Economic and Environmental Sustainability of an Integrated Direct Air Capture System with Advanced Algal Biofuel Production

Kylee Harris[1]*, Eric C. D. Tan[1], Valerie M. Thomas[2], Jaden Johnston[2], Shavonn D'Souza[2], Christopher W. Jones[2], Eric W. Ping[3], Miles Sakwa-Novak[3], Yanhui Yuan[3], Ron Chance[3]

[1]National Renewable Energy Laboratory, Golden, CO

[2]Georgia Institute of Technology, Atlanta, GA

[3]Global Thermostat LLC, Commerce City, CO

Algae Biomass Summit

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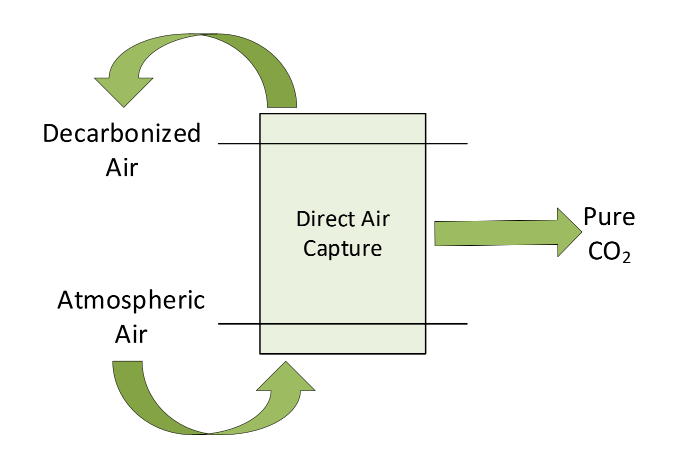
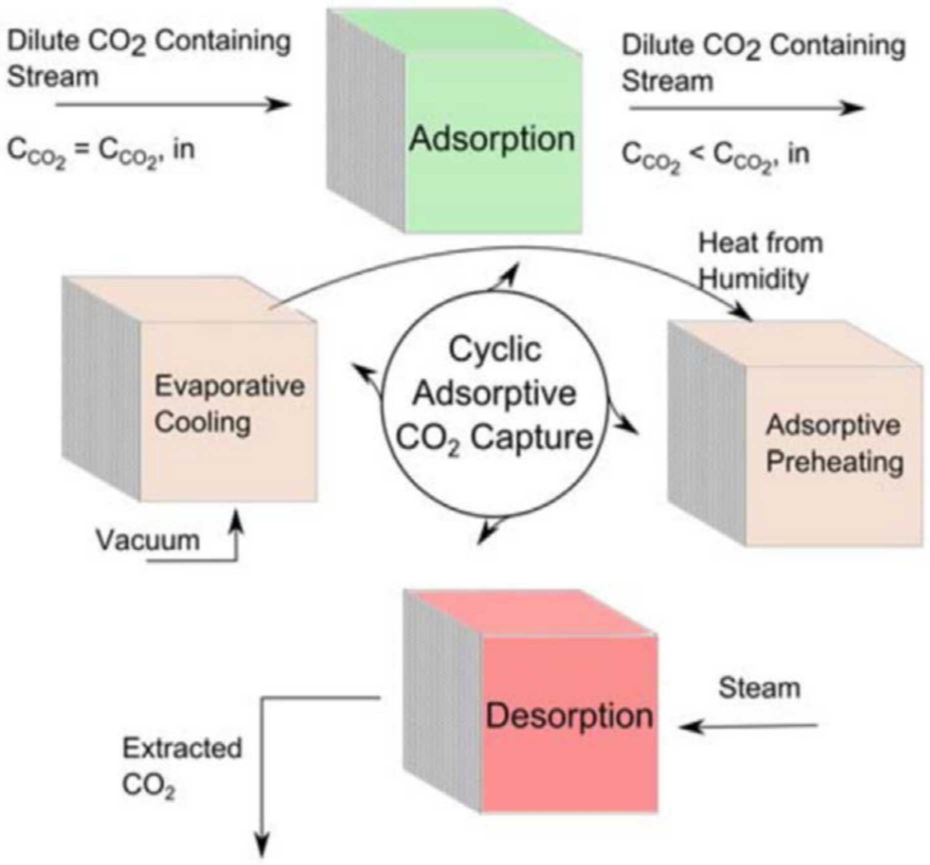
Background and Motivation

- Promote the decarbonization of the atmosphere
- Decouple algae production facilities from anthropogenic CO_2 sources
- Identify key economic drivers
- Minimize cost and greenhouse gas emissions through process integration and optimization



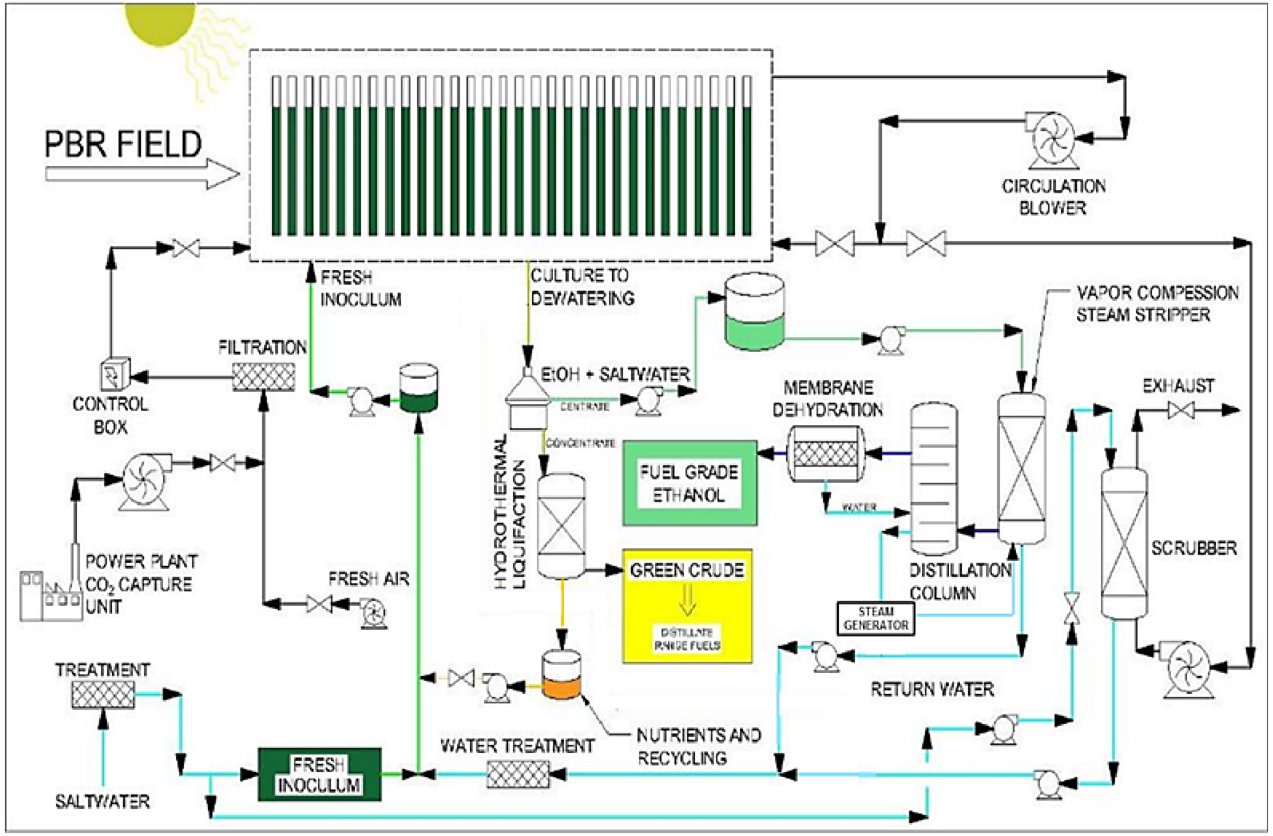
Direct Air Capture (DAC) Technology

- Modular design
- Low temperature CO_2 recovery
  - ✓ Amine-coated structured monolith
  - ✓ A novel temperature/vacuum swing adsorption (TVSA) process
- No point source CO_2 required



DOE BETO 2019 Project Peer Review, Denver, CO. "Direct Air Capture of CO2 and Delivery to Photobioreactors for Algal Biofuel Production
https://www.energy.gov/sites/prod/files/2019/03/f60/BETOPeerReview-Program2019%20%28003%29_0.pdf

Algenol Photobioreactor (PBR) Technology

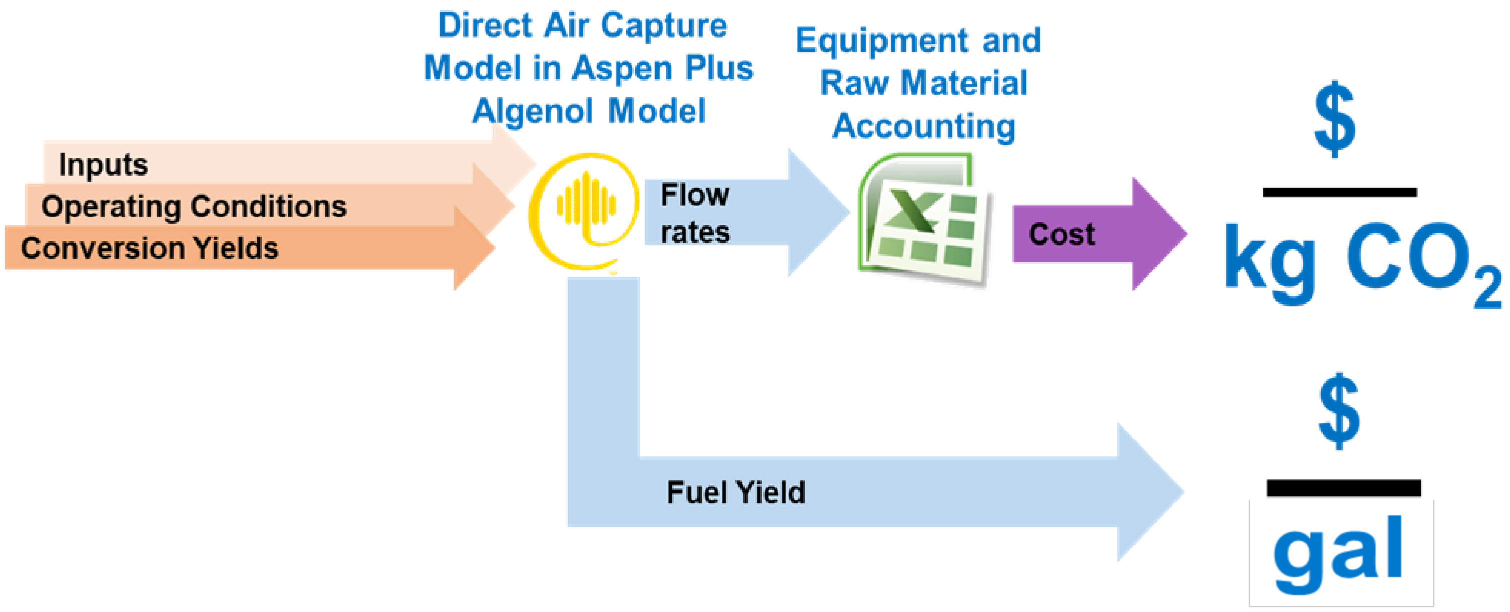


- 2,000-acre model for biorefinery
- 16MM gal ethanol/year
  - 20 tonnes/hr CO_2 required
- Genetically engineered cyanobacteria for ethanol production
- 70% of photosynthetically-fixed carbon diverted to ethanol pathway
- 85% CO_2 conversion to ethanol or biomass

Source: Legere E, 2017. "Integrated Pilot-Scale Biorefinery for Producing Ethanol from Hybrid Algae", Award Number DE-EE0002867, (May 26). Public Version Final

Techno-Economic Analysis (TEA) Methodology

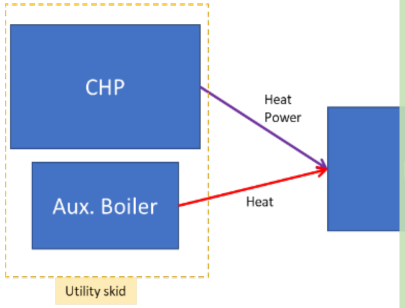
- Assumed n^{th}-plant economics
- Processes modeled in Aspen Plus using experimental data, literature data, and vendor performance information
- Capital and operating costs acquired from quoted information by Algenol and Global Thermostat, Aspen Capital Cost Estimator V10 (ACCE), and NREL internal costing libraries
- TEA material and energy flows used to generate life-cycle inventory (LCI) for LCA



DAC-PBR Integration Options

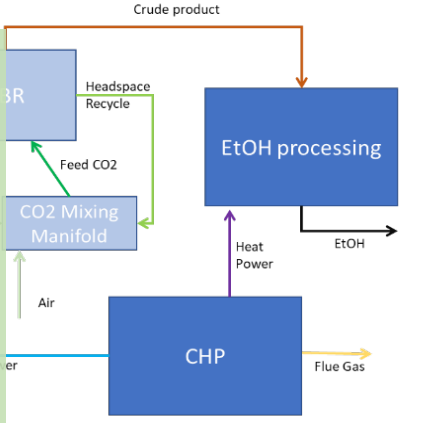
DAC System

Ethanol Production and Recovery System



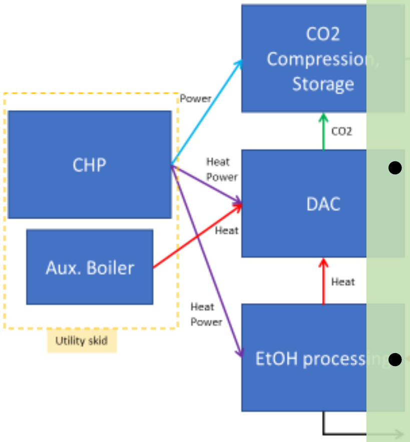
DAC System

Ethanol Production and Recovery System



Key Considerations:

- **2,000-acre algae farm can be divided into uniform subplots**
- **Heat and mass integration is critical for reducing energy requirements and process costs**
- **Each processing step can be viewed as individual modules, which can be scaled and relocated as needed**
- **Previous work determined large-scale circulation of dilute flue gases is not economically viable**
- **Smaller, modularized units will not benefit from economies of scale**

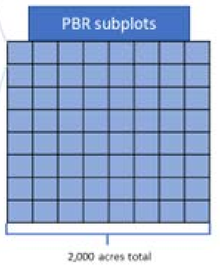


Centralized with distribution to/from subplots

Air

EtOH

Centralized with distribution to/from subplots



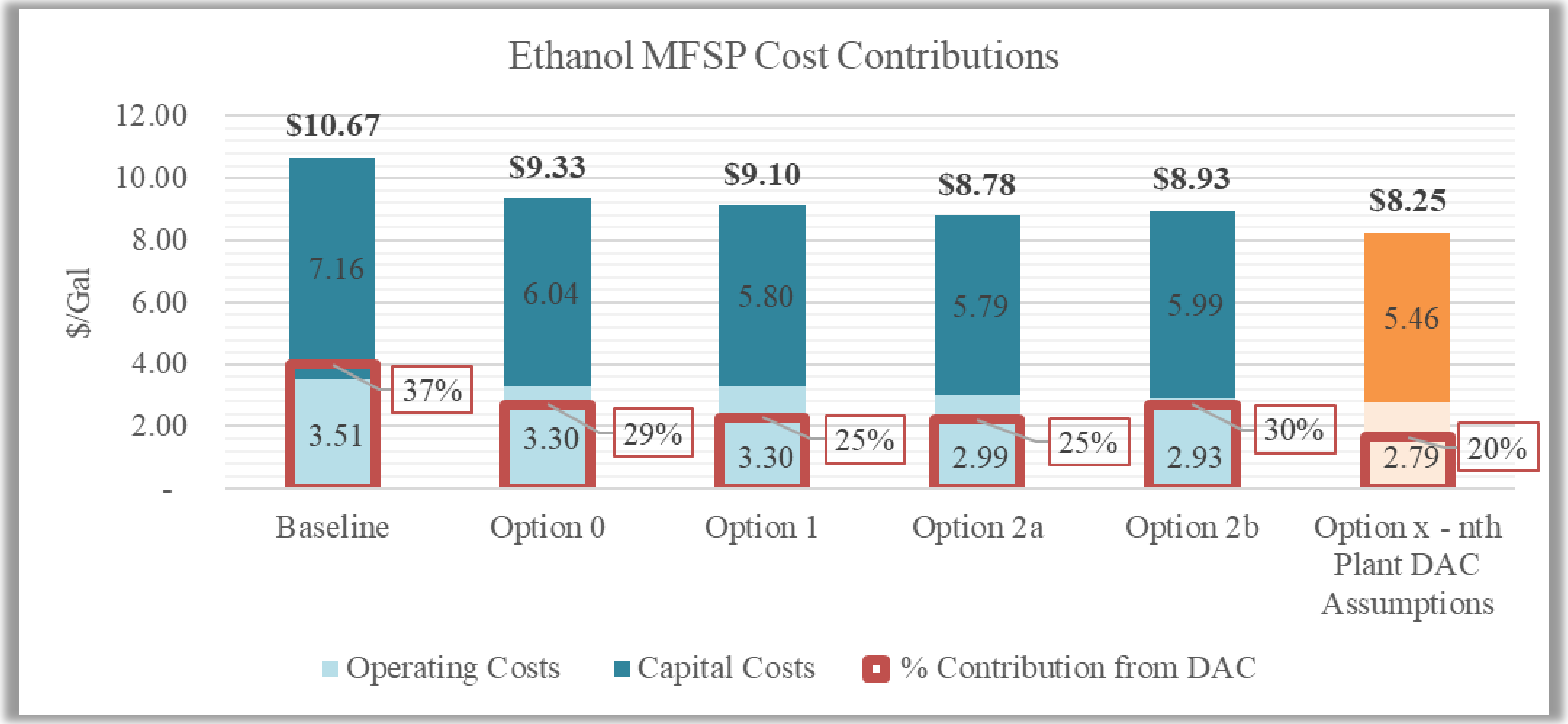
TEA Results

DAC Operating Hours	12	24	12	24	12	24	12	24	12	24	12	24
CO_2 Compressed/Stored	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Flue Gas CO_2 Utilized	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

	Baseline	Option 0	Option 1	Option 2a	Option 2b	Option 2a – nth plant DAC
MFSP ($/gal EtOH)	$10.68	$9.33	$9.10	$8.78	$8.93	$8.25
%MFSP Reduction	-	12.6%	14.8%	17.8%	16.4%	22.8%
EtOH annual production (MMGal/yr)	16.0	16.0	16.0	16.0	16.0	16.0
FCI (MM$)	860.5	724.1	695.2	694.6	719.9	654.3
Total operating costs (MM$/yr)	53.6	51.5	51.8	47.2	45.7	44.8
CO_2 from DAC (tonne/hr)	40.0	20.0	17.9	12.9	18.9	14.9
DAC operating hours (hr/day)	12	24	24	24	12	24
Percent of total CO_2 demand from DAC	100%	100%	90%	64%	47%	75%
Weighted CO_2 cost ($/tonne)*	$407	$275	$232	$226	$275	$165

*Assumes CO2 from flue gas is free

TEA Results



Reductions in MFSP attributed to two primary process considerations:

1) CO_2 storage at night reduces the capital expenses associated with DAC (increasing on-stream time)
2) Distributed DAC scenarios (2a and 2b) make use of boiler and DAC CHP flue gas CO_2 (free)

Life-Cycle Assessment

Carbon Footprint: Need $\frac{CO_2e_{emitted}}{CO_{2\ captured}} < 1$

Lifecycle GHG Emissions ($g\ CO_2e/MJ$ EtOH)[1]	Baseline	Option 0	Option 1	Option 2A	Option 2A (nth)	Option 2B
	108	104	105	73.8	47.6	71.0

Gasoline: **91.3** g $CO2_e$/MJ

US Standard[2] → Biofuel: **45.6** g $CO2_e$/MJ

MFSP ($/Gal)	Baseline	Option 0	Option 1	Option 2A	Option 2A (nth)	Option 2B
	$10.67	$9.33	$9.10	$8.78	$8.25	$8.93

[1]D'Souza, S. et al. (2021). "Life cycle assessment of an integrated direct air capture system with advanced algal biofuel production." Presented at American Chemical Society Conference.
[2]Arora, P., et al. (2020). "Lifecycle greenhouse gas emissions for an ethanol production process based ongenetically modified cyanobacteria: CO2 sourcing options." Biofuels,Bioprod.Bioref., 14: 1324-1334.

Summary

- ❖ Direct air capture technology eliminates the constraint of co-locating algal biofuel production with point-source CO_2.
  - ✓ Localized utilization of captured CO_2 versus long distance CO_2 pipelines
  - ✓ Ambient air contains fewer contaminants than flue gas
- ❖ Heat and mass integration decreases plant expenses via reduced energy consumption.
  - ✓ Flue gas utilization reduces DAC demand and reduced overall cost through use of "free carbon"
  - ✓ High capital utilization (process uptime) is crucial for minimizing DAC costs
- ❖ Further process optimization is being pursued.
  - ✓ Goal to reduce waste heat and CO_2 generation though further integration
  - ✓ Assessing increased oxidative stability and lifetime of monoliths to lower operating expenses and increase regeneration capabilities

Questions?

Speaker Information

Kylee Harris

Kylee.Harris@nrel.gov

DOE's Bioenergy Technologies Office (BETO)
http://www.eere.energy.gov/biomass

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