



Polaris™ Membranes

A Clean Approach to
Carbon Capture

Outline

- MTR membrane capture background
- MTR Polaris™ development
- Wyoming demo system overview
- Wyoming plant operations update
- Summary

Who is MTR?

Leading Developer of Membrane Technology for Carbon Capture and Industrial Separations

Overview



40+
countries



Across 6
continents

Experienced Operating History

- ▶ **1992**
First Commercial Sale
- ▶ **>150**
Patents
- ▶ **450+**
Systems Installed Around the World



MTR has served the
global industrial gas
separations markets
for decades with
system installations

Trusted by blue-chip customers in a wide range of industries including energy and chemicals



DAELIM

ExxonMobil

INEOS

NESTE

SASOL



أرامكو السعودية
saudi aramco

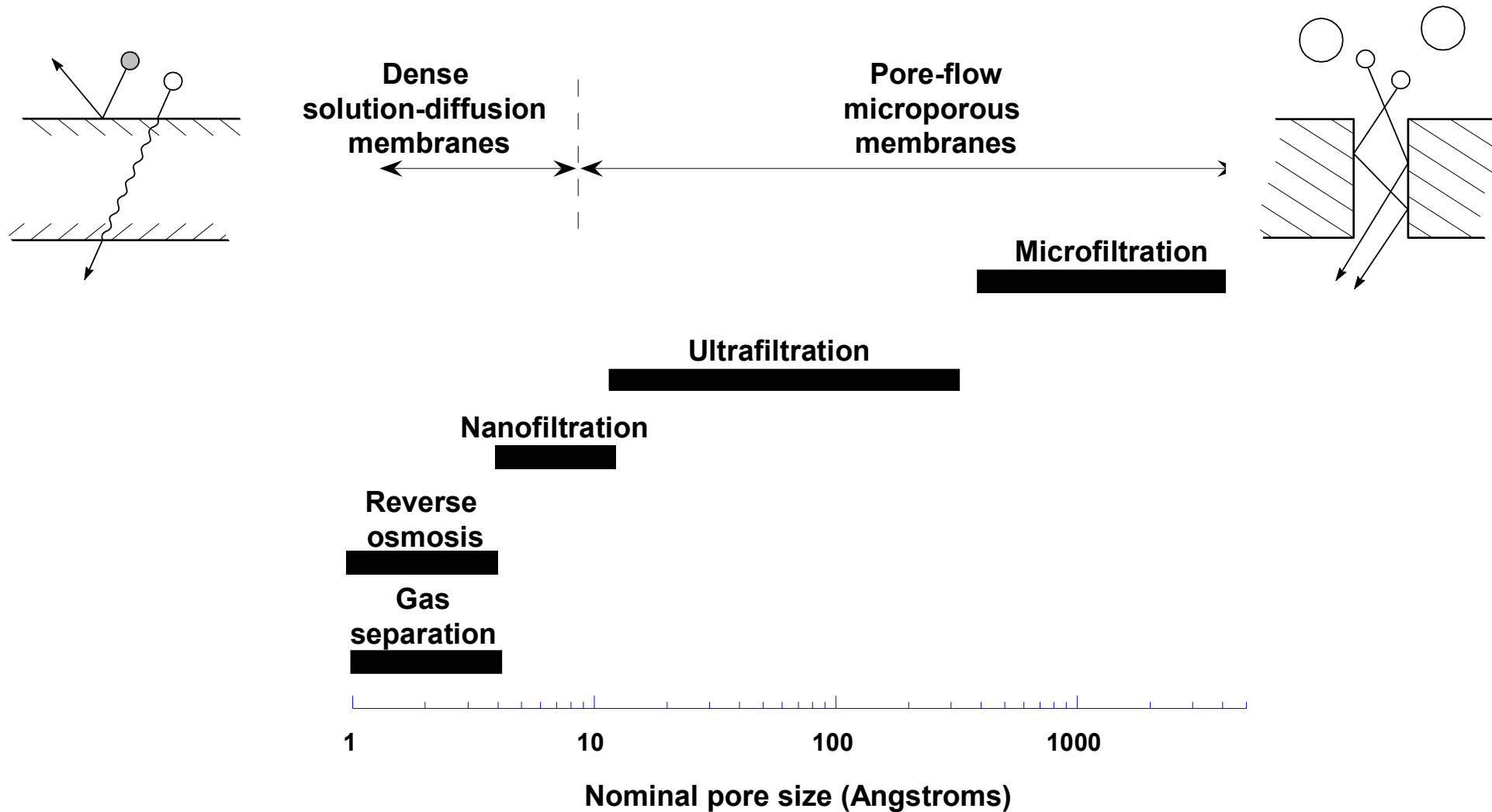


سابك
sabik

Westlake



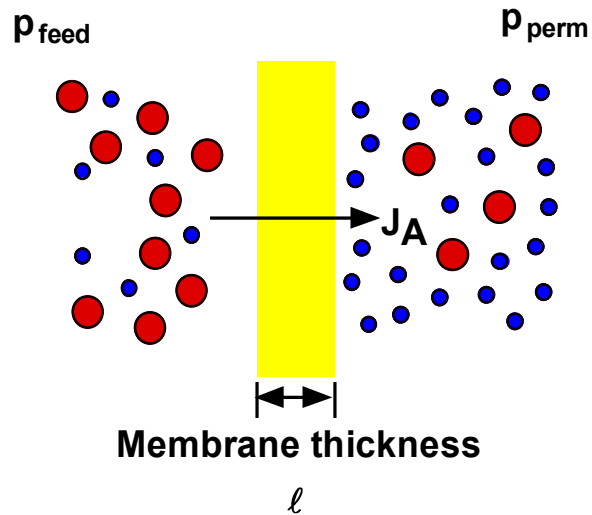
Membrane Technology Fundamentals



Membrane Technology Fundamentals

Solution-Diffusion in a Dense Selective Layer

Upstream pressure Downstream pressure



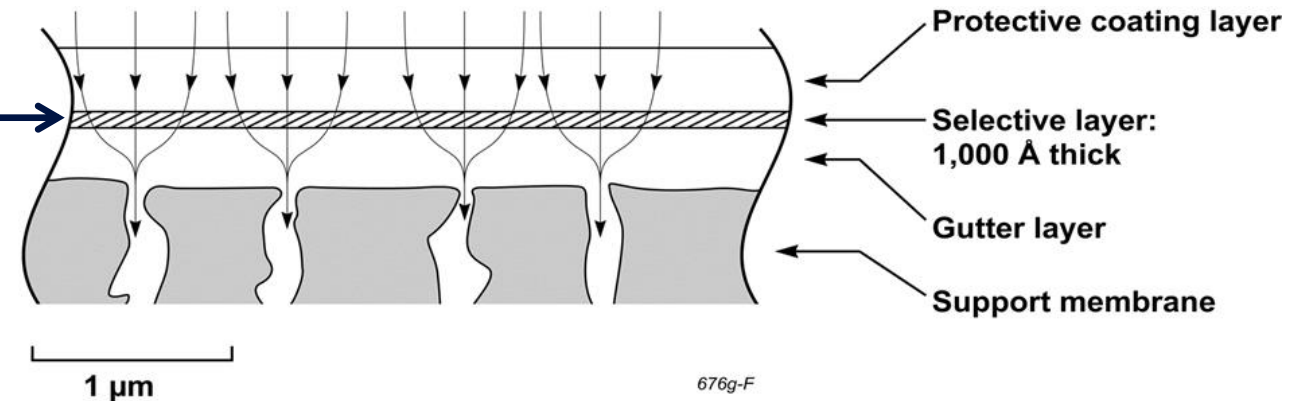
$$p_{\text{feed}} > p_{\text{perm}}$$

● Component A

● Component B

Composite Membrane Cross-Section

Upstream pressure (Feed)

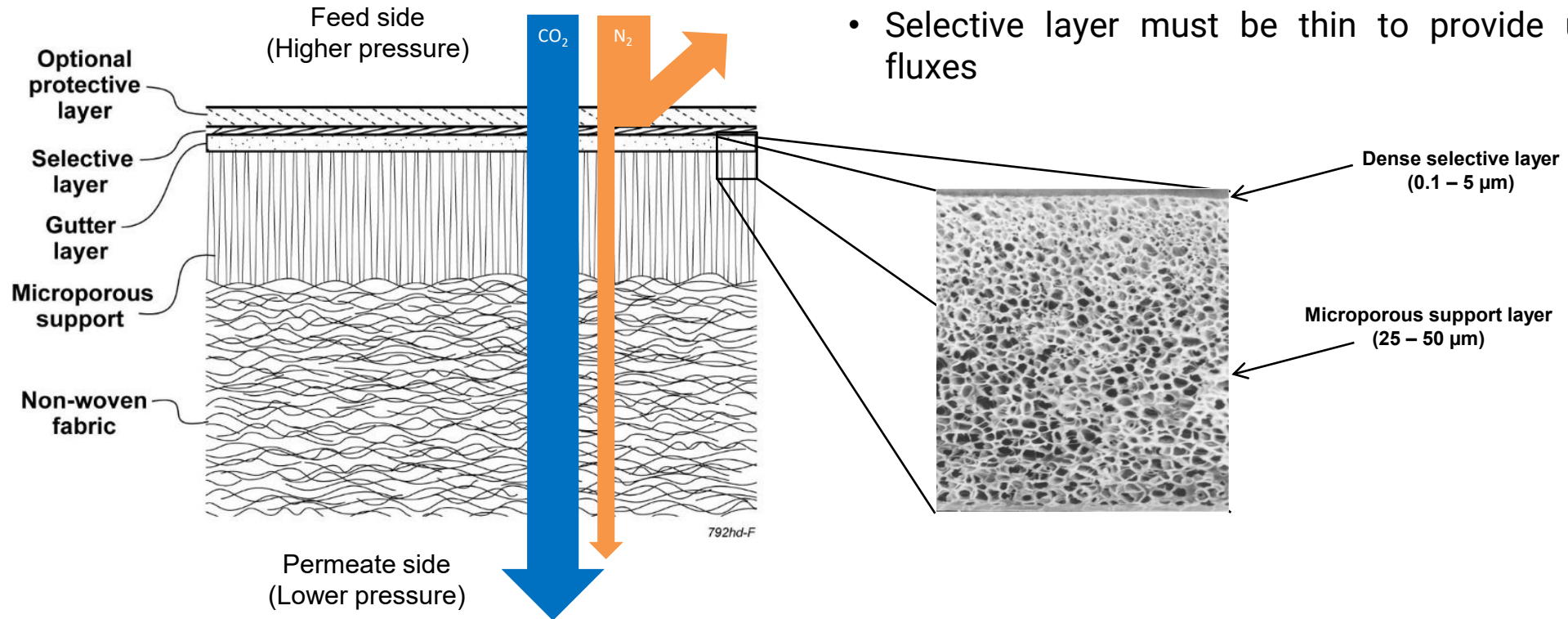


Downstream pressure (Permeate)

- (1) Sorption on upstream side
- (2) Diffusion down partial pressure gradient
- (3) Desorption on downstream side

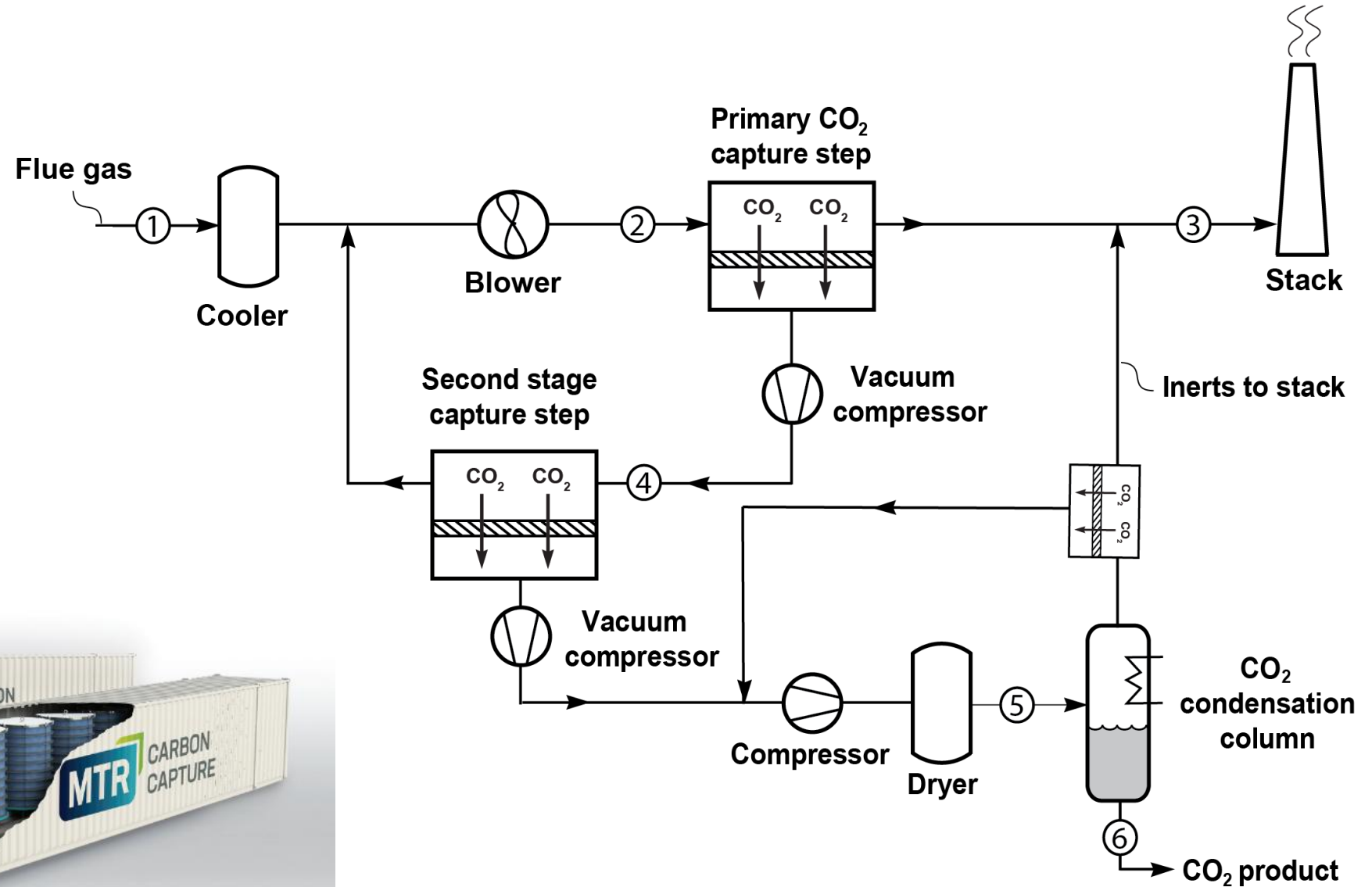
Gas Separation Membranes

Multi-Layer Composite Membrane Structure



- Dense, selective layer transports **fast gas** (for **example, CO_2**) over **slow components of a mixture** (**N_2**)
- Selectivity is determined by the relative solubility and diffusion rates in the dense polymer selective layer
- Selective layer must be thin to provide useful gas fluxes

Simplified MTR Capture Process Diagram



Membrane Advantages for Carbon Capture

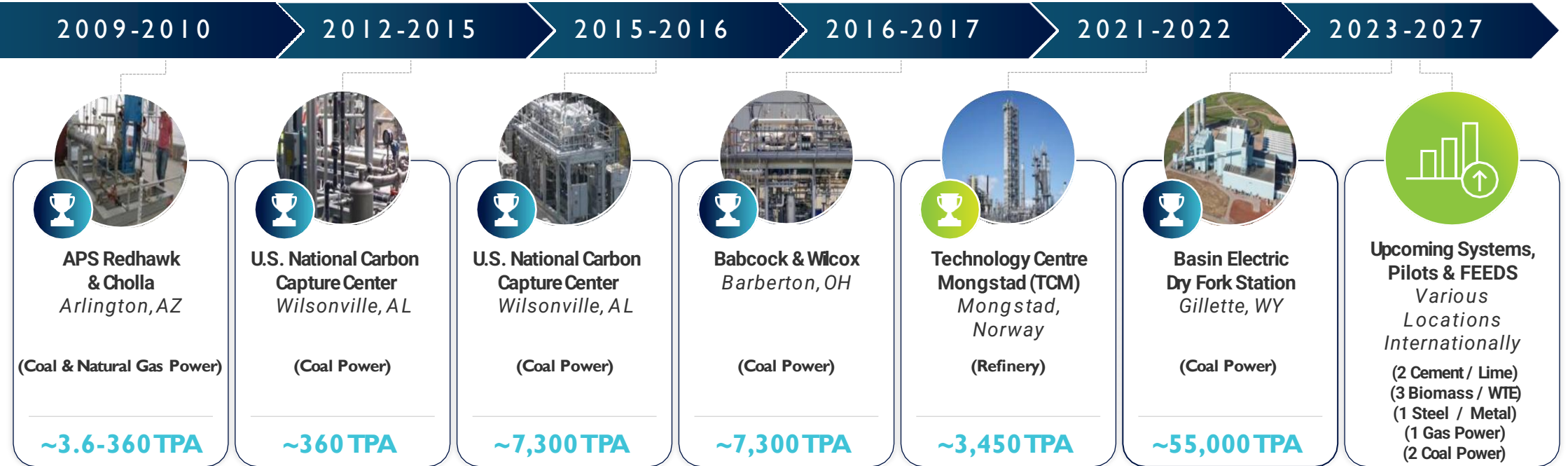
MTR Polaris Membrane Technology

- ✓ Proven technology at large scale, ready for commercialization
- ✓ Environmentally attractive: No chemical handling, emissions or disposal issues – easier permitting
- ✓ Simple passive operation, low maintenance costs
- ✓ Flexible footprint – no tall, heavy towers
- ✓ No steam use → only electricity so can be powered by renewables
- ✓ Low water usage
- ✓ High turndown and rapid response times are ideal for dynamic and intermittent processes



Proven Technology Validated by a Series of Pilot and Demonstration Plants

For more than a decade, MTR membranes have been successfully utilized in the field at an increasing scale for carbon capture



LONG HISTORY OF DOE-SUPPORTED PILOTING ACROSS A VARIETY OF INDUSTRIES

15 Year Relationship with DOE

20+ DOE Awards Won

>\$145mm Total Carbon Capture Funding Received From US Government Agencies

7+ Industries with Completed or Active Studies

9 Upcoming Pilots, FEEDs & commercial systems

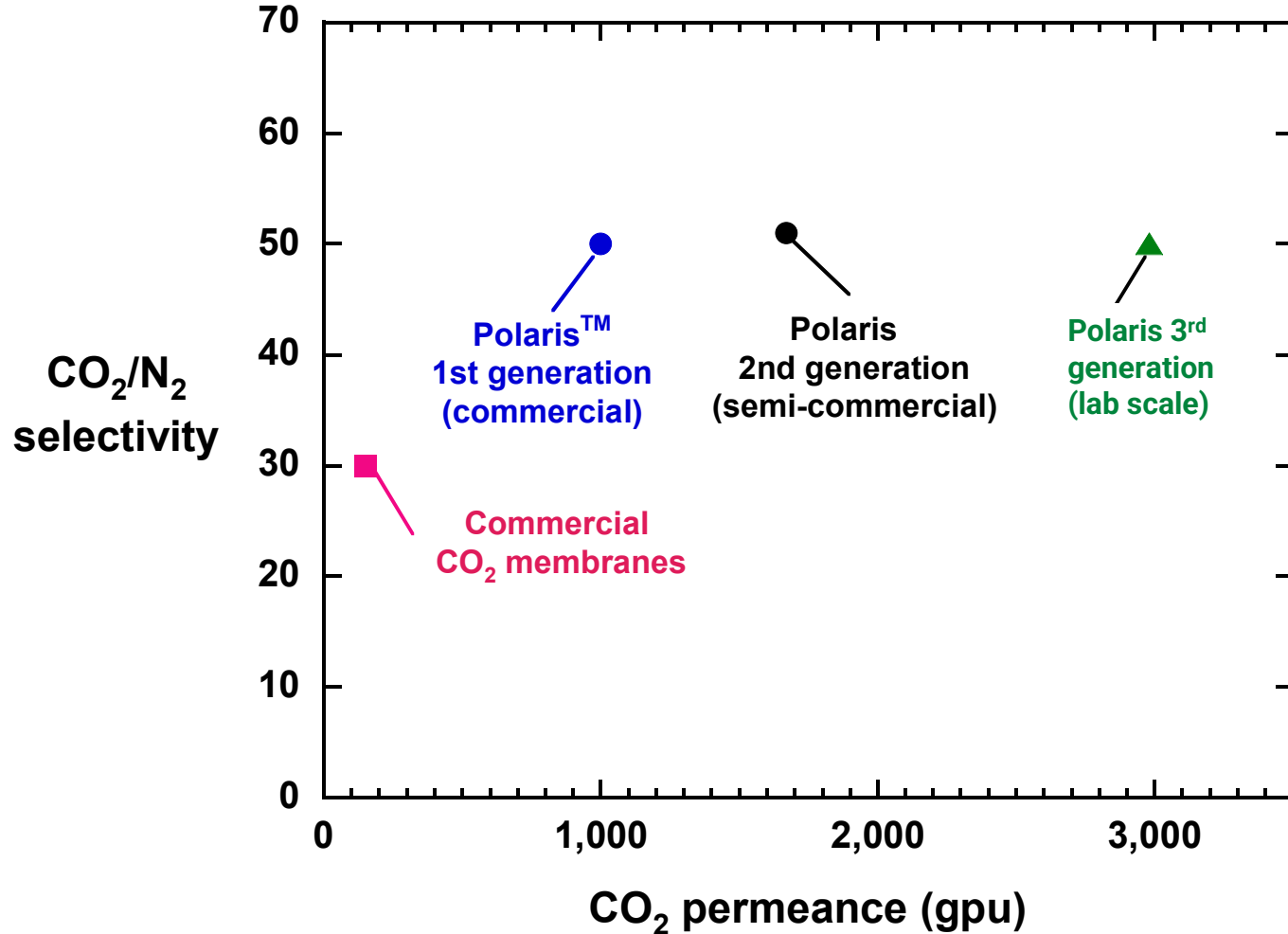


Denotes largest membrane carbon capture plant in the world at the time



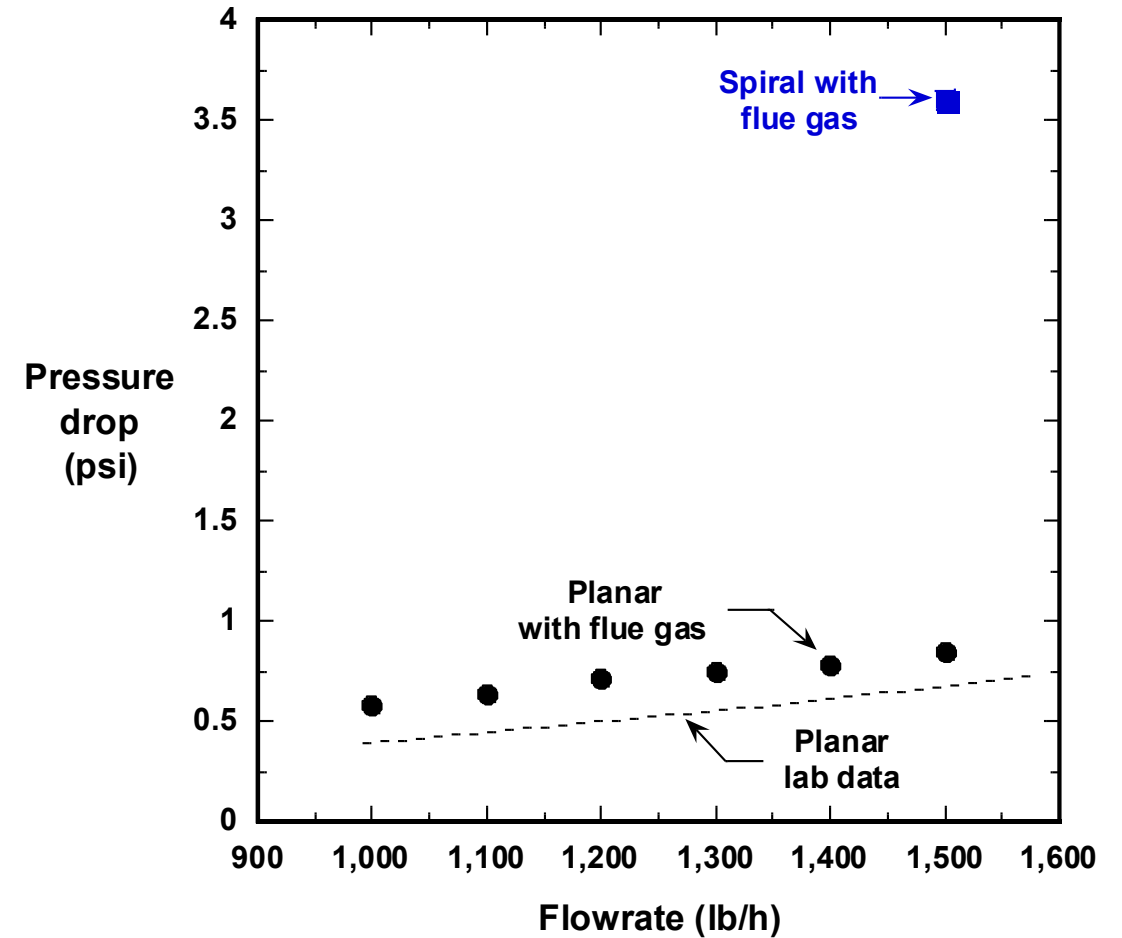
MTR tests final commercial-ready membrane system

MTR Polaris™ Membranes



- Original Polaris about 10X more permeable than prior membranes for CO₂ / natural gas separations
- Higher permeance reduces membrane area almost linearly
- Polaris Gen 1 now commercially used in shale gas and refinery applications
- Polaris Gen 2 recently demonstrated in TCM test; validation at final form (container) at Wyoming
- Polaris Gen 3 will be tested at Wyoming this summer

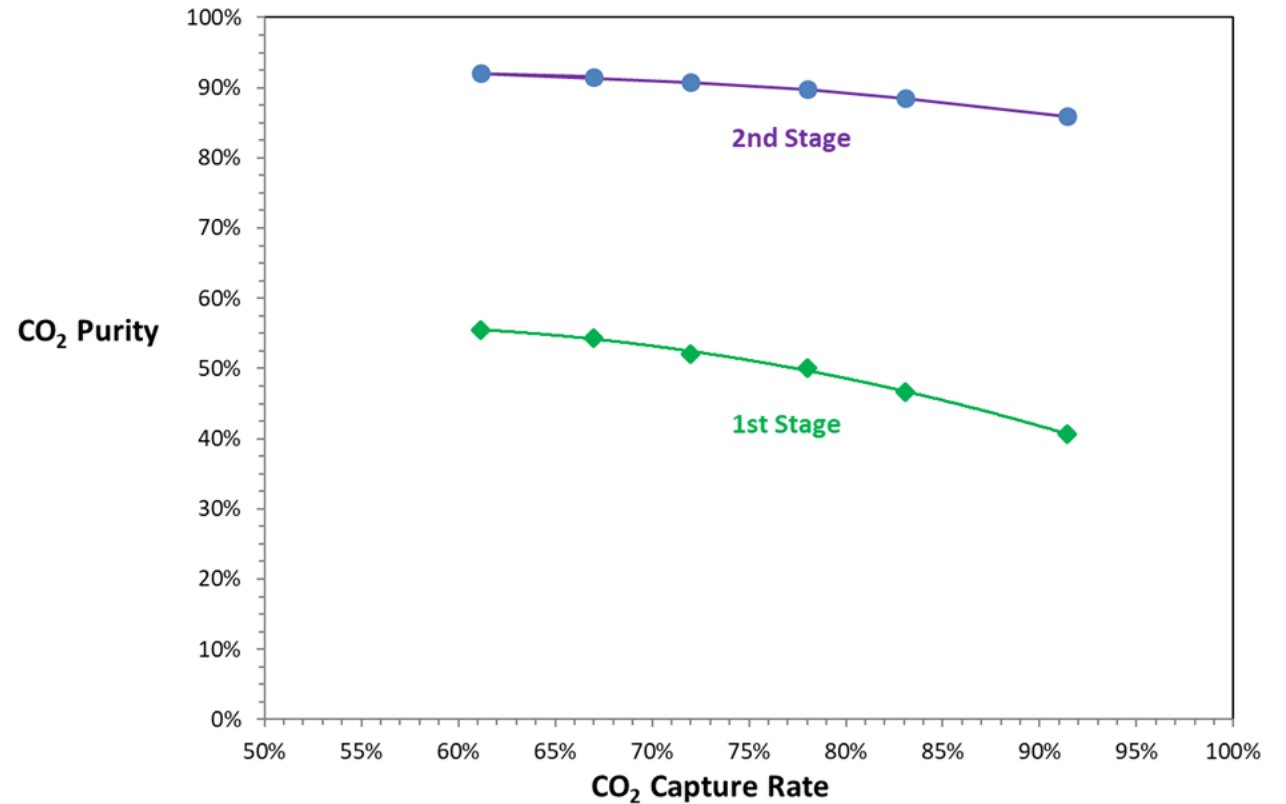
Polaris Module Development



- Prototype planar module performance validated at previous field tests
- Transition to planar modules reduced pressure-drop and saves ~10 MW_e of energy at full-scale

Testing “Containerized” Modules at TCM

- Test system at TCM in Norway used a single “container” of membrane stacks
- Larger systems will use multiples of this unit building block



- 2-stage membrane system produces >85 mol% CO₂
- Observed module pressure drop (<0.15 psi) significantly lower than target (~1.5 psi)

MTR's Demonstration Plant at the Wyoming Integrated Test Center is the Largest of its Kind in the World

Plant Progress

Ceremonial Groundbreaking Event, May 2, 2023



Todd Telesz
CEO
Basin
Electric

Tim Merkel
MTR

Brice Freeman
MTR

Mark Gordon
WY
Governor

Brett Andrews
MTR

Construction completed November 2024



Construction at WITC is complete and the plant is now fully operational; testing through end of 2025

Plant Statistics

- ▶ **~55,000**
TPA of CO₂
- ▶ **Jan 2025**
Begin 1 year of planned operations

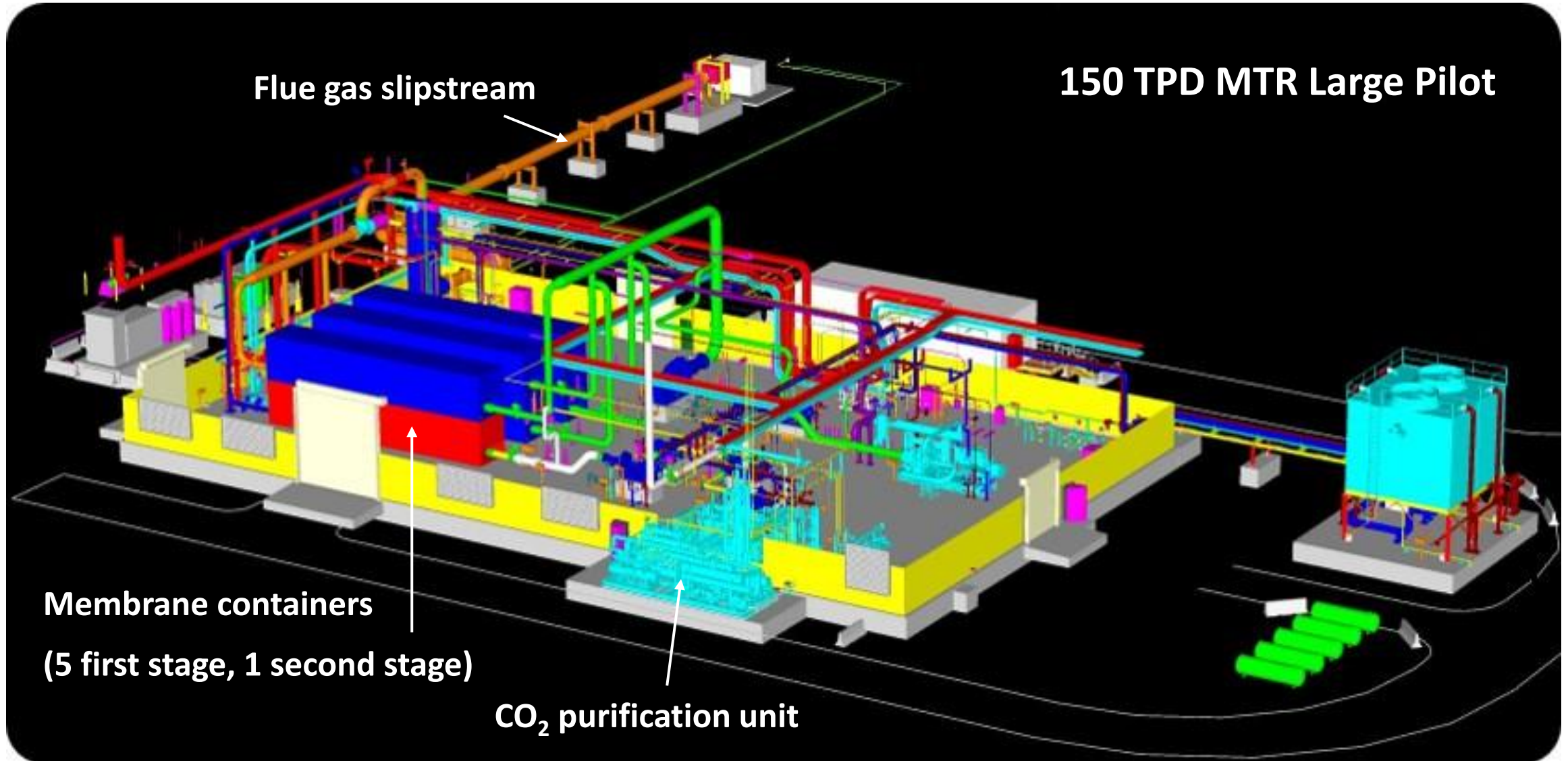
Project Team



GRAYCOR



General Arrangement of Wyoming Capture Plant



1st Set of Polaris™ Membrane Modules



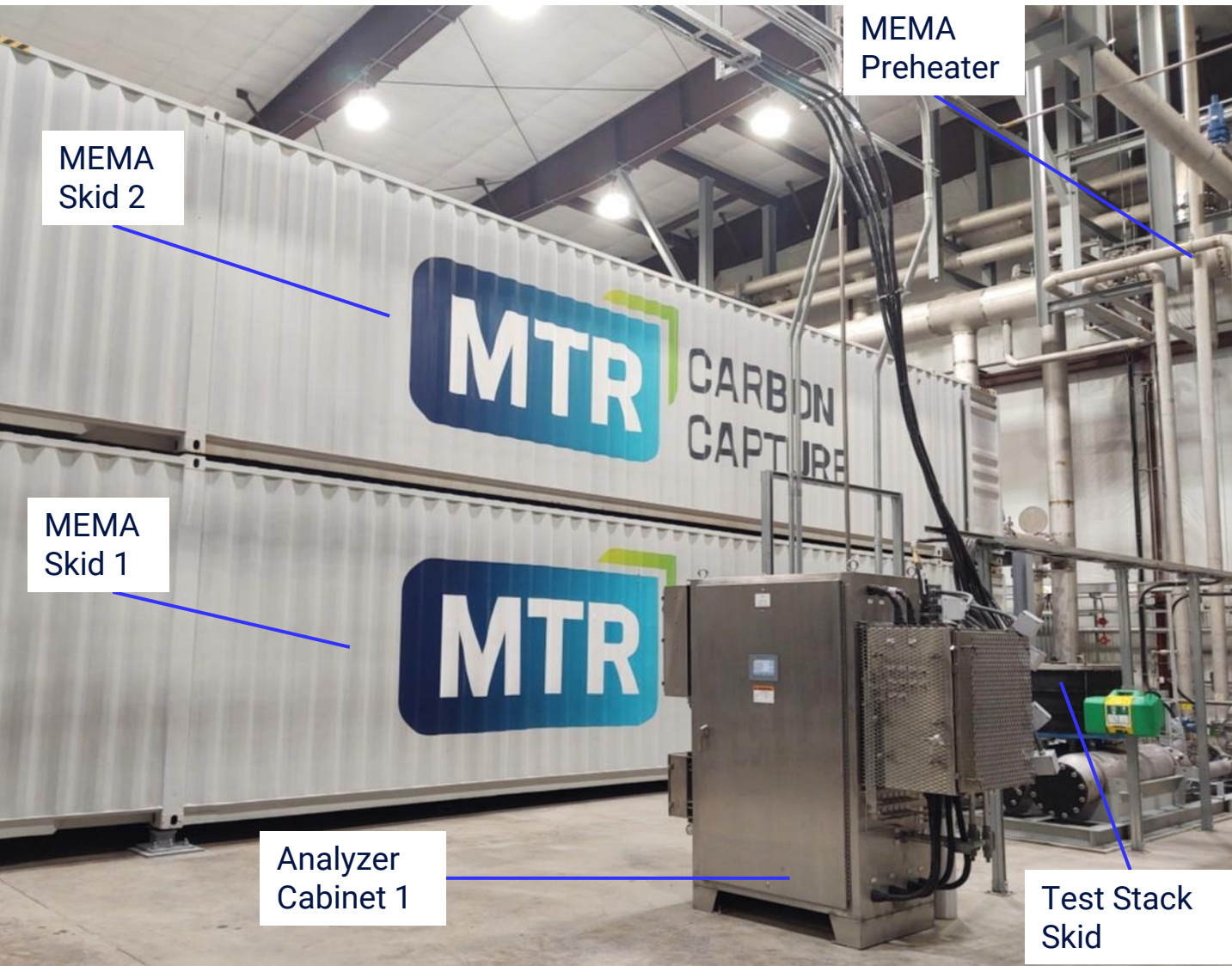
Flue Gas tie-in to Capture Plant



Power plant flue gas pressure boosted by fan and goes into building

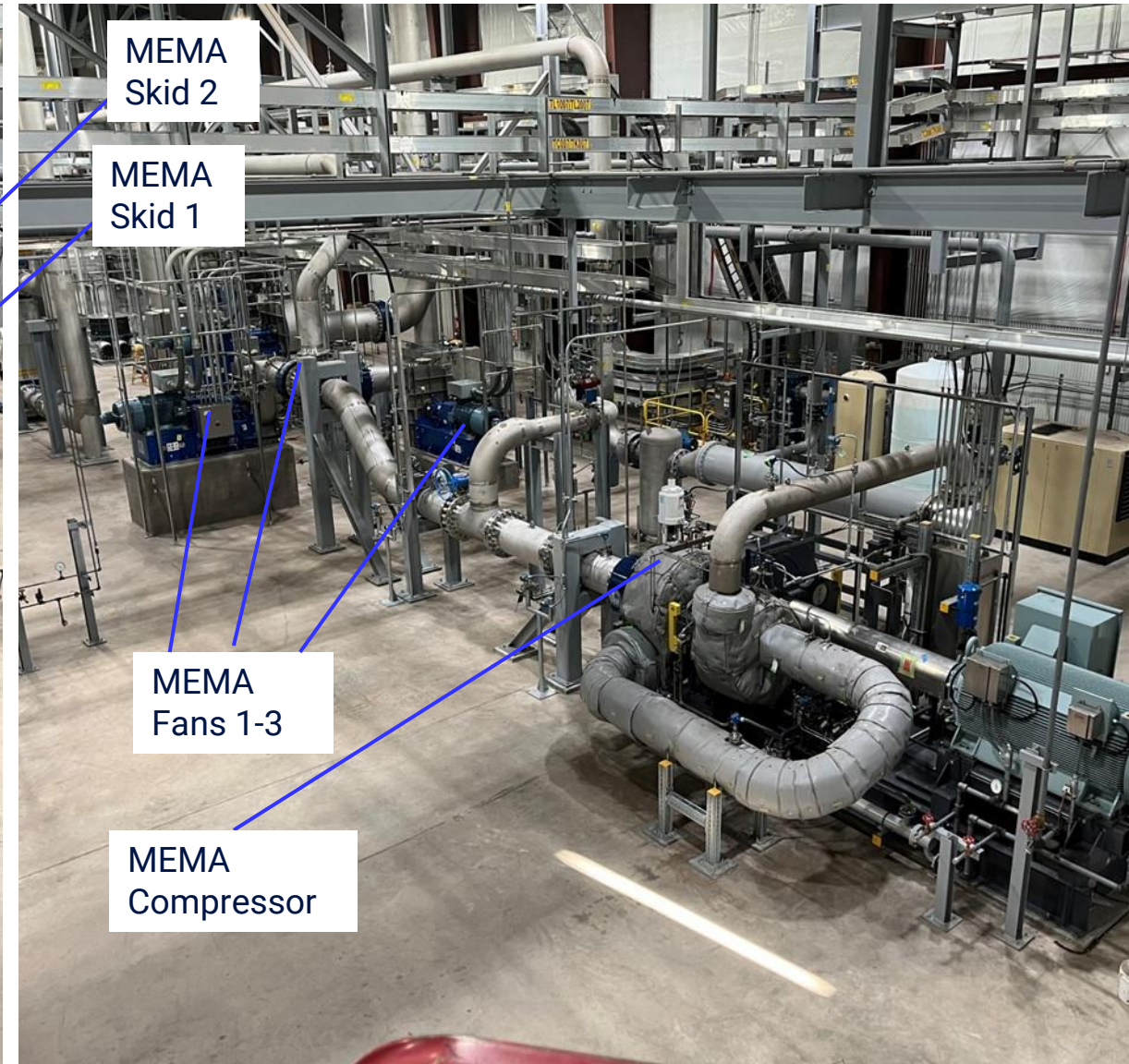
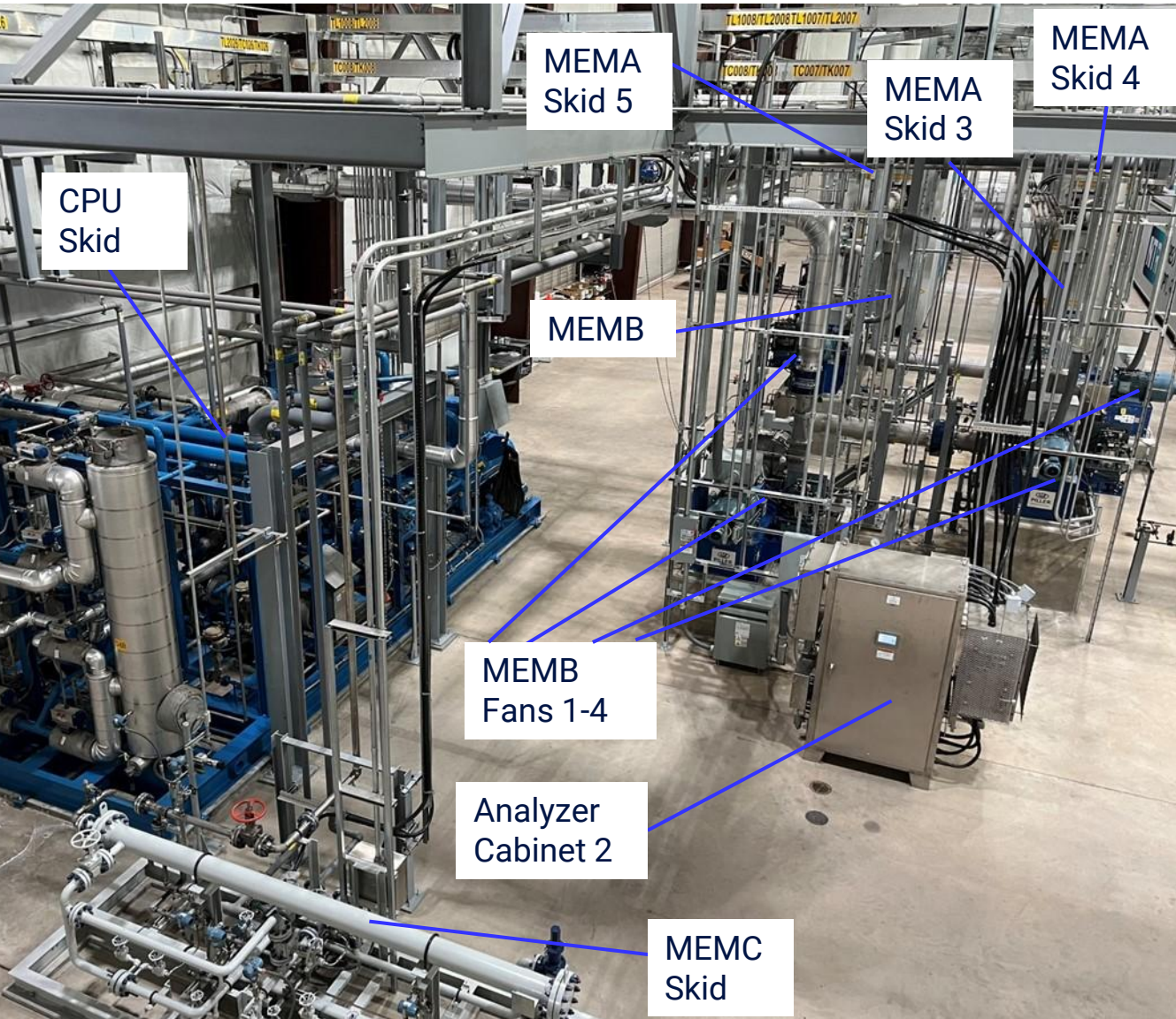
February 2025

Direct Contact Cooler, MEMA Preheater and Containers, Test Stack Skid



Flue gas cooled and pretreated at DCC then goes into container and test stack

MEMA Fans/Compressor, MEMB Container, MEMB Fans, CPU Skid, and MEMC Skid

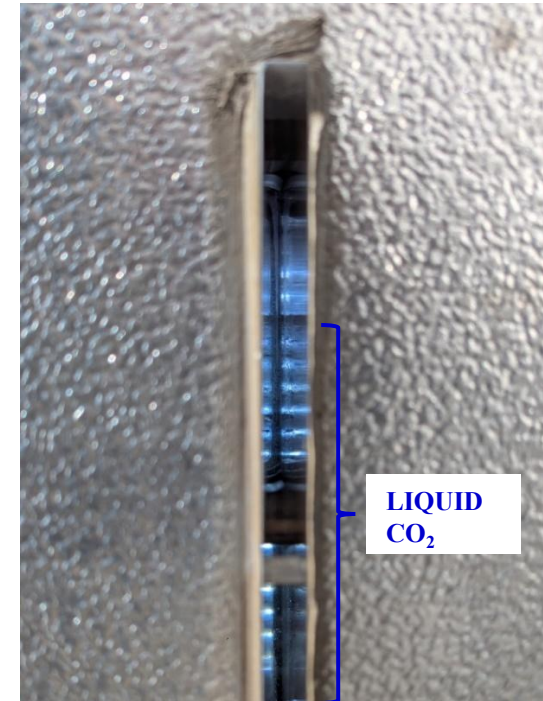


CO₂ rich permeate from second stage goes to CO₂ purification unit

CPU Refrigeration Skid



Liquid CO₂
sight glass



February 2025

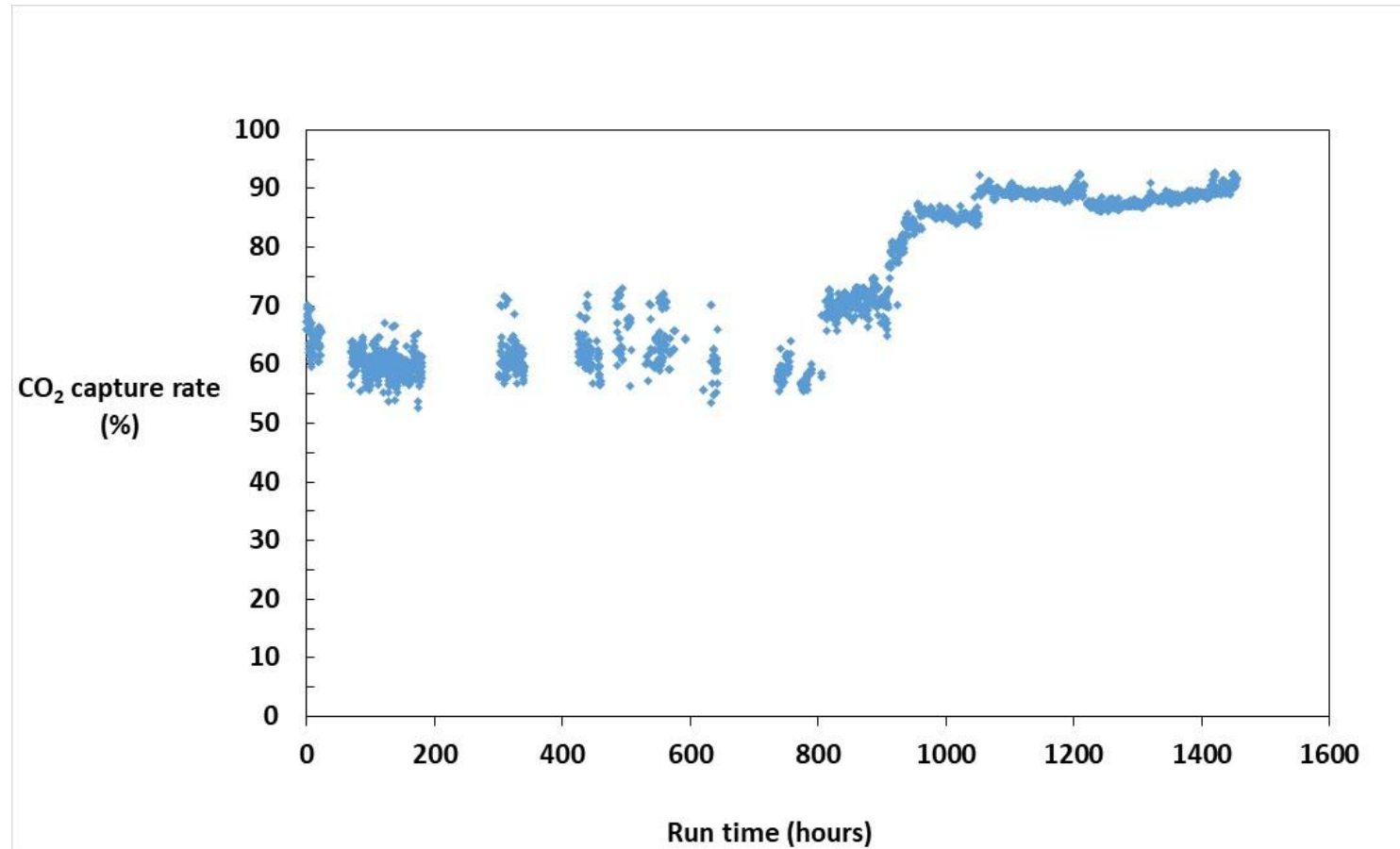
Demo Plant Run Time Summary

System Component	Cumulative Run Time (hours)
All Flue Gas Operation	2,460
Full Membrane System	1,450
Full Membrane System + CPU	600
Percent of Time Online for Capture System*	97.4%

*Includes full membrane system through April 6

- All Flue Gas Operation includes test stack operation in Dec 2024
- Full Membrane System refers to two stages of membranes producing >80 mol% CO₂
- The CO₂ liquefaction unit (CPU) was brought online last
- Overall, the membrane system has been running smoothly with a high online percentage relative to the power plant

Demo Plant Capture Rate



- The system was designed for 70% capture with plans to do parametric testing from 60 – 90% capture
- The first ~800 hours or so were mainly shakedown activities to tune fans, pumps, analyzers, instrumentation, etc.
- From 800 – 900 hours the system ran at base case conditions (70% capture)
- Capture rate was then slowly increased to ~90% from 1100 hours on
- 90% capture conditions were continued throughout March and April until power plant shutdown

Demo Plant System Data

Representative Membrane System Performance

(1) Flue Gas
to Membrane
Containers

CO2	15.27	%
O2	5.83	%
SO2	0.00	ppm
H2O	4.75	%
NH3	14.11	ppm
NO	27.12	ppm
NO2	0.02	ppm

(2) Membrane
Permeate
to CPU

CO2	82.66	%
O2	1.47	%
SO2	0.00	ppm
H2O	7.52	%
NH3	1.81	ppm
NO	10.10	ppm
NO2	0.50	ppm

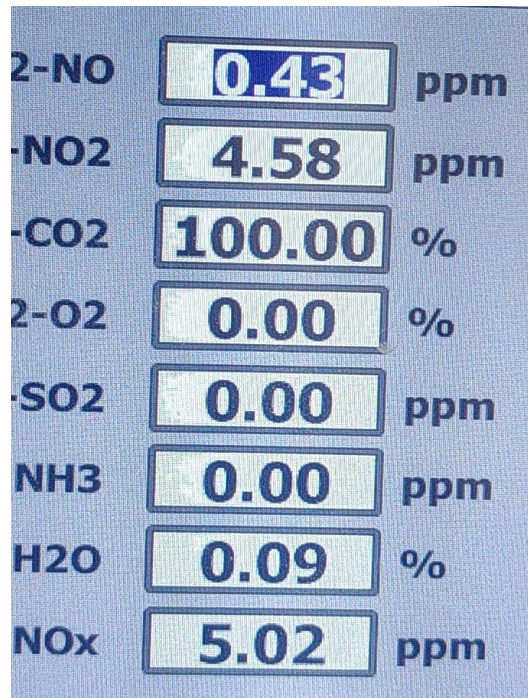
(3) Dried Gas to
Liquefaction
Column

CO2	91.19	%
O2	2.01	%
SO2	0.00	ppm
H2O	0.09	%
NH3	0.00	ppm
NO	2.84	ppm
NO2	0.00	ppm

- Membrane system is producing >80 mol% CO₂ (dry) going to the CPU as designed
- After compression and drying, permeate gas is >90 mol% CO₂
- Minor polar species (NO_x, NH₃) appear to be mostly removed in condensate and/or mole sieve (see streams 2 and 3 above)

Preliminary Liquid CO₂ Purity Measurement

(4) Vaporized Liquid CO₂



2-NO	0.43	ppm
-NO2	4.58	ppm
-CO2	100.00	%
2-O2	0.00	%
-SO2	0.00	ppm
NH3	0.00	ppm
H2O	0.09	%
NOx	5.02	ppm

- Initial analysis of the vaporized liquid CO₂ shows high CO₂ purity
- NO_x (~5 ppm) and SO_x (~0 ppm) are present in very low quantities
- However, this analyzer is not set up for ppm O₂ and N₂ measurements
- Detailed liquid CO₂ purity measurements will be conducted after June restart

Summary

- The large pilot membrane system was brought online Jan 24, 2025 and the CO₂ liquefaction section was started during the week of Feb 10
- Membrane system is producing >80 mol% CO₂ (dry) to CPU as targeted, and the CPU is generating liquid CO₂
- Currently, the full membrane system has operated >1,400 hours with over 97% online time; main issues are related to heaters and fan VFD
- In June, system will operate under design conditions to verify performance and then complete ~90% capture campaign (1,000 hours)
- In July, DOE CCSI2 parametric test matrix will be conducted along with additional analytical tests. These tests include detailed analysis of liquid CO₂ and captured water along with minor component analysis (particulates)

MTR Showcase Event at the ITC

- On March 26, we had a large pilot site tour with a group of clients
- Feedback has been overwhelmingly positive on the simplicity and commercial-readiness of membrane capture
- Two additional tours are planned:
 - Week of June 16 – 2 days for interested parties; one day reserved for DOE
 - Early September time frame



MTR Sells Capture Plant to TSMC

TSMC has committed to decarbonize 2M TPY CO₂ by 2030, 70% of which is from power used in manufacturing. TSMC has selected MTR Polaris™ as the technology of choice for their carbon capture initiatives and signed an MOU with the Taiwan Ministry of Environment to implement on multiple Waste-to-Energy (WTE) plants

PHASE 1

30 TPD (11k TPY) solvent incineration system at the TSMC Taichung Zero Waste Center, Taiwan

- Purchased MTR Polaris carbon capture membrane system with delivery in April 2025. CTCL (major Taiwanese EPC) will install the system

PHASE 2

2 x 300k TPY WTE systems at Gang-San and Lu-Tsao, Taiwan

- PO for engineering studies issued as first step to a FEED in 2025
- First WTE capture plant to be online by Q4 2027

PHASE 3

Further 2 WTE plants online 2029 and 2030

MTR CC president, Brett Andrews, between Taiwan Minister of Environment (Dr. Peng Chi-Ming) and TSMC Senior VP (Ms. Lora Ho) at MOU signing ceremony





THANK YOU

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