Mobile air to methanol

AIR2FUEL

2024 FECM/NETL Project Review

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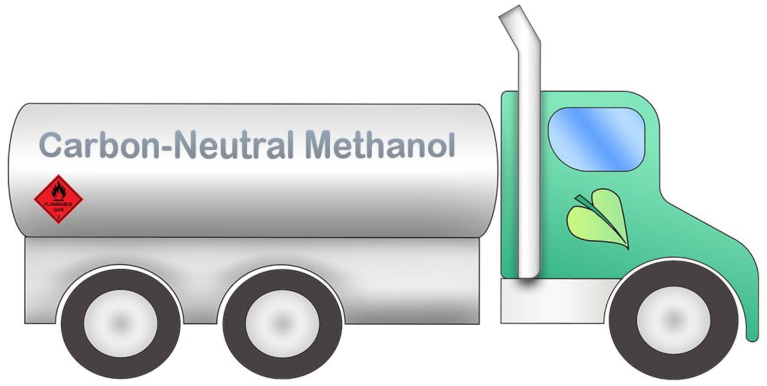
- Title: Mobile Air to Methanol (Air2Fuel)
- Award #: DE-FE0032405
- Period of Performance: 12/20/23 – 12/19/24
- Funding: $400k (DOE), $100k (cost share)
- Participants: ASU, NREL, Air Company

Aug. 8, 2024

Overview

- Conceptual Design of
  - 1) bench scale/movable system
  - 2) 1000-tonne MeOH/yr system
- Optimize heat recovery
- Integrate novel process components to reduce energy
- Integrate renewable energy
- Community Benefits Planning

Impacts



Local Fuel Production

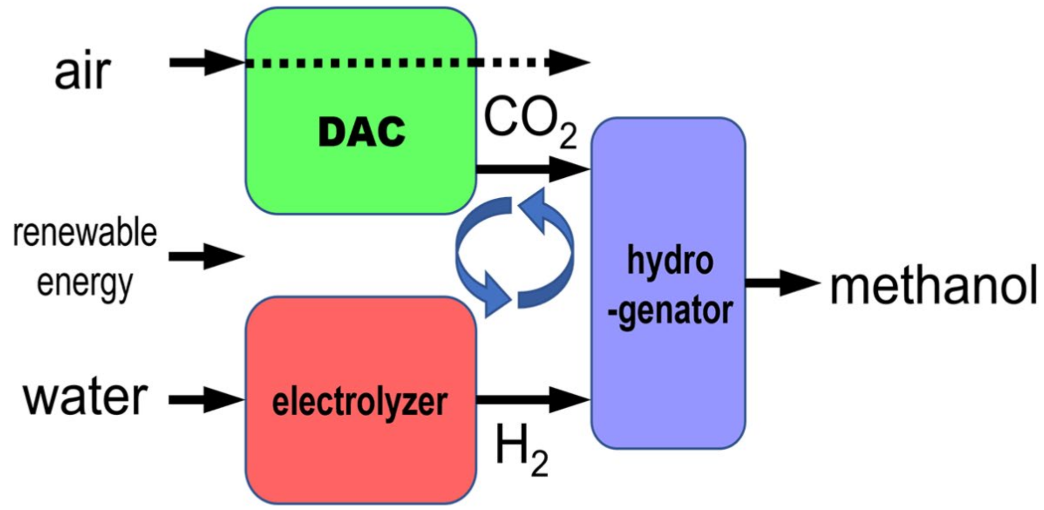
JUST ENERGY TRANSITION

ENGAGED COMMUNITY

QUALITY JOBS

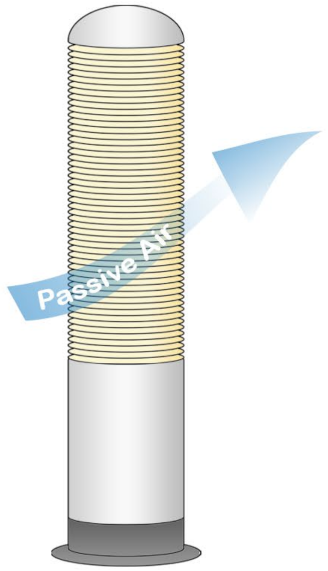
DIVERSE, EQUITABLE, INCLUSIVE, AND ACCESSIBLE RESEARCH AND DEVELOPMENT

Innovation



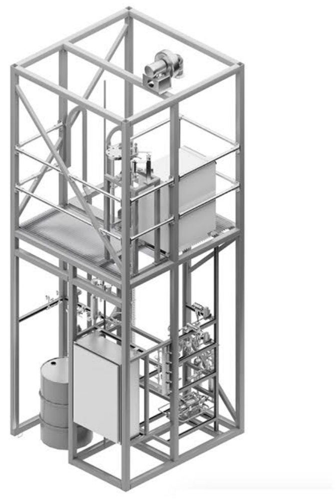
Mobile Air to Methanol System (Air2Fuel)

Core Knowledge



DAC Pilot at ASU
Low Energy Capture

Carbon-Free H_2 Pilot at NREL
Novel H_2 Designs



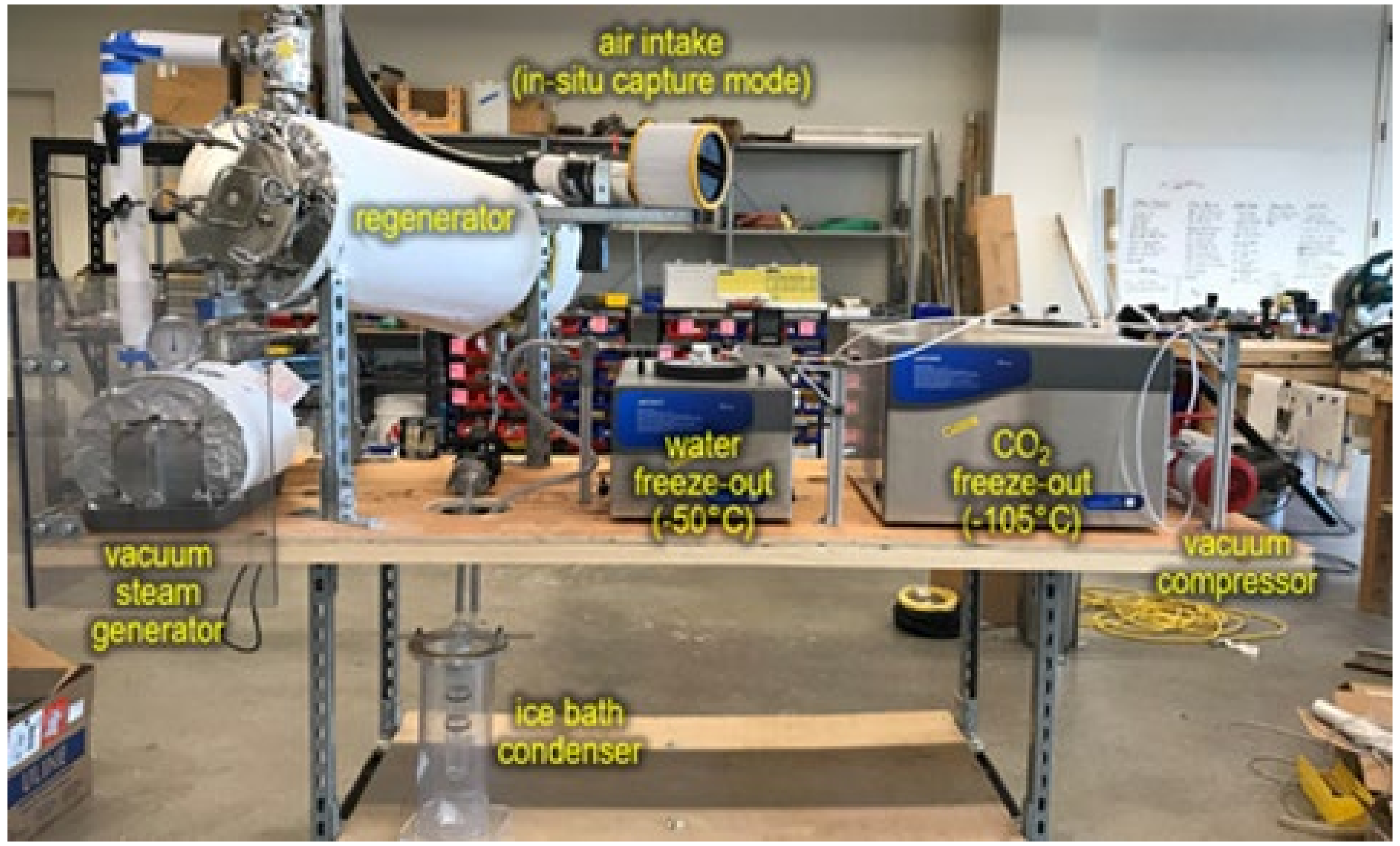
CO_2 to MeOH Pilot at Air Company
Transformational Catalysts

Technology Fundamentals/Background

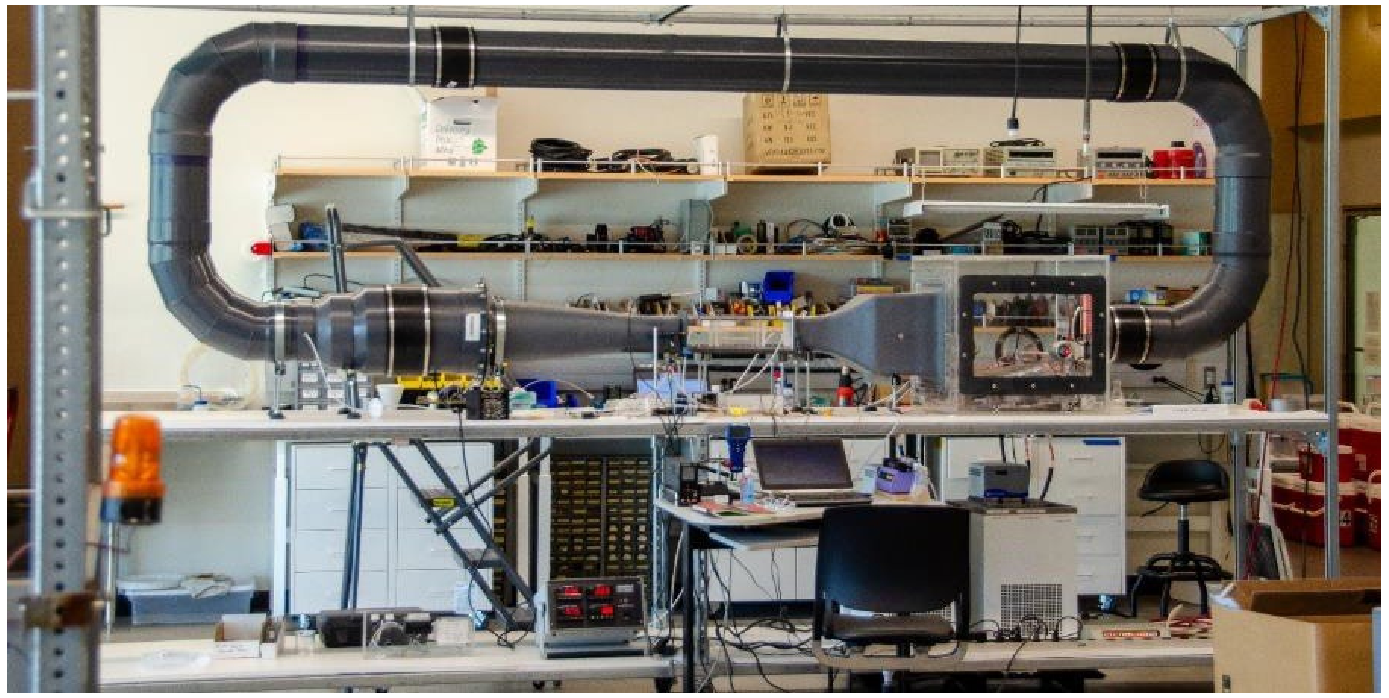
- DAC Subsystem
- H_2 Subsystem
- CO_2 to Fuel Subsystem

DAC Subsystem – ASU

- **MechanicalTree™ Pilot plant**
  - Passive direct air capture system with 30 tonnes/year design capacity.
  - Eliminate forced air making up 40-60% of energy & 50-70% of CAPEX.[1]
- **Lab scale Setups**
  - Sapling - Kilogram scale temperature vacuum swing regenerator with in situ forced air capture or outdoor capture in Mechanical Tree.
    - Scale up 2-3x for Phase II system
  - 561 L Wind tunnel – Measure CO_2 adsorption vs wind speed and sorbent form factor.



"Sapling" kilogram-scale DAC regeneration system



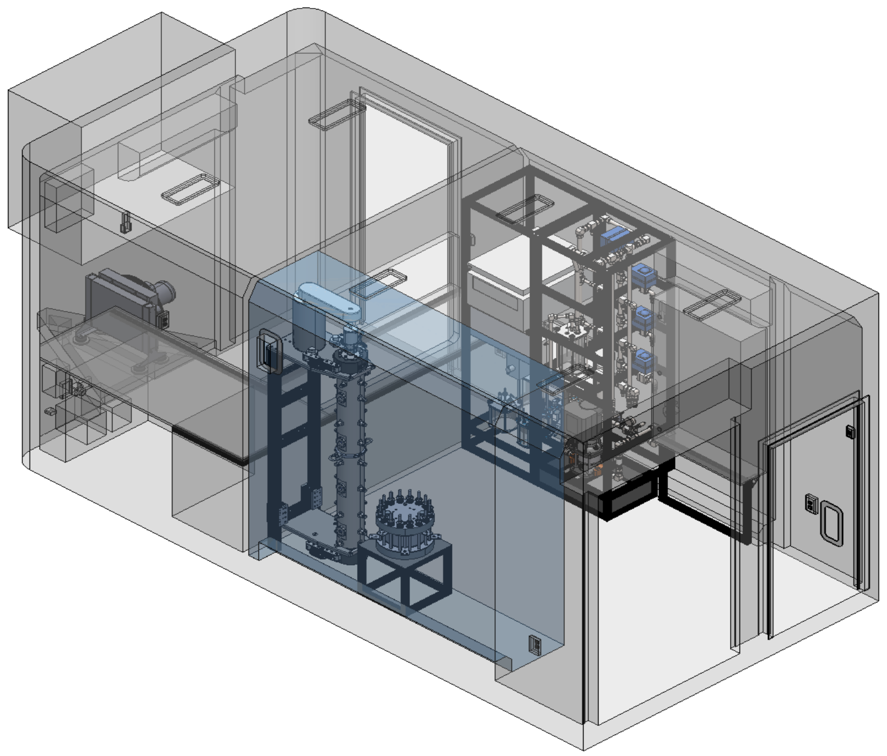
561 L wind tunnel for CO_2 sorption kinetics

Carbon Collect Inc. MechanicalTree™ installed at ASU passively collects CO_2 delivered by the wind from any direction with a low pressure drop.

1) J. Valentine, A. Zoelle, "Direct Air Capture Case Studies: Sorbent System," National Energy Technology Laboratory, Pittsburgh, PA, 2022. https://www.netl.doe.gov/energy-analysis/details?id=d5860604-fbc7-44bb-a756-76db47d8b85a

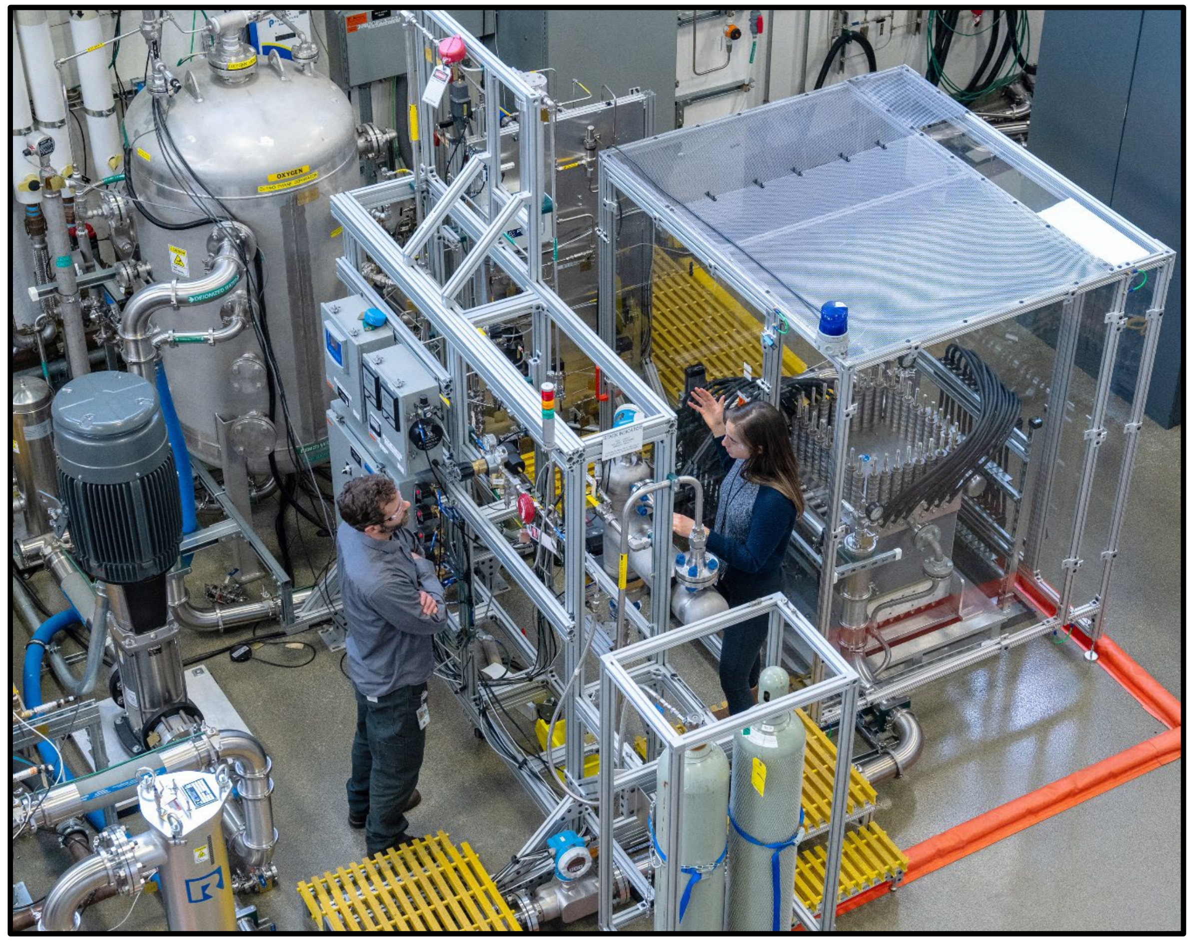
H_2 Subsystem – NREL

- **Pilot Scale**: 1MW balance of plant to support PEM performance and validation at the ESIF
- ≤ 125 cells, ≤ 4 k-Adc and 250 Vdc; safety systems; 60 °C; 3 MPa H_2
- **Lab-scale:** 2x25 kW, 100 kW, 3x150 kW electrolyzer systems
- **Relationships** with electrolyzer manufacturers (20 years)
- Advanced Research for Integrated Energy Systems (**ARIES**)
- **Lessons learned** from daily unattended operations: H_2O & Power!



NREL mobile RD&D e-fuels platform

- **Mobile (3 – 25kW) RD&D facility** for H_2, CO_2 conversion, renewable natural gas (RNG),… RD&D – Behind the meter water & power!



1 MW Pilot-scale electrolyzer at NREL

NREL mobile RD&D e-fuels platform

CO_2 to Fuel Subsystem – Air Company

Capabilities: catalysts and reactors for CO_2 to methanol, ethanol, gasoline, diesel fuel, and jet fuel

Methanol catalyst: Proprietary formulation; very low side product formation

Purity: ASTM, IMPCA grade, 99.9% selectivity after distillation

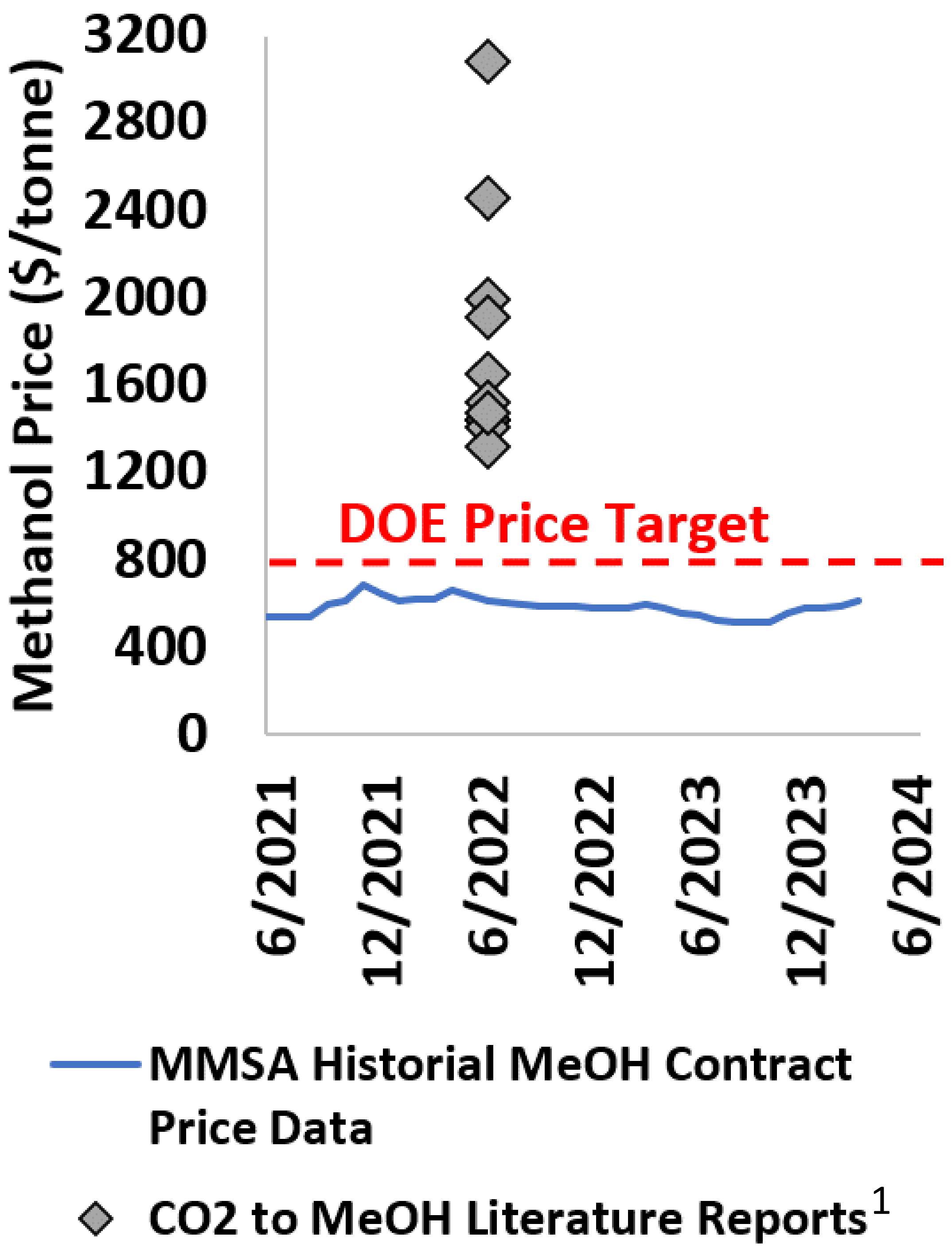
Pilot System: 280 MTPA; thermal fluid heating/cooling; demo with power plant flue gas.

Bench scale system: Clamshell furnace heat, 100–400 mL MeOH/day, sufficient for Phase II

Air Company pilot-scale CO_2 to fuels reactor system.

Air Company bench-scale CO_2 to fuels reactor system (for Phase II).

Techno- economic challenges and advantages



Challenges:

- **Cost**
  - **DAC CO_2:** \$175-530/tonne
  - **Renewable H_2**: \$5,000-6,000/tonne
  - **CO_2 to MeOH**: \$1,250-2,000/tonne
- **DAC:** variable CO_2 supply, air contamination

Advantages

- Reduce CAPEX/OPEX via process intensification / heat integration
- Supply chain resilience (vs natural gas)
- Offtake for stranded renewables
- Co-locate production and usage
- Smaller scale distributed production

1. Sarp, S., Hernandez, S.G., Chen, C. and Sheehan, S.W., 2021. Alcohol production from carbon dioxide: methanol as a fuel and chemical feedstock. *Joule*, *5*(1), pp.59-76.

Approach/ Scope

- Task 1.4 & 1.5 – TEA/LCA
- Task 1.8 – DAC subsystem design
- Task 1.9 – H_2 subsystem design
- Task 1.10 – CO_2 hydrogenator subsystem design
- Task 1.11 – Integrated Air2Fuel system design
- Task 2.0 – Community Benefits Plan

Key Milestones

Task/ Subtask	Milestone (M) or Deliverable Title & Description	Planned Completion Date	Verification method
1.4.1, 1.5.1	Develop **initial TEA and LCA** of the full-scale Air2Fuel system	3/19/2024	Quarterly Report and/or Proposal to Phase II
1.4.2, 1.5.2	**Preliminary TEA** with pathway to ≤ $800/tonne MeOH and **LCA**	12/19/2024	Quarterly Report and/or Proposal to Phase II
1.7.1	**Cost analysis** of DAC impurity cleanup (CAPEX) vs efficiency losses (OPEX).	9/19/2024	Quarterly Report and/or Proposal to Phase II
1.8.1, 1.9.1, 1.10.1, 1.11.1	**Conceptual design of the full-scale** DAC, H_2, MeOH subsystems and integrated Air2Fuel system	9/19/2024	Quarterly Report and/or Proposal to Phase II
1.8.2, 1.9.2, 1.10.2, 1.11.2	**Conceptual design of the lab-scale** DAC, H_2, MeOH subsystems and integrated Air2Fuel system	12/19/2024	Quarterly Report and/or Proposal to Phase II
2.0.1	R&D **Community Benefits Plan** (CBP)	12/19/2024	Accepted by DOE.
2.1.1	Conduct **DEIA Onboarding briefing** for project team members. Each team member passes DEIA quiz with score of ≥ 80%.	6/19/2024	Quarterly Report
2.1.2.2	Identify implicated communities from stakeholder engagement workshop and assemble data for preliminary EEJ	9/19/2024	Quarterly Report
2.1.3.2	Complete the **stakeholder engagement workshop**	4/30/2024	Quarterly Report
2.1.3.3	**Identify stakeholder needs/perceptions** related data and explore potential future sites for community visioning exercises	6/19/2024	Quarterly Report
2.1.4.1	Identify the **required skills** and potential workforce development curricula for Air2Fuel. Compare NREL jobs model with industry jobs input.	9/19/2024	Quarterly Report

Success Criteria

- <u>Conceptual design</u> of a **lab-scale** Air2Fuel system suitable for a 2-month evaluation in Phase II;
- <u>Conceptual design</u> of a **full-scale** Air2Fuel integrated DAC to methanol system for TEA/LCA;
- Preliminary TEA with pathway ≤ $800/tonne MeOH
- Preliminary cradle-to-gate LCA for carbon neutral methanol
- Community benefits planning derisks pathway to deployment and commercialization of Air2Fuel.
- Submit Phase II proposal

Risk Mitigation

Perceived Risk	Risk Rating (Low, Med, High): Probability	Impact	Overall	Mitigation/Response Strategy
Cost/Schedule Risks:				
To be named postdoctoral associate takes a while to be hired.	Medium	High	Medium	Masters Chemical Engineering students will be hired to assist with process analysis until the postdoc is onboarded.
Technical/Scope Risks:				
O_2 impurities from DAC may degrade the hydrogenator catalyst.	High	Medium	Medium	Evaluate a number of commercially available options for reducing O_2 to acceptable levels, such as cryogenic distillation or catalysts that reduce O_2 to H_2O using available H_2.
N_2 impurities from DAC may reduce CO_2 hydrogenator efficiency.	High	Medium	Medium	Evaluate cost implications of efficiency losses vs air separation and purging.
External Factor Risks:				
Low interest in community engagement workshop due to early-stage nature of project.	Medium	Low	Medium	The workshops will focus on broader issues related to alternative fuels.

Progress and Current Status

- DAC Subsystem
- H_2 Subsystem
- CO_2 to Fuel Subsystem

DAC Subsystem – Full scale design

Objective:

- DAC subsystem design to supply continuous stream of 176 kg/hr of CO_2 to achieve 1000 tonne MeOH/yr production.

Methods:

- Adapt current carbon tree system design from Carbon Collect Inc. and utilize experimental data from bench and pilot scale systems at ASU.

Key Parameters:

- DAC contactor size/number, sorbent capacity, cycle time/kinetics
- Heat recovery/exchange with MeOH and H_2 subsystems
- Minimize/remove H_2O, O_2 and N_2 contamination in crude CO_2 product
- CO_2 storage to buffer variable CO_2 supply and constant CO_2 demand

Status:

- Preliminary process flow diagram, mass and energy balances for TEA/LCA
- Ongoing analysis of CO_2 purification technologies to remove O_2 and N_2

Carbon Collect Inc. carbon tree installed at ASU

H_2 Subsystem – NREL

Objective:

- Water electrolyzer design to supply 24 kg of H_2 per hour with a 90% capacity factor to achieve 1000 tonne MeOH/yr production.

Methods:

- Adapt NREL intellectual property to reduce CAPEX / OPEX to enable integrated low-cost H_2 production

Key Parameters:

- AC/DC power conversion
- Initial clean up and continuous water purity
- Limit H_2 purity to required levels
- Gas ratio control to achieve $3H_2 : 1CO_2$ for reactor

NREL Designed/Built 1MW PEM Electrolyzer

Status:

- Preliminary process flow diagram, mass and energy balances for TEA/LCA
- Evaluating H_2 cost reduction methods

CO_2 to Fuel Subsystem – Air Company

Objective:

- CO_2 to MeOH subsystem design to supply 1,000 tonne MeOH/yr production (90% capacity factor).

Methods:

- Adapt existing proprietary and validated process simulation platform. Energy integration with DAC.

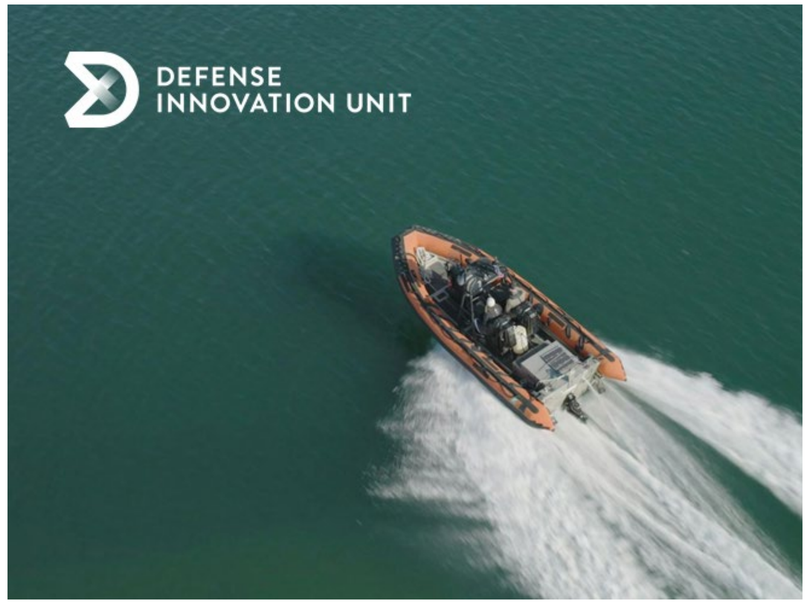
Key Parameters:

- Per pass yield, catalyst lifetime
- DAC heat integration temperature and efficiency

Status:

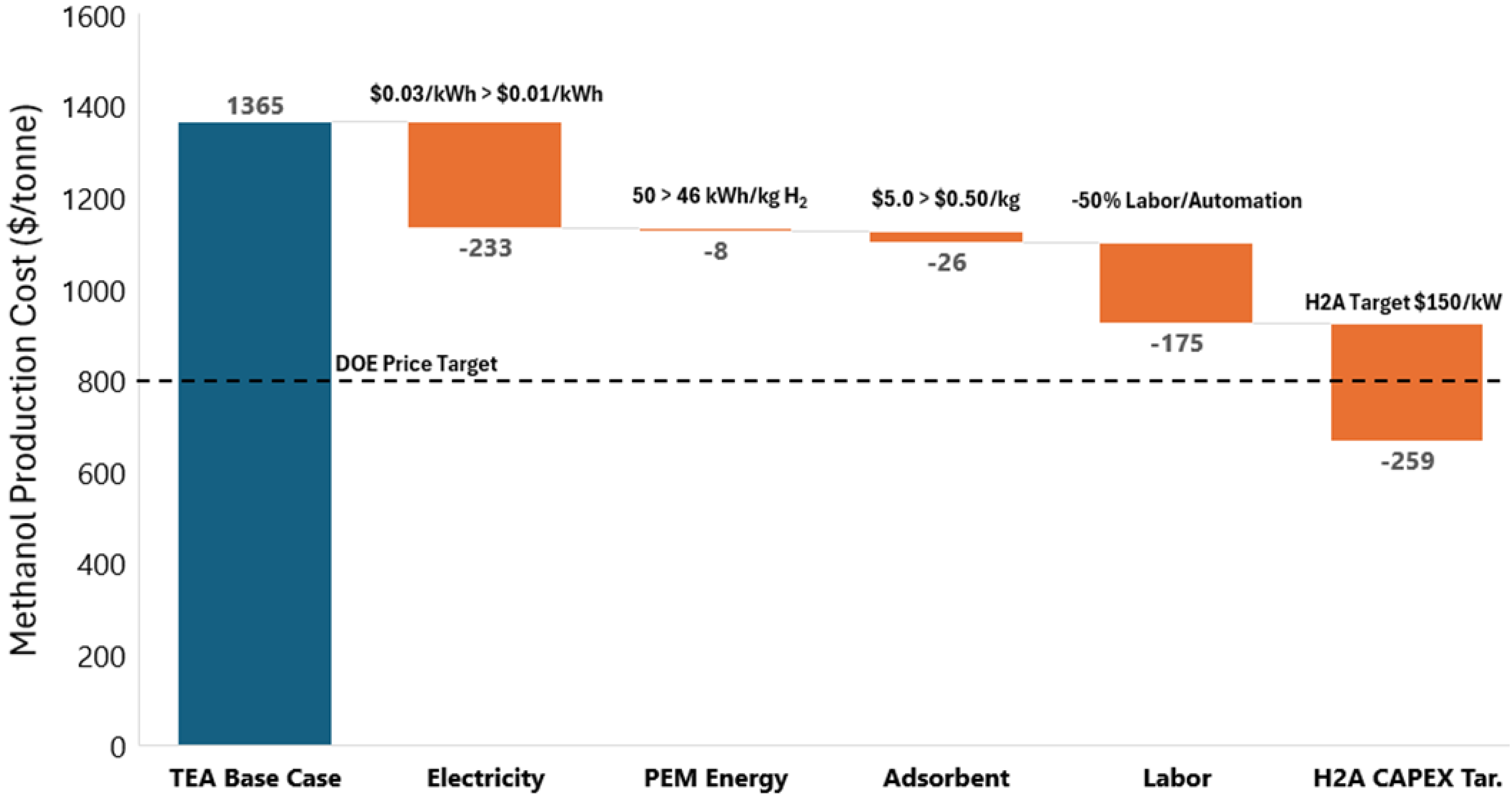
- Preliminary process flow diagram, mass and energy balances for TEA/LCA
- Analysis of impact on CO_2 impurities (O_2, N_2, H_2O) on catalyst lifetime
- Jet, diesel via Project SynCE (Synthetic Fuels for Contested Environments)

1 KMTA reactor will be comparable scale.



Fuel testing with SOCOM and DIU.

Initial TEA/ LCA – NREL



Pathway to $800/tonne exists, will be reliant on low-cost electricity, minimal labor costs, and future CAPEX reductions

Key Assumptions:

1. Scale: 1,000 tonne MeOH per year
2. Electrolyzer power: 50 kWh/kg H_2
3. Electricity: $0.03/kWh
4. Labor: 1 supervisor, 1 tech, 3 shift operators

At 1,000 tonne/yr scale, labor costs are significant.

Evaluating 1) much larger scales and 2) automation (especially for DAC).

*H2A = DOE Hydrogen Analysis Program

DEIA – ASU

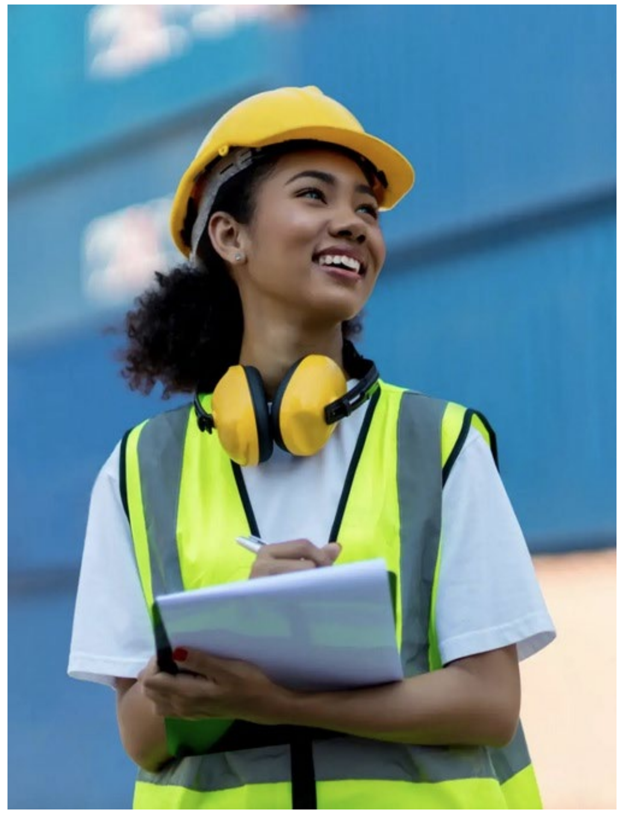
- **December 2023 -** *Examining Biases* DEIA Workshop at Project Kickoff Meeting
  - Dispel the myth that “good” people don’t enact biases.
  - Practiced noticing, examining, and balancing out our biased behaviors.

- **Spring 2024 –** Project DEIA Onboarding Briefing and Quiz (**Milestone 2.1.1**)
  - Described CNCE's approach to DEIA
  - overview of DEIA concepts
  - >80% of the team passed quiz with score > 80%.

Community Engage. / Justice 40 (ASU)

- The "Fueling Tomorrow: Virtual Workshop on the Future of Direct Air Capture for Clean Fuels" was held on May 2, 2024
- ~30 participants included representatives from DOE, academic institutions (including engineers, social scientists and humanists), utilities, local governments, and industry and consulting groups working on green methanol.
- Discussions were facilitated using Mural, with responses written on the shared board and discussed in breakout groups.
- Key insights on community benefits and workforce implications will inform the development of the Phase II community benefits plan.
- Completed Milestones 2.1.3.2 and 2.1.3.3

Quality Jobs– ASU



Workforce Needs Assessment

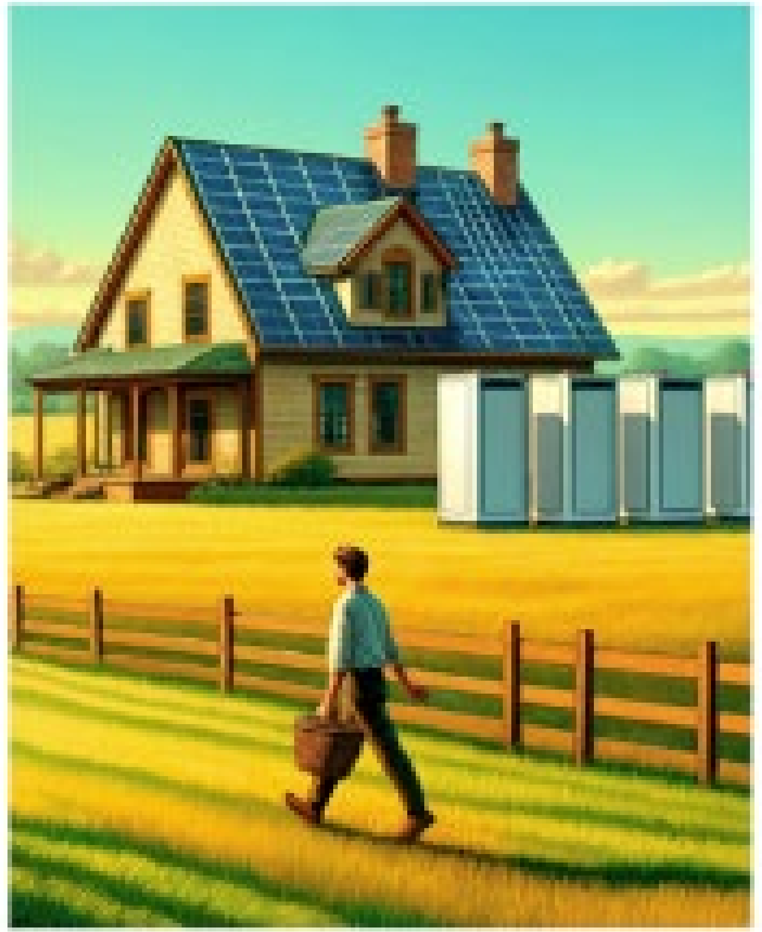
- **Identify required jobs**, associated skills, and associated educational pathways (Due September)
  - This entails researching the required skills and education for jobs directly involved with the Air2Fuel process as well as those in adjacent industries such as methanol production.
- **Identify existing jobs in the fossil fuel industry** and the new jobs that will be replacing them with minimal retraining (Due Sept.)
  - This entails identifying the specific essential skills associated with these jobs and comparing them with those required of the Air2Fuel process.
- **Phase II Quality Jobs Plan**, including scope of curricula to be developed and offered through ASU CareerCatalyst (Due Dec.)

Lessons Learned

- **Oxygen and Nitrogen** – DAC crude CO_2 product O_2 and N_2 levels must be reduced to maximize system lifetime and efficiency.

- **Distributed Air2Fuel systems** pose cost, safety and equity concerns that make them unlikely to be beneficial for individuals (e.g, rooftop solar), but community-scale systems can support small business models, and meet specific needs (net zero, remote fuel, reduce air pollution).

- **Project SynCE** provides opportunities for DAC integration in a different scenario – more ruggedized, but **higher-value fuel** – less cost sensitive to enable further R&D for scale.



$400 per gallon gas to drive debate over cost of war in Afghanistan

BY ROXANA TIRON - 10/16/09 12:34 AM ET

Summary

- Key findings
  - **Workshop:** provided insights into risks and benefits of DAC to MeOH for energy storage vs fuels/chemicals and at centralized and distributed scales.
  - **Scale:** Increasing scale well above 1,000 tonne MeOH per year is critical to ensure labor costs do not dominate in a human operated system.
- Future plans
  - Complete full-scale DAC, H_2, MeOH and integrated system design
  - Conduct preliminary safety analysis
  - Phase II: build bench scale Air2Fuel system and operate for ≥ 2 months
- Take away message
  - Air2Fuel has an exceptional team (ASU, NREL, Air Co.) that builds on established technologies and guided by TEA/LCA and community benefits to help us be successful on this project.

Thank you!

DOE NETL
Lei Hong, PhD
Program Manger

Project Management
Subtasks 1.1, 1.2, 1.3, & 1.6

Justin Flory
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Enabling All Tasks

Technoeconomic & Life Cycle Analysis
Subtasks 1.4 & 1.5

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TEA/LCA, NREL
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DAC Subsystem
Subtask 1.8

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Edward Shin
Masters student, ASU

Carbon-Free H_2 Subsystem
Subtask 1.9

Kevin Harrison
H_2, NREL

Air2Fuel System Design
Subtasks 1.7 & 1.11

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Process Design, NREL
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Process Analysis, NREL
Kevin Harrison
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CO_2 to MeOH Subsystem
Subtask 1.10

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Process Design, AirCo
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Government Affairs, AirCo

Community Benefits Plan (CBP)
Task 2.0

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Quality Jobs, ASU
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Questions?

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Air Company

National Renewable Energy Laboratory