the Energy to Lead

Pilot Test of a Nanoporous, Super-Hydrophobic Membrane Contactor Process for Post-Combustion CO_2 Capture

DOE Contract DE-FE0012829

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NATIONAL ENERGY TECHNOLOGY LABORATORY

CO_2 Capture Technology Project Review Meeting

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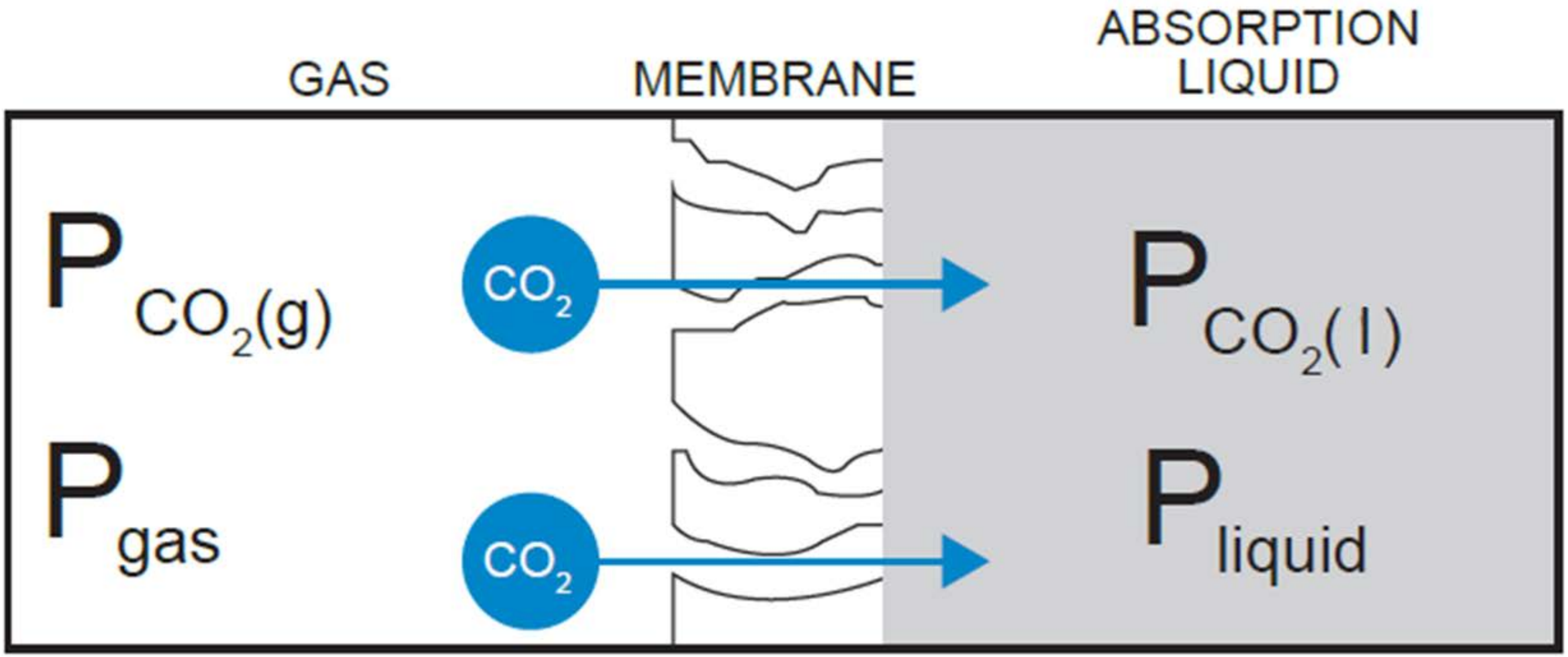
Project overview

- **Performance period**: Oct. 1, 2013 – June 30, 2019
- **Total funding**: \$13.7MM (DOE: \$10.6MM, Cost share: \$3.1MM)
- **Objectives**:
  - Build a 0.5 MW_e pilot-scale CO_2 capture system and conduct tests on coal flue gas at the National Carbon Capture Center (NCCC)
  - Demonstrate a continuous, steady-state operation
- **Goal:** achieve DOE's goal of 90% CO_2 capture rate with 95% CO_2 purity at a cost of \$40/tonne of CO_2 captured by 2025
- **Team**:

Member	Roles
gti	• Project management and planning • Process design and testing
AIR LIQUIDE ALaS PoroGen	• Membrane and module development
TRIMERIC CORPORATION	• Techno-Economic Analyses (TEA)
NCCC	• Site host

What is a membrane contactor?

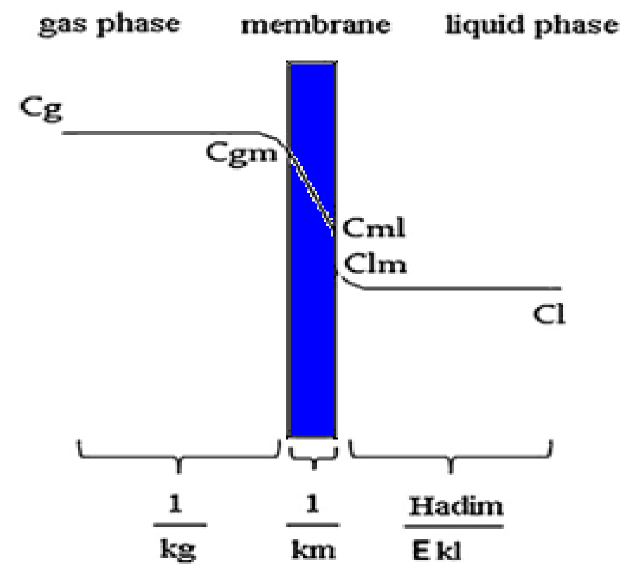
- High surface area membrane device that facilitates mass transfer
- Gas on one side, liquid on other side



- Membrane does not wet out in contact with liquid
- **Separation mechanism**: CO_2 permeates through membrane, reacts with the solvent; N_2 does not react and has low solubility in solvent

Technical challenges of applying HFMC to existing coal-fired plants

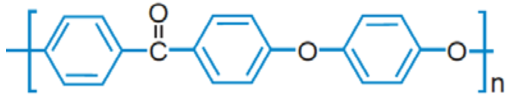
- **Performance** – Overall mass transfer resistance consists of three parts
  - Minimize each resistance
- **Module design and durability** – Long-term membrane wetting in contact with solvent
  - Make membrane surface super hydrophobic
  - Improve membrane potting to provide good seal between the liquid and gas sides
- **Fouling –** Flue gas contaminants and/or particulates may affect performance
  - Determine required pretreatments
- **Scale-up and cost reduction**
  - Make larger diameter modules



$$\frac{1}{K} = \frac{1}{k_g} + \frac{1}{k_m} + \frac{H_{adim}}{E \cdot k_l}$$

- Overall mass transfer coefficient K (cm/s)
  - In the gas phase, k_g
  - In the membrane, k_m
  - In the liquid phase, k_l
- H_{adim}: non-dimensional Henry's constant
- *E:* enhancement factor due to reaction

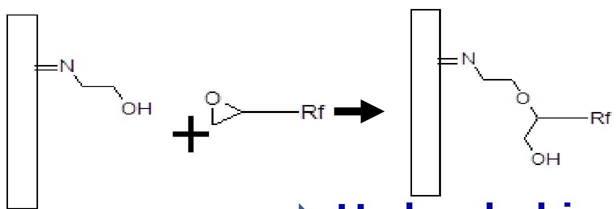
HFMC = **H**ollow **f**iber **m**embrane **c**ontactor

PEEK () characteristics and advantages of PEEK HFMC

- Exceptional thermal & mechanical resistances

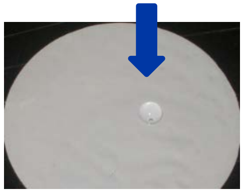
Polymer	Tensile modulus (GPA)	Tensile strength (MPa)	Max service temperature (°C)
Teflon™	0.4-0.5	17-21	250
Polysulfone	2.6	70	160
PEEK	**4**	**97**	**271**

- Surface modified to be super hydrophobic

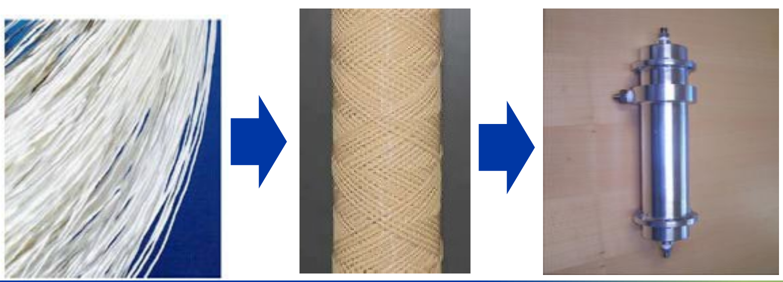


Hydrophilic → **Hydrophobic**

Ethanol



- Hollow fibers w/ high CO_2 flux and packing density



PEEK HFMC advantages (compared to conventional absorbers)

- **High packing density** results in over 100x increase in mass transfer coefficient, and thus much smaller equipment size
- **Reduction in weight** for over 30%
- **Reduction in footprint** due to versatile modular layout
- **Easy scaleup** by adding membrane modules
- **Flexibility**: commercial solvent aMDEA being used; advanced solvents can be used for additional savings
- **Reduction in solvent degradation** due to an indirect contact of flue gas contaminants and solvent

PEEK = **Poly**ether **E**ther **K**etone

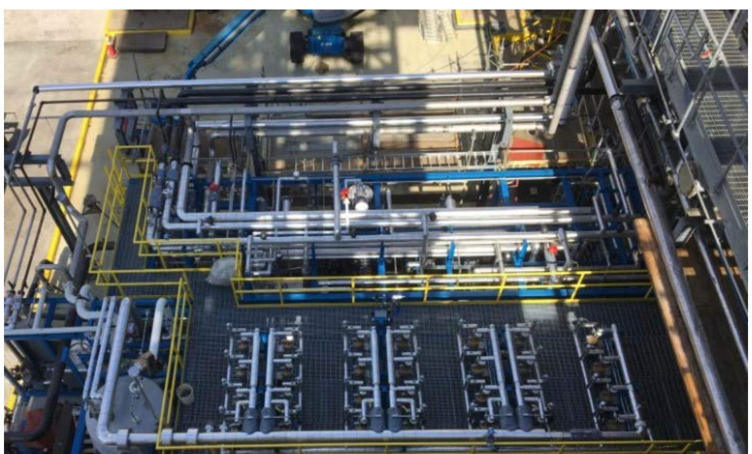
Module scaled to 8-inch by ALaS and tested at GTI with aMDEA solvent using air/CO_2 mixed feed

- **Intrinsic CO_2 permeance: 2,000 GPU**
- **Improved mass transfer coefficient of 2.0 $(sec.)^{-1}$ obtained in lab CO_2 capture testing**

GPU= **G**as **P**ermeation **U**nit, 1 GPU = 3.348×10^{-10} $mol/m^2/s/Pa$

0.5 MW_e pilot plant designed, constructed and installed at the NCCC

Plant constructed

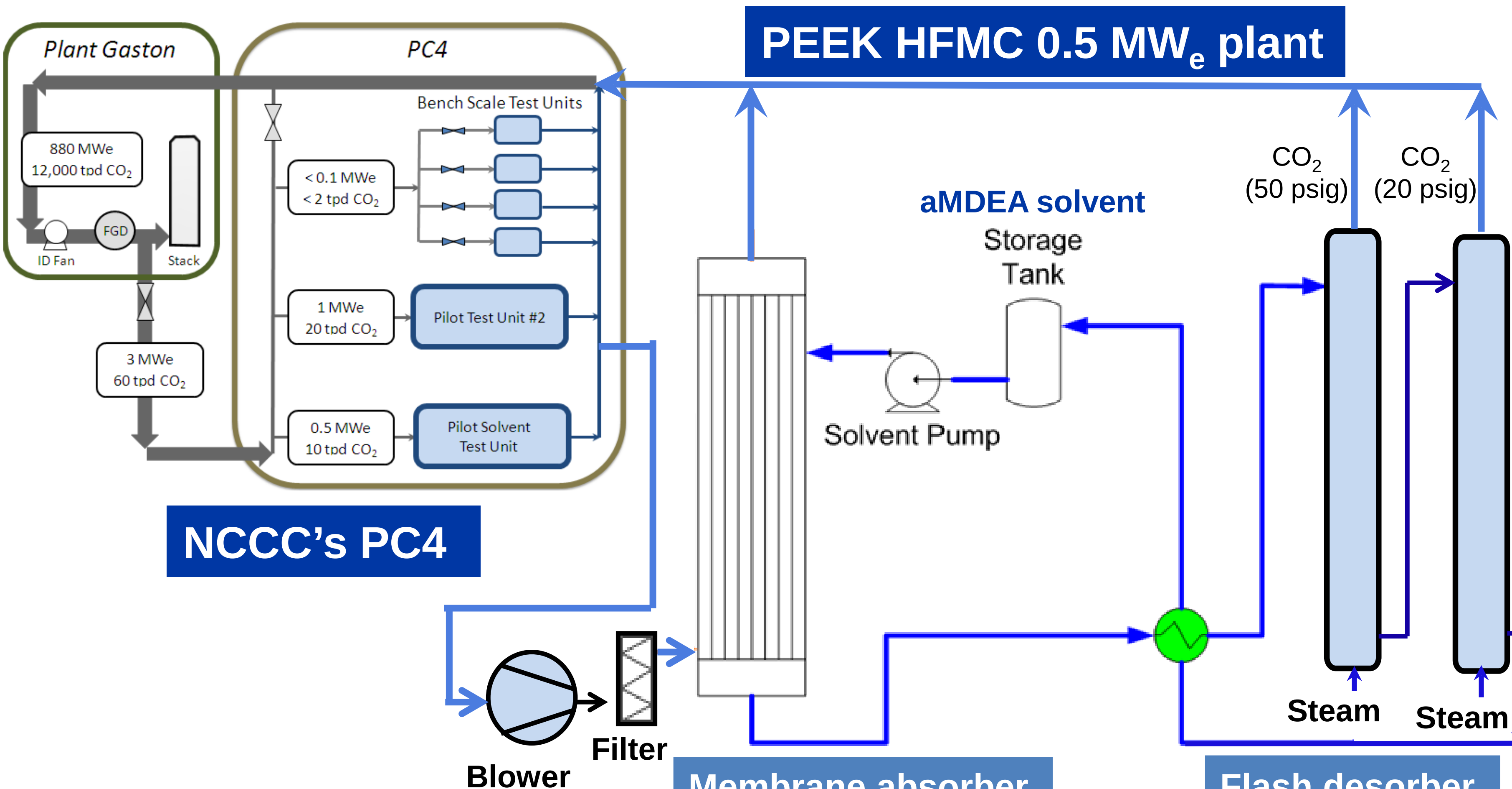


Plant installed at the NCCC
12 m (L) x 7.5 m (W) x 3.5 m (H)

NCCC PSTU system (0.5 MW_e)

GTI HFMC system (0.5 MW_e)

Process description



Membrane absorber

T (ºC)	P (psig)
40-60	1-10

Flash desorber

T (ºC)	P (psig)
~130	1-50

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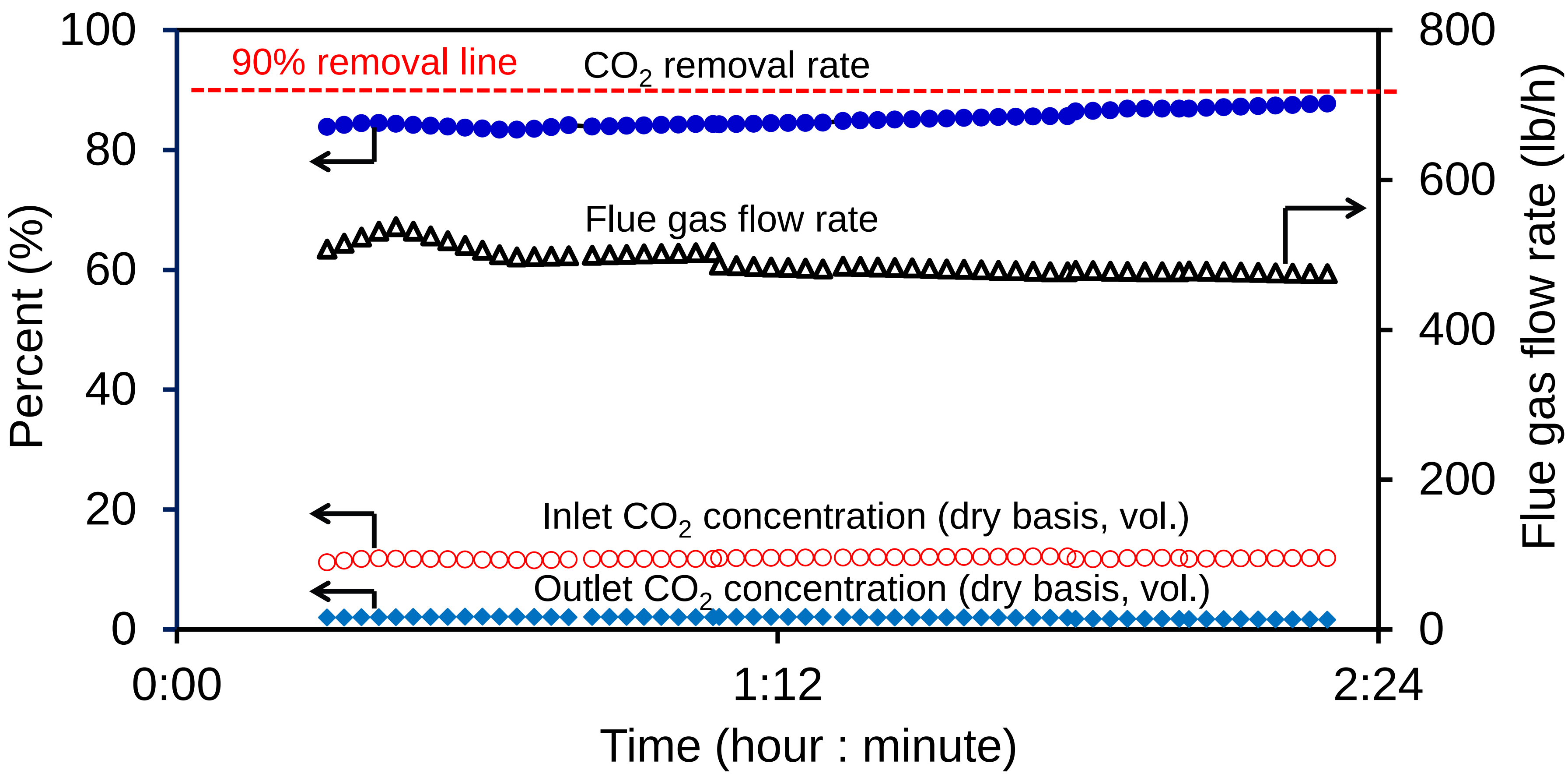
Initial tests with 4 modules and flue gas at NCCC indicates DOE's technical target can be achieved

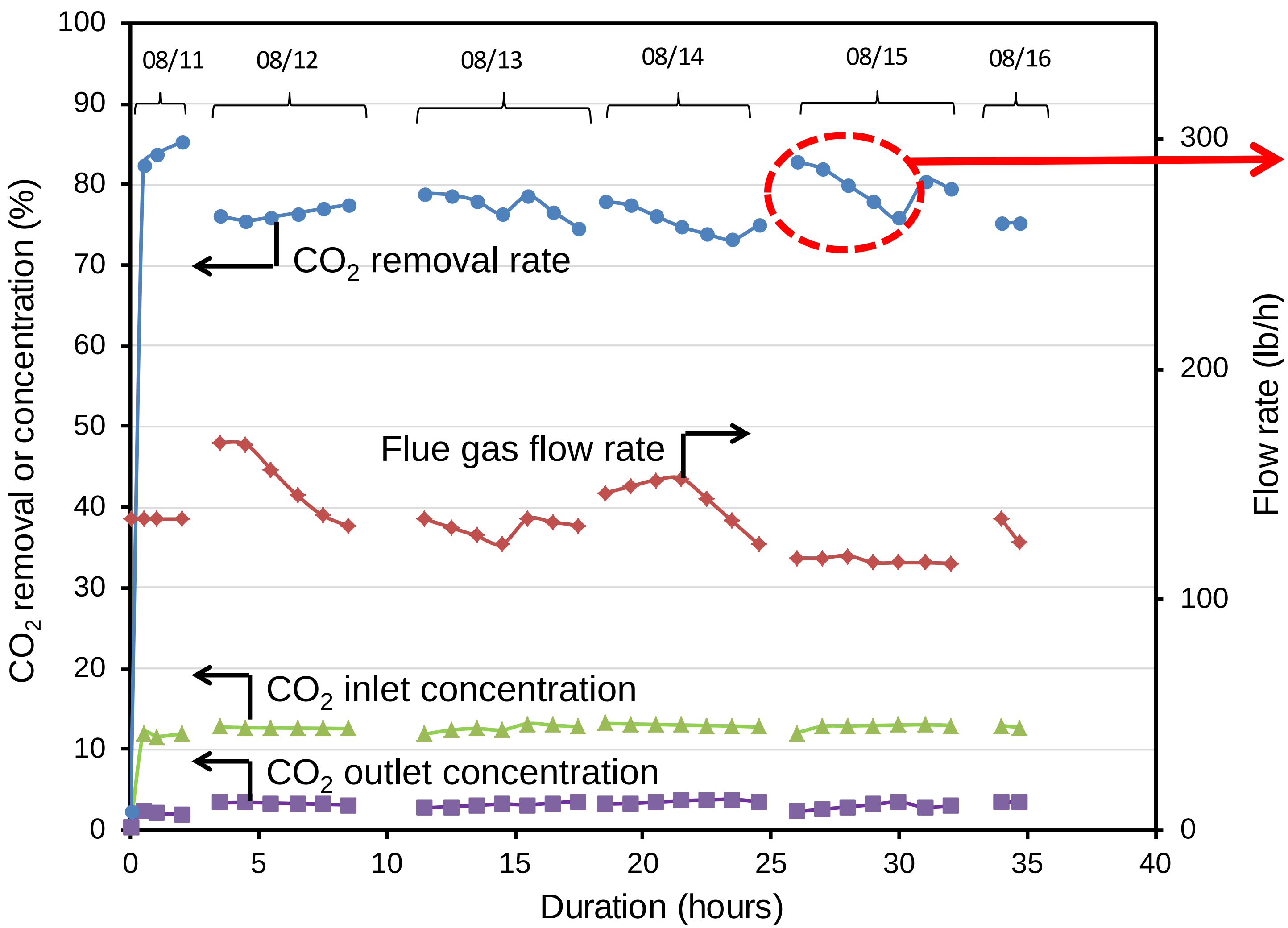
- **CO_2 removal rate:**



- **CO_2 purity: > 98.6% CO_2**

Issues observed: 1) water vapor capillary condensation in PEEK pores, 2) concentration polarization

Example of liquid side concentration polarization issue



Concentration polarization issue: higher CO_2 concentration in the fluid boundary layer (next to the fiber) relative to the bulk flow stream

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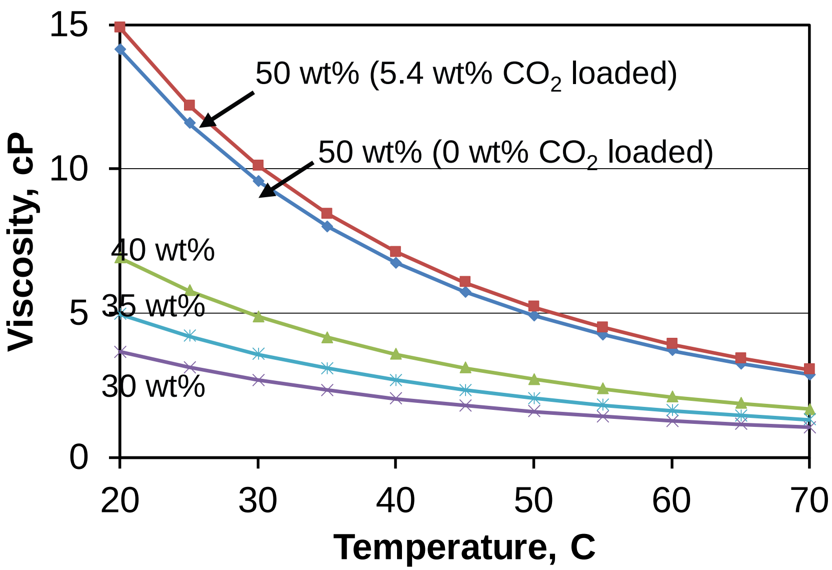
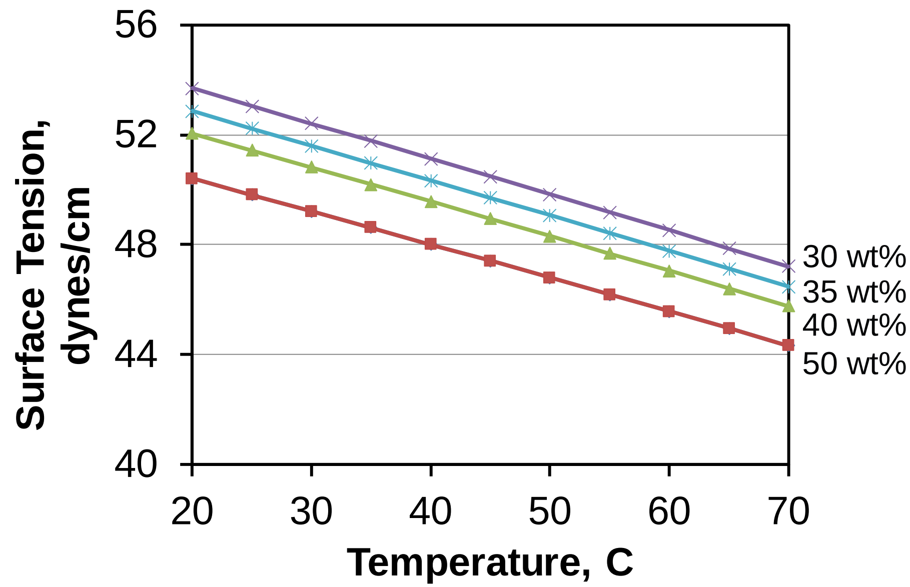
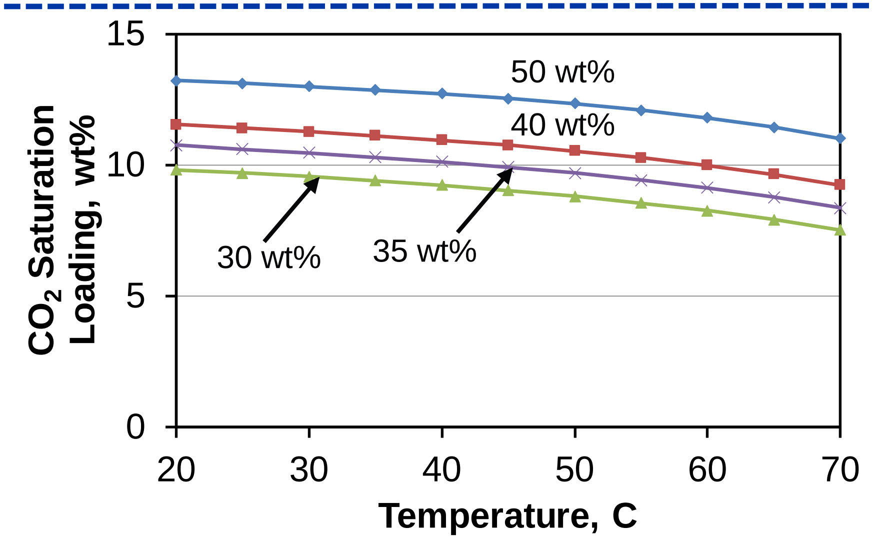
Concentration polarization issue was resolved by decreasing aMDEA concentration

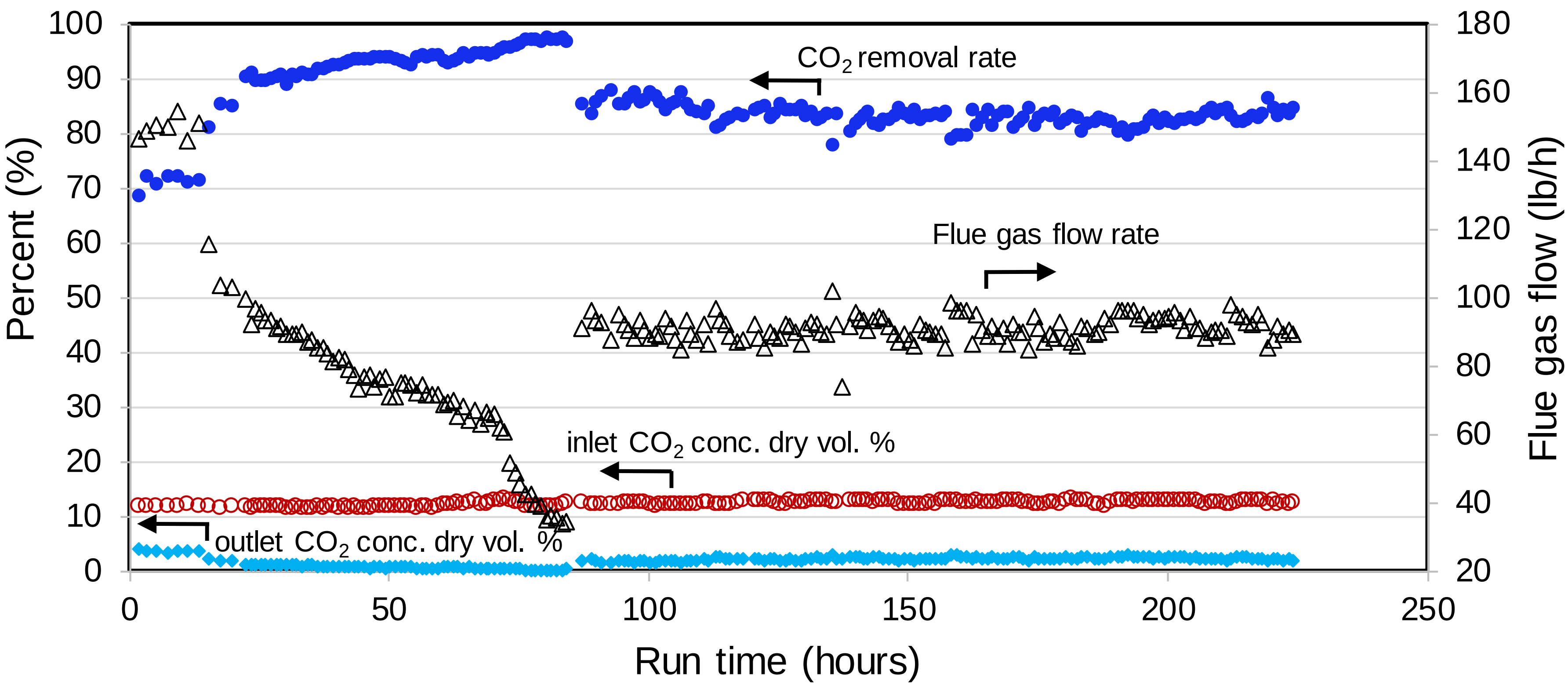




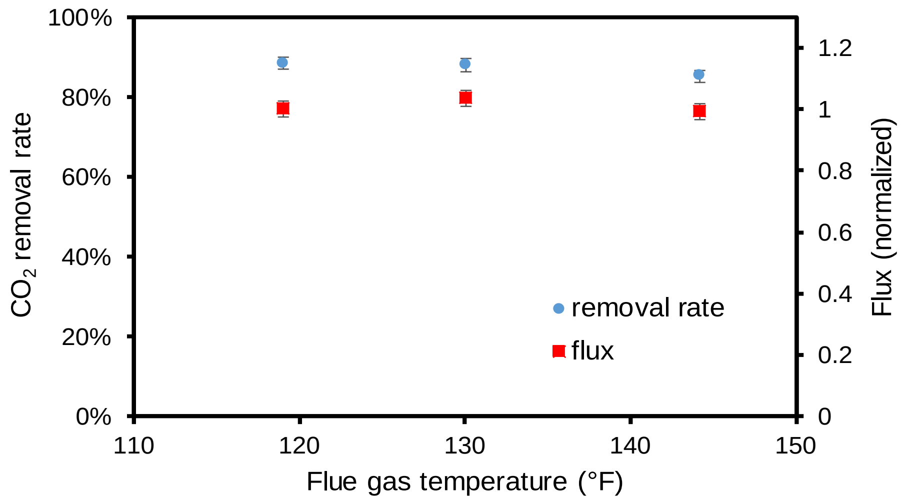


- The concentration change (from 50 wt.% to 35 wt.%) moves in a good direction for reducing both liquid side concentration polarization and membrane wetting

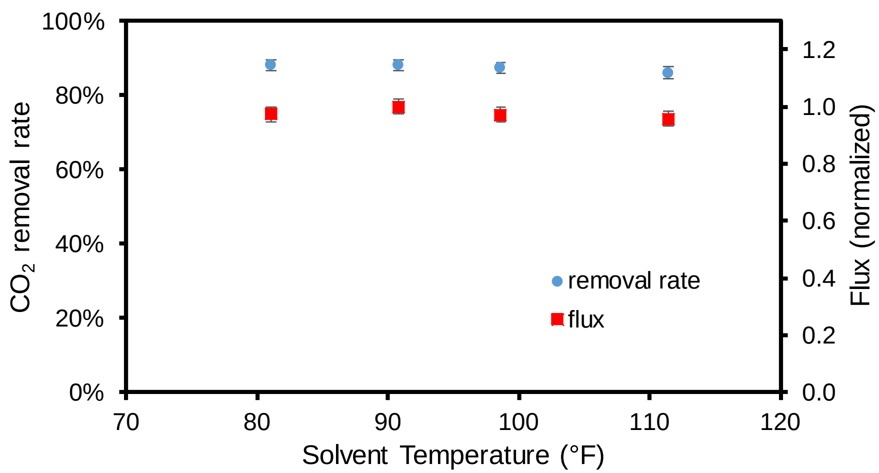
Issues resolved, steady state performance achieved for a single module during 224-h continuous testing

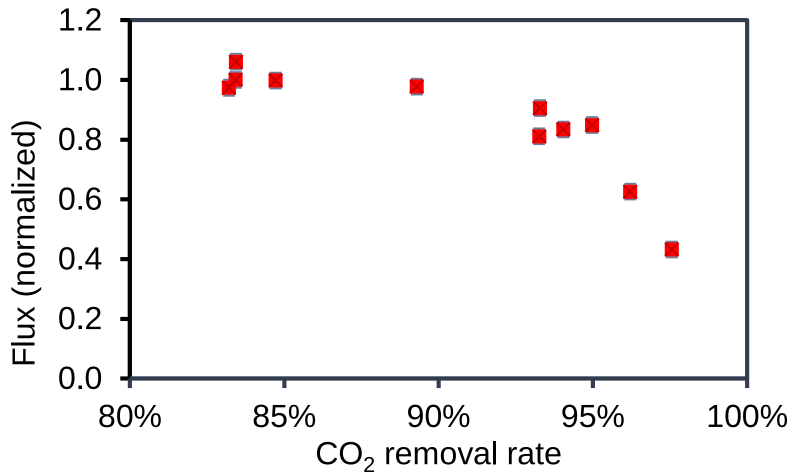


Examples of parametric testing results



- Parameters investigated:
  - Flue gas temperature
  - Solvent temperature
  - CO_2 capture rate
  - Flue gas feed pressure
  - Solvent flow velocity





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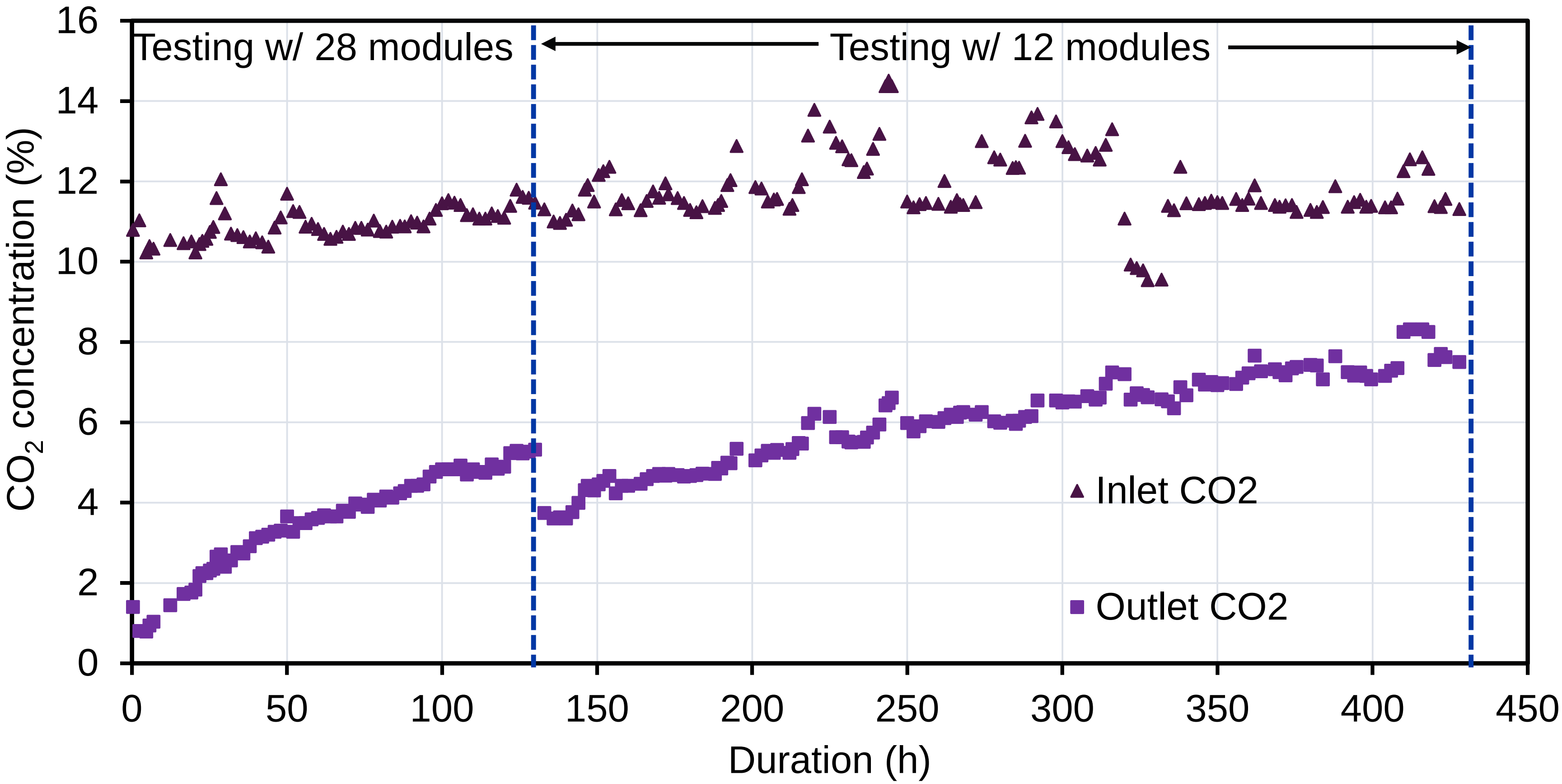
Continuous testing with 28 membrane modules performed during May-June 2018

- **Timeline**
  - May 25-30 (0-133 h): testing with all 28 membrane modules (A-G clusters)
  - May 30-June 12 (133-430 h): testing with better performance clusters A, E, F continued (clusters B, C, D, and G isolated during this period)
- **Integrated absorption/desorption worked properly during testing**
  - CO_2 purity target met, with CO_2 purity >99% during the long term testing
- **Solvent regeneration system reliable**
  - Rich and lean solvent samples collected daily and the CO_2 loadings analyzed by NCCC's lab indicate solvent regeneration worked as HYSYS predicted
  - Solvent analysis indicates solvent oxidation and thermal degradation was not an issue during our continuous operation

	Fresh solvent	Used solvent
Ratio of amine to activator (normalized)	1.00	1.04
Concentration of degradation products	< 0.01 wt. %	< 0.3 wt. %
Concentration of metals	Below detection limit	< 0.002 wt. %

Continuous testing with 28 membrane modules performed during May-June 2018 *(Cont'd)*

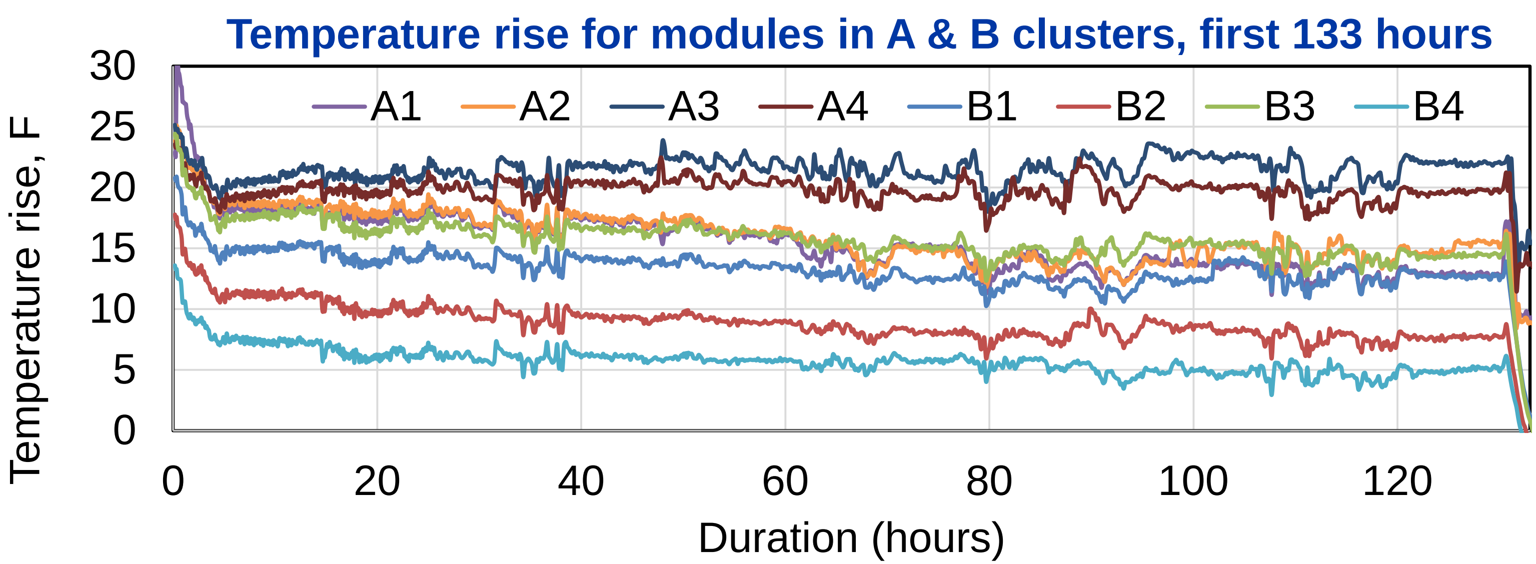
- **Membrane absorption:** CO_2 capture performance declined with time



- **Fault tree analysis (FTA) ongoing**, two major issues identified

Issue 1: potential reproducibility of membrane module fabrication

- In order to evaluate the consistency of capture for the individual modules, the temperature rise of the amine was measured for each module. The measured temperature rise varied from the expected value of ~22 °F down to 4 °F, indicating some modules were not functioning well



- **Approaches to resolve the issue**
  - ALaS to further improve membrane module fabrication
  - GTI to conduct QA/QC tests (CO_2 permeation and water flow ΔP tests) for selecting membrane modules

Issue 2: potential partial blockage of hollow fibers

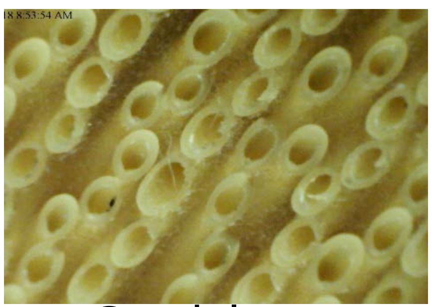
Clean cartridge

Gas inlet

Cartridge after May-June testing

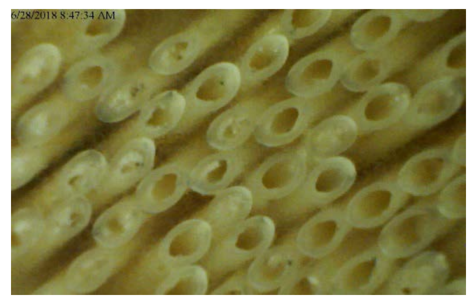
Gas inlet

Analysis indicates the white material is calcium sulfate (possibly from FGD system) or sodium sulfate (possibly from PSTU pre-scrubber system)

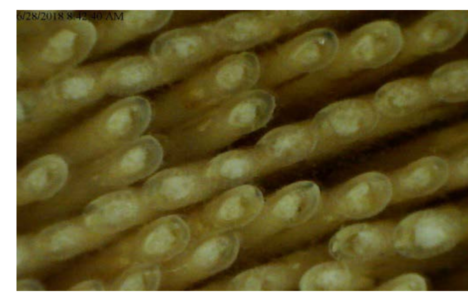


Gas inlet

Gas outlet



Gas inlet



Gas outlet

- **Approaches to resolve the issue**
  - Additional filtration before the membranes
  - Add pre-scrubber as needed

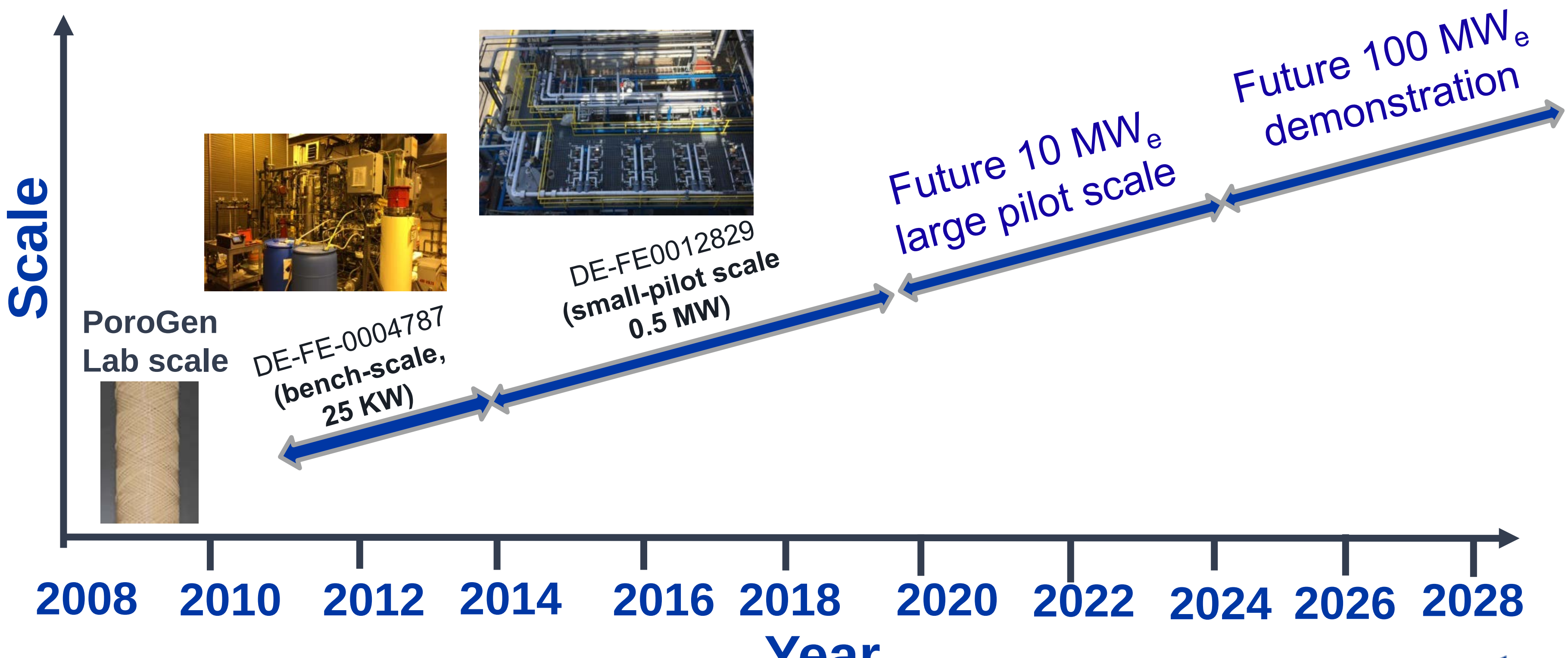
Future plans

- **In this project**

Complete FTA and resolve issues → Further testing → Final TEA

November 2018 | March 2019 | June 2019

- **After this project**



Summary

- Commercial 8-inch-diameter membrane modules with intrinsic CO_2 permeance of 2,000 GPU fabricated for pilot scale testing of the PEEK HFMC technology (preliminary TEA based on bench-scale field testing: PEEK HFMC costs 16% less than DOE Case 12)
- 0.5 MW_e pilot plant designed, constructed, installed, and being tested at NCCC
- Achieved steady state CO_2 capture performance with single module during our 224-h continuous operation at NCCC
- Continuous testing with 28 membrane modules did not match single module results
  - Fault tree analysis ongoing
  - Some potential issues and approaches to resolve the issues identified
  - Plan to resume testing after we resolve the issues

Acknowledgements

- **Financial and technical support**

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NATIONAL ENERGY TECHNOLOGY LABORATORY

Contract DE-FE0012829

gti **JIP Partners**

AIR LIQUIDE ADVANCED BUSINESS & TECHNOLOGIES ALaS

- **DOE NETL: Steven Mascaro, José Figueroa and Lynn Brickett**
- **Southern Company Services: National Carbon Capture Center**

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