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PRODUCTION OF LOW-CARBON METHANOL THROUGH THE USE OF DIRECT-AIR CAPTURE OF CO2 AND SOLID-OXIDE CO-ELECTROLYSIS OF CO2 AND H2O TO SYNGAS (AIR2MEOH)
DE-FE0032413

Dr. Donald Whisenhunt

2024 FECM/NETL Carbon Management Research Project Review Meeting
August 5 – 9, 2024

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GE Vernova Advanced Research Mission

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POWER
Decarbonize

Carbon Capture, 100% H_2 ,eFuels
Next Gen Nuclear

WIND
Accelerate

Scalable Workhorse Product,
AI Enabled Service Tech

ELECTRIFICATION
More Resilient

A Secure, Flexible
& Resilient Grid

Bringing Research to Reality … Energy Innovation to Change the World

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DOE program for Power to Liquids (Air2MeOH)

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Department of Energy

Fossil Energy and Carbon Management

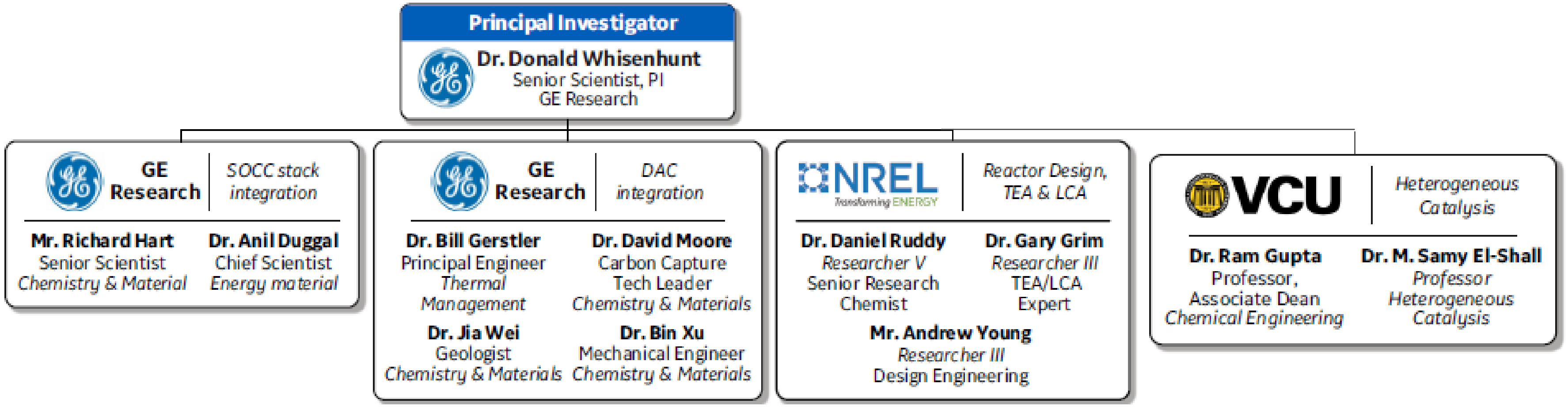
Program Manager – Mike Bergen

PI – Donald Whisenhunt

POP – 12/20/23-12/19/24

$500K – 12 month* Feasibility Study
to couple direct air capture (DAC) +
Solid-oxide co-electrolysis (SOCC) + MeOH synthesis
to produce green Methanol

Institution	Federal Share ($)	Cost Share($)
GE Vernova Advanced Research	174,664	124,888
National Renewable Energy Lab	125,000	
Virginia Commonwealth University	75,000	



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* The actual Period of Performance is 18 months but this includes a 6 month evaluation period where no technical work is done

Concept

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Program Team

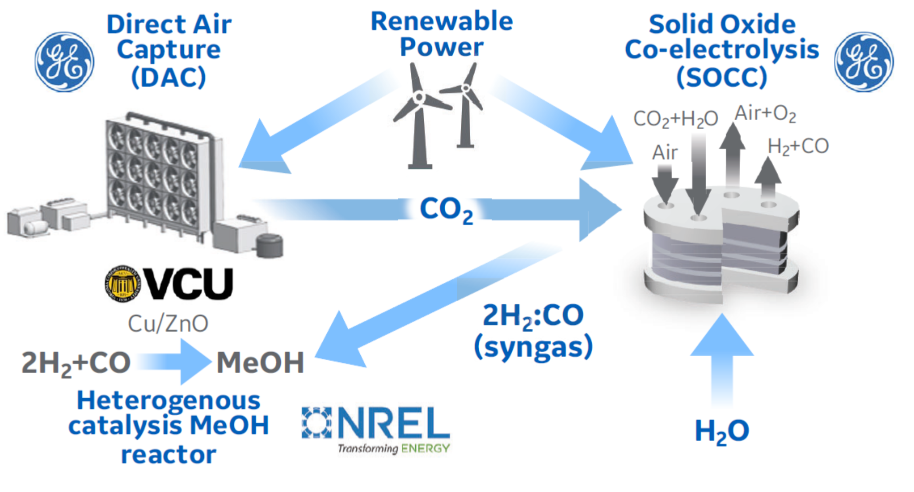
GE Research
Syngas electrode SOCC stack

NREL Transforming ENERGY
LCA, TEA, Heterogenous catalysis (MeOH syn)

VCU
Heterogenous catalysis (MeOH syn)

12-month, $500K Program to Conduct a Concept Design and Feasibility Study to produce Carbon Neutral Methanol from Syn-gas produced by Solid-Oxide Co-electrolysis (SOCC) from CO_2 captured via Direct Air Capture (AIR2MeOH)

Conceptual Design to Produce ~3 gallon Low-Carbon Methanol /day – AIR2MeOH



Technical Approaches

- SOCC combines hydrogen electrolysis and Reverse Water Gas shift to produce syn gas
- World class sorbent material to reduce thermal requirements for DAC
- Thermal spray technology for the lowest cost SOCC

Technical Challenges

- Optimizing thermal integration
- Designing the controls for 2 months of continuous operation

Relevant Prior Work

- FLYCLEEN (ARPA-E)
- Redox Stable electrode
- (DE-FE-26169)
- AIR2CO2 (DE-FE0031956), AIR2CO2 Contactor (DE-FE0032126), PLASTIC4CO2 (DE-FE0032132)

Program Deliverables

- Conceptual Design for the Integration of DAC, SOCC and MeOH synthesis
- Techno-Economic Analysis to establish a path to a MeOH cost of $800/t
- Life-Cycle Assessment to quantify the carbon mitigation value of the MeOH produce via this route
- Finalized design to propose a Phase II program to integrate DAC+SOCC and MeOH to run a 2-month demo

Anticipated Benefits

- Low-carbon, low cost MeOH could lead to low-cost transportation fuels
- Determine the benefit of thermal integration between the different unit operations

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Project Objectives

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Concept Design in 3 Stages (at 2 scales)

Stage 1 – P&ID

Stage 2 – Dynamic ASPEN model

Stage 3 – CAD of the Integrated System

Model	3 gal/day (11kg/day)	0.16 gal/day (0.6kg/day)	Integrated
P&ID	❑ DAC ❑ SOCC ❑ MeOH Syn	❑ DAC ❑ SOCC ❑ MeOH Syn	❑ Complete
ASPEN model	❑ DAC ❑ SOCC ❑ MeOH Syn	❑ DAC ❑ SOCC ❑ MeOH Syn	❑ Complete
CAD	❑ DAC ❑ SOCC ❑ MeOH Syn	❑ DAC ❑ SOCC ❑ MeOH Syn	❑ Complete

Complete

In Progress

NREL just got under contract July 1st so MeOH reactor design and TEA just started

GE DAC Technology

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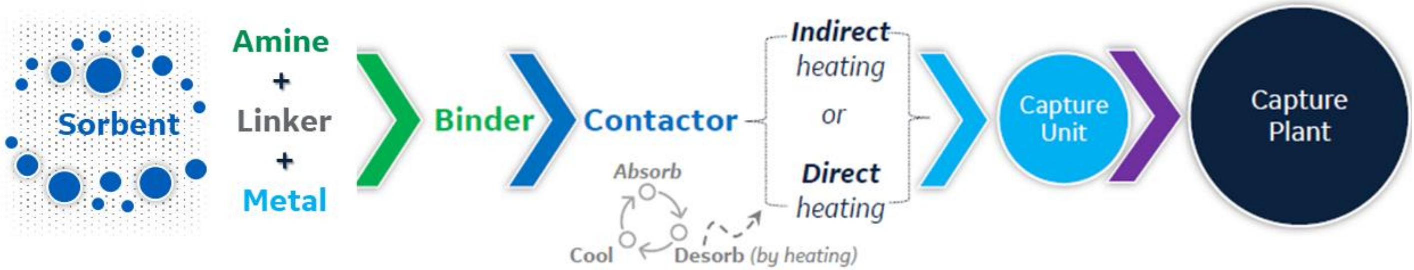
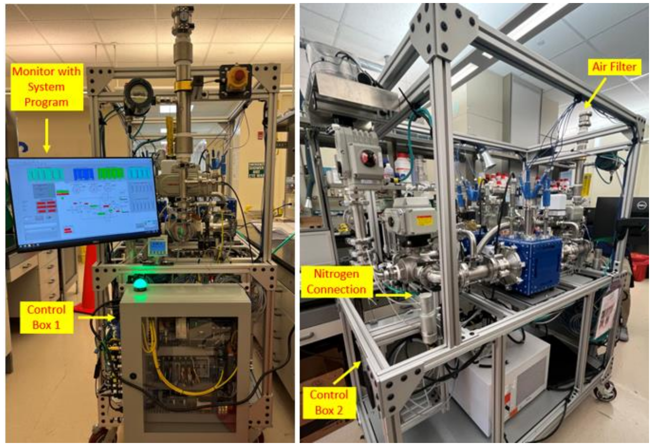
Driving Innovation with Sorbent-based Capture Solutions:

Carbon Capture… "Powder to Plant"



2021 Single Contactor



2023 Dual Contactor
Integration with Bioreactor
97% pure CO_2

2023 Dual Contactor
1 kg/day capacity

➔ 10 t/yr Design And Build 2024

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Direct Air Capture

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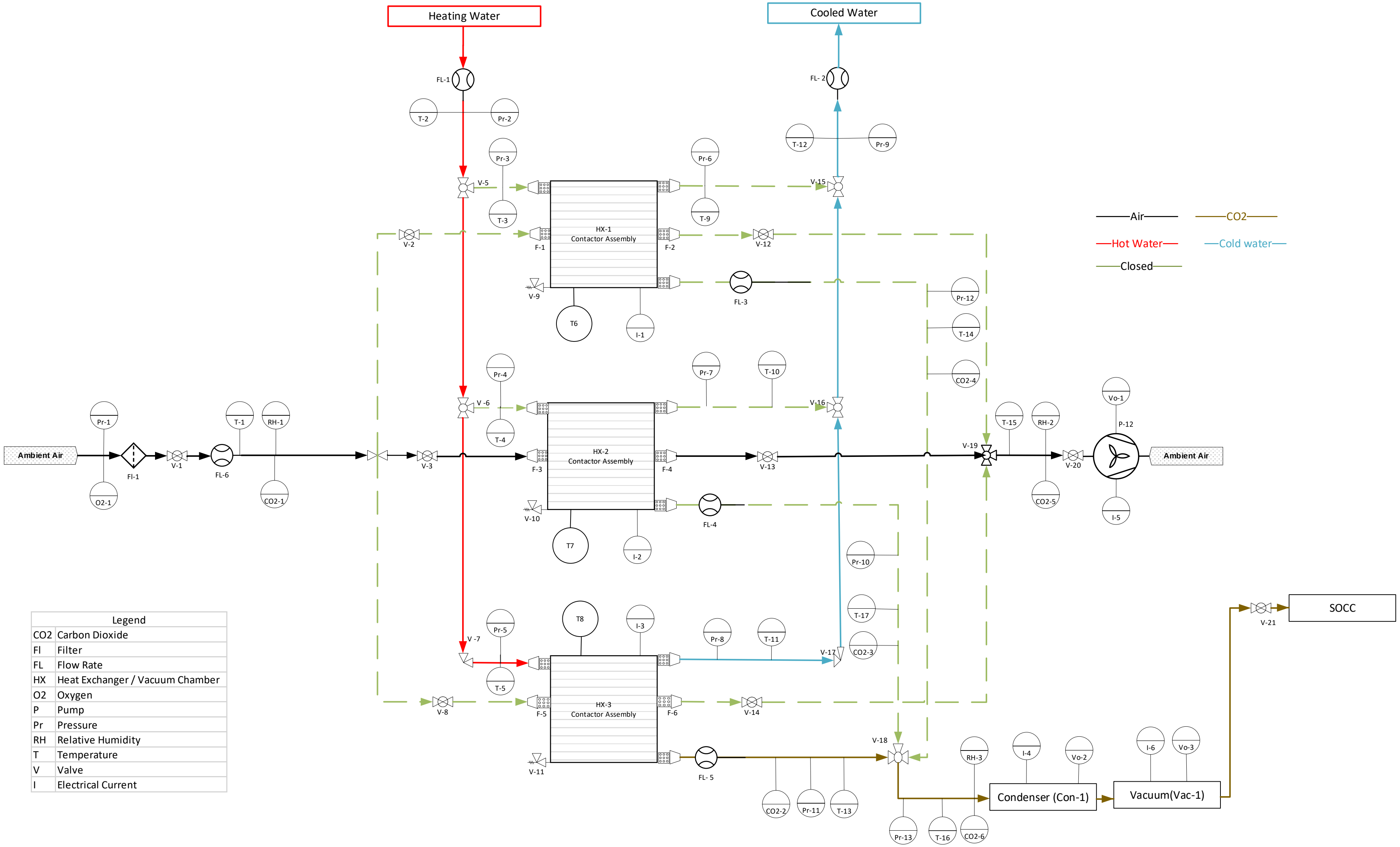

Legend	
CO2	Carbon Dioxide
FI	Filter
FL	Flow Rate
HX	Heat Exchanger / Vacuum Chamber
O2	Oxygen
P	Pump
Pr	Pressure
RH	Relative Humidity
T	Temperature
V	Valve
I	Electrical Current

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Key GE SOCC Features

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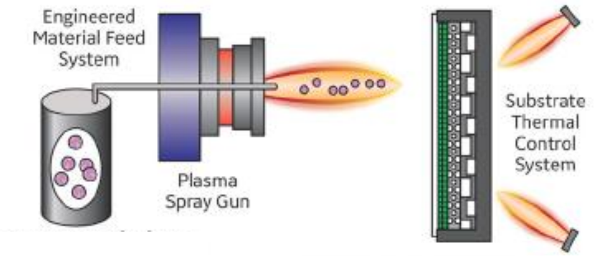
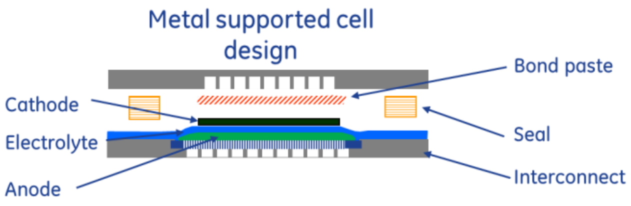
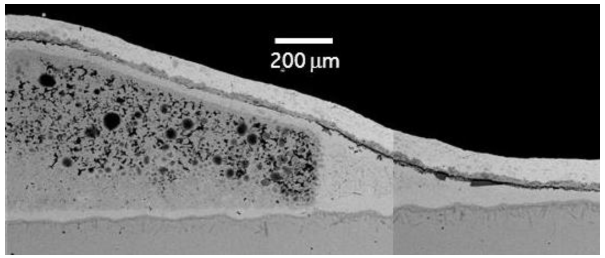
Feature	Technical Advantages	System Advantages	Next-Best Alternative
High temperature reaction	• Highest Efficiency (>99% with steam) • High reaction rate	• Lowest power requirement • Small footprint	Low temperature PEM H2 electrolyzer + Reverse Water Gas Shift Reactor
Thermal spray coated onto metal substrate	• Integral fuel-side sealing • Scalable to large area	• Small footprint • Reduced controls complexity	SOCC with ceramic substrate and bulk ceramic processing.

Thermal Spray Process – High deposition rate and area-scaleable

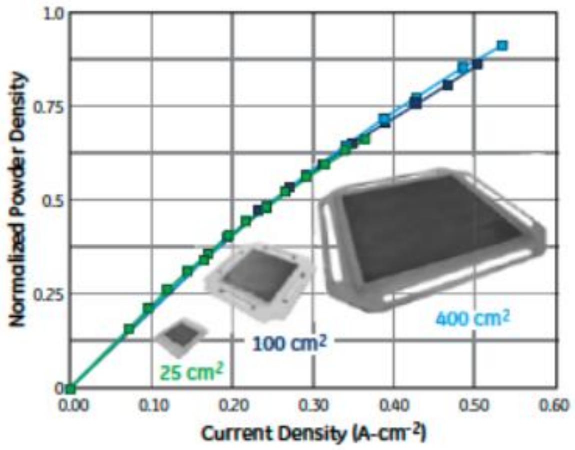




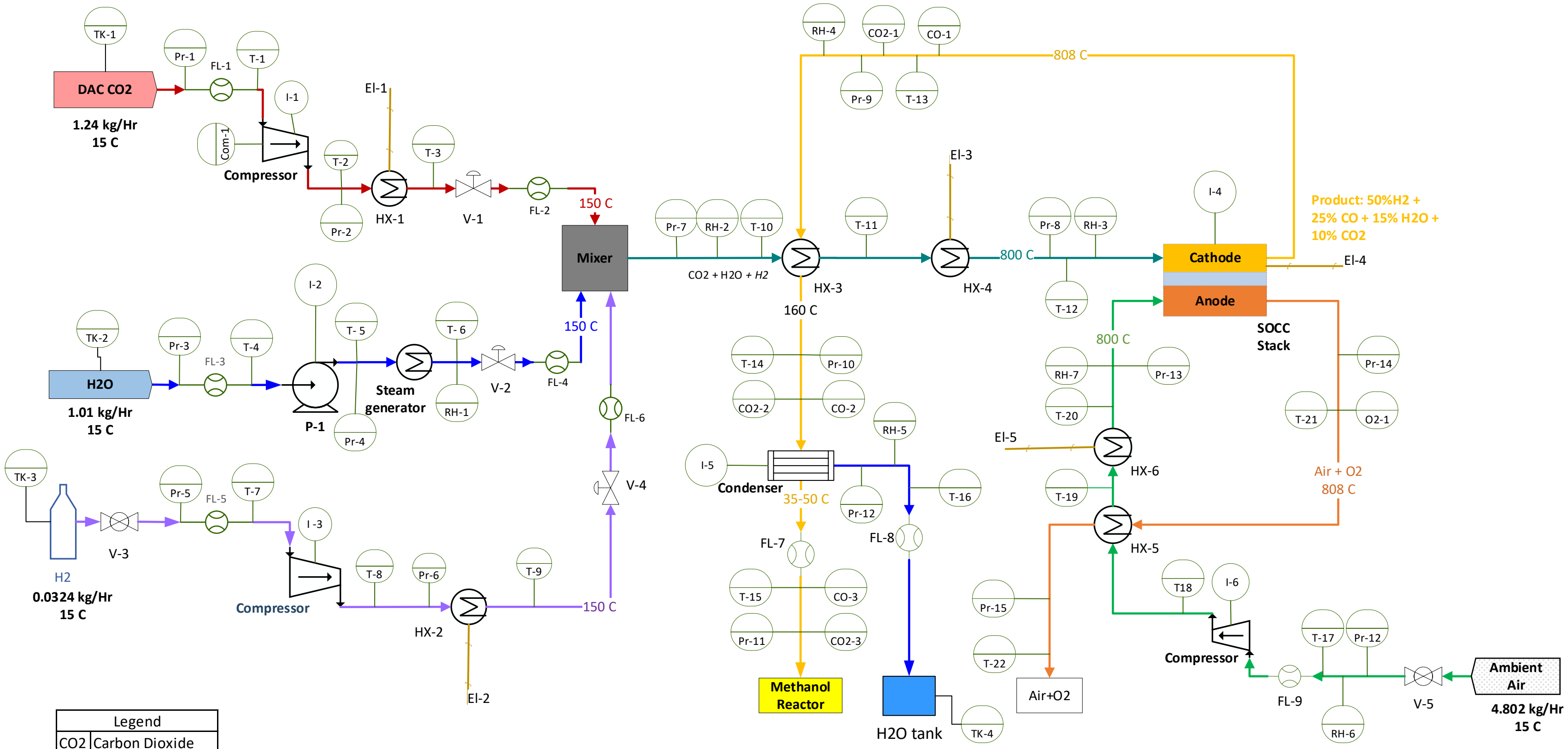
Integral fuel-side sealing



No change in performance with scaling



Solid-oxide Co-electrolysis to convert H_2O and CO_2 to syngas



Legend	
CO2	Carbon Dioxide
CO	Carbon Monoxide
FL	Mass Flow Rate
HX	Heat Exchanger
O2	Oxygen
P	Pump
Pr	Pressure
RH	Relative Humidity
T	Temperature
V	Valve
I	Electrical line
F	Filter

Note: HX-3 and HX-5 are notional at full scale. The laboratory prototype design may include a furnace to heat up the incoming and outgoing gasses to/from the SOCC (replacing HX-4 and HX-6).

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CATALYST SYNTHESIS

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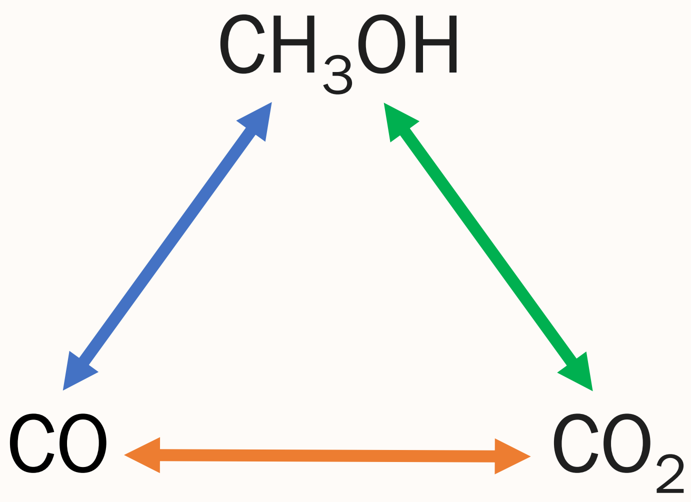
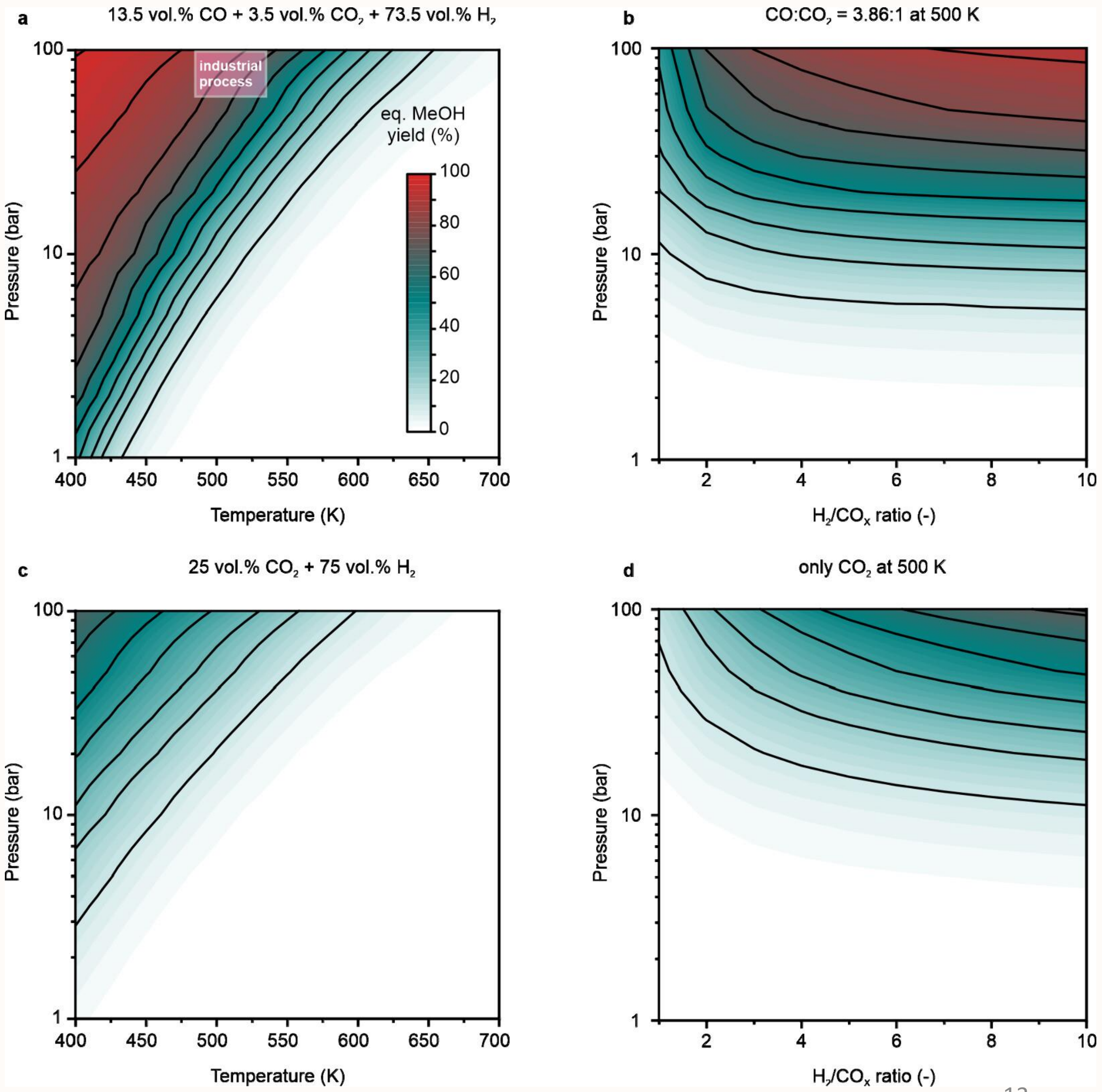
Equilibrium Reactions for Methanol Synthesis

$CO + 2H_2 \rightleftharpoons CH_3OH$	$\Delta H_{298} = -90.6\ KJ\ mol^{-1}$	(1)
$CO_2 + 3H_2 \rightleftharpoons CH_3OH + H_2O$	$\Delta H_{298} = -41.2\ KJ\ mol^{-1}$	(2)
$CO_2 + H_2 \rightleftharpoons CO + H_2O$	$\Delta H_{298} = +49.5\ KJ\ mol^{-1}$	(3)



Arik Beck, Mark A. Newton, Leon G. A. van de Water, and Jeroen A. van Bokhoven. *Chemical Reviews*, **2024.**

Thermodynamics



Thermodynamic equilibrium yields of methanol as a function of temperature and pressure from
(a) $CO/CO_2/H_2$ and
(c) CO_2/H_2 feedstocks and
(b, d) as a function of H_2/CO_x ratio.
Catalyst: $Cu/ZnO/Al_2O_3$ (CZA)

Equilibrium compositions were calculated using the Gaseq software tool.

Morley, C. *Gaseq: A Chemical Equilibrium Program for Windows, Ver. 0.79*; Gaseq, **2005**

Arik Beck, Mark A. Newton, Leon G. A. van de Water, and Jeroen A. van Bokhoven. *Chemical Reviews*, **2024.**

Preparation of the Cu/ZnO/Al_2O_3 (6:3:1) Catalyst

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1. Vacuum filtration to recover solids
2. Wash using 1 L of DI H_2O

Drying at 80 °C, 12 hours

Sample ID: CHP-100-A-03

Weight: 6.5 grams

$((Cu,Zn)_{1-x}Al_x)(CO_3)_y(OH)_z$

Calcination in Air

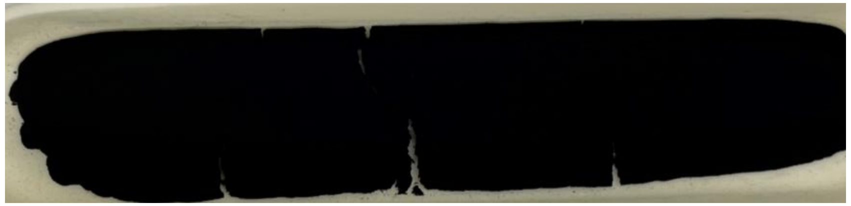
(300 °C, 3 hours)

Sample ID: OxP-100-A-03

$CuO/ZnO/Al_2O_3$

5% H_2-Ar

(300 °C, 3 hours)



Sample ID: CZA-100-A-03

$Cu/ZnO/Al_2O_3$

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XRD of the $Cu/ZnO/Al_2O_3$ (6:3:1) Catalyst

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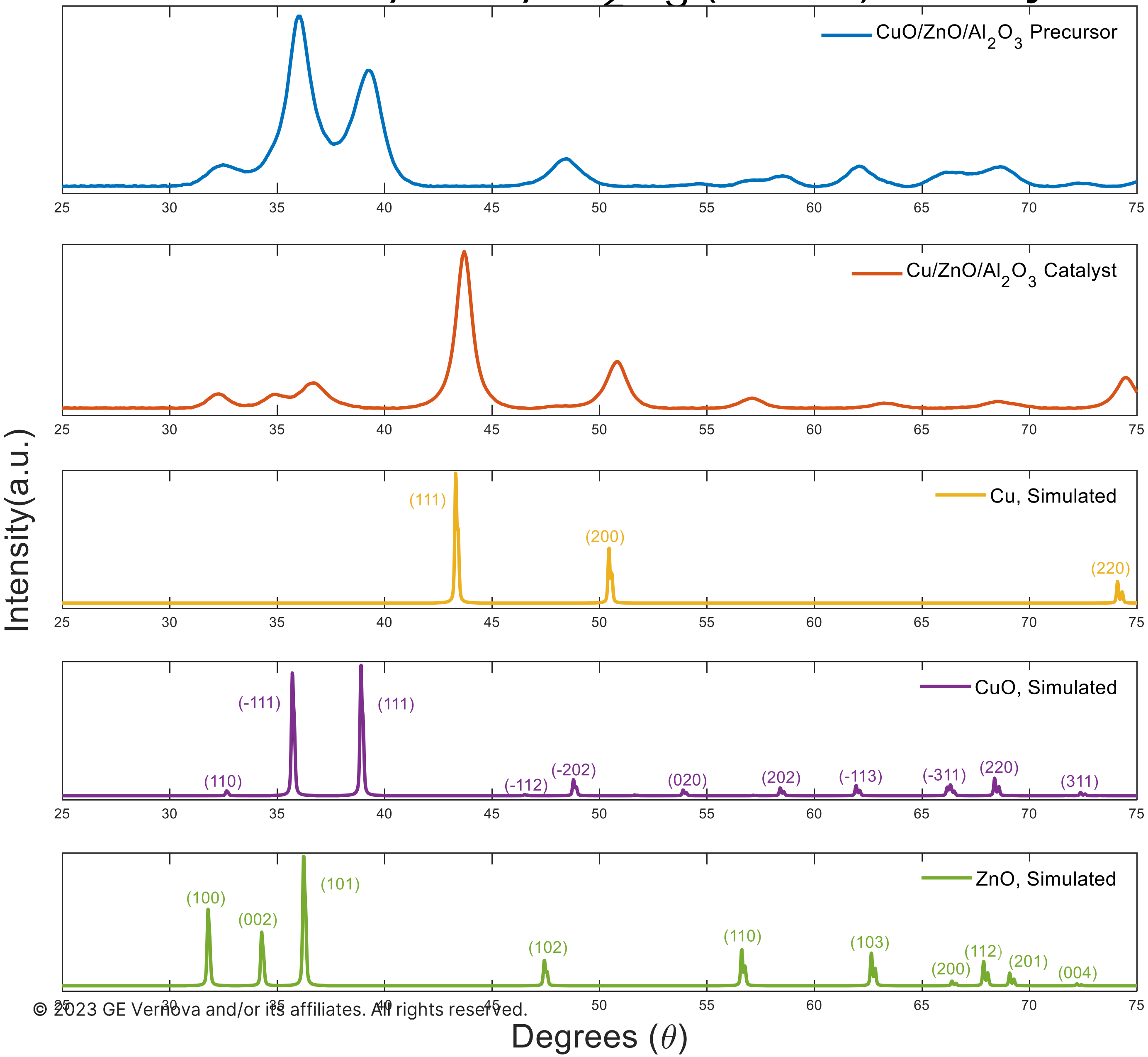

The simulated results were generated from the PANalytical HighScore Plus software

Scherrer Equation:

$$L = \frac{K\lambda}{\beta cos\theta}$$

L: Mean size of the particle

K: Dimensionless shape factor (0.9)

λ: X-ray wavelength

β: Line broadening at FWHM

θ: Bragg angle

L = 14 nm for CuO in $CuO/ZnO/Al_2O_3$

L = 20 nm for Cu in $Cu/ZnO/Al_2O_3$

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COMMUNITY BENEFITS

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Siting a potential Air2MeOH facility

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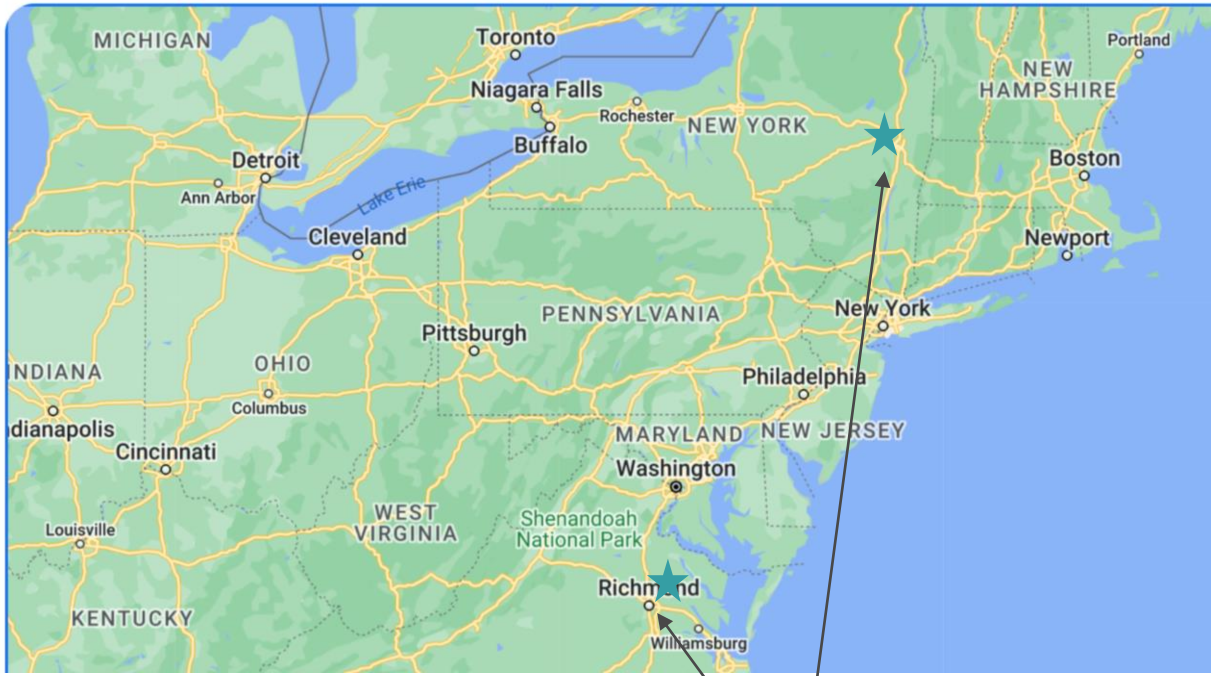
- Direct Air Capture utilizes a significant number of fans to move air over the solid sorbent.
- These fans create a significant amount of noise and therefore must be located in rural areas.
- Calculation show that to meet a nighttime level of 50dB a 1MTPY DAC facility would need to be 3km from the nearest residential building.
- The size of a potential Air2MeOH plant has not been determined but is unlikely to be using 1M tonne of CO_2/year. So as a starting point we will site the plant ~1km from the nearest residential building.
- While an Air2MeOH facility could be sited anywhere in the country this analysis will use two example locations, one in Virginia near Richmond and one in upstate NY near Schenectady.



Sites utilized to determine community impacts

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Community Benefits Plan

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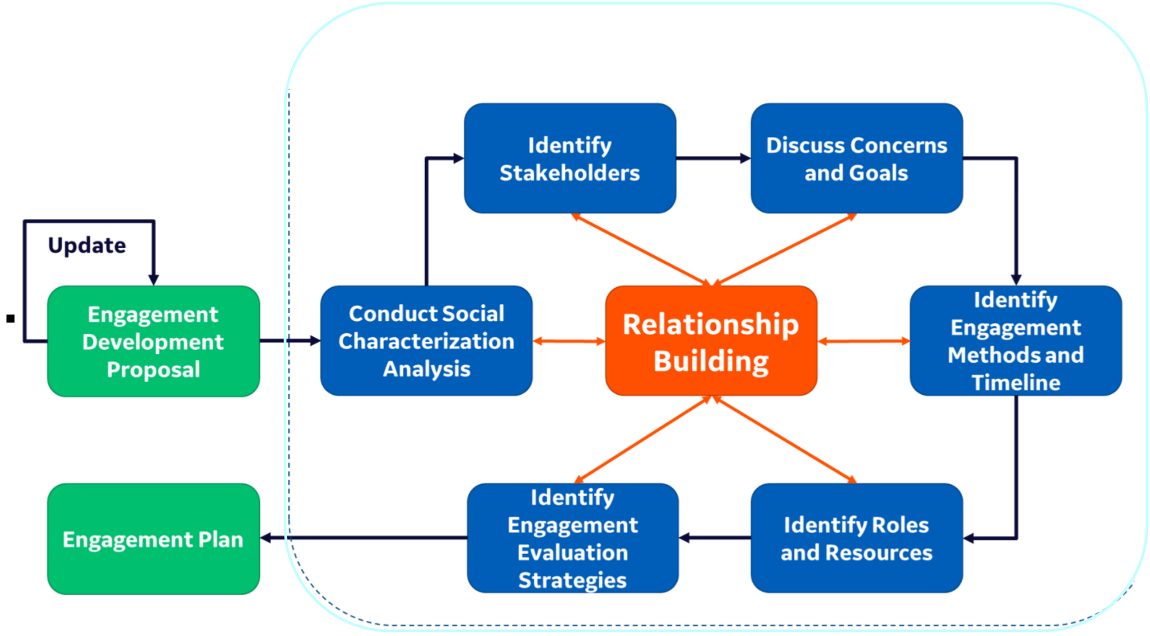
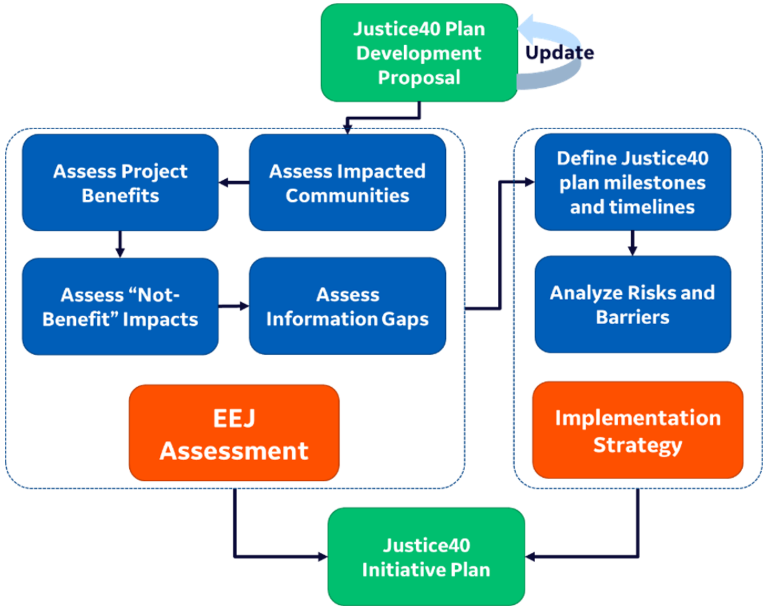
Community Benefits Plan Development Proposal (CBPDP) -> Community Benefits Plan (CBP)



Community Engagement Workflow



Justice 40 Workflow

University of Texas Bureau of Economic Geology will sub-contract with Lamar University to develop a plan for community outreach, quality jobs plan, DEIA training and Justice40 Initiative.

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BACKUP

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Air2MeOH Team

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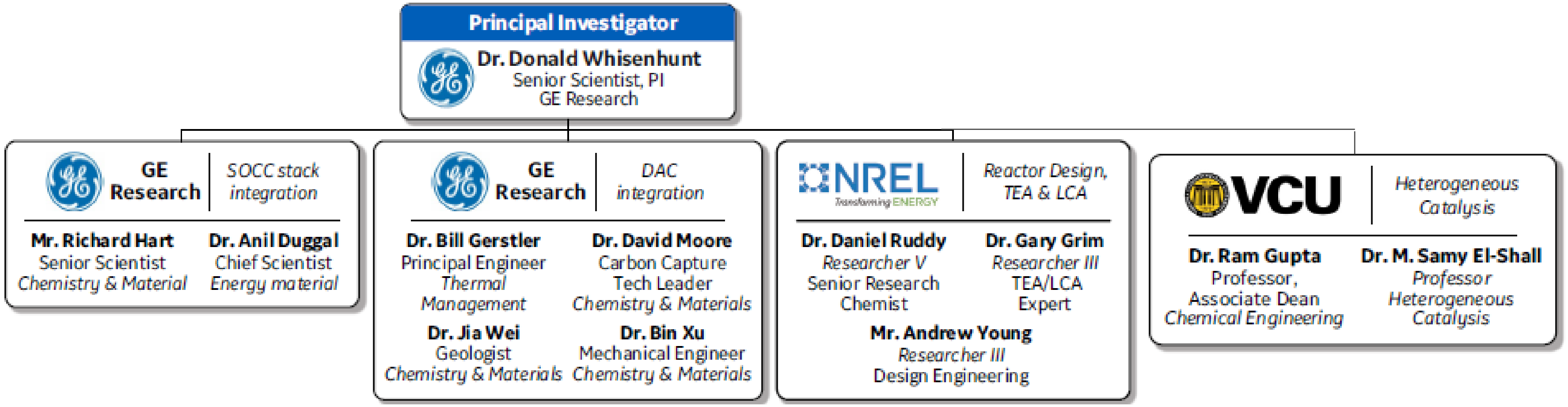

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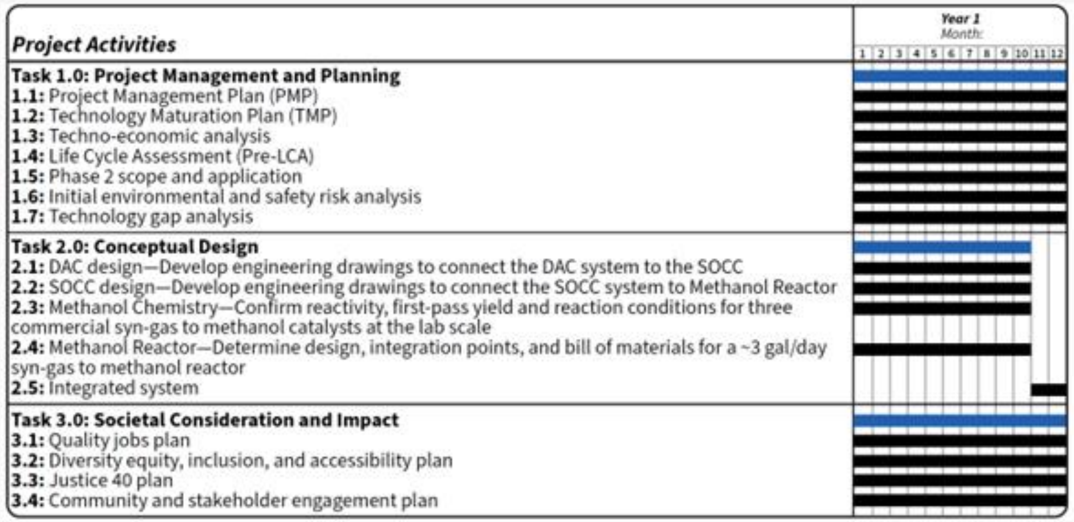
SOPO - Timeline



Task/ Subtask	Deliverable Title	Due Date
1.1	Project Management Plan	Update due 30 days after award. Revisions to the PMP shall be submitted as requested by the NETL Project Manager.
1.2	Technology Maturation Plan (TMP)	The initial TMP is due 90 days after award. Updates to the TMP shall be submitted, as needed, throughout the project period of performance. A final TMP is due at end of the 12-month technical period of performance.
1.3	State Point Data Table	Due at end of the 12-month technical period of performance.
1.4	Preliminary Techno-Economic Analysis (TEA)	Due at end of the 12-month technical period of performance.
1.5	Preliminary Life Cycle Analysis (LCA)	Due at end of the 12-month technical period of performance.
1.6	Technology Gap Analysis (TGA)	Due at end of the 12-month technical period of performance.
1.7	Technology EH&S Risk Assessment	Due at end of the 12-month technical period of performance.
2.0	Conceptual Design	Due at end of the 12-month technical period of performance.
3.0	R&D Community Benefits Plan (CBP)	Full package due at end of the 12-month technical period of performance; including Quality Jobs Plan, DEIA Plan, J40 Plan, Engagement Plan.
3.3	J40 PDP	Update due 90 days after award. Revisions shall be submitted, as needed, throughout the project period of performance.
3.4	Engagement PDP	Update due 90 days after award.

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