Climate and Infrastructure Friendly Hydrocarbon Fuels and Chemicals via CO_2 Recycling

Opening Remarks

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What Problem Are We Trying to Solve?

- Today: US runs on 1 G ton/yr carbon from oil and gas liquids
- One Future: US runs renewable and/or nuclear-based electricity, H_2, minimal carbon
- Our hypothesis: Create "drop-in" carbon options for most difficult to decarbonize sectors
  - Aviation, marine, plastics
  - Leverage trillions of dollars of existing infrastructure
- Challenge: Where to get the carbon?
  - Must be "zero-carbon" carbon
  - Likely need to augment biomass sources (food vs fuel, cost, environmental impact)
- Solution: Recycle CO_2 from point sources, air, and/or water

Current CO_2 "Recycling" Approaches

- Many sequential CO_2 capture/reaction processes produce reduced C_1 and C_2 products
  - CO/syngas, MeOH, methane, ethylene
    - Dry reforming (react CO_2 with methane)
    - CO_2-based Power-to-X
      - Electrochemical cells
      - Catalytic reaction with renewable H_2

- Multiple commercial processes to convert C_1 and C_2 molecules to higher hydrocarbons
  - Syngas-to-anything
  - Ethylene to fuels and plastics

- Many US and international research programs making advances
  - Sustainable Aviation Fuel Grand Challenge
  - EU IDEALFUEL and ENGIMMONIA alternative marine fuels
  - BETO biofuel and BOTTLE (plastics) programs
  - ARPA-E EcoSynBio (maximize carbon utilization)

Opportunities for Disruption?

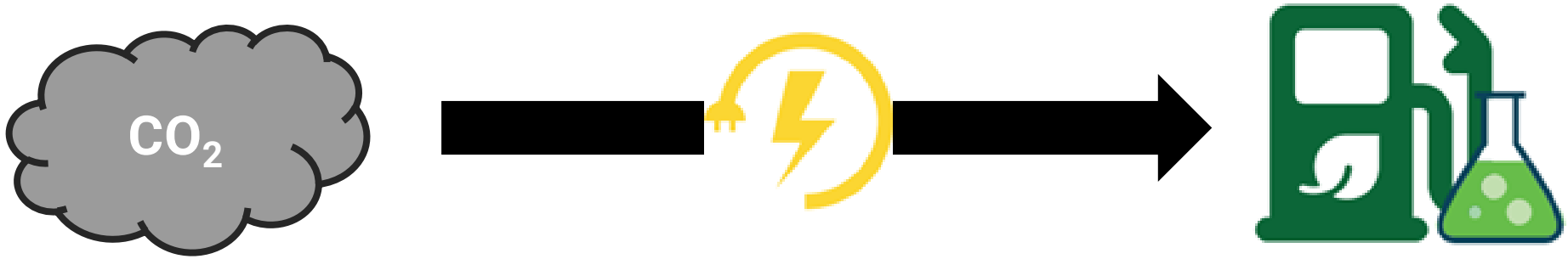
- Re-imagine the problem
  - Focus on dramatically reduce cost and environmental footprint of C_1 and/or C_2 products
  - Leverage commercial downstream processes
  - Skip steps, and their related hardware and energy inputs
  - Leverage new materials/chemistry (ionic liquids, MOFs, homogeneous catalysts)
  - Maximize process intensification

- Reactive Carbon Capture
  - Capture CO_2 and react it while in adsorbed/absorbed state
    - No intermediate CO_2 production, purification, compression
    - https://netl.doe.gov/projects/files/SummaryReportoftheReactiveCO2CaptureProcessIntegrationfortheNewCarbonEconomyWorkshop_08242021.pdf

- React CO_2 and separate the product(s), esp where CO_2 is hot and in reducing environment
  - Replace CO_2 capture with easier product separation (ie MeOH in water wash)

- Other ideas? This is ARPA-E!

Target Metrics



C_1 and/or C_2 Intermediate Synthesis

$15 / GJ-$C_1$ (LHV)

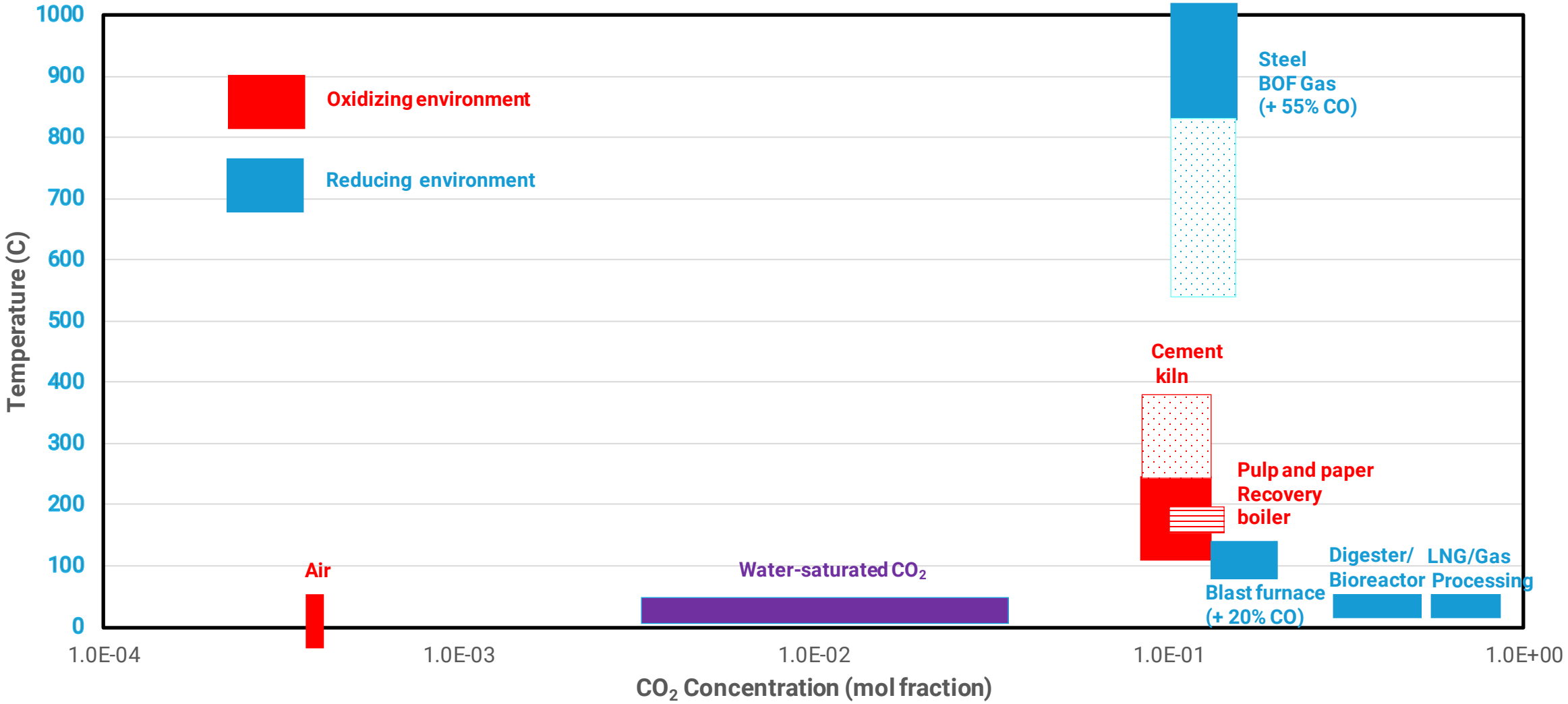
$18/ GJ C_2 (LHV)

90% reduction in GHG_e compared to fossil

Not limited by land resources (excludes biomass to X)

Address other impacts (water, by-products, wastes)

CO_2 Sources and Attributes



System-Level Considerations

- "Contaminants"
  - O_2, possibly SOx and NOx from oxidizing environment (air and combustion point sources)
  - H_2S, NH_3, particulates from reducing environments
  - Possibly many from water-borne CO_2
- Temperature
  - Adsorption/absorption favors low temperature
  - Reaction favors high temperature
  - Not clear if there is a good middle ground
  - Cooling below 40 C is not easy or cheap
- Pressure drop to contact CO_2 from air or flue gas can be energy-intensive
- Liquids can be pumped, easy to change temperature
- Solids are hard to move, hard to change temperature. Adsorption system capturing CO_2 from oxidizing environments usually require multiple beds with interim purge steps
- Operating intermittently (to access off-peak electricity or accommodate variable flow CO_2 sources) can be difficult, lowers capital utilization, and increases costs

Needed: Ideas, Teams, and Program Directors

Today's Agenda

Time (EST)	Topic	Speaker/Organization
12:00 PM	Logistics/Housekeeping	Nancy Hicks Meetings Team, Booz Allen Hamilton
12:05 PM	Welcome	Dr. Jennifer Gerbi Deputy Director for Technology, ARPA-E
12:10 PM	Climate and Infrastructure Friendly Hydrocarbon Fuels and Chemicals via CO_2 Recycling	Dr. Jack Lewnard Program Director, ARPA-E
12:30 PM	Need for a Paradigm Shift in Carbon Sourcing	Dr. David Babson Program Director, ARPA-E
Session 1 – Needs and Challenges in Carbon to X		
1:00 PM	The Potential Impact of Combining Carbon Capture and Utilization	Dr. Ian Robinson Fellow, ARPA-E
1:30 PM – 1:45 PM	**Break**	
1:45 PM	Challenges of Creating Impactful Value from Carbon Dioxide	Dr. Robert Zeller Oxy Low-Carbon Ventures
2:15 PM	Customers Panel	Customers of Fuels/Chemicals •Aviation – Dr. James Hileman, FAA •Maritime - Torben Nørgaard, Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping •Chemicals - Dr. Jeff Siirola, Purdue University Moderated by Kirk Liu (T2M Advisor, ARPA-E)
3:00 PM – 3:15 PM	**Break**	
Breakout Session 1 – Problem Definition		
3:15 PM	Groups 1-6 – Same questions for all sessions	
4:30 PM	Day 1 Concluding Remarks	Dr. Jack Lewnard ARPA-E Program Director
4:45 PM – 6:00 PM	**Networking Session - Gatherly**	

Tomorrow's Agenda

12:00 PM	Day 2 Opening Remarks	Dr. David Tew, ARPA-E Program Director
12:10 PM	Electrochemical CO_2 Utilization	Professor Ted Sargent, Northwestern University
12:40 PM	Reactive Carbon Capture: Status, Challenges, and Opportunities	Dr. Josh Schaidle, National Renewable Energy Laboratory
1:10 PM – 1:30 PM	**Break**	
Breakout Session 2: Potential Solutions, grouped by technologies		
1:30 PM	Group 1 – Biochem	
	Group 2 – Thermochem	
	Group 3 – Electrochem	
	Group 4 - Plasma Catalysis	
	Group 5 – Process Synergies	
2:30 PM	Reactive CO2Capture | DAC-DFM	Dr. Raghubir Gupta, Susteon Technologies
3:00 PM	National Carbon Capture Center: Building a Successful Test Collaboration	Frank Morton, Southern Company/NCCC
3:30 PM – 3:45 PM	**Break**	
3:45 PM	Industry Panel	Fuels/Chemicals Producers •Dr. Sumit Verma, Shell •Dr. Rob McGinnis, Prometheus Fuels •John Murphy, The Catalyst Group •Dr. Carl Stevens, Honeywell UOP •Dr. Todd Wilke, Carbon Engineering Moderated by Dr. Ian Robinson (Fellow, ARPA-E)
4:30 PM	Wrap-up and Breakout Readout	Dr. Jack Lewnard ARPA-E Program Director