Efficient Integrated Methanol Synthesis Using Carbon from Direct Air Capture, Contract DE-FE0032400

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Project Objective

DOE Share = $400,000
Cost Share = $100,000
Total Project = $500,000

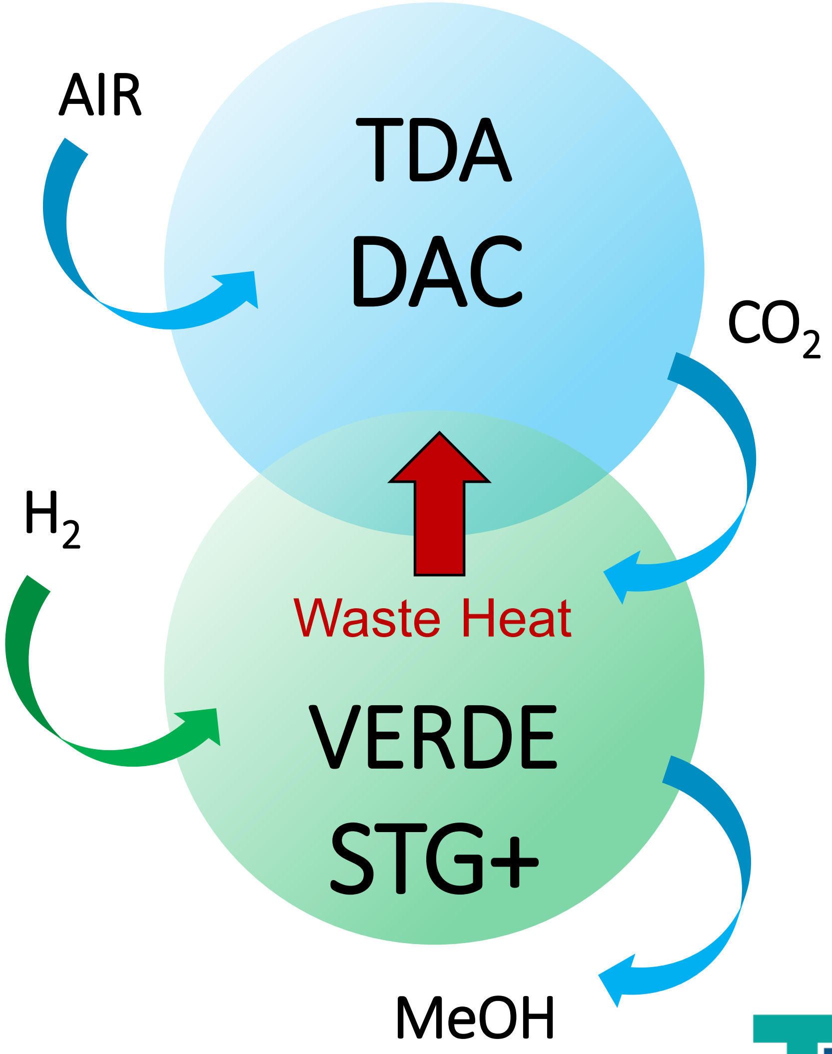
Technical PoP = 1 year

DE-FOA-0002614 AOI-2G

- Complete a Conceptual Design Study for an integrated Direct Air Capture (DAC) and Carbon Dioxide Utilization System (DACUS) that captures and utilizes CO_2 in an integrated methanol (MeOH) synthesis process
  - Design of a DACUS is based on Verde's STG+ process CO2 to methanol process that uses green H_2 to synthesize green methanol
  - with negative carbon emissions
- Project Objectives
  - Complete a **technoeconomic analysis (TEA)** for the integrated system
  - Complete a **Life Cycle Analysis (LCA)** for the system
  - Conduct a **technology gap analysis (TGA)**
  - Create a **technology maturation plan (TMP)**
  - Develop a **Community Benefits Plan (CBP),** including Quality Jobs Plan (QJP), Diversity, Equity, Inclusion, and Accessibility (DEIA) Plan; Justice40 (J40) Plan

Introduction

- New DACUS process removes CO_2 from air and converts it into “green methanol” via a thermochemical process
- The H_2 used in the methanol synthesis is generated via electrolysis of water using renewable energy
- Methanol could be used as a fuel or H_2 carrier and it is a building block chemical that can be converted into other chemicals and fuels
    - E.g., synthetic green gasoline via ExxonMobil’s MTG process
- Combines two transformational technologies
    - TDA’s DAC process
    - Verde’s STG+ process

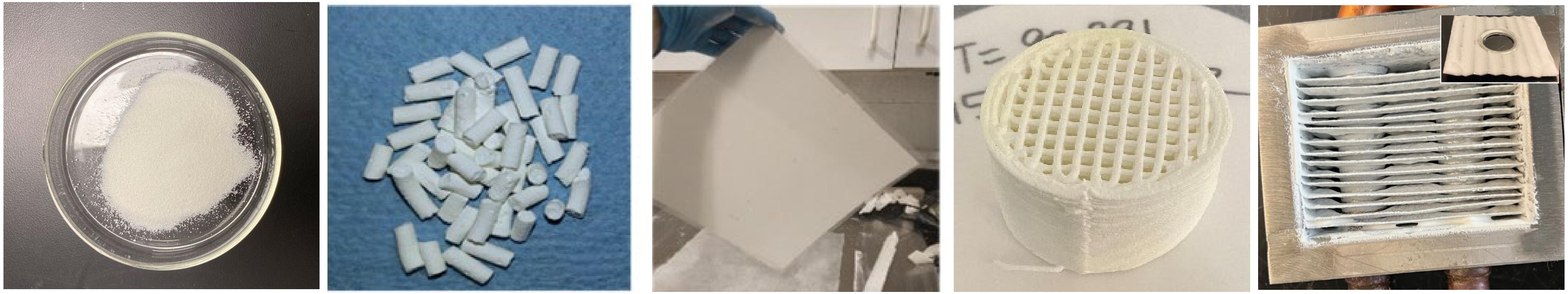


Verde's Clean Fuel Technology

Verde Clean Fuels is a publicly traded company in NASDAQ, specializes in converting municipal waste and biowaste to methanol or gasoline

TDA's Sorbent for DAC

- **TDA has been developing a new polymer sorbent for DAC and life support applications (DE-SC-00020846, 80NSSC18C0135, N00178-18-C-8009)**
  - **Sorbent has very high CO_2 uptake in dilute gas streams (e.g., 400 ppm CO_2 in air; 2,500 ppm spacecraft cabin; up to 5,000 ppm in submarines)**
  - **The sorbent maintains its stability at high temperatures**
- **The sorbent can be prepared in the form of pellets, laminates, 3D printed monoliths, and as coated layers on HEX surfaces**

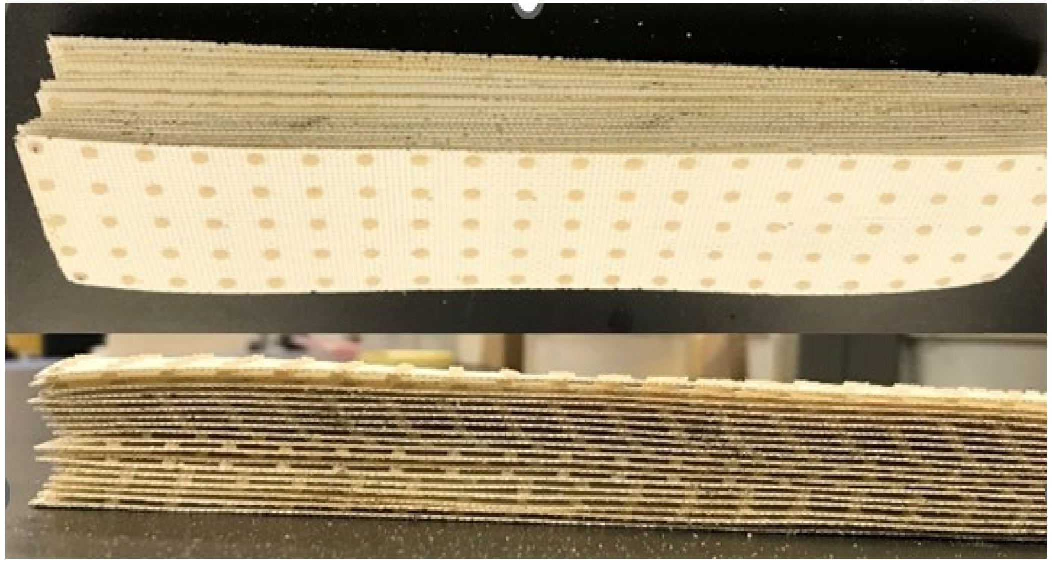


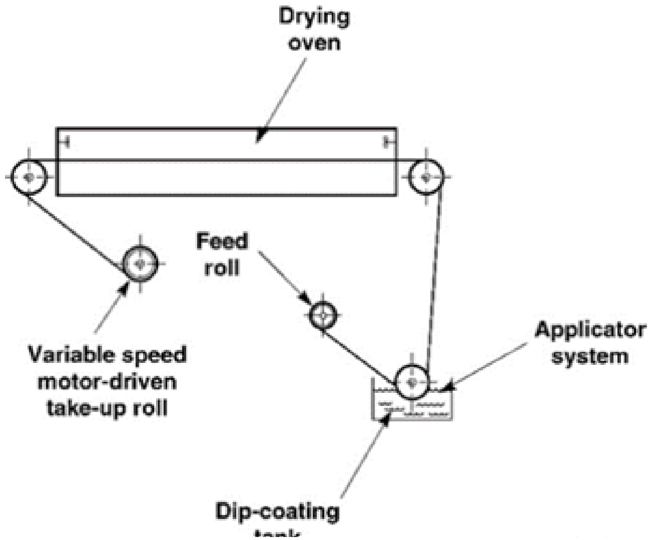
(a) *(b)* *(c)* *(d)* *(e)*

Various forms of polymer sorbent: (a) powder (b) pellets (c) single laminate layer (d) 3D printed monolith (e) applied as a coating on HEX surfaces

Preparation of Structured Sorbent

12" x 12" laminate





Scale-Up is in progress in collaboration with Membrane Technology Research (DE-FE0032151)

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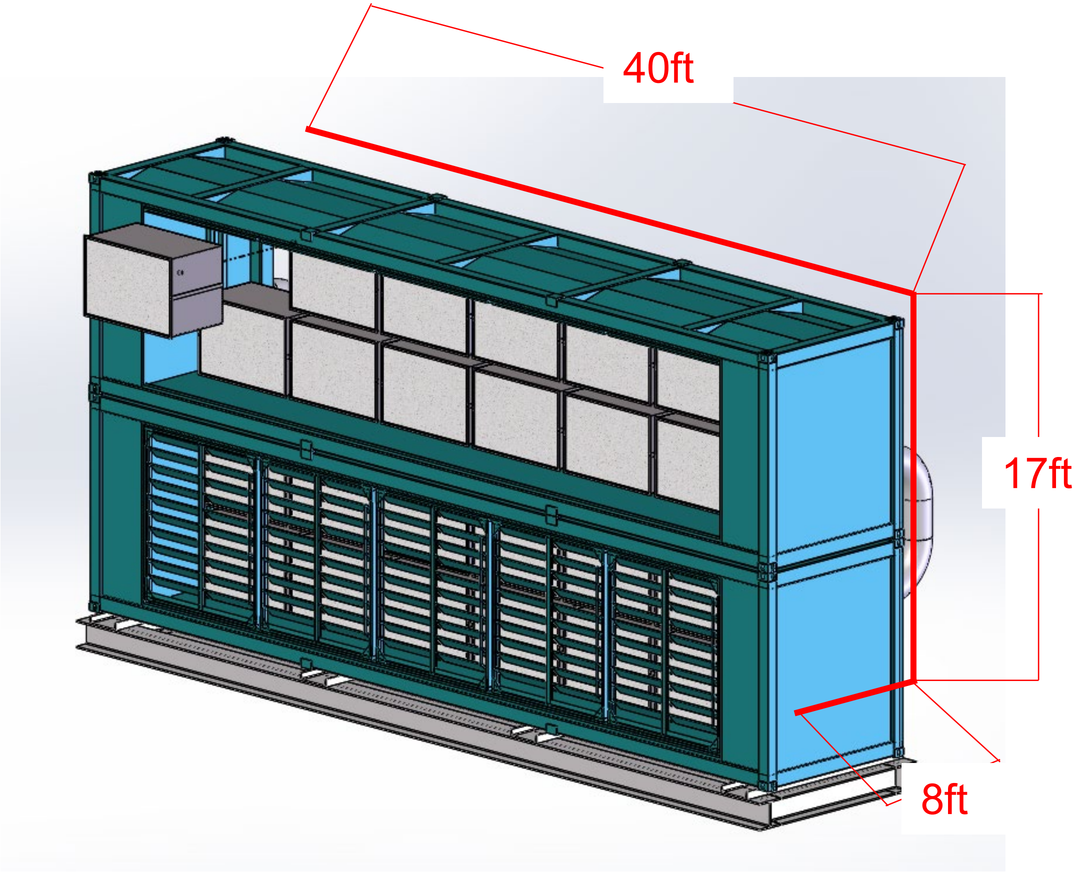
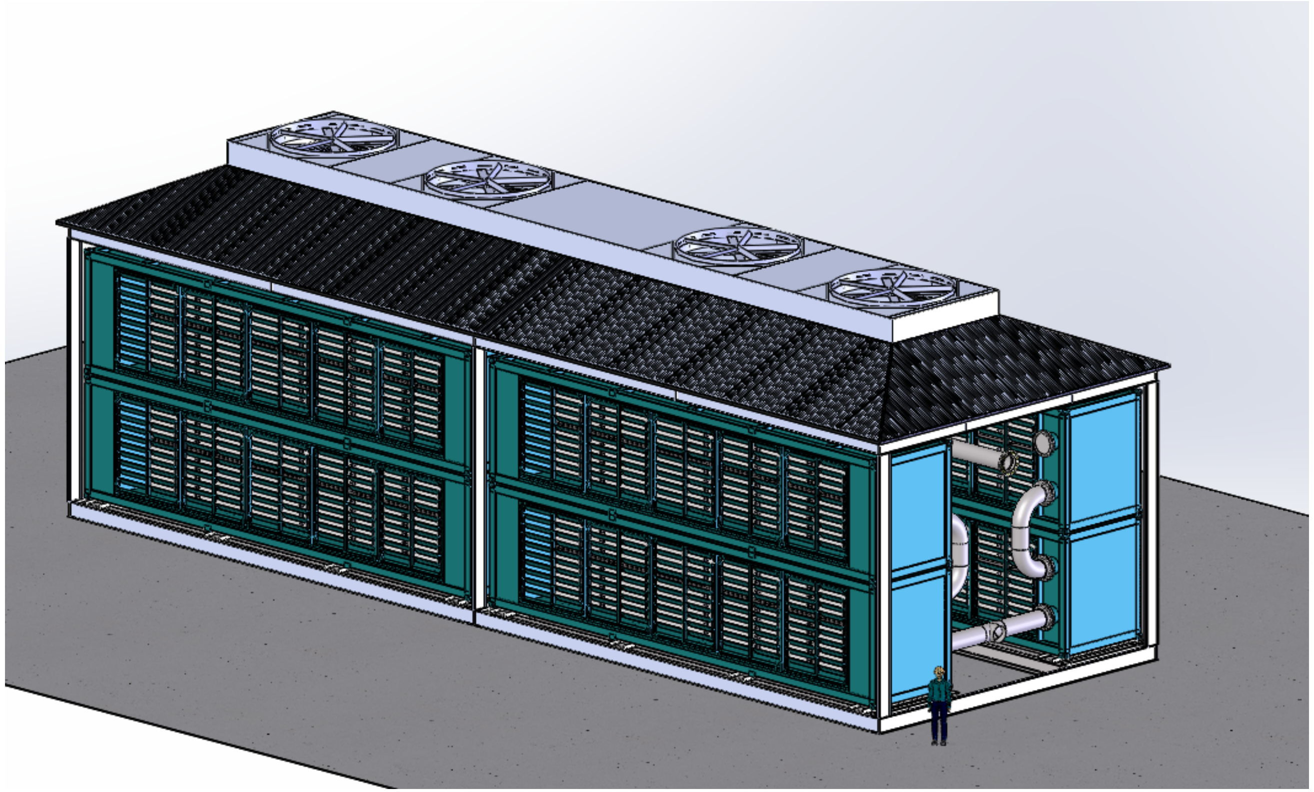
Design of DAC System

- Modular Design with easy to install Sorbent Cartridges
- Each contactor designed to the dimensions of a 40ft shipping container to allow for ease of transportation and installation





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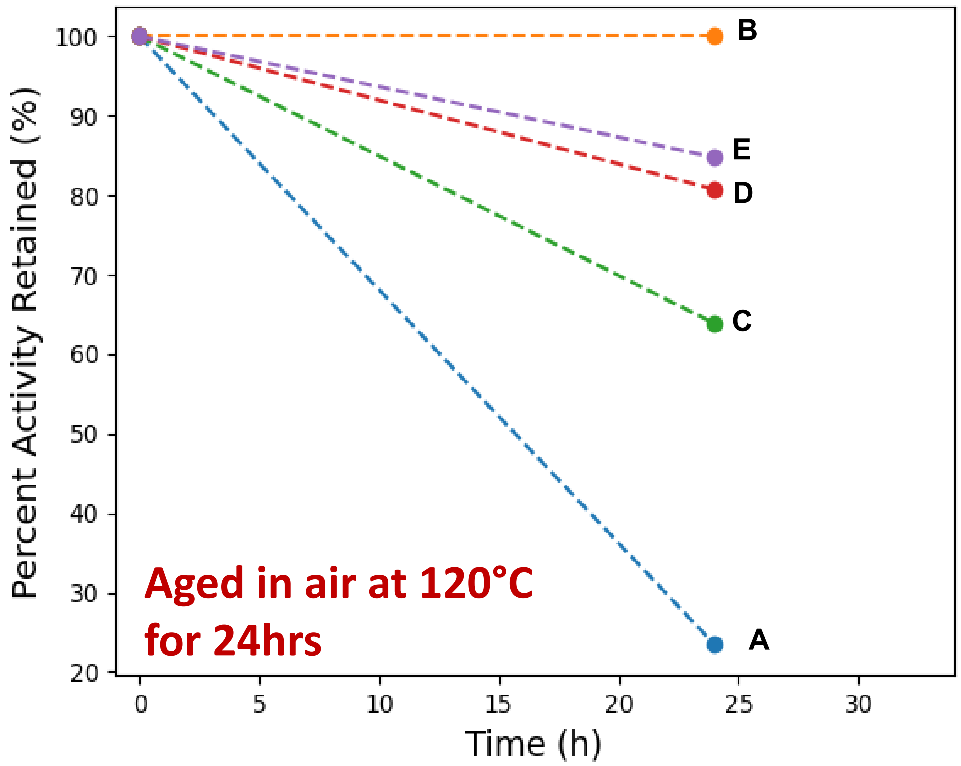
System Design

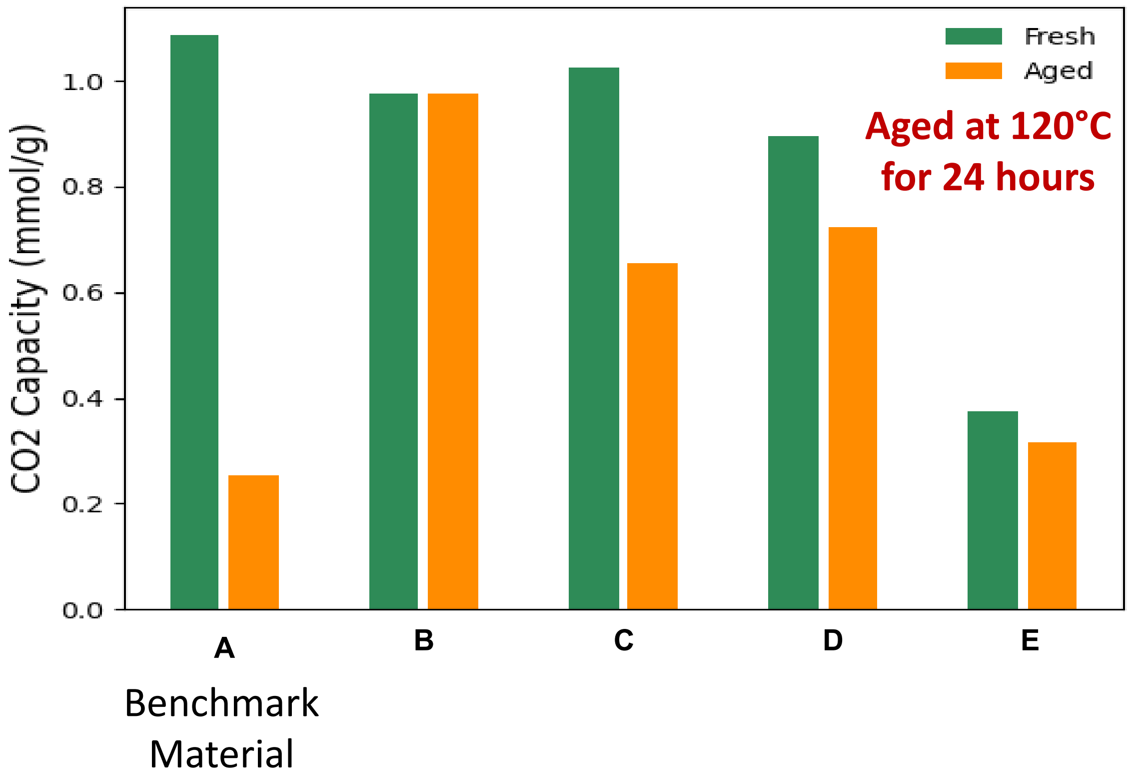
- Design Basis:
  - 100,000 MTPY CO_2 captured
  - 72,206 MTPY MeOH produced
- CO2 Capture Efficiency – 90%
- Laminate microchannel contactor design
  - 10-15 mbar pressure drop
- TSA adsorption cycle
  - Adsorption at 15-40°C
  - Regeneration at 100+°C

Preliminary Carbon Balance:

Inputs	kmol/h	mol frac C	kmol/h C
Atmospheric Air	729,009	400 ppm	288
Outputs			
Exhaust Air	728,747	40 ppm	29
Crude Methanol	461	0.56	257
Vent Gas	4	0.44	2

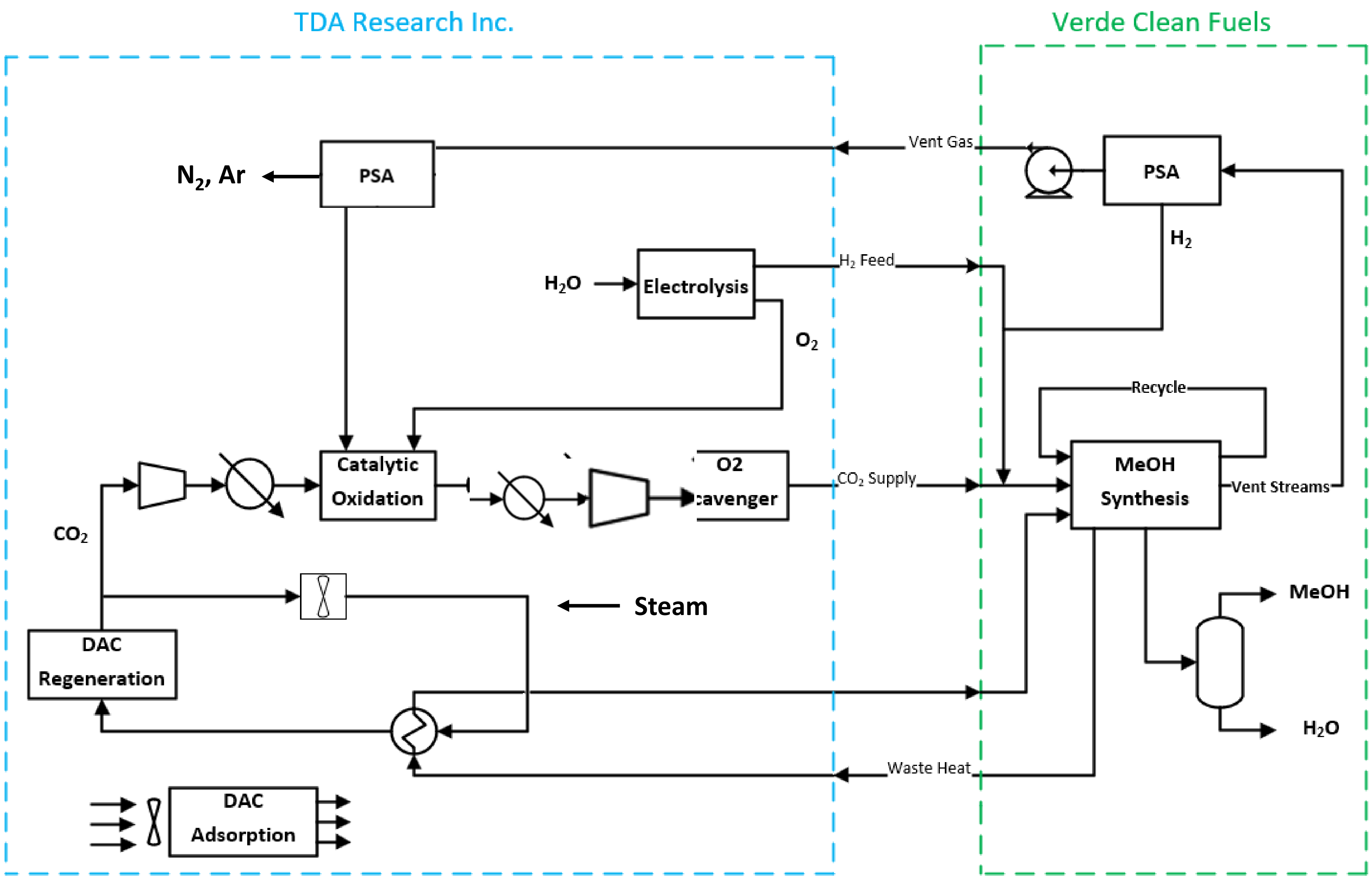
High Temperature Oxidative Stability





- TDA identified several formulations that can provide high temperature oxidative stability
- An aggressive test method is used to accelerate aging effects in air for 24 h at 120°C under dry conditions
- CO_2 uptake performance is tested before and after the aging test in a 5 min concentration swing cycle at 60°C

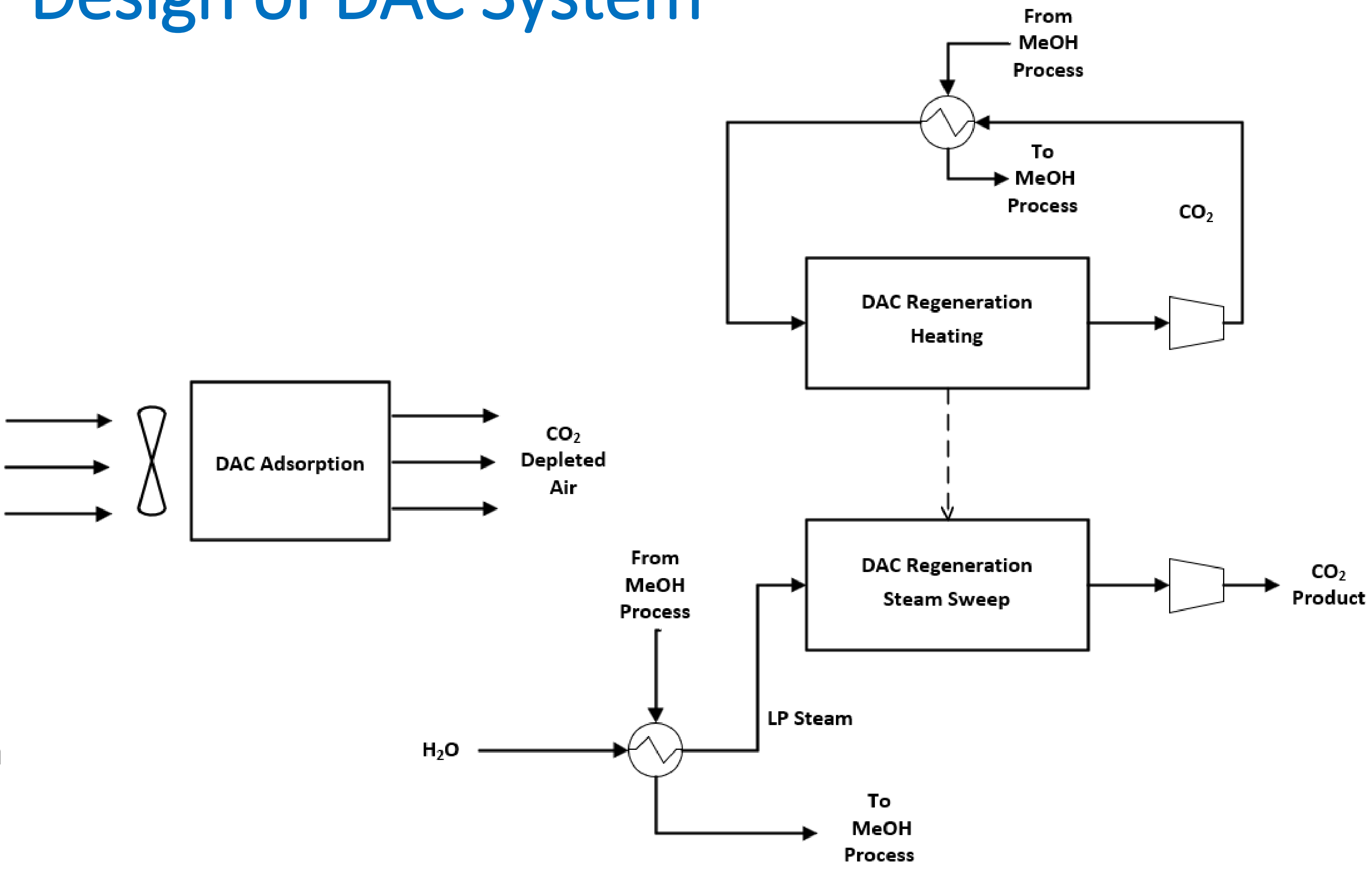
Integrated Process Summary



Design of DAC System

<u>Process Steps</u>

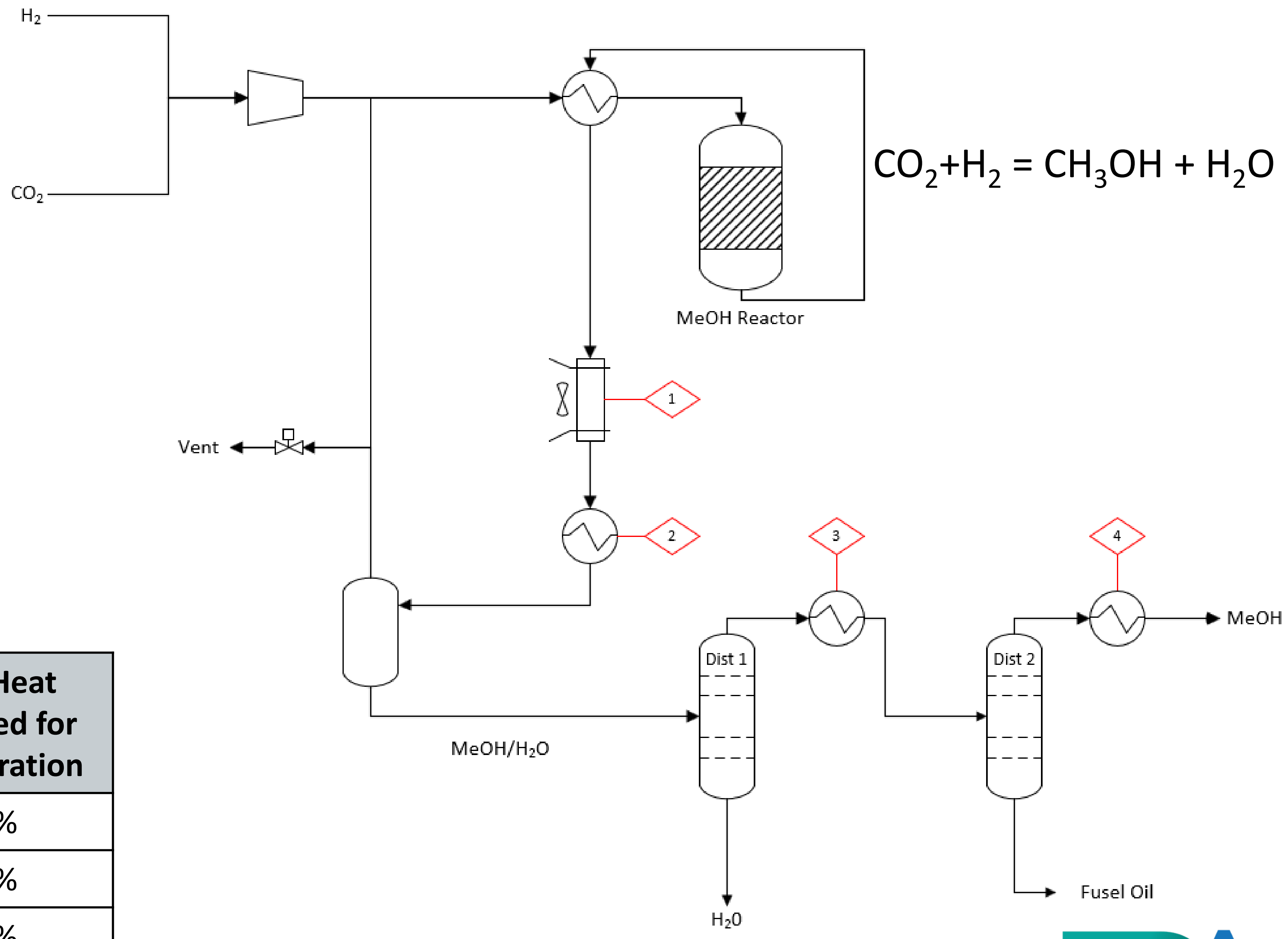
- Fan draws air across structured sorbent which captures CO_2 ,
- Contactor is then isolated to begin the regeneration process.
- Product CO_2 is heated and recirculated to pre-heat the sorbent.
- Steam sweep under slight vacuum is used to remove the adsorbed CO_2
- CO_2 is is compressed and sent to a MeOH synthesis reactor.
- Fans and compressors operate continuously.



Heat Integration

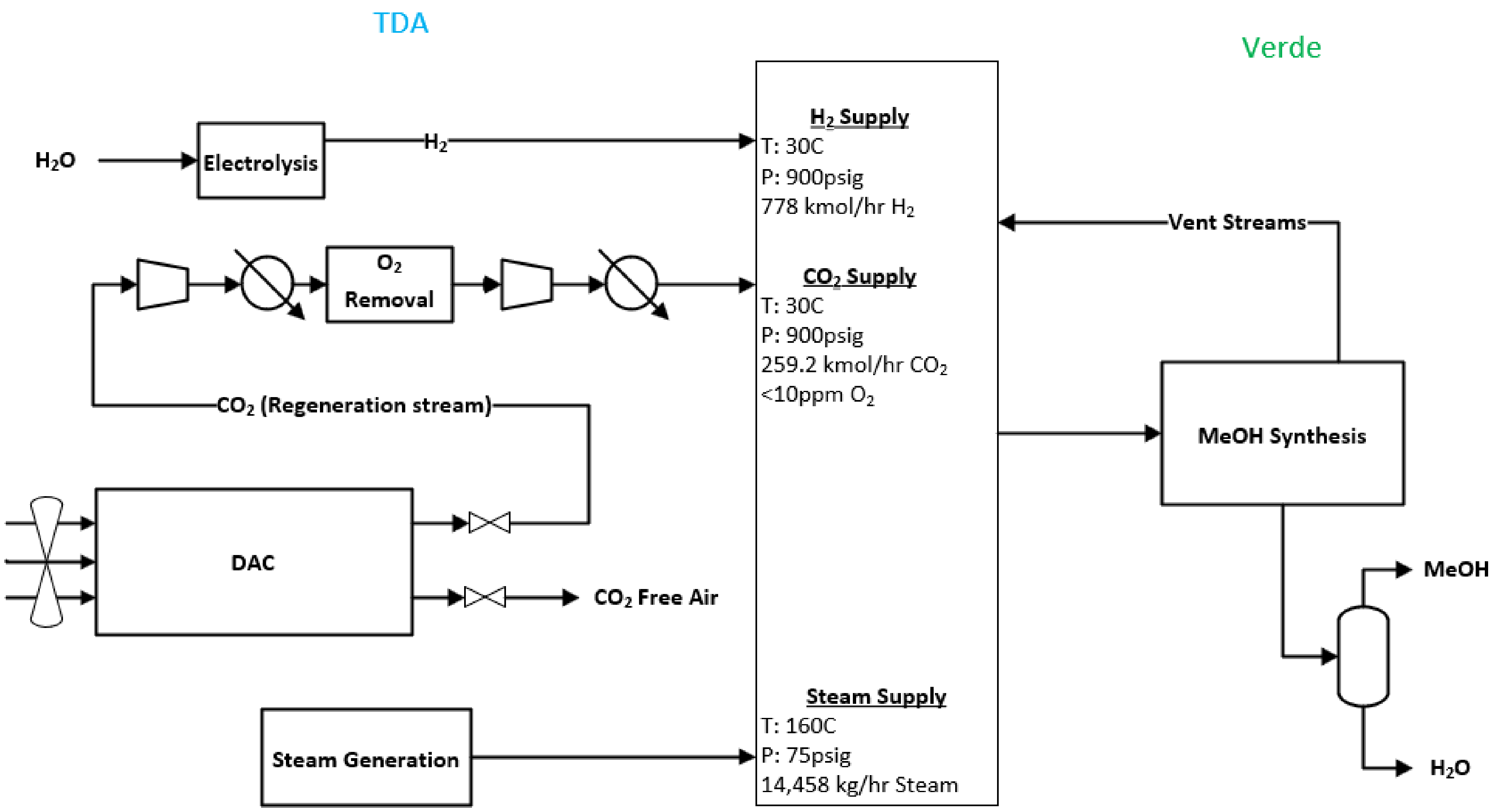
- MeOH synthesis is exothermic where this heat (potentially) can be used for regenerating the DAC sorbent
- MeOH reactor effluent can be cooled by raising low pressure steam for regeneration
- Additional heat sources include the overhead streams in distillation

Heat Integration Point	Available Heat (MMBTU/hr)	% of Heat Required for Regeneration
1	13.4	25%
2	11.4	21%
3	13.0	24%
4	16.8	31%



$$CO_2 + H_2 = CH_3OH + H_2O$$

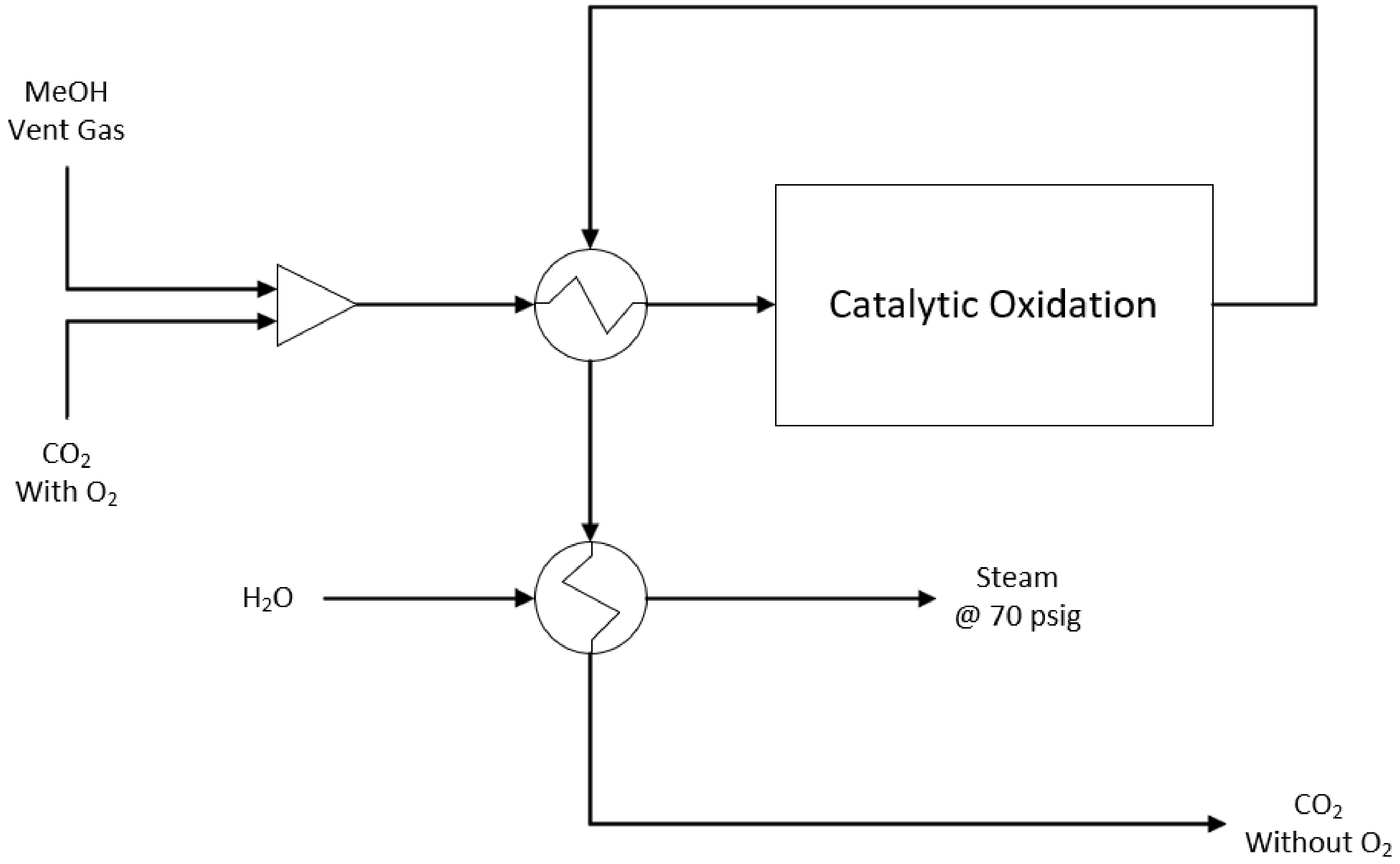
DAC Output Requirements



- CO_2 and H_2 supplied at 900 psig at a 1:3 carbon to hydrogen ratio
- Steam generated from vent gas combustion is saturated at 75 psig
  - Used for MeOH distillation

Heat Integration (Steam Generation)

- After adsorption, air is present in the contactor void space and is captured during regeneration
- O_2 must be removed prior to MeOH synthesis to protect Verde's catalyst
- Using catalytic oxidation, we can remove O_2 from the CO_2 stream and raise steam to support MeOH distillation
- MeOH vent gas is burned with O_2 in CO_2 stream



Life Cycle Analysis

- UC Denver will lead the LCA work
  - Dr. Arunprakasj Karunanithi's group
- Calculate carbon footprint of the DAC system
  - Cradle to gate basis – mining, shipping, construction, etc.
  - Explore design approaches to mitigate upstream impacts
- Sensitivity Analysis on critical inputs to minimize CO_2 generation and optimize CO_2 consumption
- Preliminary analysis assumptions:
  - All electricity is renewable
  - Waste heat supplied by STG+

Work Plan

- Task 1. Project Management and Planning
  - Task 1.1 Project Management Plan (PMP)
  - Task 1.2 Technology Maturation Plan (TMP)
  - Task 1.3 State Point Data Table
  - Task 1.4 Preliminary Technoeconomic Analysis (TEA)
  - Task 1.5 Preliminary Life Cycle Analysis (LCA)
  - Task 1.6 Technology Gap Analysis (TGA)
  - Task 1.7 Technology Environmental Health (EH&S) and Safety Risk Assessment
- Task 2. Community Benefits Plan (CBP)
- Task 3. Experimental Work/Validation
- Task 4. Process Design
- Task 5. Design of the DAC Contactor
- Task 6. Heat Integration and Thermal Management

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