

Combined Techno-Economic Analysis and Life Cycle Assessment of an Integrated Direct Air Capture System with Advanced Algal Biofuel Production

Kylee Harris^{1*}, Eric C. D. Tan¹, Valerie M. Thomas², Jaden Johnston²,
Shavonn D'Souza², Christopher W. Jones², Eric W. Ping³, Miles
Sakwa-Novak³, Yanhui Yuan³, Ron Chance³

¹National Renewable Energy Laboratory, Golden, CO

²Georgia Institute of Technology, Atlanta, GA

³Global Thermostat LLC, Commerce City, CO

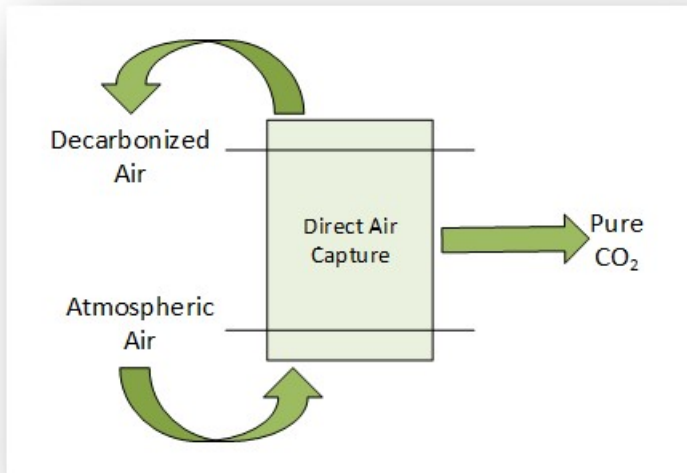
AICHE Annual Meeting

November 17th, 2021 (Boston, MA - Virtual)



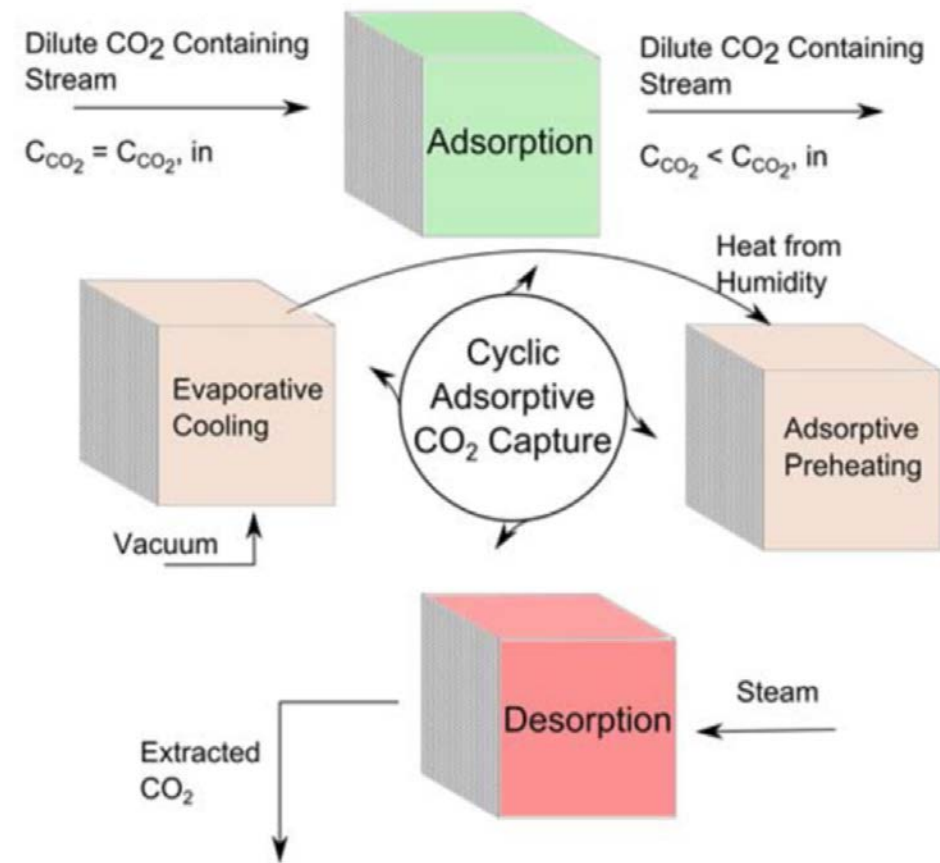
Background and Motivation

- Promote the decarbonization of the atmosphere
- Decouple algae production facilities from anthropogenic CO₂ sources
- Identify key economic drivers
- Minimize cost and greenhouse gas emissions through process integration and optimization



Direct Air Capture (DAC) Technology

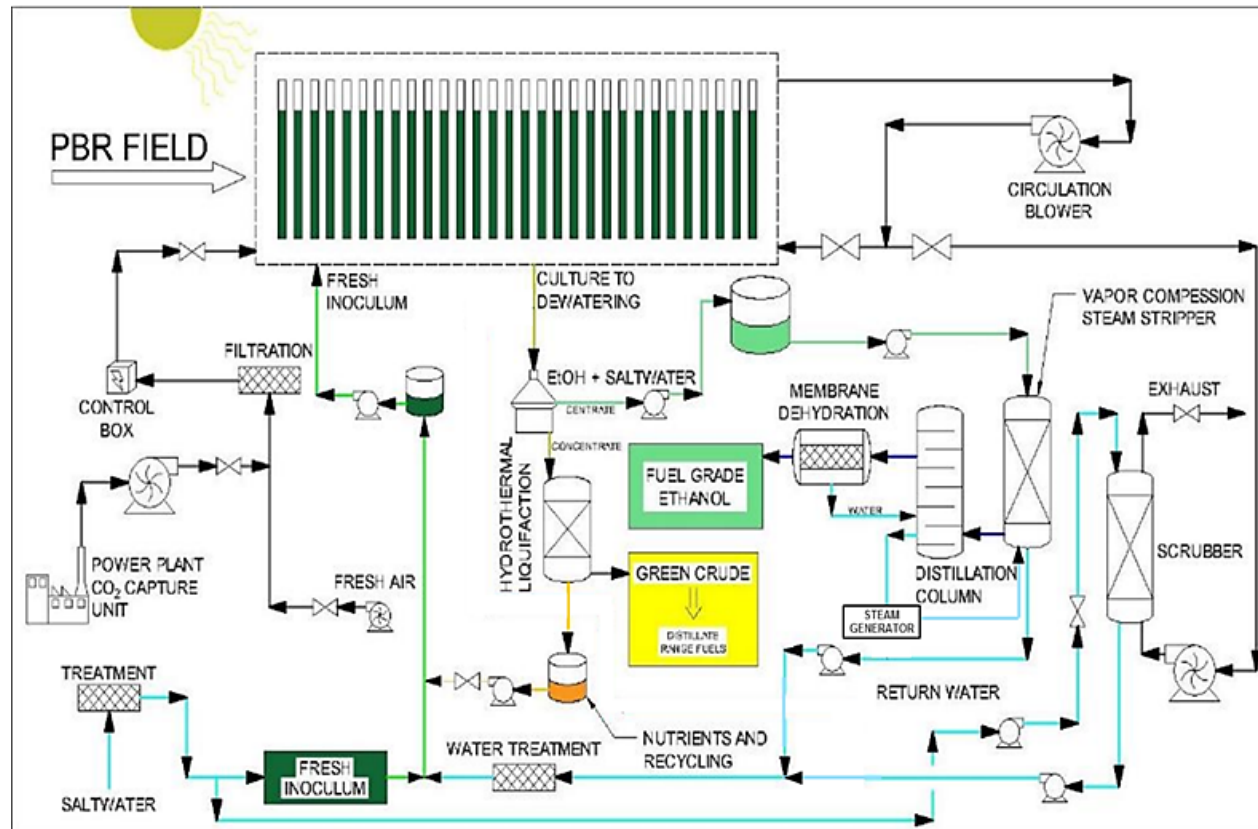
- Modular design
- Low temperature CO₂ recovery
 - ✓ Amine-coated structured monolith
 - ✓ A novel temperature/vacuum swing adsorption (TVSA) process
- No point source CO₂ required



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

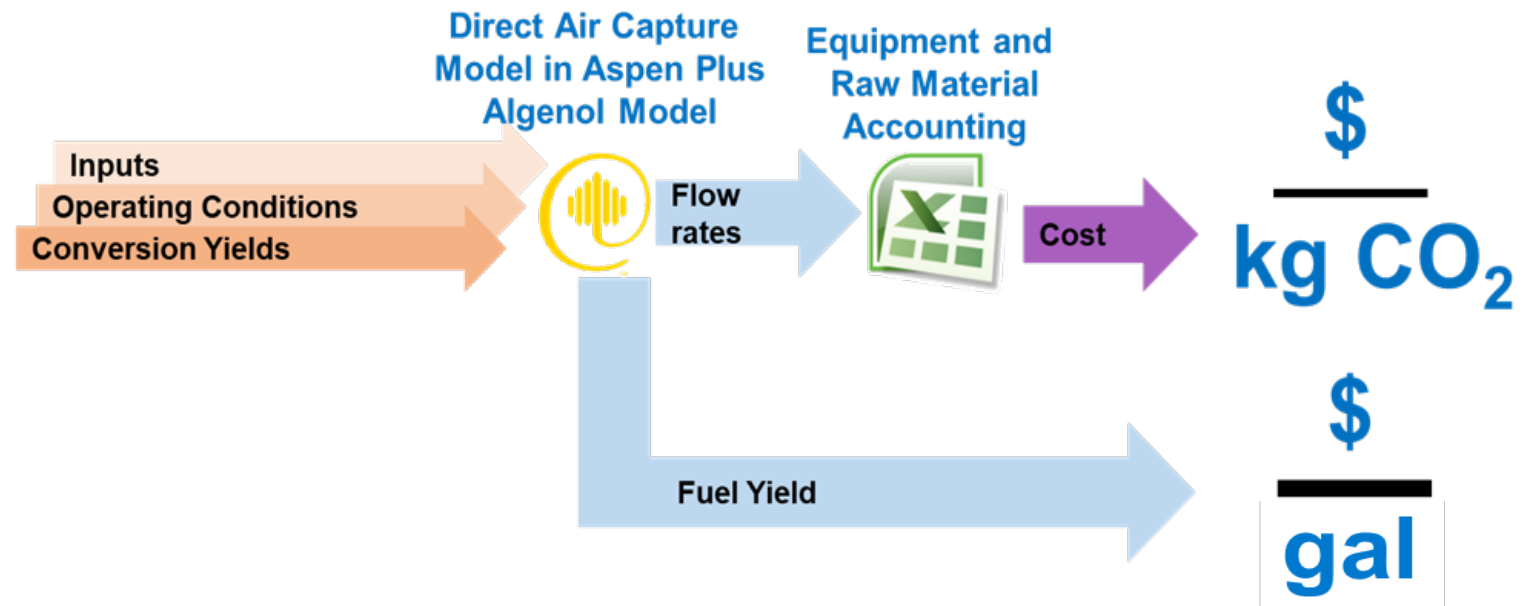
- 2,000-acre model for biorefinery
- 16MM gal ethanol/year
 - 20 tonnes/hr CO₂ required
- Genetically engineered cyanobacteria for ethanol production
- 70% of photosynthetically-fixed carbon diverted to ethanol pathway
- 85% CO₂ conversion to ethanol or biomass



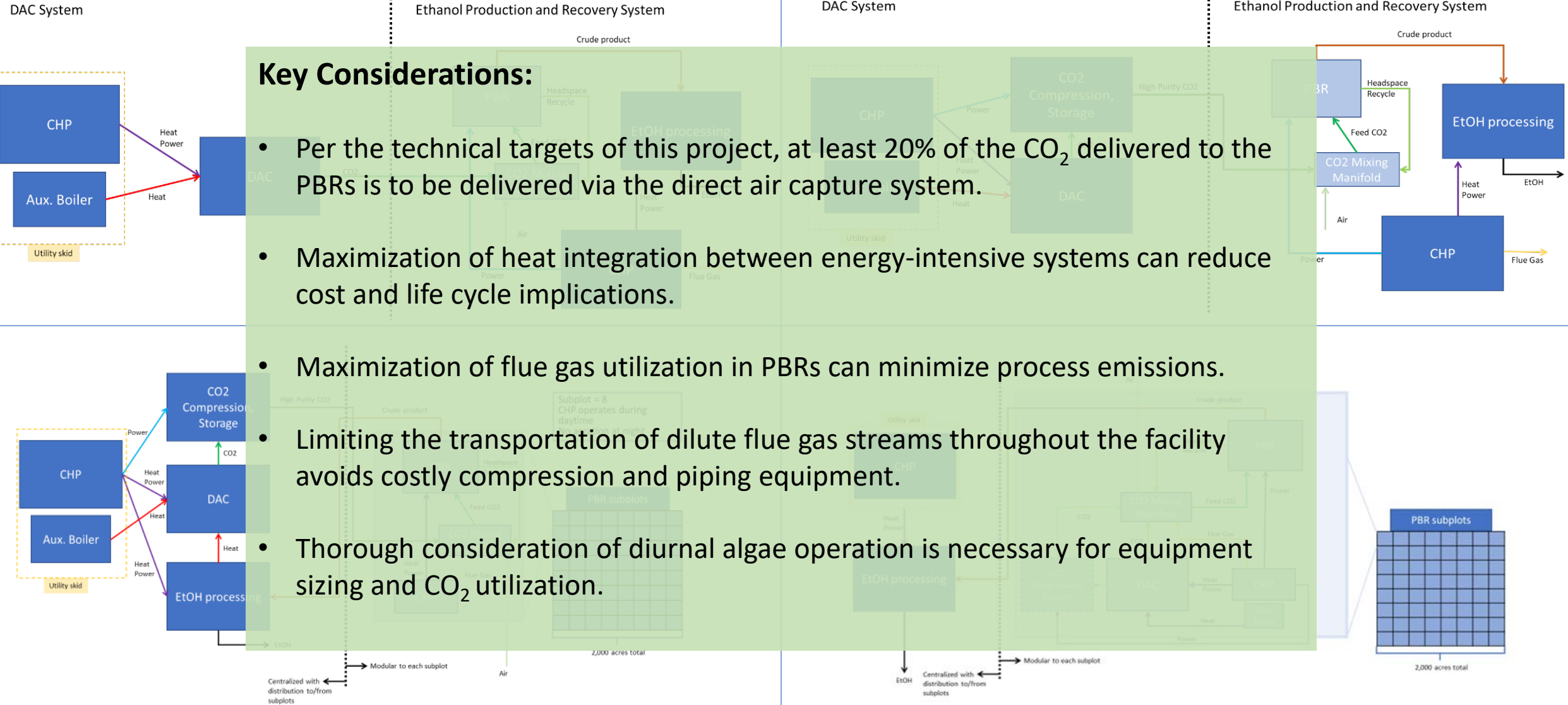
Source: Legere E, 2017. "Integrated Pilot-Scale Biorefinery for Producing Ethanol from Hybrid Algae", Award Number DE-EE0002867, (May 26). Public Version Final

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

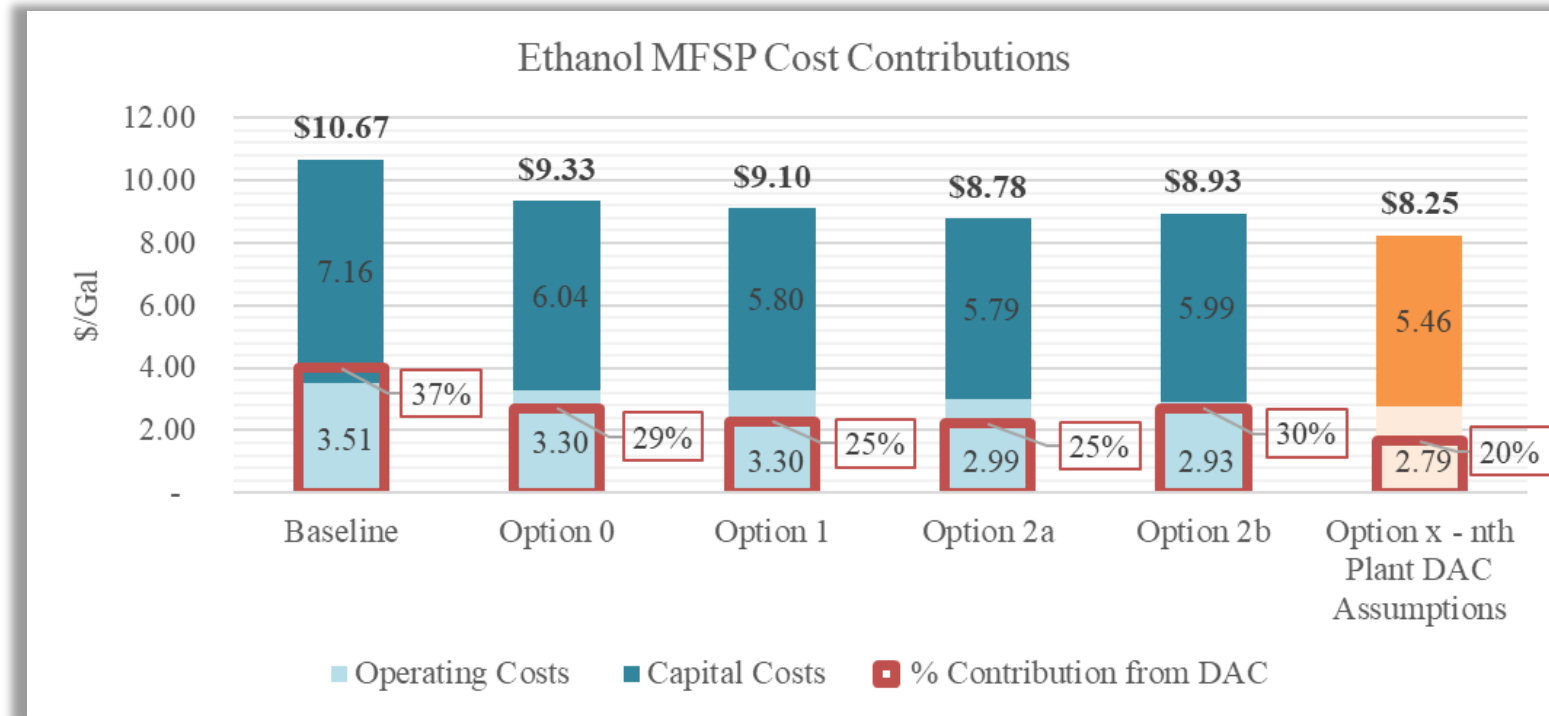


TEA Results

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) CO₂ 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 CO₂ (free)

Life-Cycle Assessment

Carbon Footprint: Need $\frac{CO_2e_{emitted}}{CO_2\ captured} < 1$

Lifecycle GHG Emissions (g CO ₂ e/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 Standard² → 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

¹D'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.

²Arora, 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 CO₂.
 - ✓ Localized utilization of captured CO₂ versus long distance CO₂ 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 CO₂ generation through 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>



This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Bioenergy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL/PR-5100-81411