Scale-Up and Testing of Advanced Polaris Membrane CO_2 Capture Technology (DE-FE0031591)

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Project Kickoff Meeting
September 24, 2018

Presentation Outline

- Introduction
- Project objectives
- Technology background
- Project approach / work plan
- Wrap up

Project Overview

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

Project period: 8/1/18 to 7/31/21

Funding: $7.4 million DOE; $2.4 million cost share ($9.8 million total)

DOE program manager: Bruce Lani

Participants: MTR, Technology Centre Mongstad (TCM), Siemens/Dresser Rand, Trimeric, WorleyParsons

Project scope: Design, build, and operate a system at TCM with Advanced Gen 2 Polaris membranes and modules; optimize integration of compression and CO_2 purification equipment with membranes.

Project plan: The project is organized in three phases:

- **Phase 1/Year 1** – Design system, fabricate membrane modules
- **Phase 2/Year 2** – Build and install system; commission at TCM
- **Phase 3/Year 3** – Operate system, analyze results, decommissioning

Project Objectives

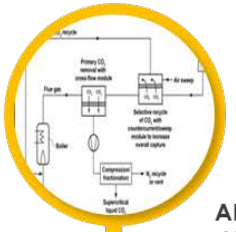
- Scale-up and validate in field testing at TCM recent innovations in membrane (Polaris Gen2) and modules (low-pressure-drop)
- Demonstrate low-cost “containerized” skid as final modular form for future large-scale systems
- With partners, perform an engineering study to optimize integration of pump/compression equipment (Siemens) and CO_2 purification unit (Trimeric)
- Focus TCM testing and TEA analysis on membrane “sweet spot” at 40% – 80% capture

Roles of Participants

- MTR – project lead and liaison with DOE; responsible for membrane system design, construction, installation and operation; will lead data analysis and all reporting to DOE
- TCM – host site for the 6 month field test; with MTR, will coordinate system installation, operation, and data analysis
- Siemens/Dresser Rand – will lead engineering study focused on optimization of rotating equipment (blowers, vacuum pump, CO_2 compression) for MTR process
- Trimeric – will lead the CO_2 purification unit (CPU) optimization study and responsible for overall process TEA
- WorleyParsons – responsible for process environmental impact study

MTR/DOE CO_2 Capture 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 (50kWe)

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

NCCC 1 MWe Demo
(FE0005795)
- 10,000 hrs of 1 TPD system operation
- 1 MWe (20 TPD) system operation

Low Pressure Mega Module
(FE0007553)
- Design and build 500 m² optimized module

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

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

10 MWe Large Pilot
(FE0031587)
- Phase I (feasibility) for 200 TPD large pilot
- Potential for Phase II (design) and Phase III (construction/operation)

TRL3 TRL4 TRL5 TRL6 TRL7 TRL8

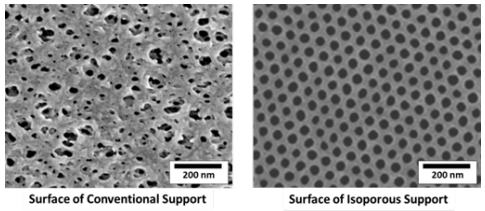
2006 2008 2010 2012 2014 2016 2018 2020

MTR

New MTR/DOE Projects

Self-Assembly Isoporous Supports, CA (DE-FE31596)

- Transformational new membrane (TRL 3 – 4)
- Reduces membrane area and energy use
- Build small system and test new membrane at NCCC



Pilot Testing at TCM, Norway (DE-FE0031591)

- Advanced Gen 2 Polaris™ membrane and modules
- Containerized skid
- Partial capture for low cost-of-capture

Full-Scale FEED at Duke Energy's East Bend Station, KY (DE-FE31589)

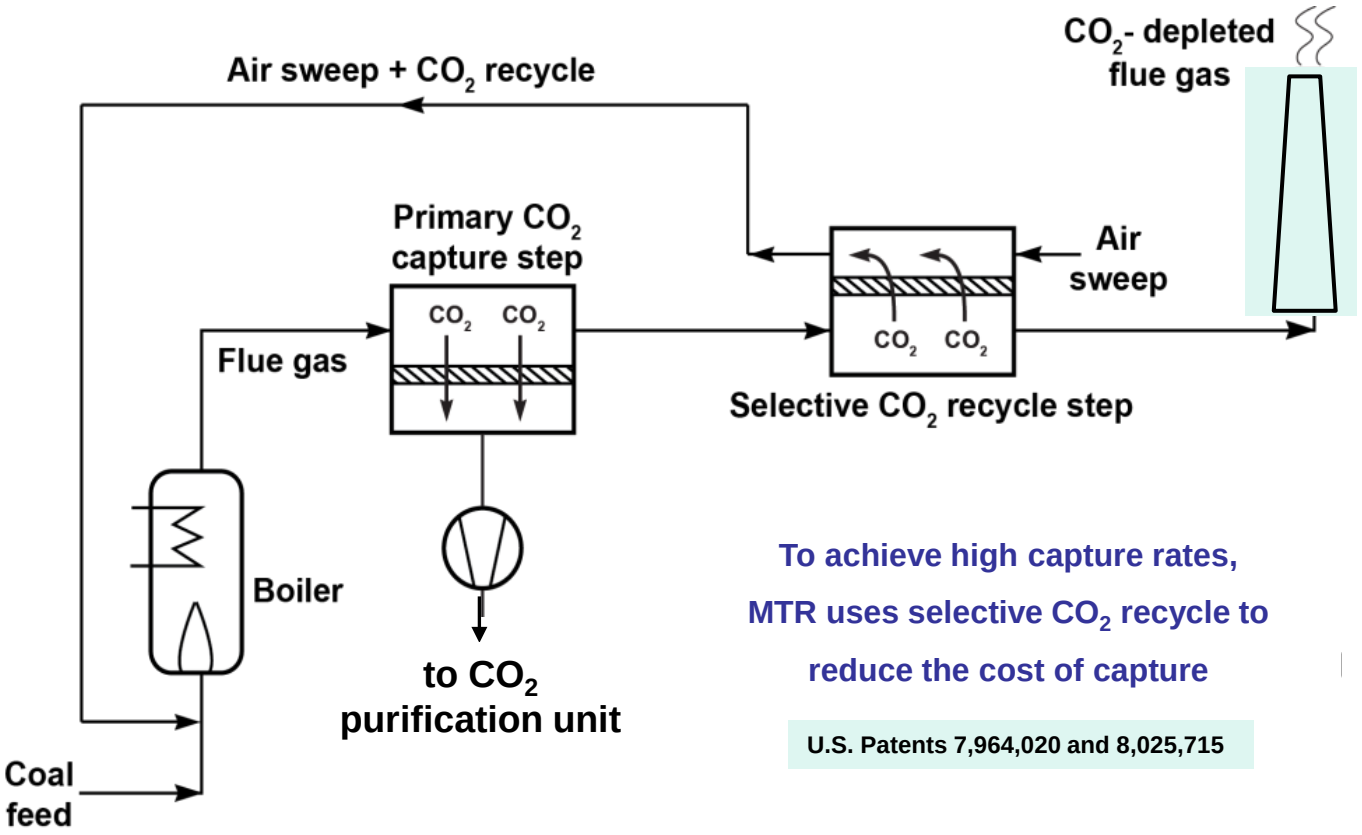
- EPRI is lead
- 460 MWe – using Advanced Polaris™
- Partial capture / Rapid retrofit deployment

Large-Pilot Testing at WY ITC, WY (DE-FE31587)

- Phase I – Design ~16 MWe 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

Background:
Selective Exhaust Gas Recycle Process

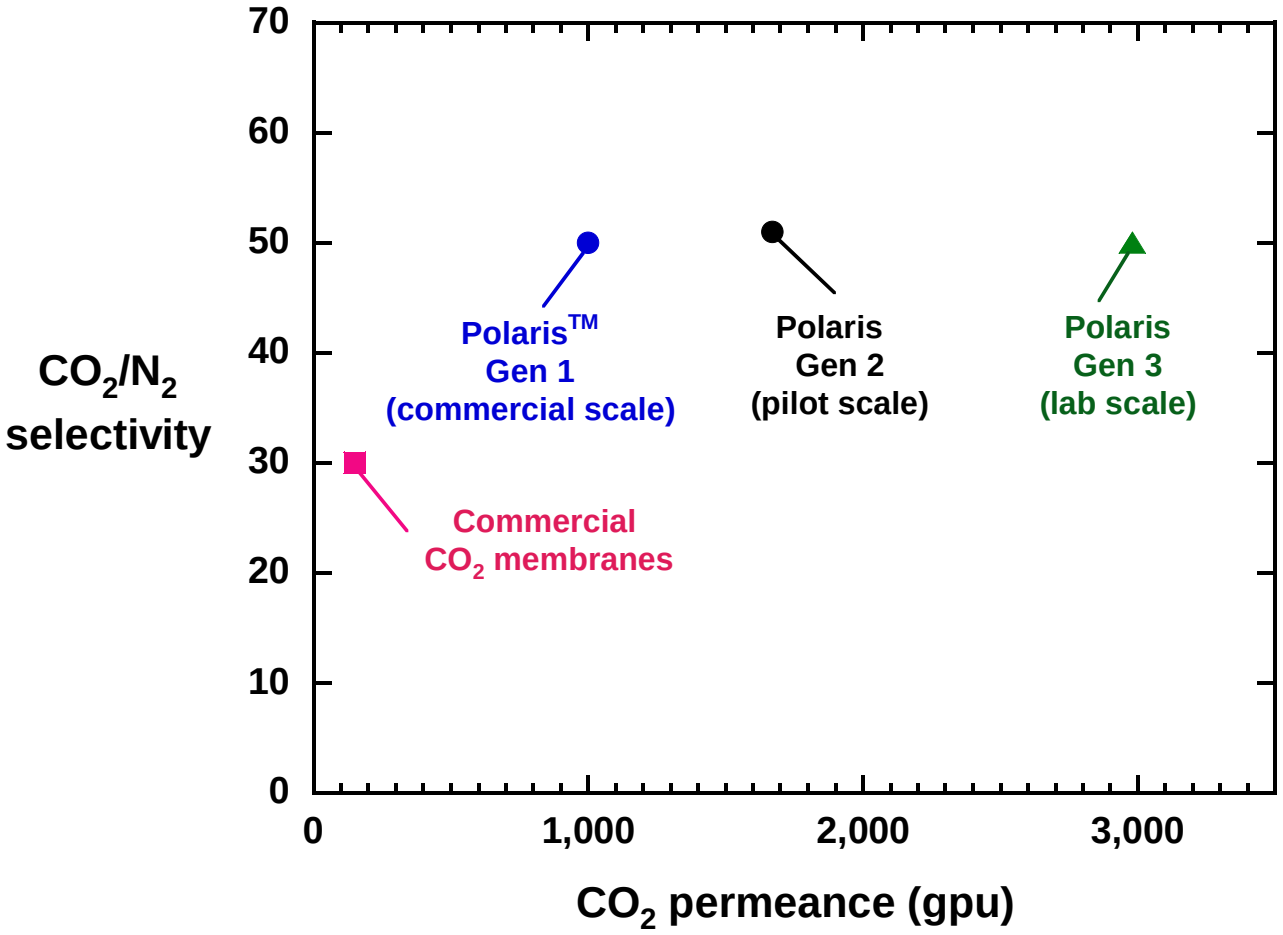


To achieve high capture rates, MTR uses selective CO_2 recycle to reduce the cost of capture

U.S. Patents 7,964,020 and 8,025,715

- Selective recycle is particularly effective at high capture rates (~90%)
- The impact on the boiler was quantified in small pilot testing at B&W

Background: Polaris™ Membranes



- Polaris Gen 1 evaluated in extensive testing at NCCC (>11,000 hours)
- Gen 2 is subject of this project; previously pilot tested at NCCC
- Today, Polaris Gen 1 is used commercially in shale gas treatment

Background: Advantages and Challenges

Advantages:

- Simple, passive operation with no chemical handling, emissions, or disposal issues; no chemical reactions or degradation problems
- No steam use; no modifications to existing steam turbines
- Less water use than other capture approaches; recovers flue gas H_2O
- Modular technology – high volume manufacturing to lower cost, pre-assembled, containerized skids
- High turndown, rapid response to dynamic conditions

Challenges:

- High permeance membrane is required to lower capital cost
- Pressure drops must be minimized to reduce energy losses
- Balance of plant equipment cost/efficiency, particularly for rotating equipment, are critical to system performance

Background:
Small Pilot Testing at NCCC

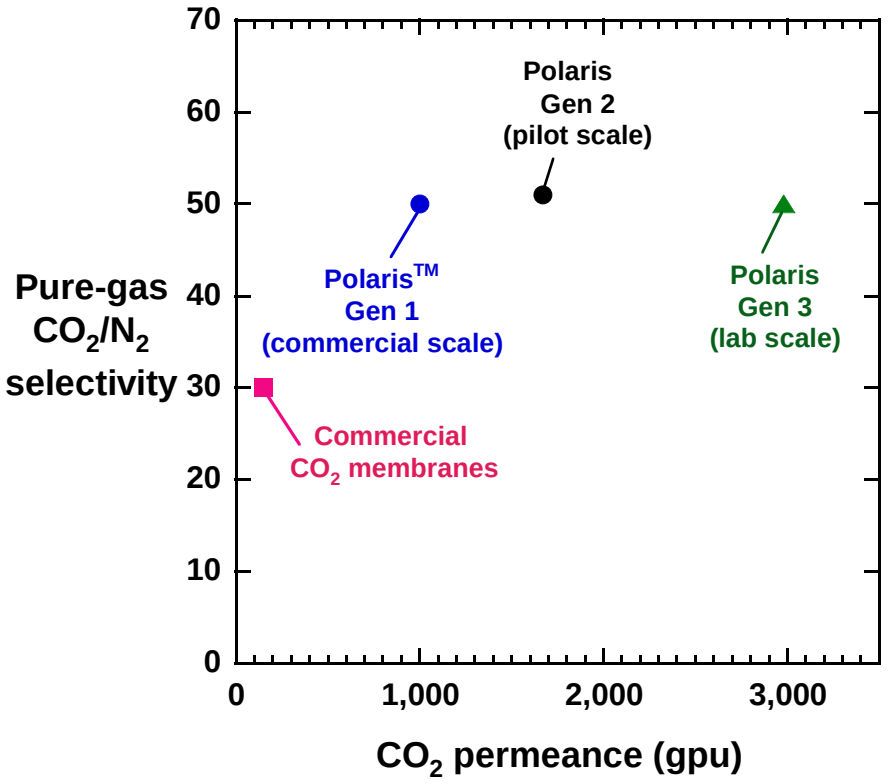
- MTR small pilot completed 6 months of operation at NCCC followed by an integrated boiler test at B&W

Photo Courtesy of NCCC

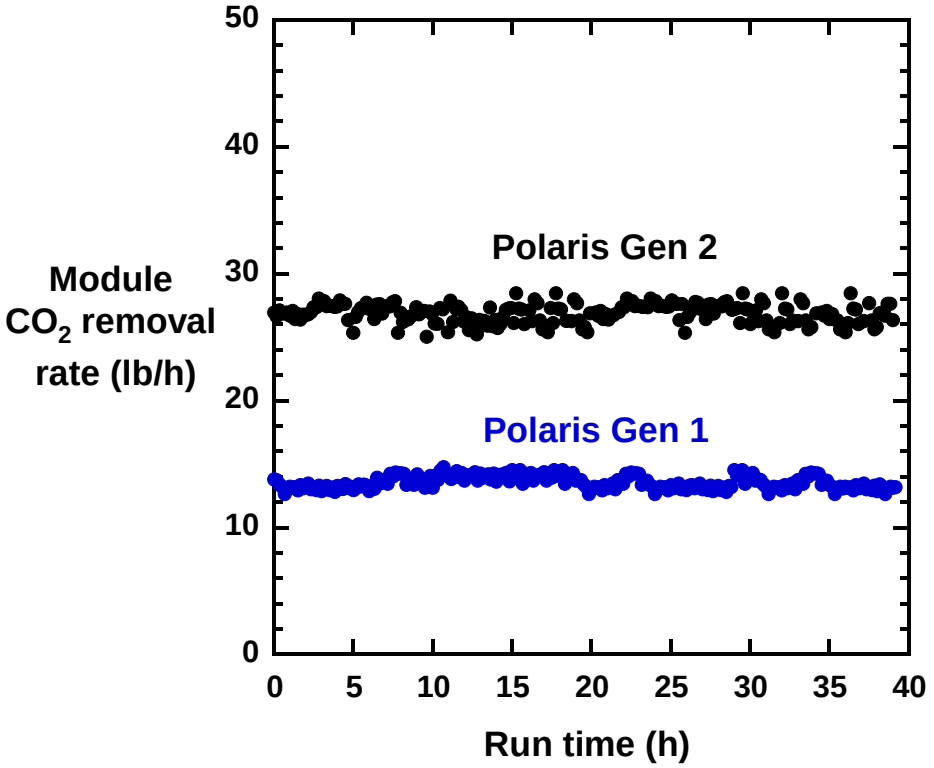
- System used Gen 1 Polaris and bundled spiral modules
- Parametric testing included prototype Gen 2 Polaris membrane and new low-pressure-drop modules

Testing at NCCC Confirmed Better Performance with Gen 2 Polaris

Stamp tests at MTR



Module tests at NCCC



- Membrane system-size scales almost linearly with CO_2 permeance
- Higher permeance reduces capital cost and footprint

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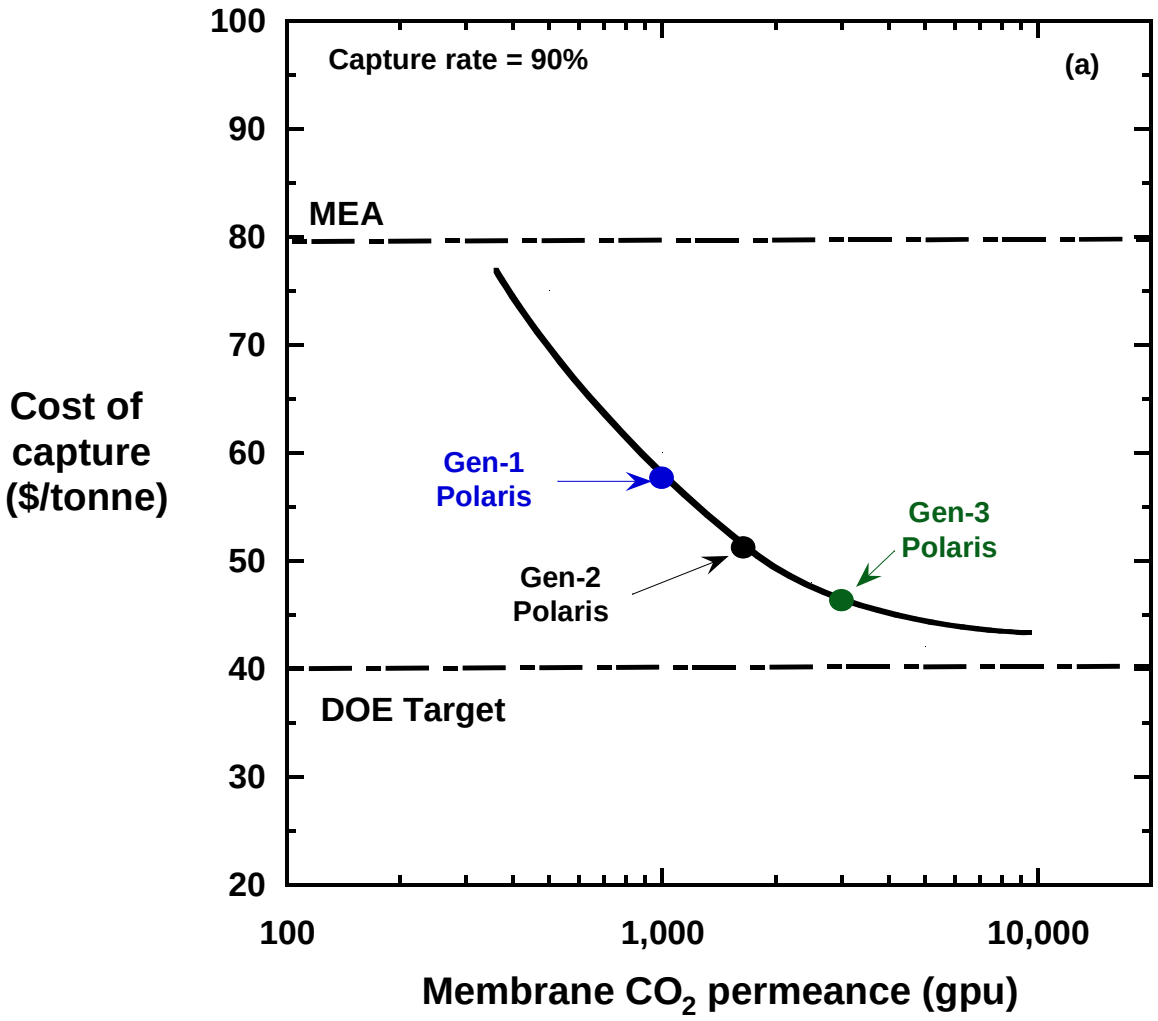
Importance of Membrane Improvements

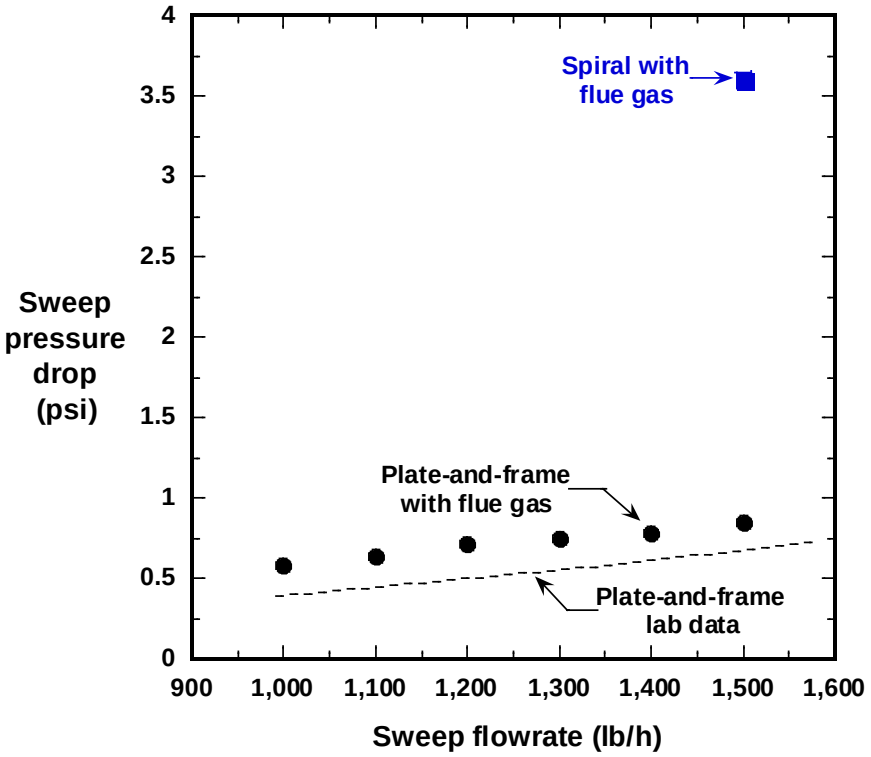


- Membrane CO_2 permeance directly impacts system size and capital cost
- Beyond Gen 3 (3,000 gpu), diminishing returns for additional permeance increases

New Modules Have Much Lower Pressure-Drop

Module size

Module pressure-drop



- Reduced pressure-drop with new module saves ~15 MW_e of blower energy at full-scale
- New module performance validated at both NCCC and B&W field tests

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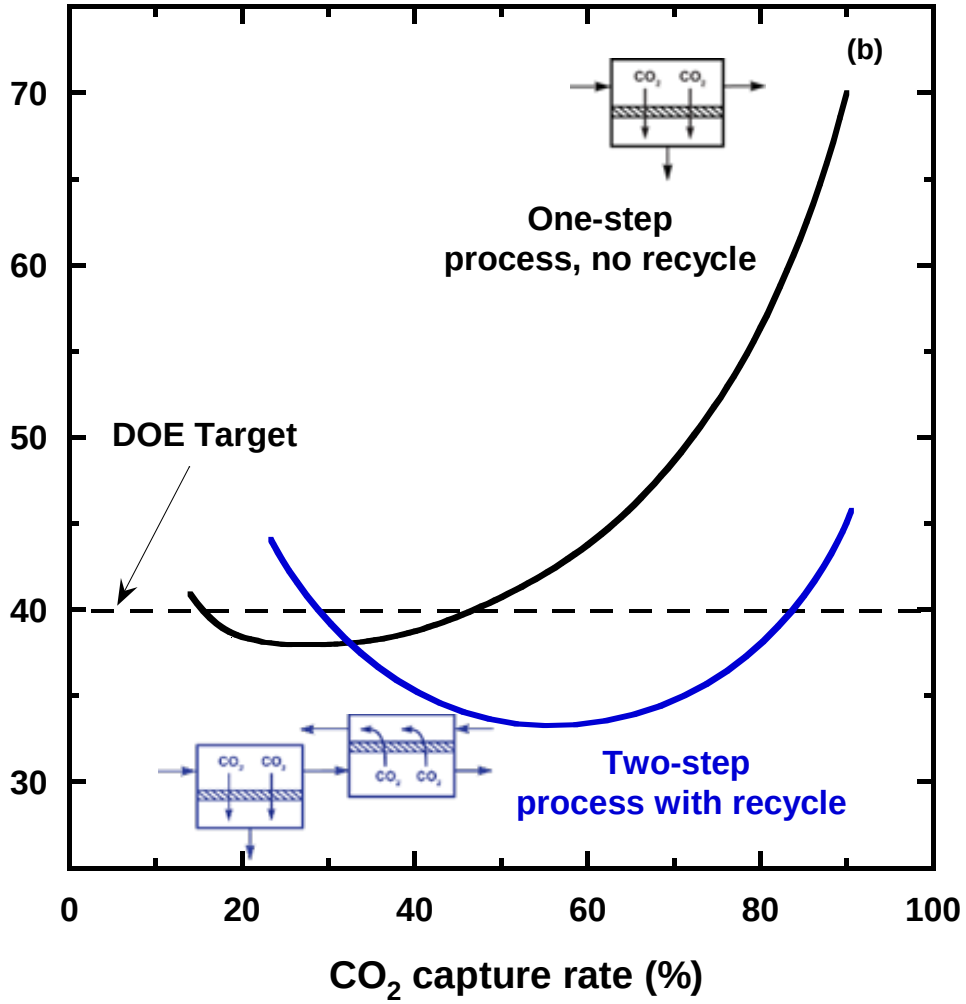
Membrane "Sweet Spot"



- Even with Gen 2 membranes and low pressure drop, cost at 90% capture is >$40/tonne
- Membranes are best for bulk separations. There is a sweet spot for the technology between 40 – 80% capture
- Selective recycle design reduces capture cost by as much as $25/tonne at high capture rates (including boiler de-rate measured at B&W)

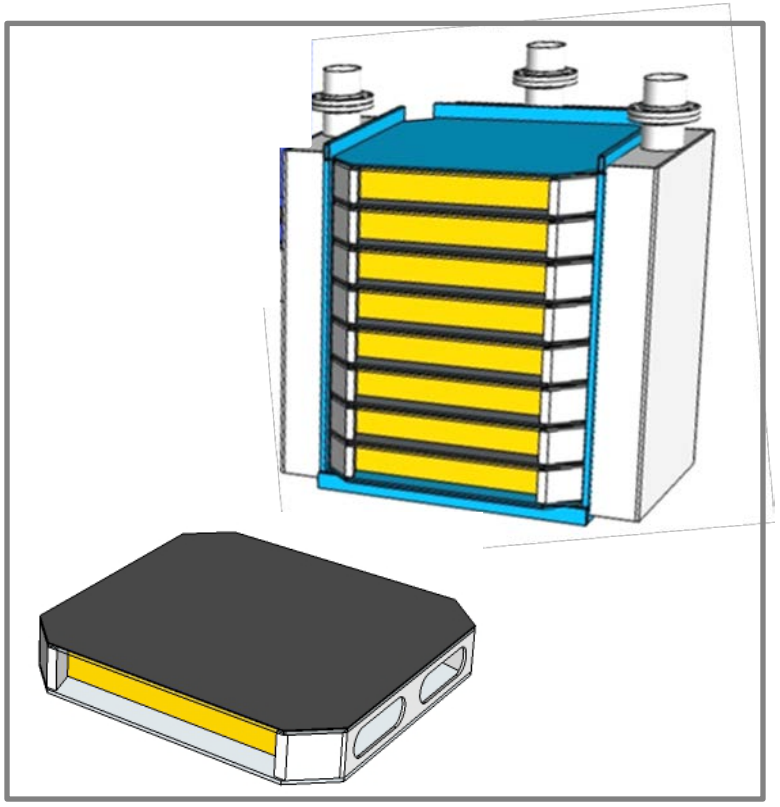
Key Goals of This Project

- Scale-up and validate in field testing at TCM improved membrane (Gen 2 Polaris) and modules (low-pressure-drop plate-and-frame)
- Demonstrate “containerized” skid as final form factor for future large-scale systems
- With partners, perform an engineering study to optimize integration of pump/compression equipment (Siemens) and CO_2 purification unit (Trimeric)
- Focus TCM testing and TEA on membrane “sweet spot” → 40% – 80% capture

Membrane Modules for TCM System

Prototype Module 2016/17

TCM Modules 2020

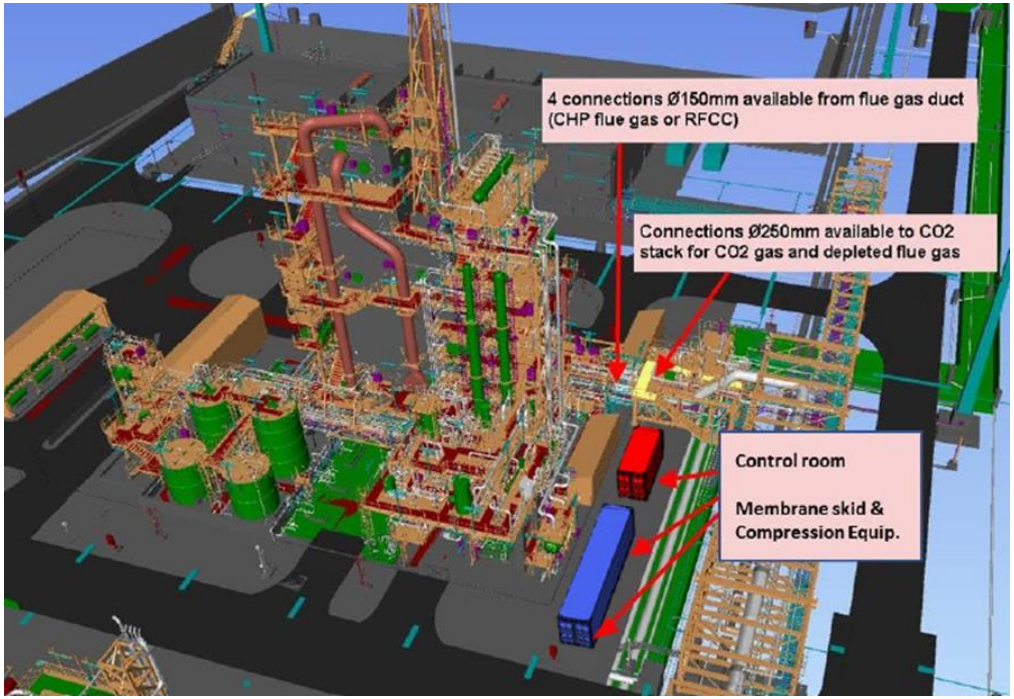


- Polaris Gen 2 membrane will be packaged in low-pressure-drop plate-and-frame modules
- Plastic module components used to reduce cost

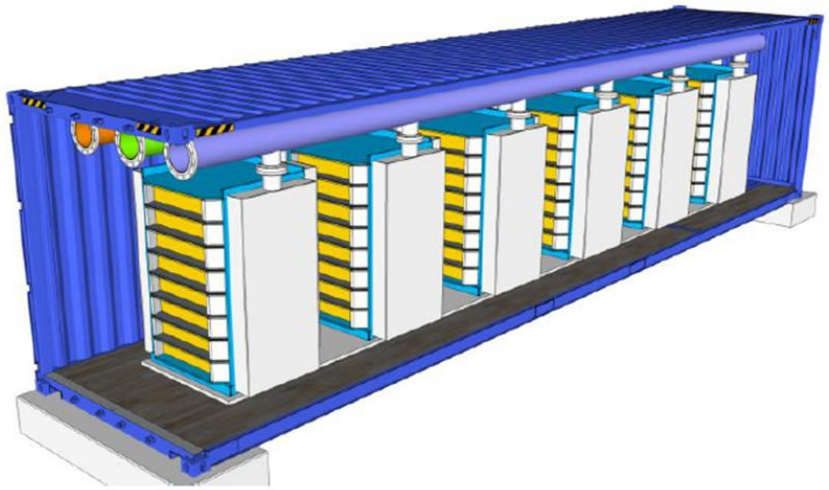
MTR

Preliminary Drawings of Advanced Polaris System

TCM layout showing possible MTR skid location

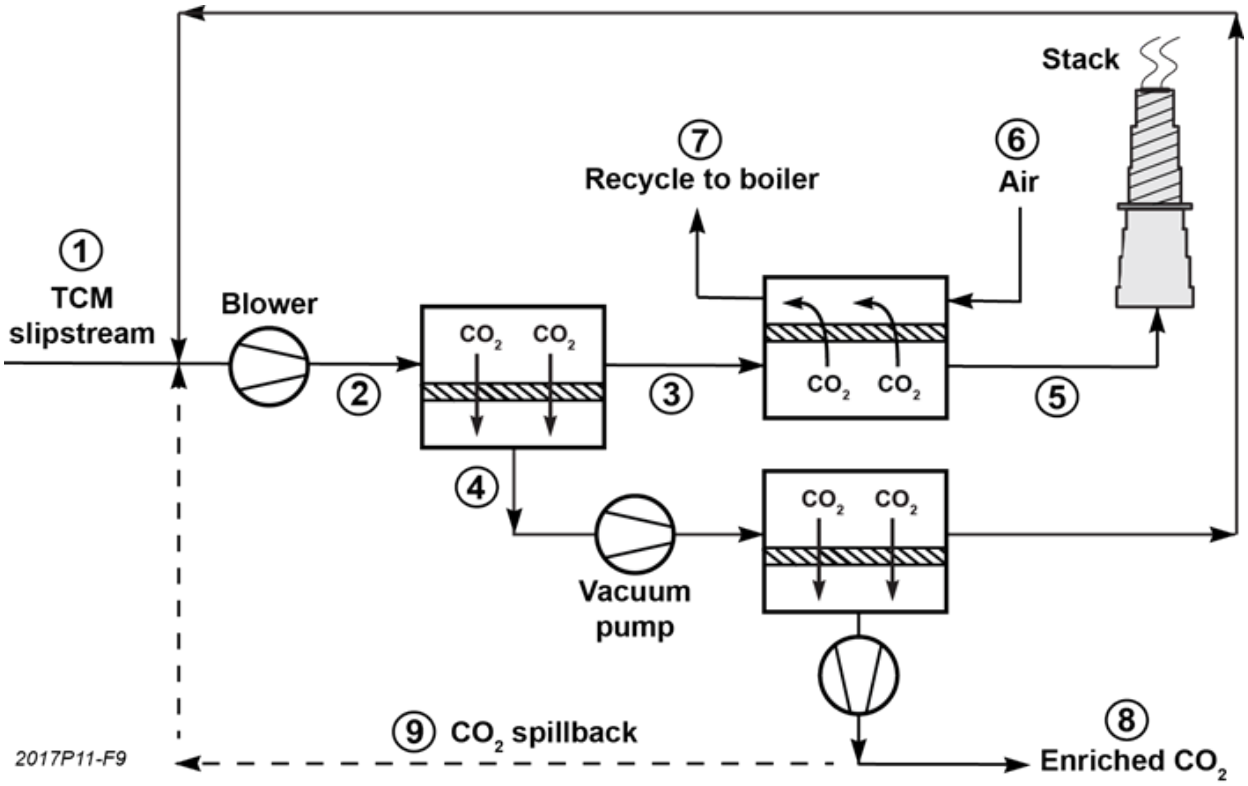


Polaris Gen 2 modules bundled in low-cost container



- Goal is 6 months of parametric and steady state testing in project year 3 (2020/21)

PFD for TCM System



- Initial startup with first step only treating ~13% CO_2 doing ~50% capture
- Bring spillback online to boost feed CO_2 to ~20%
- Add sweep step to increase capture rate from 50% to 90%

Initial TCM Test Plan

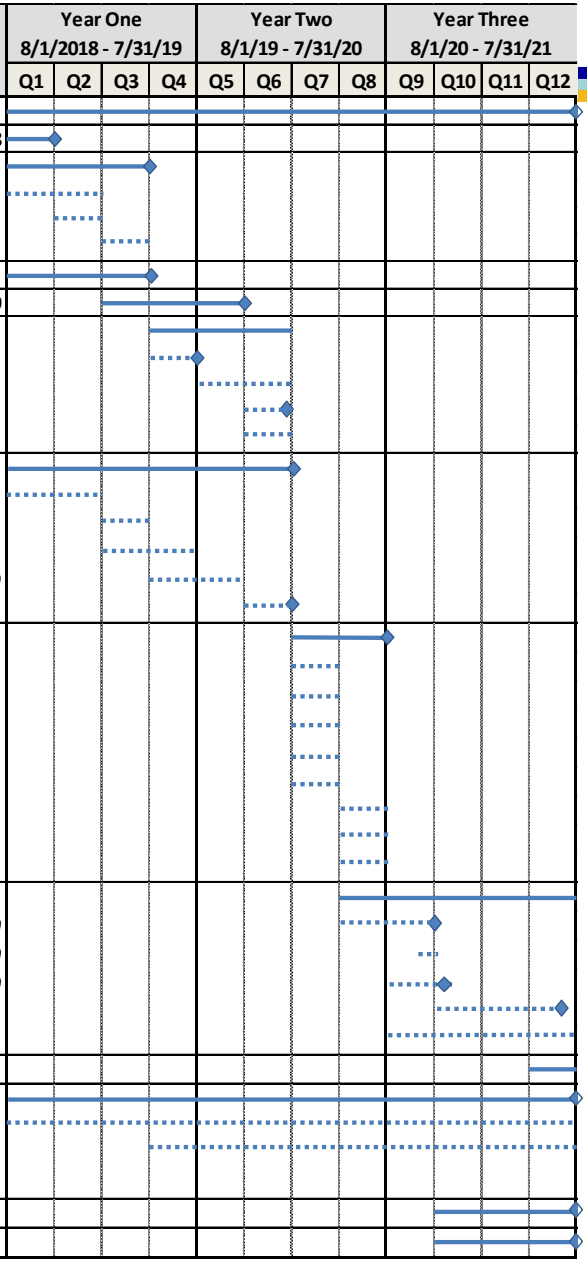
- Vary capture rate without sweep step or spillback
- Vary capture rate with sweep step using spillback to mimic enriched CO_2 feed content
- During these parametric steady state tests, monitor separation efficiency, system pressure drops, and gas compositions to CPU
- Run dynamic tests (startup/shutdown, load change) to document membrane response time
- Based on parametric test data, select optimum condition (probably ~60% capture with sweep), and run steady state test
- Final test plan to include input from CCSI2

Equipment Optimization Engineering Study

- Initial test systems, including NCCC small pilot, used liquid ring vacuum pumps and air compressors because they were durable and relatively cheap (~$500/kW)
- However, larger systems will need to use high efficiency (>80%) centrifugal machines (TEAs assume these efficiencies with costs in $1000 - $2000/kW range)
- Moreover, for advanced membrane systems, vacuum pumps/CO_2 compressor (~40%) and CO_2 purification (~25%) are the largest capital items (membranes ~20%)
- In this project, Dresser Rand and Trimeric will examine equipment options for field and full-scale systems, including integration of advanced compression equipment

Project Gantt Chart

Project Tasks	Task Participants	Task Start Date	Task End Date
Task M1. Project Management and Planning	**MTR/TCM**	**8/1/2018**	**7/31/2021**
Task 1. Technology Maturation Plan	**MTR**	**8/1/2018**	**10/31/2018**
Task 2. Design and Engineer Membrane Test System	**MTR**	**8/1/2018**	**4/30/2019**
Task 2.1. Preliminary Design		*8/1/2018*	*1/31/2019*
Task 2.2 Review TCM Site Specifications		*11/1/2018*	*1/31/2019*
Task 2.3. HAZOP Review and Finalize Design		*2/1/2019*	*4/30/2019*
Task 3. Make Membrane Rolls with Target Performance	**MTR**	**8/1/2018**	**4/30/2019**
Task 4. Prepare Low Pressue Drop Field Test Modules	**MTR**	**2/1/2019**	**10/31/2019**
Task 5. Fabricate Membrane Test System	**MTR**	**5/1/2019**	**1/31/2020**
Task 5.1. Select Vendors and Fabricator		*5/1/2019*	*7/31/2019*
Task 5.2.. Fabricate Skids		*8/1/2019*	*1/31/2020*
Task 5.3. Factory Acceptance Test (FAT) at Fabricator Site		*11/1/2019*	*1/7/2020*
Task 5.4. Installation of Membrane Modules at Fabricator Site		*11/1/2019*	*1/31/2020*
Task 6. Host Site Preparations	**TCM/MTR**	**8/1/2018**	**1/31/2020**
Task 6.1. Site Engineering		*8/1/2018*	*1/31/2019*
Task 6.2. Skid Foundation		*2/1/2019*	*4/30/2019*
Task 6.3. Prepare Electrical and Water Utilities		*2/1/2019*	*7/31/2019*
Task 6.4. Prepare Process Connections		*5/1/2019*	*10/31/2019*
Task 6.5. Shipment of Membrane Test System to TCM Field Test Site		*11/1/2019*	*1/31/2020*
Task 7. Membrane Test System Installation and Pre-Commissioni	**TCM/MTR**	**2/1/2020**	**7/31/2020**
Task 7.1. Membrane Test System Mechanical Installation		*2/1/2020*	*4/30/2020*
Task 7.2. Utility Connections		*2/1/2020*	*4/30/2020*
Task 7.3. Process Line Connections		*2/1/2020*	*4/30/2020*
Task 7.4. Installation of Heat Tracing and Insulation		*2/1/2020*	*4/30/2020*
Task 7.5. Data Acquisition and Control Installation		*2/1/2020*	*4/30/2020*
Task 7.6. Pre-Commissioning Operations		*5/1/2020*	*7/31/2020*
Task 7.7. Develop Preliminary Test Plan		*5/1/2020*	*7/31/2020*
Task 7.8. Job Site Safety Practices Review and Operator Training		*5/1/2020*	*7/31/2020*
Task 8. Operate Membrane Test System	**MTR/TCM**	**5/1/2020**	**7/31/2021**
Task 8.1. System Commissioning		*5/1/2020*	*10/31/2020*
Task 8.2. Finalize Test Plan		*10/1/2020*	*10/31/2020*
Task 8.3. Parametric Operation of Test System		*8/1/2020*	*11/15/2020*
Task 8.4. Long-Term Operation of Test System		*11/1/2020*	*6/30/2021*
Task 8.5. Analyze System Performance		*8/1/2020*	*7/31/2021*
Task 9. Decommissioning and Site Clean-Up*	**MTR/TCM**	**5/1/2021**	**7/31/2021**
Task 10. Refine Techno-Economic Analysis	**MTR**	**8/1/18**	**7/31/21**
Task 10.1 Advanced Compression Integration	**Dresser-Rand**	*8/1/18*	*7/31/21*
Task 10.2 Update Techno-Economic Assessment	**Trimeric**	*5/1/19*	*7/31/21*
Task 11. Technology Gap Analysis	**MTR/WP**	**11/1/2020**	**7/31/2021**
Task 12. Environmental Health and Safety Risk Assessment	**MTR/WP**	**11/1/2020**	**7/31/2021**



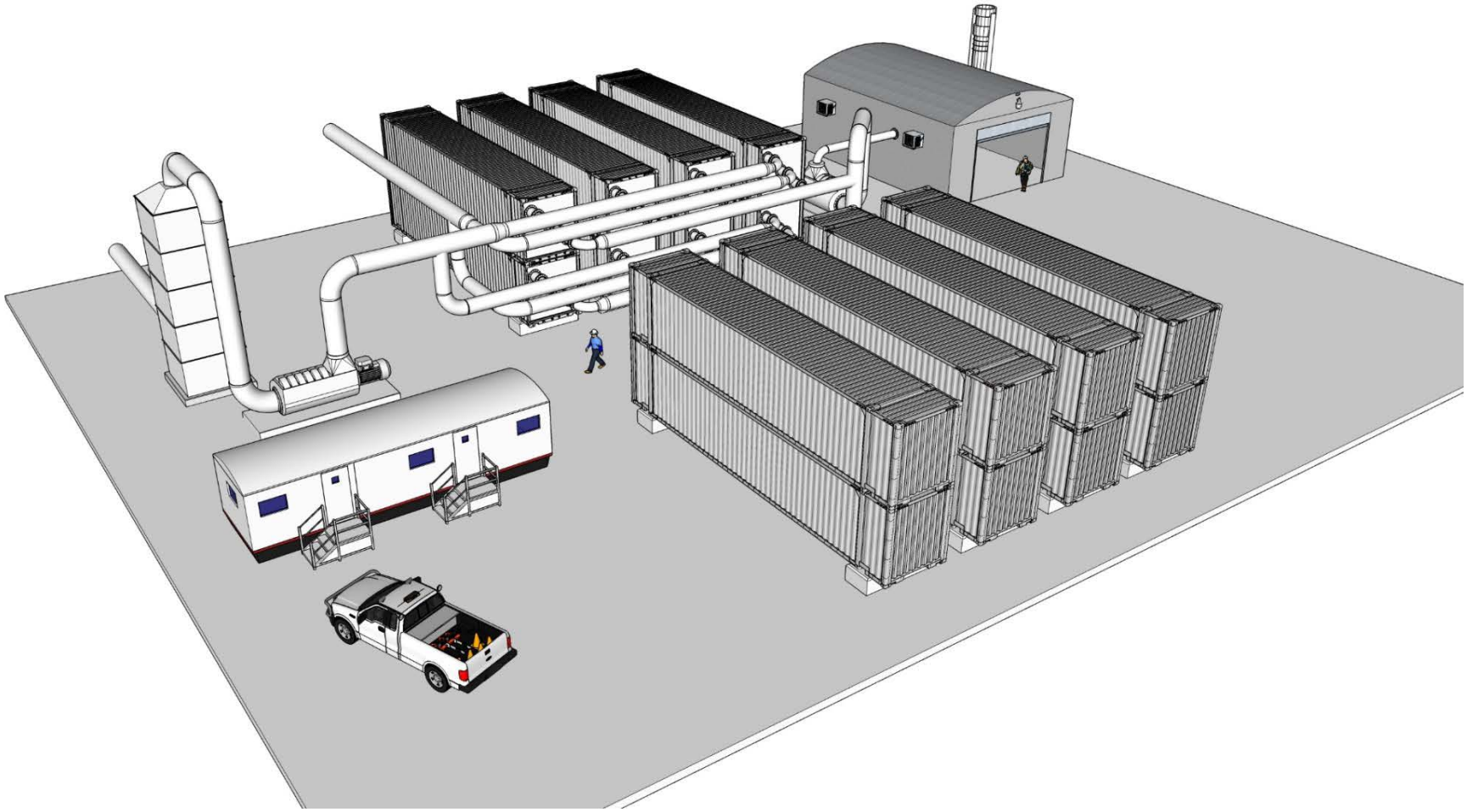
Key Project Milestones

Milestone Number and Task	Milestone Title	Planned Completion Date	Actual Completion Date	Variance Comment	Verification Method (if complete; e.g., summary report, quarterly progress report)
Budget Period 1 / Year 1					
3 (Task 2)	Finalize Test System Design	4/30/19	TBD	N/A	Quarterly Progress Report
4 (Task 3)	Gen-2 Polaris Membrane Rolls Fabricated	4/30/19	TBD	N/A	Quarterly Progress Report
Budget Period 2 / Year 2					
6 (Task 4)	Field Test Gen-2 Polaris Membrane Modules Made	10/31/19	TBD	N/A	Quarterly Progress Report
7 (Task 5.3)	Test System Passes Factory Acceptance Test (FAT) at Fabricator Site	1/7/20	TBD	N/A	Quarterly Progress Report
10 (Task 7)	Test System Installed at TCM and All Pre-Commissioning Activities Completed	7/31/20	TBD	N/A	Quarterly Progress Report
Budget Period 3 / Year 3					
13 (Task 8.4)	Long Term Performance Testing Completed	6/30/21	TBD	N/A	Quarterly Progress Report
14 (Task 10)	Complete Techno-Economic Analysis Report	7/31/21	TBD	N/A	Topical Report to be included in the Final Report

Current Project Status

- Project started August 1, 2018
- Teleconferences with TCM and subcontractors focused on getting contracts in place and collecting system design information
- Technology maturation plan to be completed by end of Oct
- Design of low-cost modules components nearly complete; receiving bids from fabricators

Path Forward: Importance of Work



- Conceptual drawing of ~15 MW_e large pilot using containerized skids developed in this program

Summary

- Project is just underway with initial effort focused on finalizing subcontracts, technology maturation plan, and module/system design work
- Primary project goal will be field testing at TCM of Polaris Gen 2 membranes packaged in low pressure drop modules
- This modular technology will be the final form used in future scaled-up systems
- A secondary goal will be an engineering study to aid in the optimization of balance of plant equipment (advanced compression, CO_2 purification)

MTR

Acknowledgements

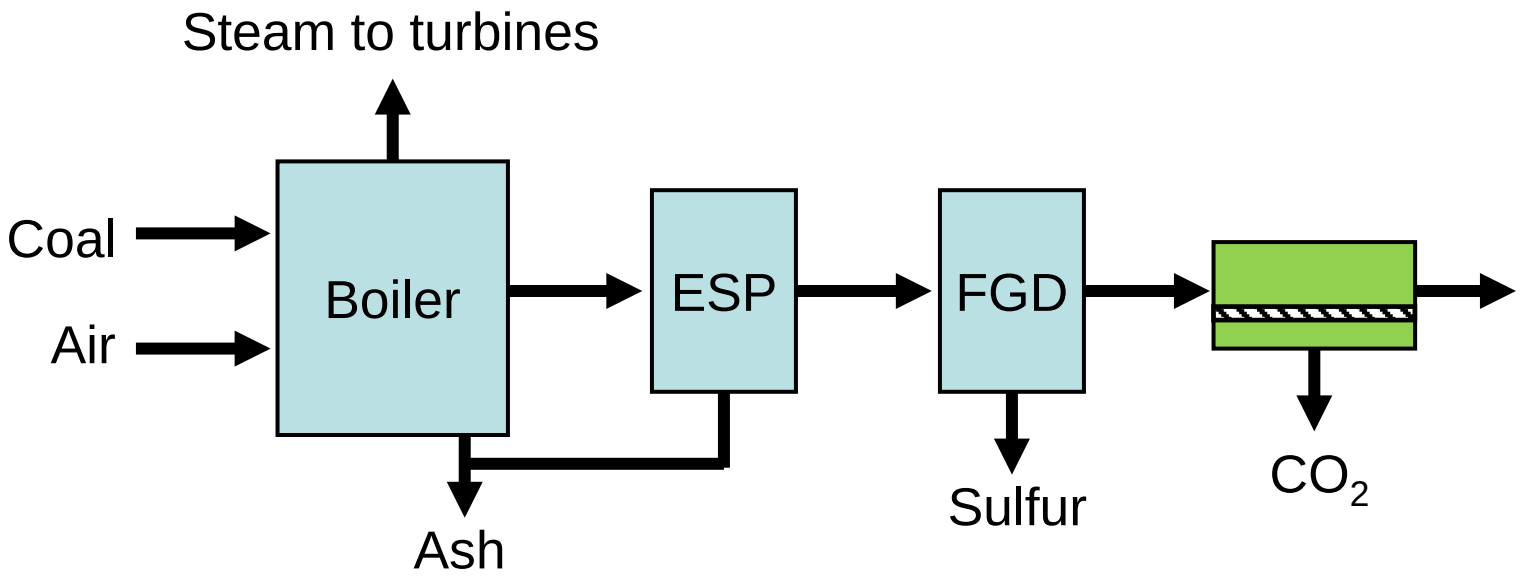
- **U.S. Department of Energy,**

  National Energy Technology Laboratory
  - José Figueroa
  - Bruce Lani

MTR

Extras

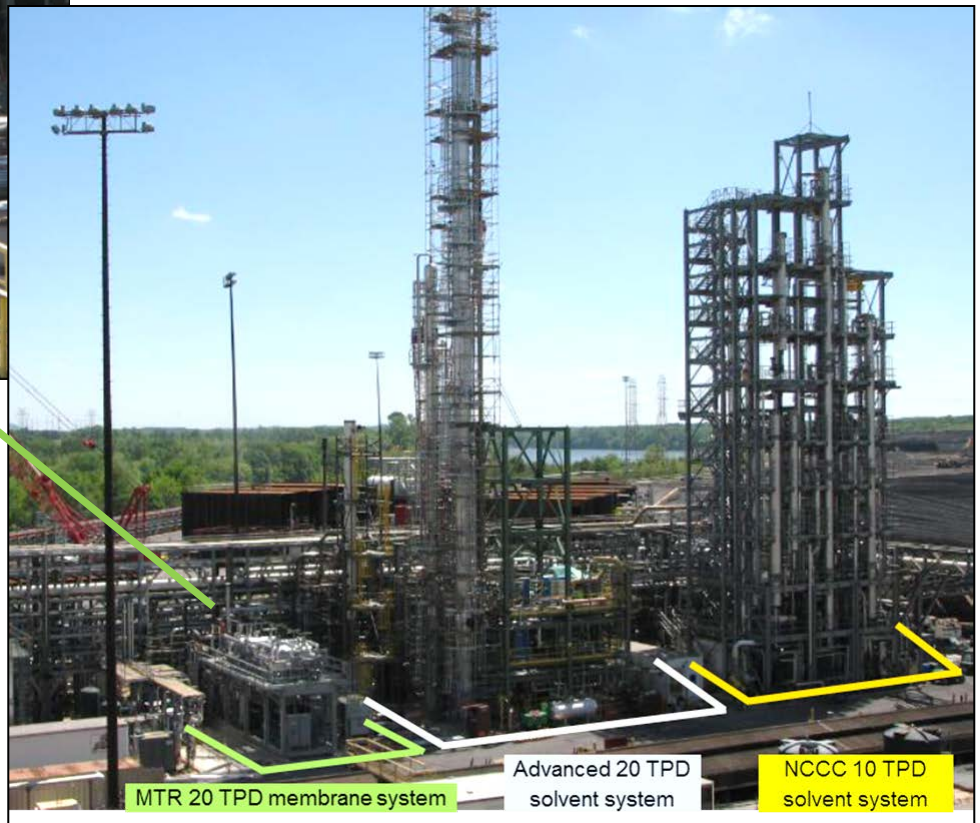
Post-Combustion CO_2 Capture with Membranes



- Like other capture approaches, membranes would be used downstream of current flue gas cleanup technologies (ESP, FGD)
- Membranes offer some advantages such as no chemical handling/emissions, no steam use, instantaneous response, low water use, pre-assembled modular technology, efficient bulk capture

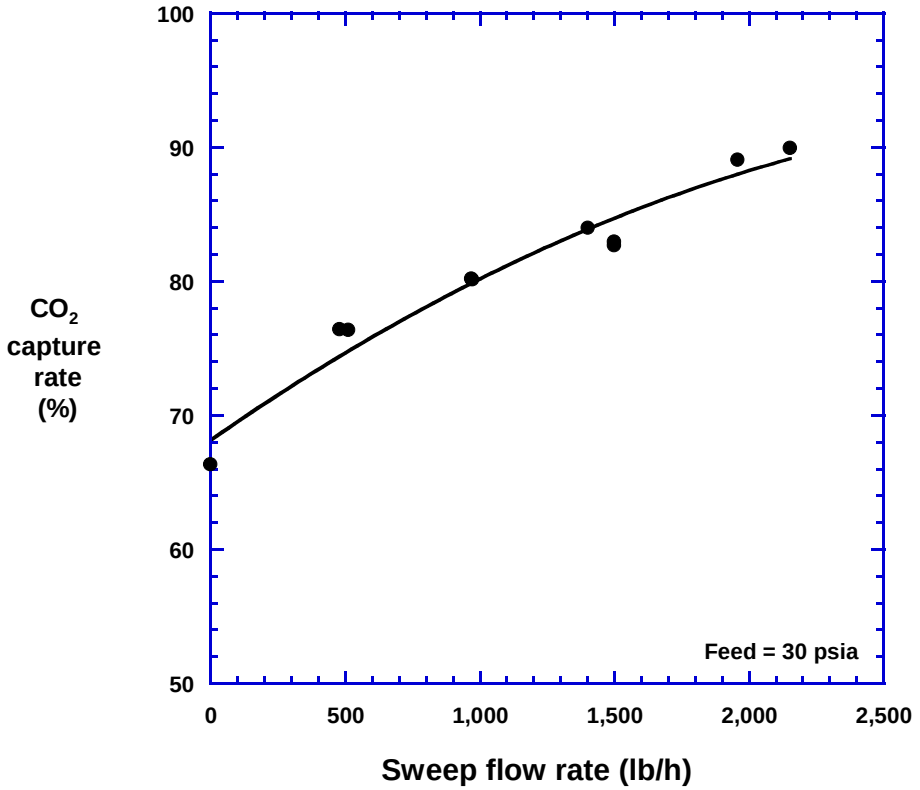
Background:
Small Pilot Testing at NCCC

- MTR small pilot completed 6 months of operation at NCCC followed by an integrated boiler test at Babcock & Wilcox (B&W)



- Testing included validation of prototype Gen 2 Polaris membrane and low-pressure-drop modules

Test Results from B&W



- B&W campaign demonstrated varying capture rate by changing sweep flow