Low Carbon Intensity Formic Acid Chemical Synthesis from Direct Air Captured CO_2 Utilizing Chemical Plant Waste Heat (ChemFADAC)

Project Number: DE-FE0032157

Front End Engineering Design Studies for Direct Air Capture Systems at Existing (retrofit) Domestic Industrial Plants Coupled with CO_2 Conversion Producing Low Carbon Intensity Products

Principal Investigator: Matt Atwood, Aircapture
Co-Principal Investigator: Arun Agarwal, OCOchem Inc.

Presenter: Andy Louwagie, Aircapture

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 7th, 2024

Agenda

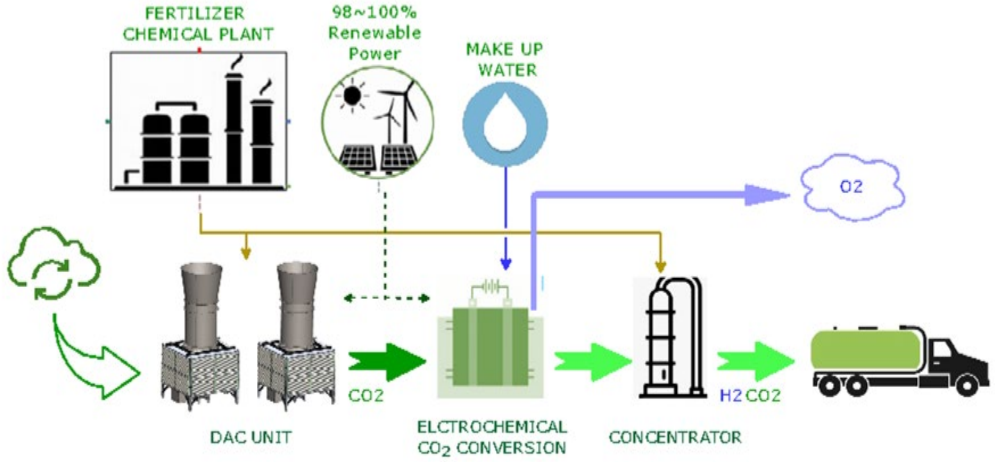
- Project Overview and Objectives
- Technology Background
  - Aircapture
  - OCOchem
- FEED Review
- Business Case Analysis
- Life Cycle Analysis
- Workforce Readiness
- Environmental Justice and Workforce Revitalization
- Summary Project Highlights
- Acknowledgements and Questions

Project Overview

Period of Performance:
September 2022 through September 2024

Project Funding Summary:

Total Project:	$3,703,308
Fed Share (80%):	$2,943,828
Cost Share (20%):	$759,480



Aircapture
THE UNIVERSITY OF ALABAMA
OCO CHEM
BENTON P·U·D
SACRÉ DAVEY
TRIDEC Tri-City Development Council
Nutrien

Project Objectives – FOA 2560 AOI-3

1. Conduct FEED study with Class 3 project cost estimate using waste heat from host site
2. Perform LCA from the results of the FEED Study
3. Perform BCA from results of the LCA, FEED Study, and Cost Estimate
4. Quantify socio-economic impact through environmental justice, economic revitalization and job outcomes analysis

Project Breakdown

Task 1.0 PM

Task 2.0 FEED Study

Task 3.0 Project Economics and BCA

Task 4.0 LCA and EH&S Analysis

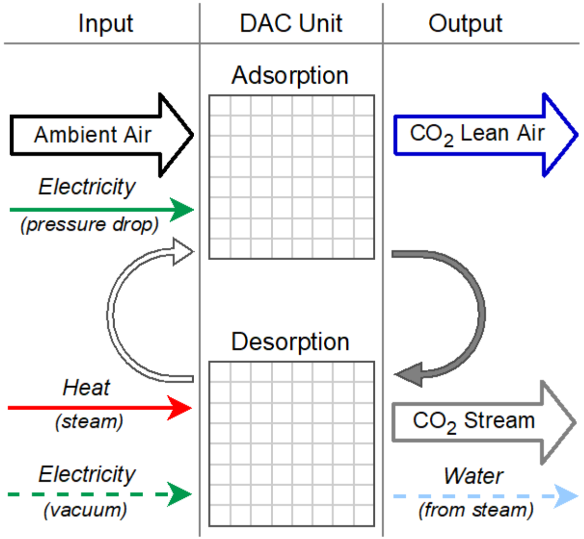
Task 5.0 Social and Environmental Impact

DE-FE0032157 ChemFADAC		Budget Period 1									Deliverable Complete?	Verification Method
TASK No.	DESCRIPTION	Month 1 9/15/2022 10/14/2022	Month 2 10/15/2022 11/14/2022	Month 3 11/15/2022 12/14/2022	Month 16 12/14/2023 1/14/2024	Month 17 1/14/2024 2/14/2024	Month 18 2/14/2024 3/14/2024	Month 19 3/14/2024 4/14/2024	Month 20 4/14/2024 5/14/2024	Month 24 8/14/2024 9/14/2024		
1.0	**Project Management and Planning**											
1.1	Subtask 1.1 - Project Management Plan (PMP)										Y	PMP Submittal to DOE
1.2	Subtask 1.3 - Technology Maturation Plan (TMP)										Y	TMP Memo Submittal to DOE
1.3	Subtask 1.3 - Workforce Readiness Plan										Y	WRP Memo Submittal
1.4	Subtask 1.4 - Cross-cutting Project Management and Site Access			M1						M8	Scheduled Wrap Up for End of August	Memo to DOE and Project Stakeholders
2.0	**Project FEED Study**											
2.1	Subtask 2.1 - Project Scope and Design										Y	Memo to DOE
2.2	Subtask 2.2 - Project Design Basis			M2							Y	Memo to DOE
2.3	Subtask 2.3 - Engineering Design Package					M3					Y	Memo to DOE
3.0	**Project Economics and Business Case Analysis**											
3.1	Subtask 3.1 - Project Cost Estimate & Cost Model					M3					Y	Memo to DOE
3.2	Subtask 3.2 - Business Case Analysis (BCA)								M7		Y	Memo to DOE
4.0	**Life Cycle Analysis and EH&S Analysis**											
4.1	Subtask 4.1 - Life Cycle Analysis (LCA)								M4		Y	Memo to DOE
4.2	Subtask 4.2 - Environmental Health and Safety (EH&S) Analysis						M5				Y	Memo to DOE
5.0	**Social and Environmental Impact**											
5.1	Subtask 5.1 - Environmental Justice Analysis (EJA)							M6			Y	EJA Memo
5.2	Subtask 5.2 - Economic Revitalization and Job Creation Analysis							M6			Y	ER&JCA Memo

DAC Technology Background

Step 1 (Capture): CO_2 is collected by moving air or mixtures of air and CO_2 rich gases across a proprietary contactor which adsorbs CO_2.

Step 2 (Regeneration): The contactor is moved into a regeneration box where low-temperature steam flows across the contactor, removing CO_2 from the contactor, and the CO_2 is collected.



Polymeric Amine Sorbent

Monolithic Contactor

- Low pressure drop
- Low thermal mass
- High geometric surface area
- Compatible with various construction methods

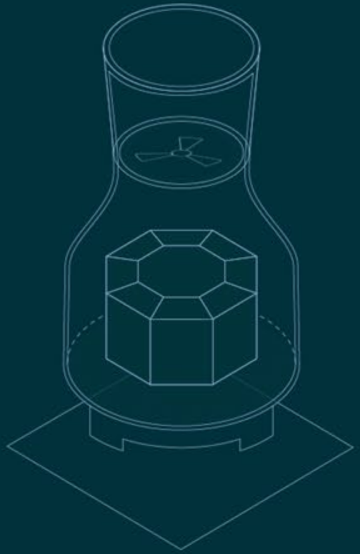
Adsorption

- 900 seconds / monolith in ambient air

Desorption

- Saturated Steam in less than 90 seconds

Modular technology platform enables scaling and low-cost, volume manufacturing with reasonable install cost factors.



Aircapture DAC Technology Progression Since Project Kickoff

SN1: March 2023 to July 2024
NCCC, Wilsonville, AL
5 Campaigns, +140 days of operations, >92% uptime
(DE-FE0031961)

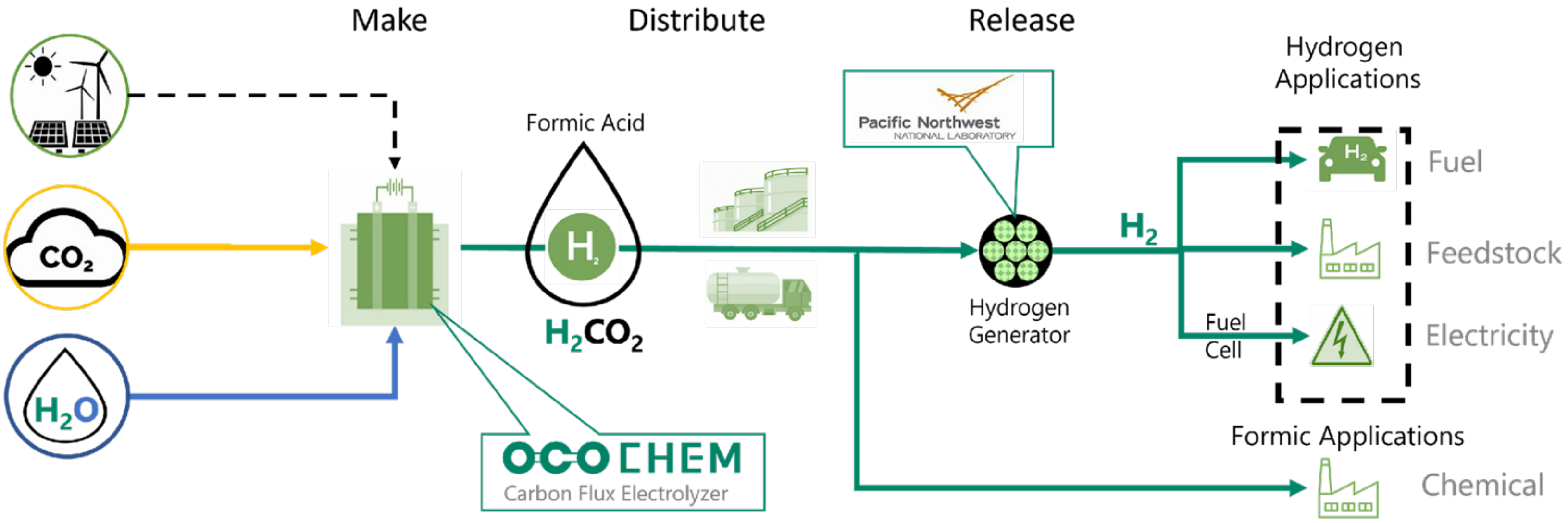
SN3: Aircapture Berkeley, CA
April 2024
>50% CAPEX Reduction
>20% OPEX Reduction

Project Hajar, 8x SN3 DACs June 2024
Deploying DAC Grove concept first designed in DE-FE0032157 ChemFADAC & DE-FE0032160 NuDACCS

TRL 7+ achieved by EOY 2024

Potential Impact: Using CO_2 to Carry H_2 in a Liquid Form

OCOchem's process directly converts CO_2, water and clean electricity into a liquid hydrogen carrier, which can be stored and moved like a conventional liquid, and then reformed to generate H_2 on-demand



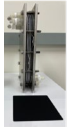
Scale-Up Progress - Carbon FluX Electrolyzer

OCOchem has significantly de-risked the technology by scaling up device size by a factor of 1500 over the last 3 years, while improving performance, and is now scaling out to a multi-cell pilot plant system.

Scale-Up (larger cells)					Scale-Out (more cells)		Production
2020	2021	2022	2023	2024	2025	2026	2027

OCOchem has built and commissioned the world's largest reported CO_2 electrolyzer at an industrial-scale height of 1.15m and width of 1.35m

Tiny Cell
10 cm²

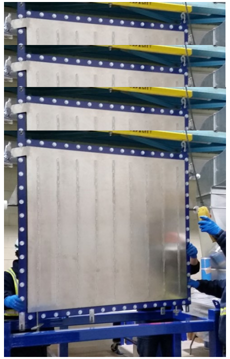


Small Cell
100 cm²

Mid Cell
150 cm²

Tall Cell
1500 cm²

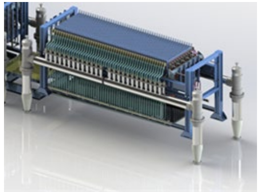
Full Cell (final size)
15,000 cm²



Multi-Cell (4) Pilot Plant
60,000 cm2 (6 m²)
4+ Cells

Build-in-Progress

Industrial-Scale Formate Production Module



Industrial Cell Stack Module
60+ m²
40+ Cells per Module

Design-in-Progress

First Industrial-Scale Formate Production Plant

1st Production Plant
6,000 m²
100+ Modules/Plant

OCO CHEM Carbon FluX Electrolyzer

OCOchem has developed and commissioned the world's largest CO_2 Electrolyzer at commercial-grade industrial-scale cell dimensions

Process Performance

- Efficient. >80% Faradaic Efficiency
- Selective. >99% Liquid Product Selectivity
- Concentrated. >40% Reactor Outlet Product Concentration
- Ambient. Operating Conditions: ~20C, ~1atm
- Durable. Tested to 800 hours of operation at smaller scale

Intellectual Property – Full Stack

- 18 Patents Issued (process, catalyst, operations, chemistry, separations)

Equipment Fabrication

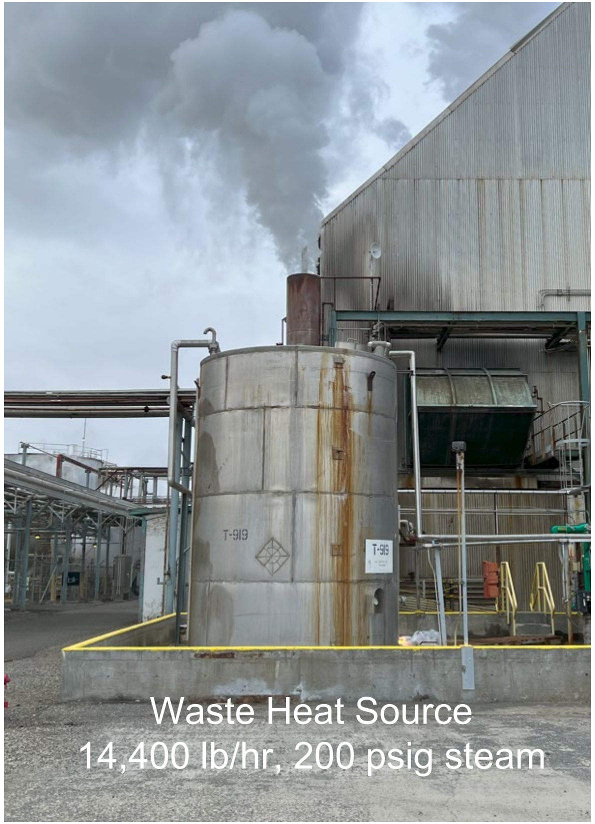
- Scaled to industrial scale and size cell dimensions (1.15m x 1.35m, 15,000 cm^2)
- Cellular, mass-producible, side-stackable architecture
- In-house fabricated porous carbon/metal gas diffusion electrode

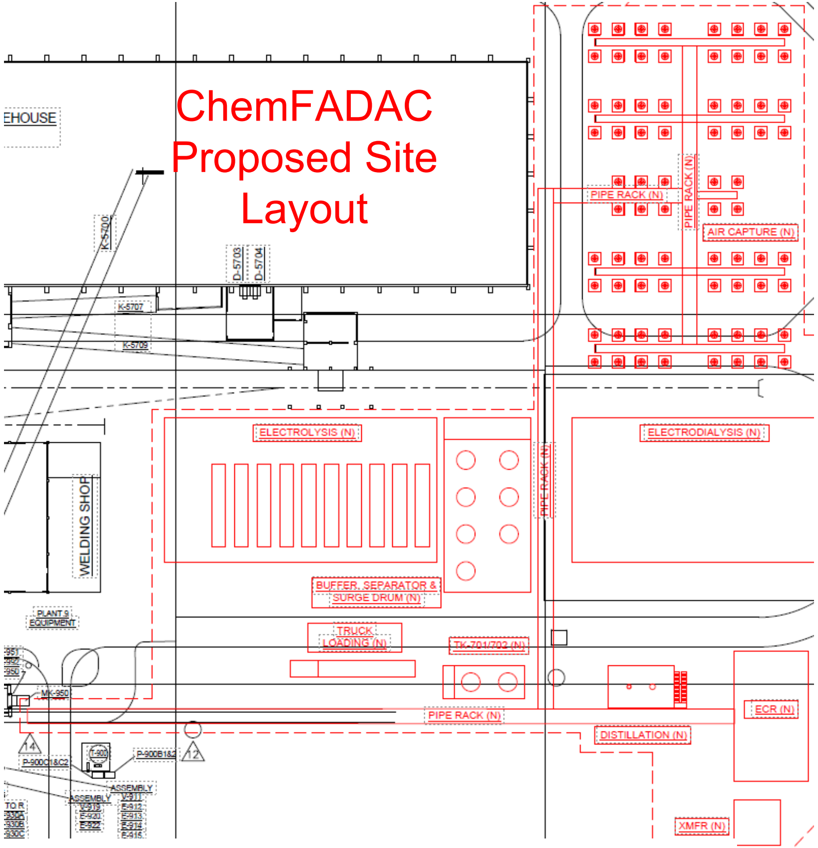
World's Largest CO_2 Electrolyzer
Single Industrial-scale Cell Electrolyzer - 15,000 cm^2.

World's Largest CO_2 Gas Diffusion Cathode
Single Industrial-scale Quilt-Weave GDE - 15,000 cm^2.

Field Commissioned on January 18, 2024 in New York

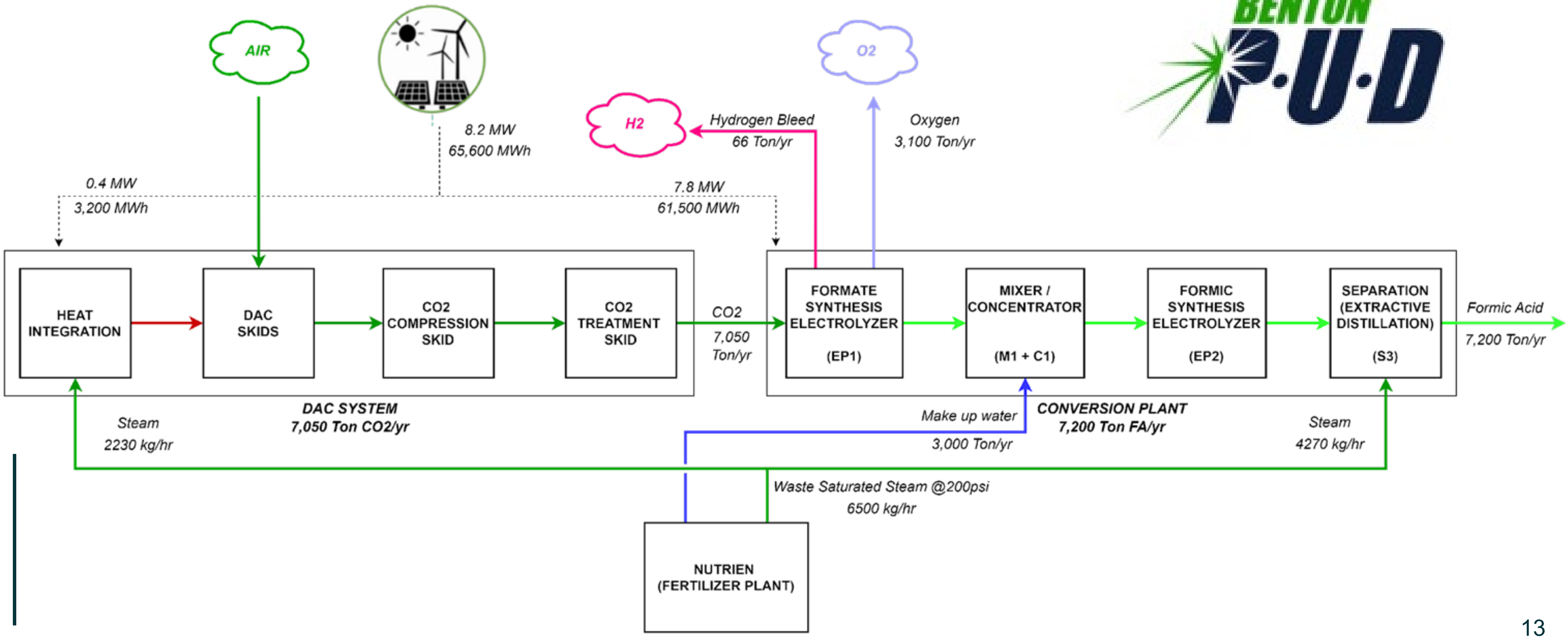
Nutrien Site Layout – Kennewick Fertilizer Operations



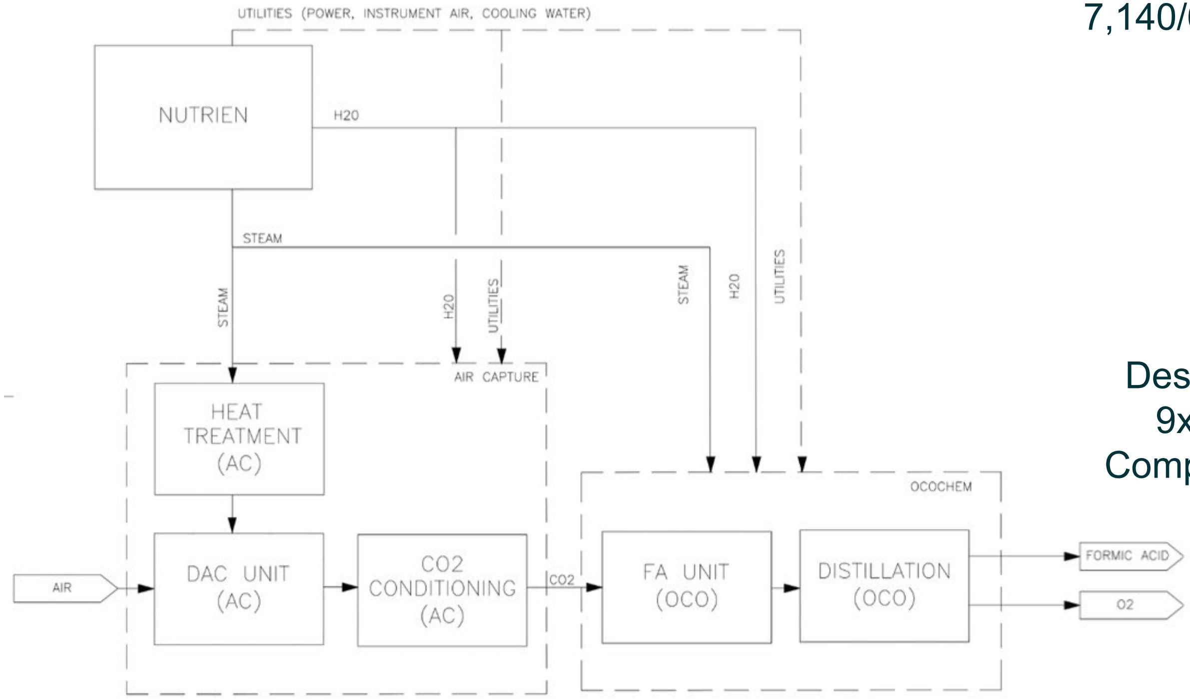


$$2\,NH_3(g) + 4\,O_2(g) + H_2O(l) \longrightarrow 3\,H_2O(g) + 2\,HNO_3(aq)\ (\Delta H = -740.6\ kJ/mol)$$

General Process Flow
Updated per 2023 FEED Heat and Material Balance



Process Block Flow Diagram



ChemFADAC Summary

7,140/6,040 MT Gross/Net CO_2 Reduction (84.6% Removal)

>98% Renewable Energy

100% Waste Heat Utilization

Aircapture

Desuperheater + Steam Accumulator

9x modular groves of 8 DAC Units

Compression + Oxygen Scavenger Unit

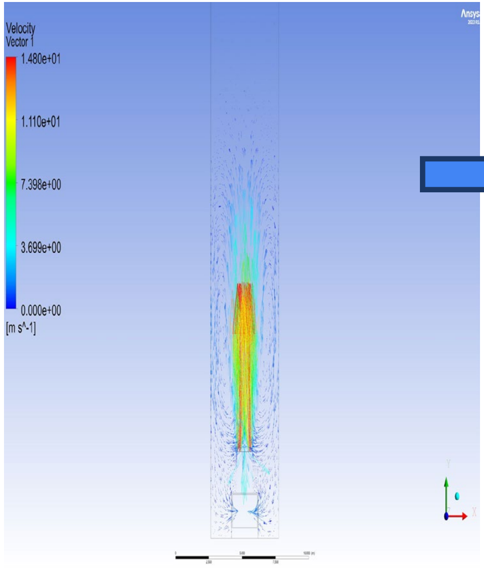
OCO CHEM

Electrolyzer + Electrodialysis

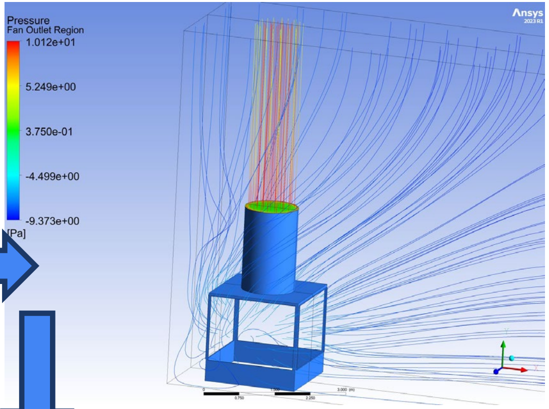
Two-step Extractive Distillation

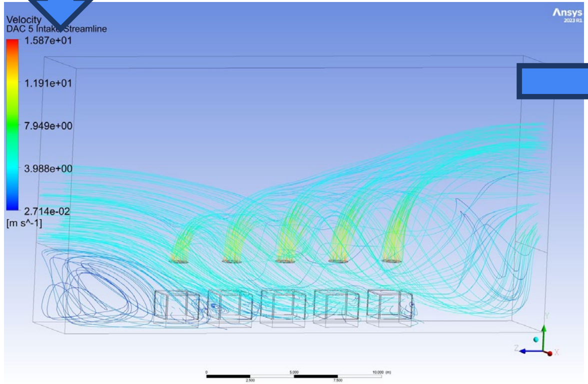
Computational Fluid Dynamic (CFD) Modeling

Single DAC Velocity Vectors
Typical Fan Speed



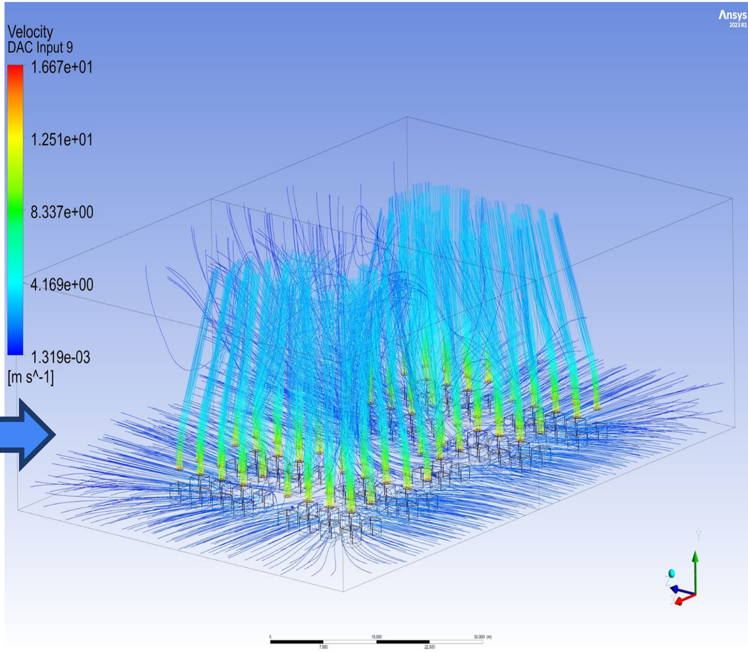
Representative Single DAC Unit in Forest



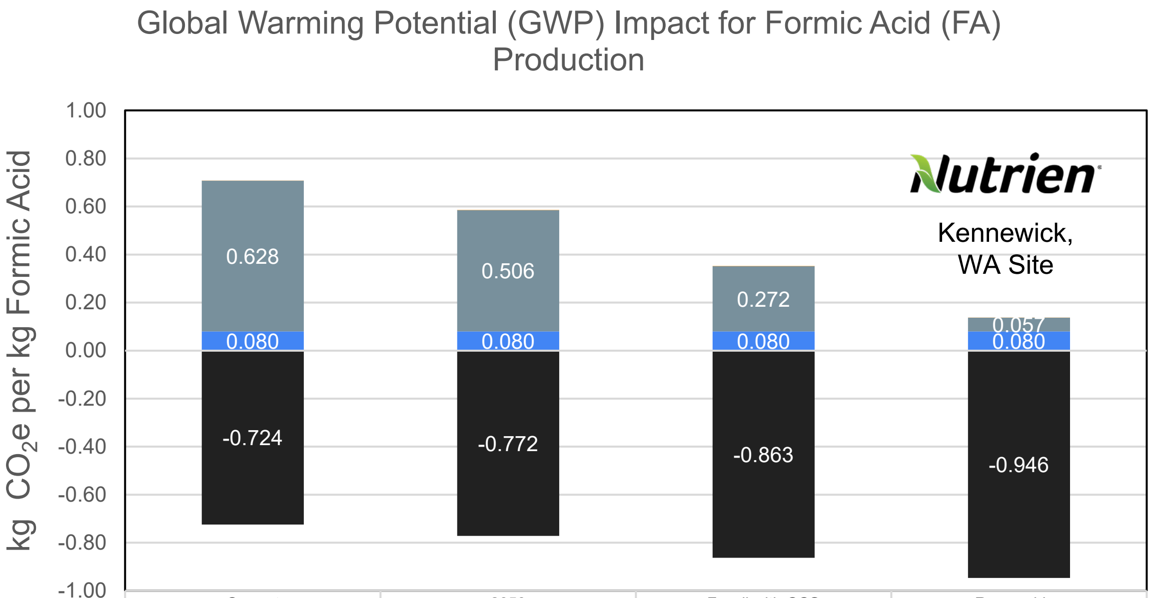


Representative DAC Row In Grove

DAC Forest Calm (0 mph wind)



Lifecycle Analysis – As of 2023 Design Freeze



	Current	2050	Fossil with CCS	Renewables
EOL	0.001	0.001	0.001	0.001
Formic Acid	0.628	0.506	0.272	0.057
DAC	-0.724	-0.772	-0.863	-0.946
Construction	0.080	0.080	0.080	0.080

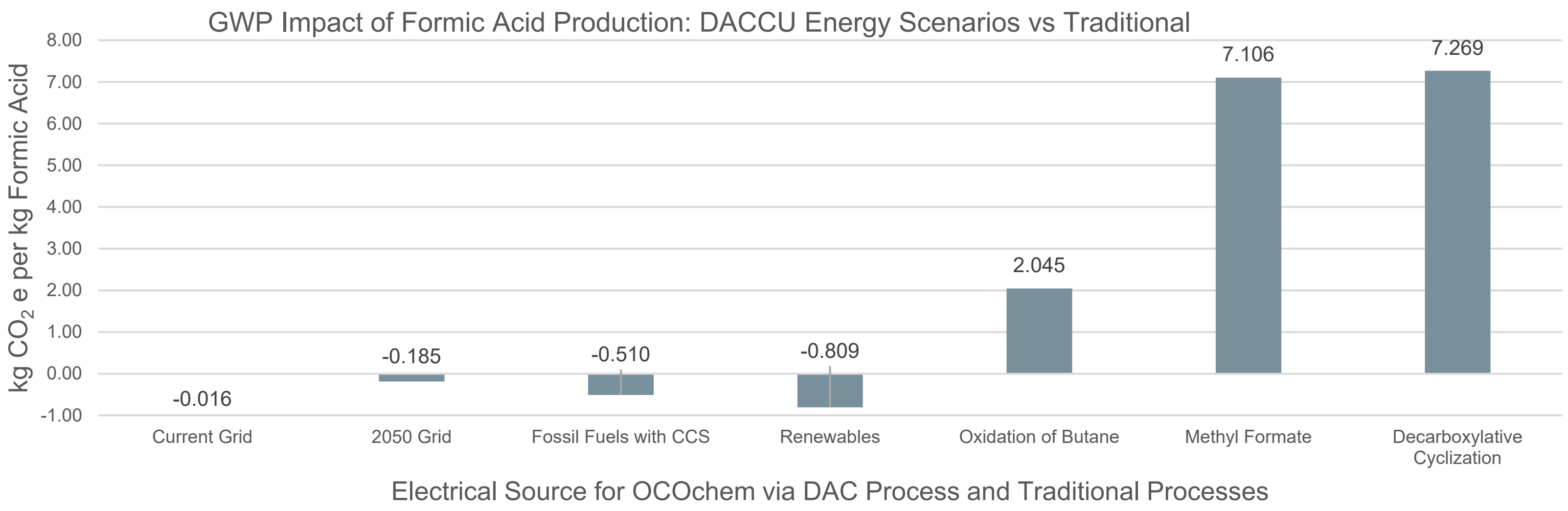
Contributions by Electrical Source Category

Construction DAC Formic Acid EOL

LCA Summary

- SimaPro v9.5 Modeling
- Waste Heat
  - → No LCA impact
- Electricity at Site
  - → 23 g CO_2e / MWh
- Construction
  - → Detailed Inventory/BOM over 20 years
  - → 0.08 kg CO_2e per kg Formic Acid
- End of Life (EOL)
  - → Waste treatment with some recycling of metals
- Aircapture Process
  - → -0.946 kg CO_2e per kg Formic Acid
- OCOchem Process
  - → +0.057 kg CO_2e per kg Formic Acid
- Overall Project
  - → -0.809 kg CO_2e per kg Formic Acid

Lifecycle Analysis – Comparisons



Formic Acid DACCU versus traditional processes has net negative emissions showing attractive sustainable alternative to traditional processes

<u>Other DACCU Processes Evaluated at High Level at Nutrien Kennewick Site</u>

→ Liquid CO_2 (-0.954 kg CO_2e per kg LCO_2 via DAC vs. +1.83 traditional processes)

→ Synthetic Methanol (-0.995 kg CO_2e per kg via DAC vs. +1.42 traditional processes)

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Environmental Justice + Economic Revitalization & Jobs Analysis

Task 5.1: Environmental Justice Analysis

- Utilizing waste heat from Nutrien, water from the Columbia River, and electricity from Benton PUD.
- Electricity utilized is 23 g CO_2e / MWh, largely from hydroelectric sources.
- New, reliable source of formic acid could support hydrogen-based diesel-alternative trucks for logistics.
- The potential to become a significant contributor to alternative transportation enabling feedstocks moving into the future.

Environmental Justice + Economic Revitalization & Jobs Analysis

Task 5.2: Economic Revitalization & Jobs Analysis

- Approximately 24 jobs created directly by the formic acid plant generation (listed at right)
- An estimated 77 new jobs created in the general economy of Kennewick-Richland MSA.
- Kennewick-Richland, WA is a major hub for this kind of technical manufacturing/chemical synthesis. 42.6% of local jobs are within production occupations.
- Significant demand for individuals with these technical skills; many positions do not require advanced degrees.

TRIDEC
Tri-City Development Council

Position	Number of Roles
Technicians	8
Jr. Operators	6
Sr. Operators	6
Supervisors	3
Managers	1

Summary of Highlights

FEED Study

- Project funding allowed Aircapture and OCOchem to create a Class 3 estimate for a process producing a low carbon intensity product from DAC utilizing waste heat from an industrial site
- Used as a basis to create a Life Cycle Analysis and cost estimate
- In conjunction with the LCA and cost estimate, a Business Case Analysis was performed

Project Economics and BCA

- Current state of technologies do not support investment to produce formic acid due to electrical requirements and current capital costs of CO_2 electrolyzers and required post-processing
- Evaluation of production of liquid CO2 from DAC using industrial waste heat on site was performed and shown to be profitable and an investment is economically justified

LCA and EH&S Analysis

- LCA showed a net negative 84.6% reduction of CO_2e making this an attractive sustainable process to produce formic acid going forward compared to traditional formic acid processes
- The Nutrien Kennewick site with its >98% renewable energy is an ideal site to deploy DAC technology

Aircapture

OCO CHEM

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Acknowledgements

Elliot Roth, Department of Energy Project Manager

Cost Share Partners

Aircapture

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Questions?

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