas/thoughts are welcome – give everyone a chance to contribute
- Keep an open mind
- Please step out if you need to take a call
- Think big, check your baggage at the door, and have fun

Thank You!

- Speakers and Panelists
- All attendees
- Linda Stolmack
- Co-Organizers
- Department of Energy











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