# Scale-Up and Testing of Advanced Polaris Membrane CO$_2$ Capture Technology (DE-FE0031591)

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National Energy Technology Laboratory
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# Outline

- Project overview

- Technology background

- Project objectives

- Progress to date

# Project Overview

**Award name:** Scale-Up and Testing of Advanced Polaris Membrane $CO_2$ Capture Technology (DE-FE0031591)

**Project period:** 8/1/18 to 12/31/21

**Funding:** $8.2 million DOE; $2.6 million cost share ($10.7 million total)

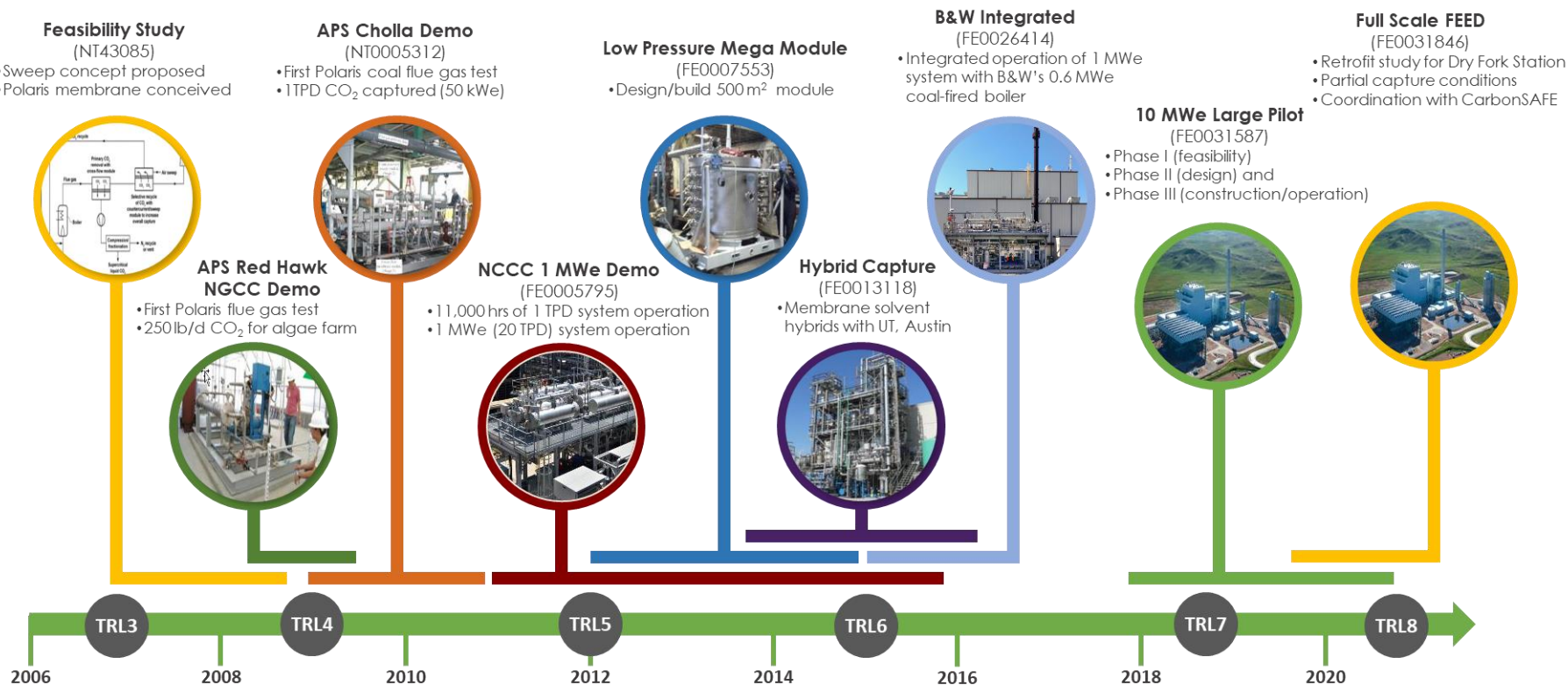**DOE program manager**: Isaac "Andy" Aurelio

**Participants:** MTR, TCM, Trimeric, Siemens/Dresser Rand, WorleyParsons

**Project scope:** Design, build, and operate a system at TCM with Gen 2 Polaris modules

**Project plan**: The project is organized in three phases:

- **Phase 1** – Design system, fabricate membrane

- **Phase 2** – Build and install system at TCM

- **Phase 3** – Operate system, analyze results, decommissioning

# MTR/DOE Development Timeline



**Feasibility Study**
(NT43085)
- Sweep concept proposed
- Polaris membrane conceived

**APS Cholla Demo**
(NT0005312)
- First Polaris coal flue gas test
- 1TPD $CO_2$ captured (50 kWe)

**Low Pressure Mega Module**
(FE0007553)
- Design/build 500 $m^2$ module

**B&W Integrated**
(FE0026414)
- Integrated operation of 1 MWe system with B&W's 0.6 MWe coal-fired boiler

**Full Scale FEED**
(FE0031846)
- Retrofit study for Dry Fork Station
- Partial capture conditions
- Coordination with CarbonSAFE

**10 MWe Large Pilot**
(FE0031587)
- Phase I (feasibility)
- Phase II (design) and
- Phase III (construction/operation)

**APS Red Hawk NGCC Demo**
- First Polaris flue gas test
- 250 lb/d $CO_2$ for algae farm

**NCCC 1 MWe Demo**
(FE0005795)
- 11,000 hrs of 1 TPD system operation
- 1 MWe (20 TPD) system operation

**Hybrid Capture**
(FE0013118)
- Membrane solvent hybrids with UT, Austin

TRL3 — TRL4 — TRL5 — TRL6 — TRL7 — TRL8

2006    2008    2010    2012    2014    2016    2018    2020
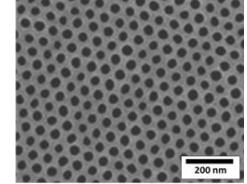
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# Current MTR Projects

**Self-Assembly Isoporous Supports, CA (DE-FE31596)**
- Transformational new membrane (TRL 3 – 4)
- Reduces membrane area and energy use
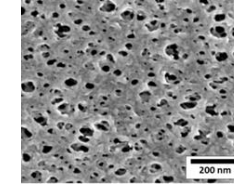

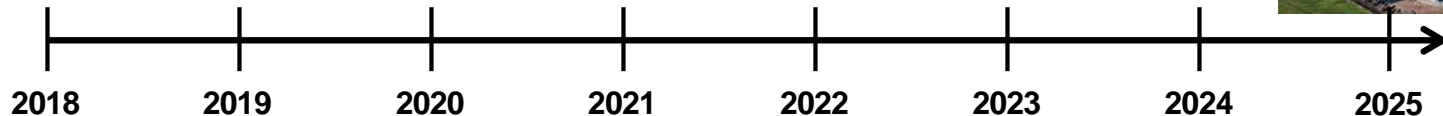Surface of Conventional Support    Surface of Isoporous Support
200 nm    200 nm

**Pilot Testing at TCM, Norway (DE-FE0031591)**
- Gen 2 Polaris™ membrane
- Low pressure-drop modules
- Containerized skid, 1 MW pilot scale



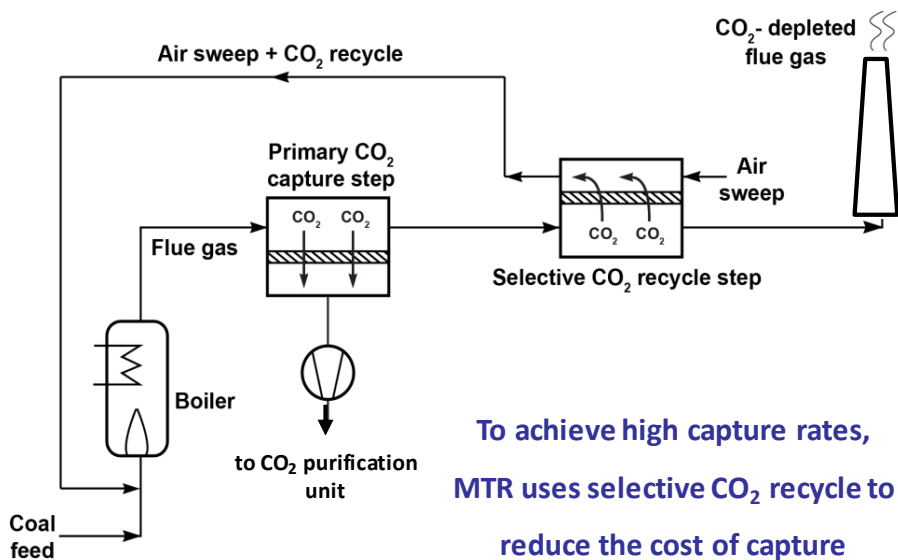**Large-Pilot Testing at WY ITC, WY (DE-FE31587)**
- Phase I – Design 200 TPD pilot; secure host site
- Phase II – FEED and permitting
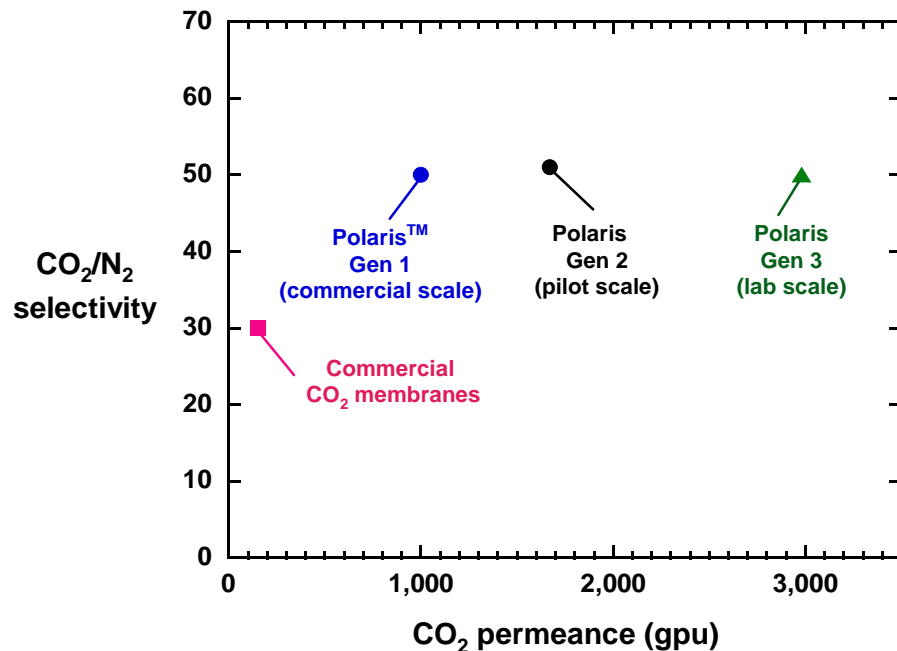- Phase III – Fabricate, install and operate (TRL 7 – 8)



2018    2019    2020    2021    2022    2023    2024    2025

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# Background: Process & Material Developments

## Selective Exhaust Gas Recycle Design



Air sweep + CO$_2$ recycle

CO$_2$- depleted flue gas

Primary CO$_2$ capture step

CO$_2$  CO$_2$

Flue gas

Air sweep

CO$_2$  CO$_2$

Selective CO$_2$ recycle step

Boiler

to CO$_2$ purification unit

Coal feed

U.S. Patents 7,964,020 and 8,025,7

**To achieve high capture rates, MTR uses selective CO$_2$ recycle to reduce the cost of capture**

## Polaris™ Membranes



CO$_2$/N$_2$ selectivity

Polaris™ Gen 1 (commercial scale)

Polaris Gen 2 (pilot scale)

Polaris Gen 3 (lab scale)

Commercial CO$_2$ membranes

CO$_2$ permeance (gpu)

- Selective recycle to boiler was validated in testing at B&W
- Gen 1 Polaris evaluated in extensive testing at NCCC (>11,000 hours)

# Background:  Small Pilot at NCCC



- Membranes are simple and compact
- MTR pilot system was tested at NCCC and B&W



- Conducted comparison of Gen1 and 2 membrane
- $CO_2$ removal performance was good, but pressure drop was relatively high

MTR 20 TPD membrane system
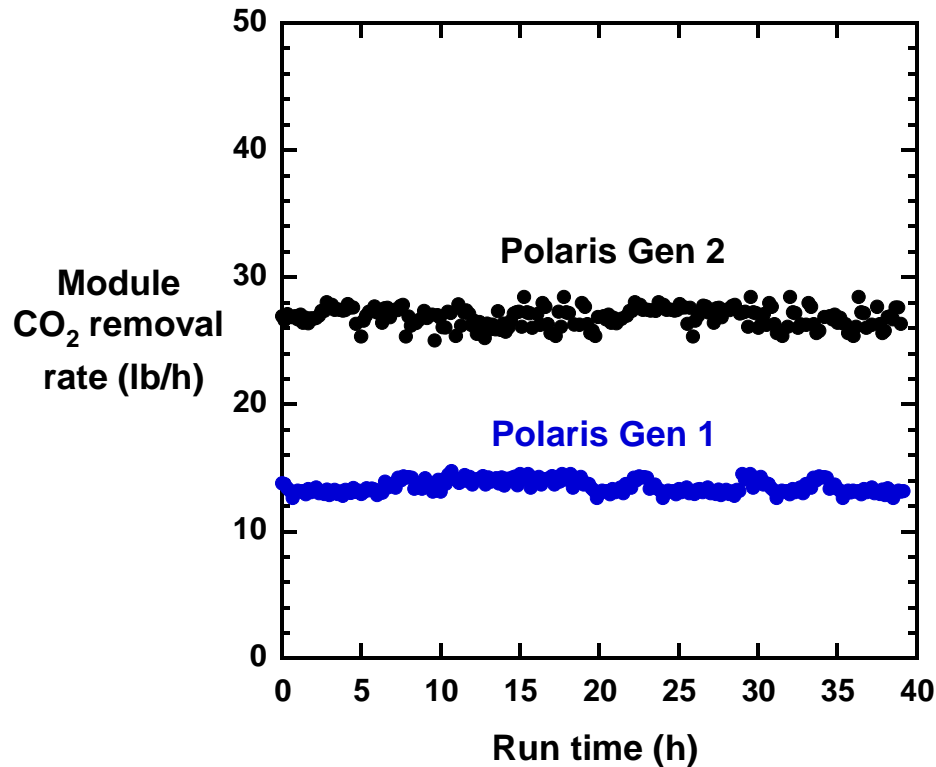Advanced 20 TPD solvent system
NCCC 10 TPD solvent system

# NCCC Testing Confirmed Better Gen2 Performance



**Stamp tests at MTR**
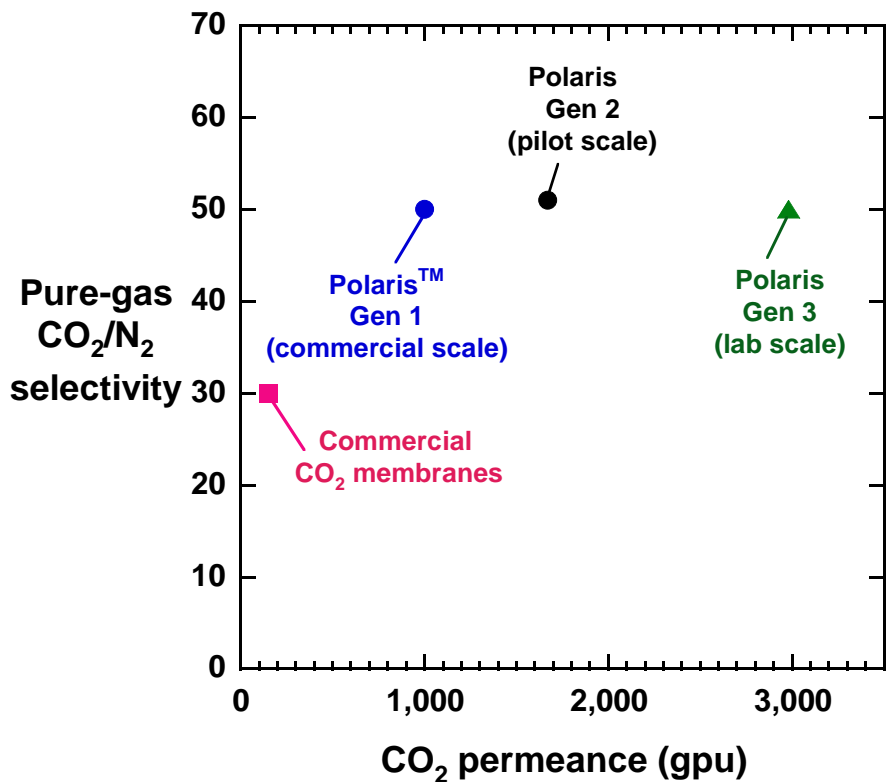
**Module tests at NCCC**

- Higher permeance reduces capital cost and footprint
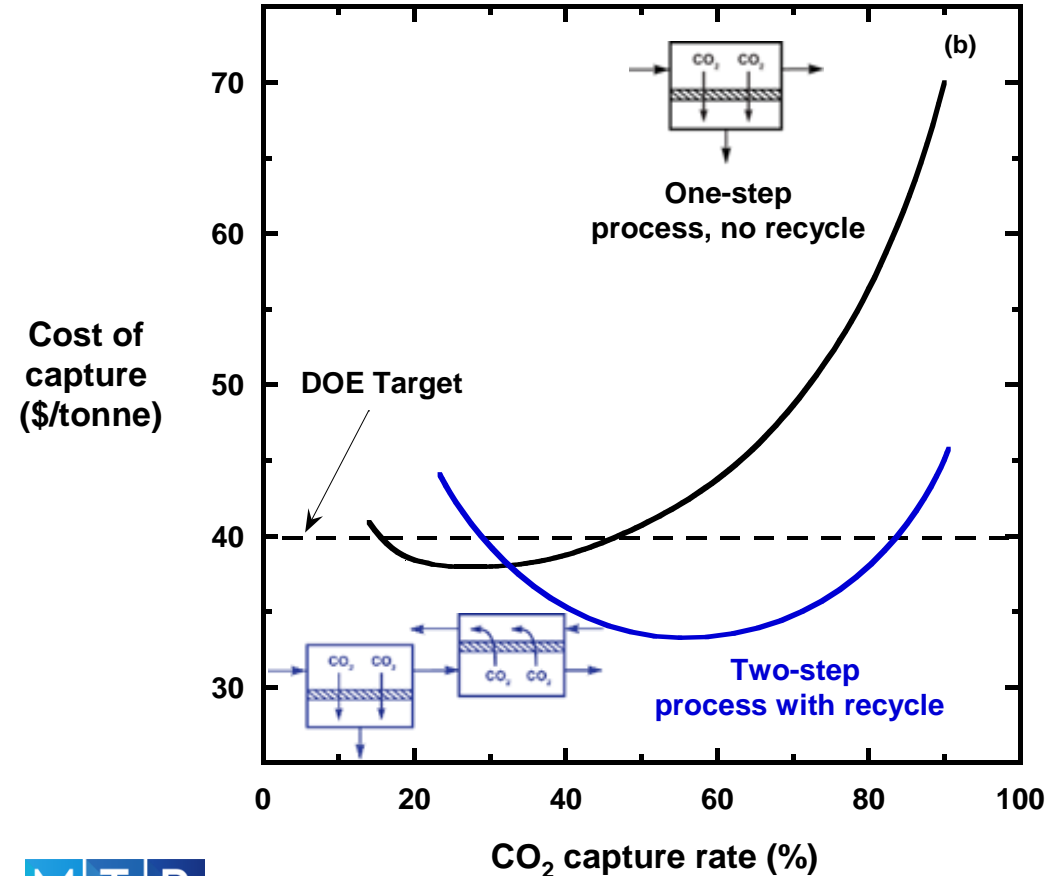
# New Modules Have Lower Pressure Drop

## Module size



New module          Main skid

## Module pressure-drop



Sweep pressure drop (psi)

Spiral with flue gas

Plate-and-frame with flue gas

Plate-and-frame lab data

Sweep flowrate (lb/h)

- Reduced pressure-drop with new module saves ~15 $MW_e$ of energy at full-scale
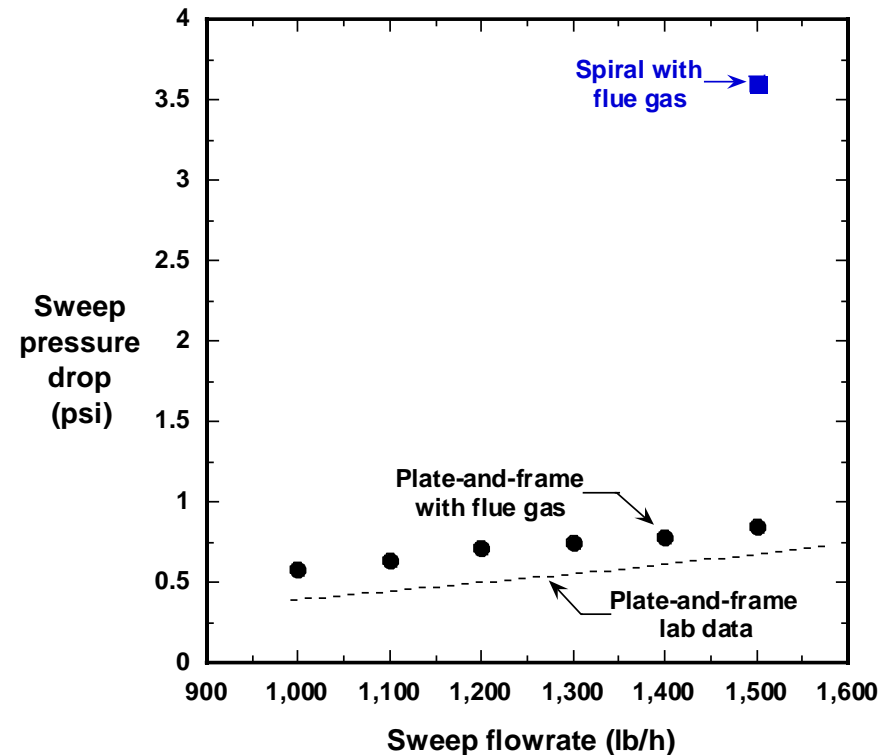
# Membrane Capture Cost vs Rate



- Membranes are best for bulk separations. There is a sweet spot for the technology between 50 – 80% capture

- Selective recycle design reduces capture cost by as much as $25/tonne at 90% capture (including boiler de-rate measured at B&W)

# Project Objectives

- Scale-up Gen 2 Polaris packaged in low-pressure-drop, low-cost module stacks and test at TCM

- Demonstrate "containerized" skid as final form factor for future large-scale systems

- Test pilot system (~1 MW) over range of $CO_2$ capture rates and feed $CO_2$ content

- With partners, update TEA

# TCM Test Will Use Improved Modules
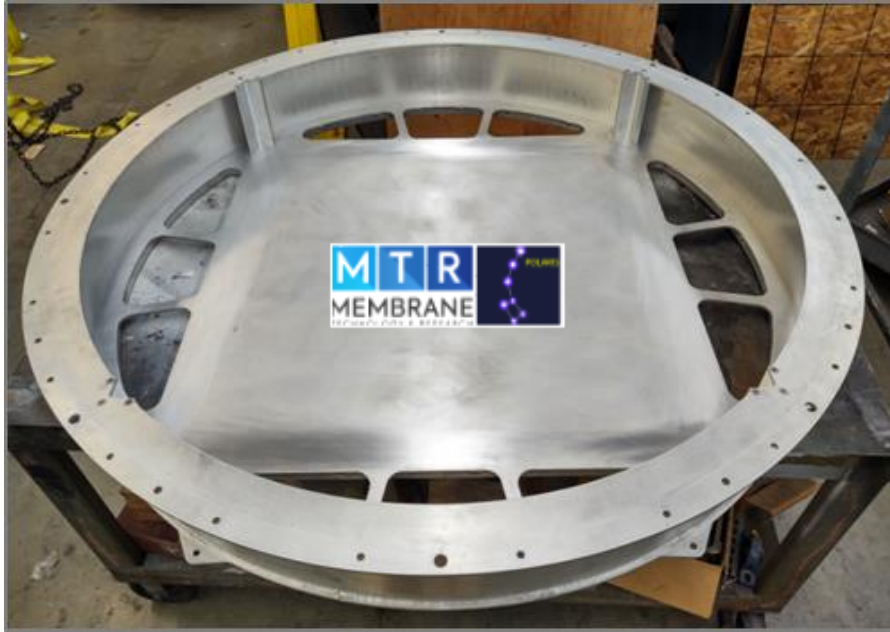
**Prototype at NCCC/B&W 2015-17**



**Polaris Planar Stack at TCM 2021**
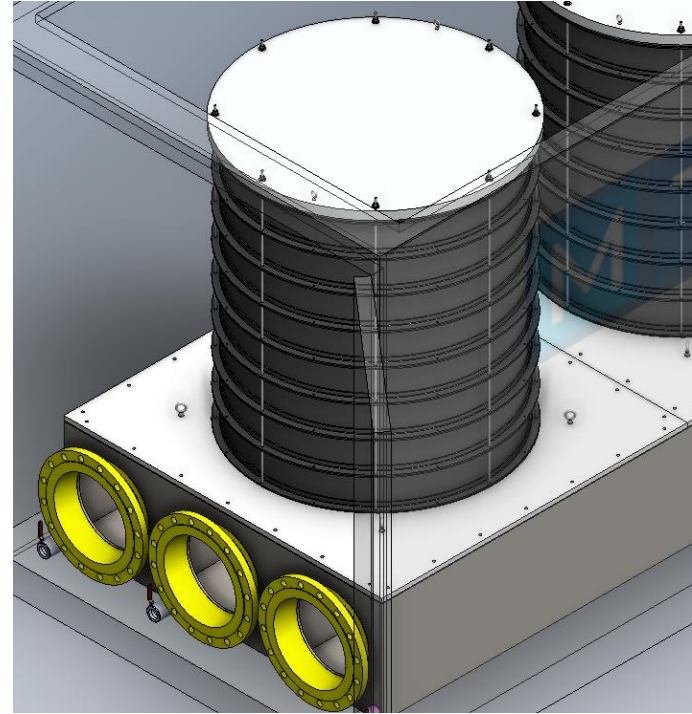


- New module housing is low-cost, lightweight

# Planar Modules Have Been Assembled

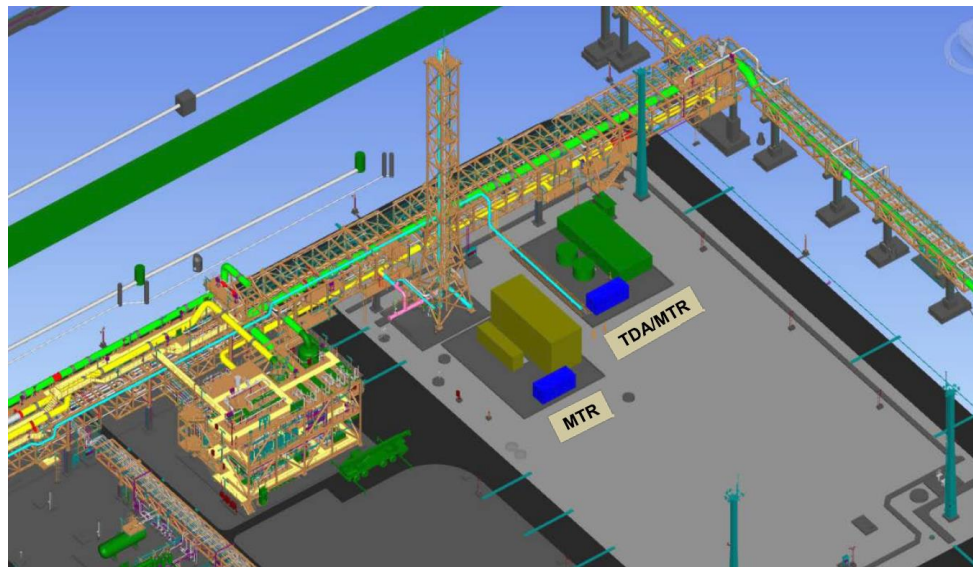**A Single Planar Polaris Module**



**A Module Stack**



- All Polaris membrane modules for TCM test skid have been finished and Q/C tested

# Containerized Skid at TCM

**Cutaway of Container Skid
with Membrane Stacks**

**Layout for Skid at TCM**



- Membrane skid will be installed at TCM "3rd site" being developed for new technologies

# TCM Site Preparation

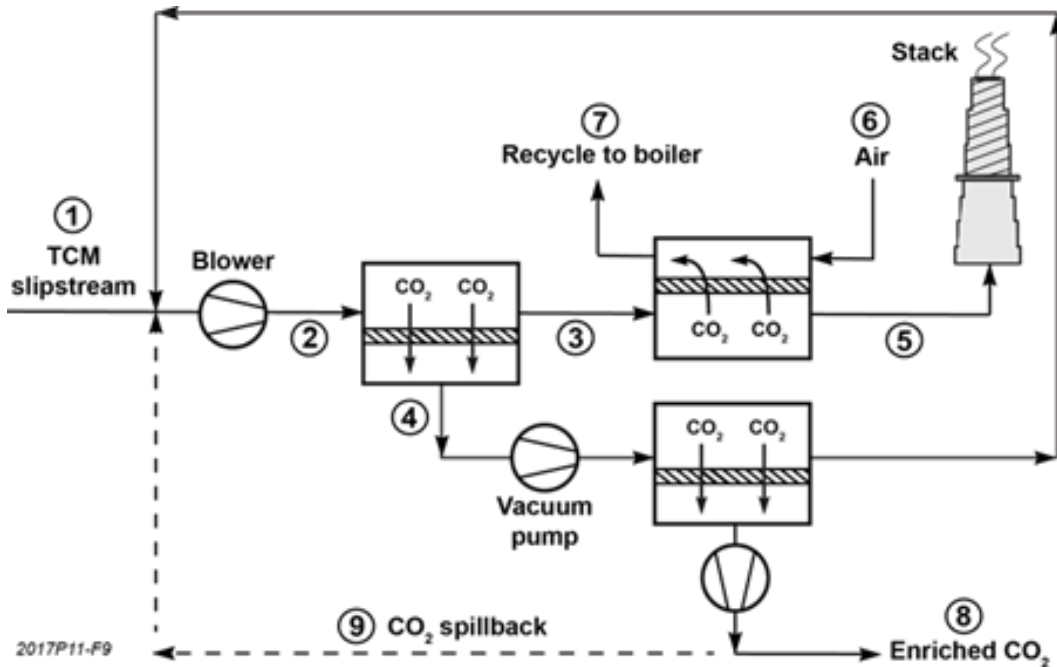**View of TCM with 3rd site in foreground**

**Close up view of 3rd site foundation**

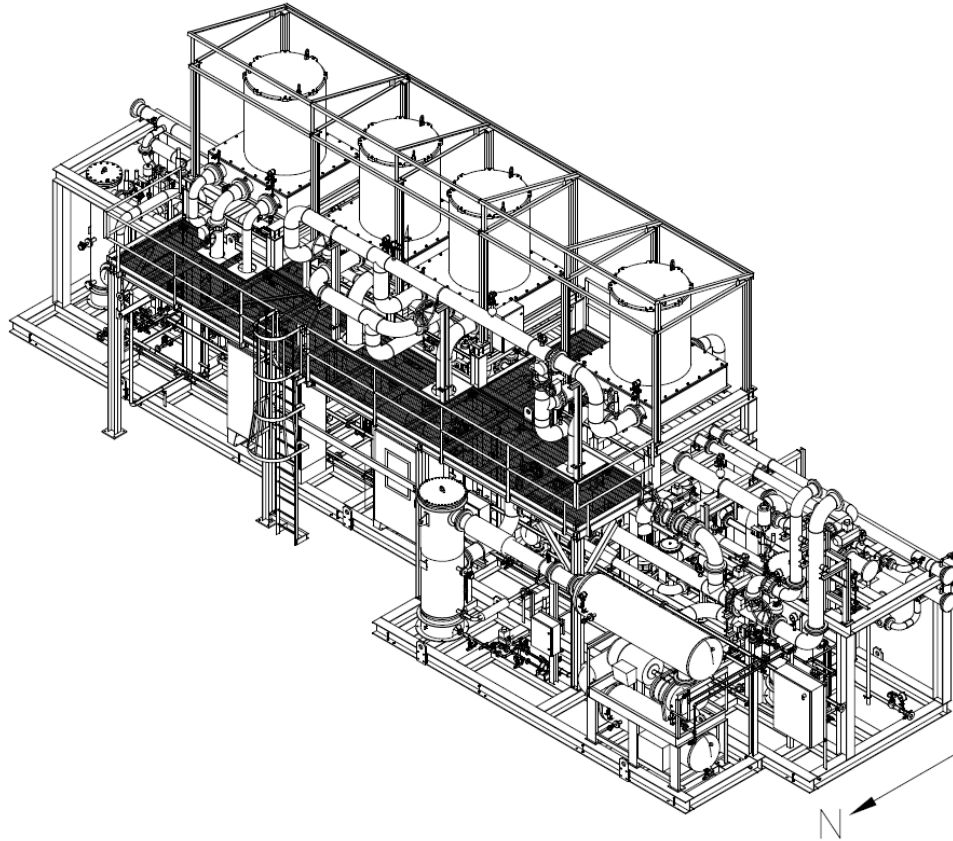



- Site is ready for system installation

# Membrane Skid Design



- 2 stage system with ability to test air sweep step (stream 5) and varying feed $CO_2$ content using recycle (stream 9)

- Can test a range of capture rates from 50-90%

- System will produce ~85% $CO_2$; does not include CPU

- Skid design finalized at the end of 2019 after Hazop with TCM

# Membrane Skid GA Drawing



- System contains four membrane module stacks on the top floor container

- Bottom floor houses fans, vacuum pumps, controls, BOP

- Construction is ongoing and has been impacted by Covid-19; supply chain and fabricator delays

- FAT now scheduled for end of October

# Preliminary Test Plan

- Vary capture rate without sweep step or spillback

- Vary capture rate with sweep step using spillback to mimic enriched $CO_2$ feed content

- During these parametric steady state tests, monitor separation efficiency, system pressure drops, and gas compositions to CPU

- Run dynamic tests (startup/shutdown, load change) to document membrane response time

- At end of program, vary particulate feed to system and monitor fouling/pressure drop

- Final test plan to include input from CCSI2

# Current Status

- All Gen 2 Polaris membrane modules have been made and Q/C tested; ready for installation on the TCM skid

- System is under construction; FAT is planned for the end of October

- TCM site preparation is complete; ready to receive system

- Plan is for skid to be delivered to TCM and positioned at site by the end of the year

- Testing at TCM (BP3) planned for first half of 2021

# Path Forward: Large Pilot System



Treated gas to stack

Flue gas feed

$CO_2$ Concentrate (~85% $CO_2$) to CPU

380 TR1-F10 tm
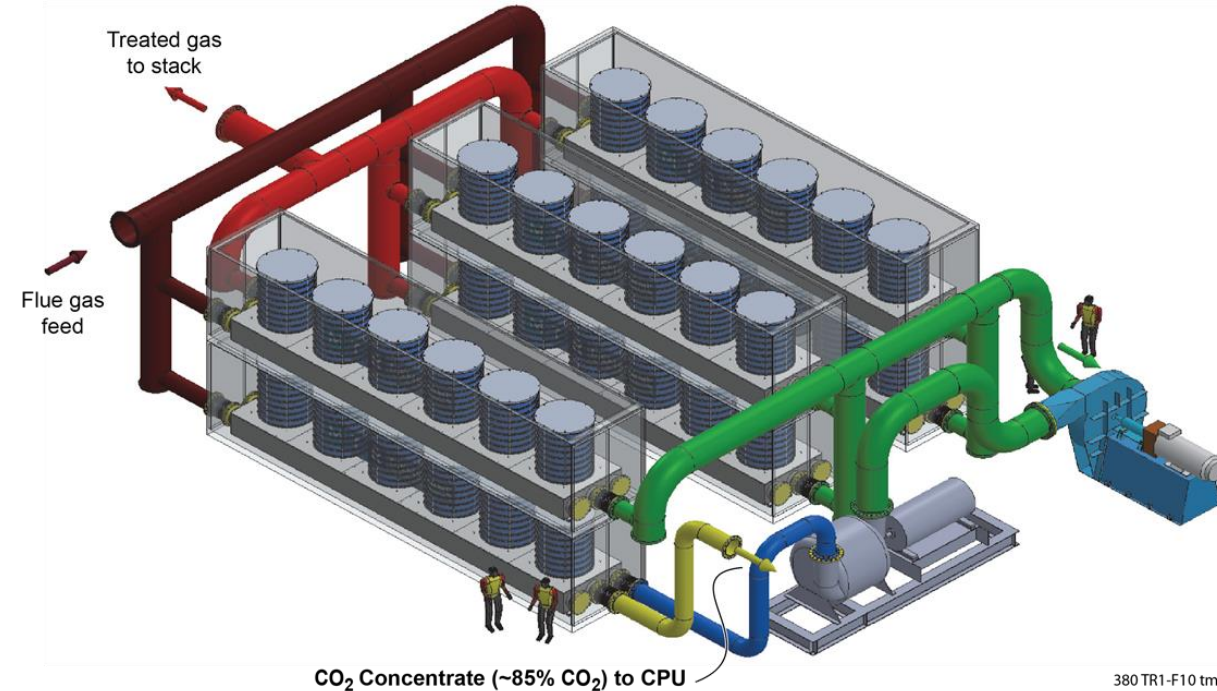
- Containerized membrane stack, demonstrated at TCM, is envisioned as the final form factor for this capture technology

- Future, larger systems, such as the proposed large pilot at the Wyoming ITC, will simply use multiples of this modular building block

# Summary

- Main goal is to validate recent innovations in membranes (Gen 2 Polaris) and modules (low-pressure-drop) in field testing at TCM

- Membranes will be packaged in a container that represents the final form factor for this capture technology

- Project is nearing the end of the construction phase (BP2) with testing (BP3) planned in 2021

# Acknowledgements

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## Thank you for your attention!