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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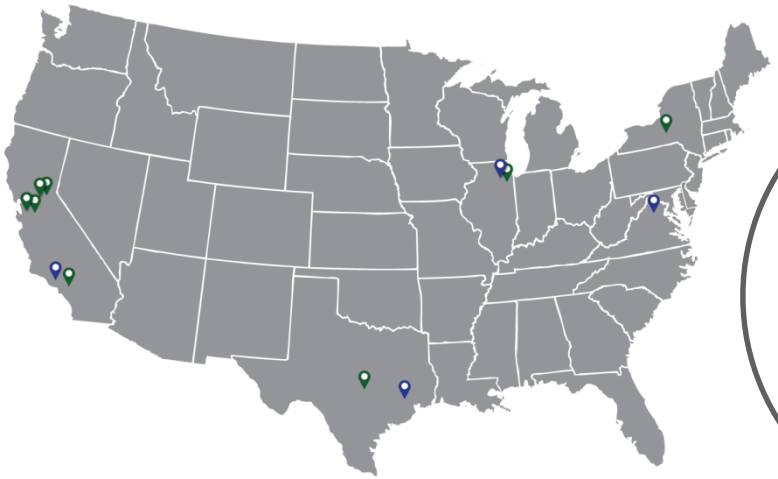
Introduction to GTI

- Research organization, providing energy and environmental solutions to the government and industry since 1941
- Facilities: 18 acre campus near Chicago



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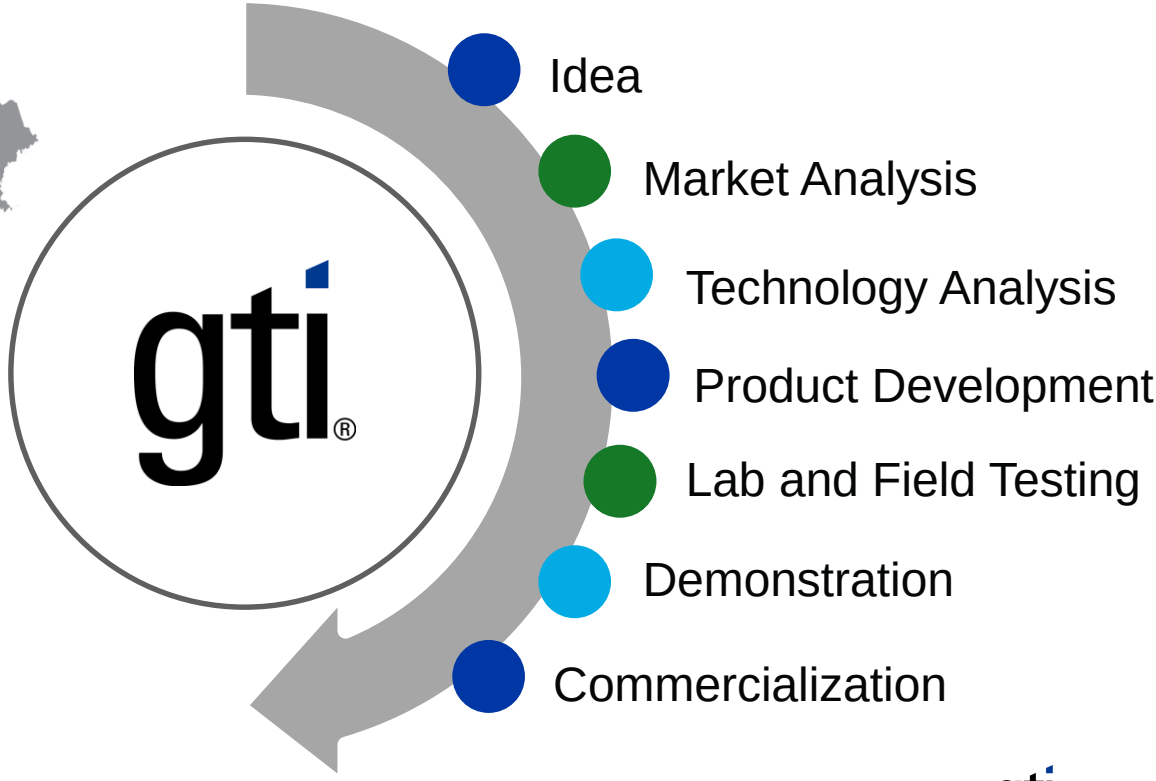


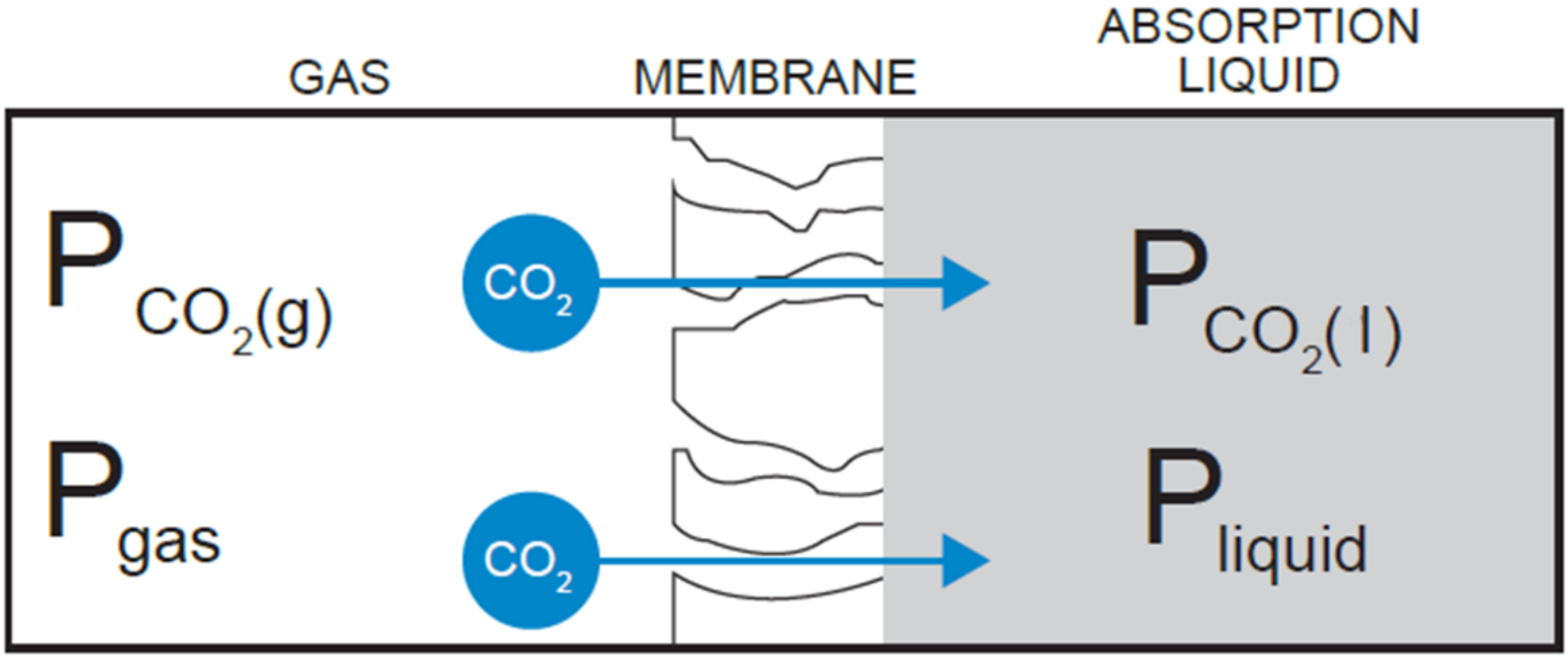
Project overview

- **Performance period**: Oct. 1, 2013 – June 30, 2018
- **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 flue gas at the National Carbon Capture Center (NCCC)
  - Demonstrate a continuous, steady-state operation for ≥ 2 months
- **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 ADVANCED BUSINESS & TECHNOLOGIES ALaS PoroGen INNOVATIVE MEMBRANE PRODUCTS PEEK	• Membrane and module development
TRIMERIC CORPORATION	• Techno-Economic Analyses (TEA)
NCCC	• Site host

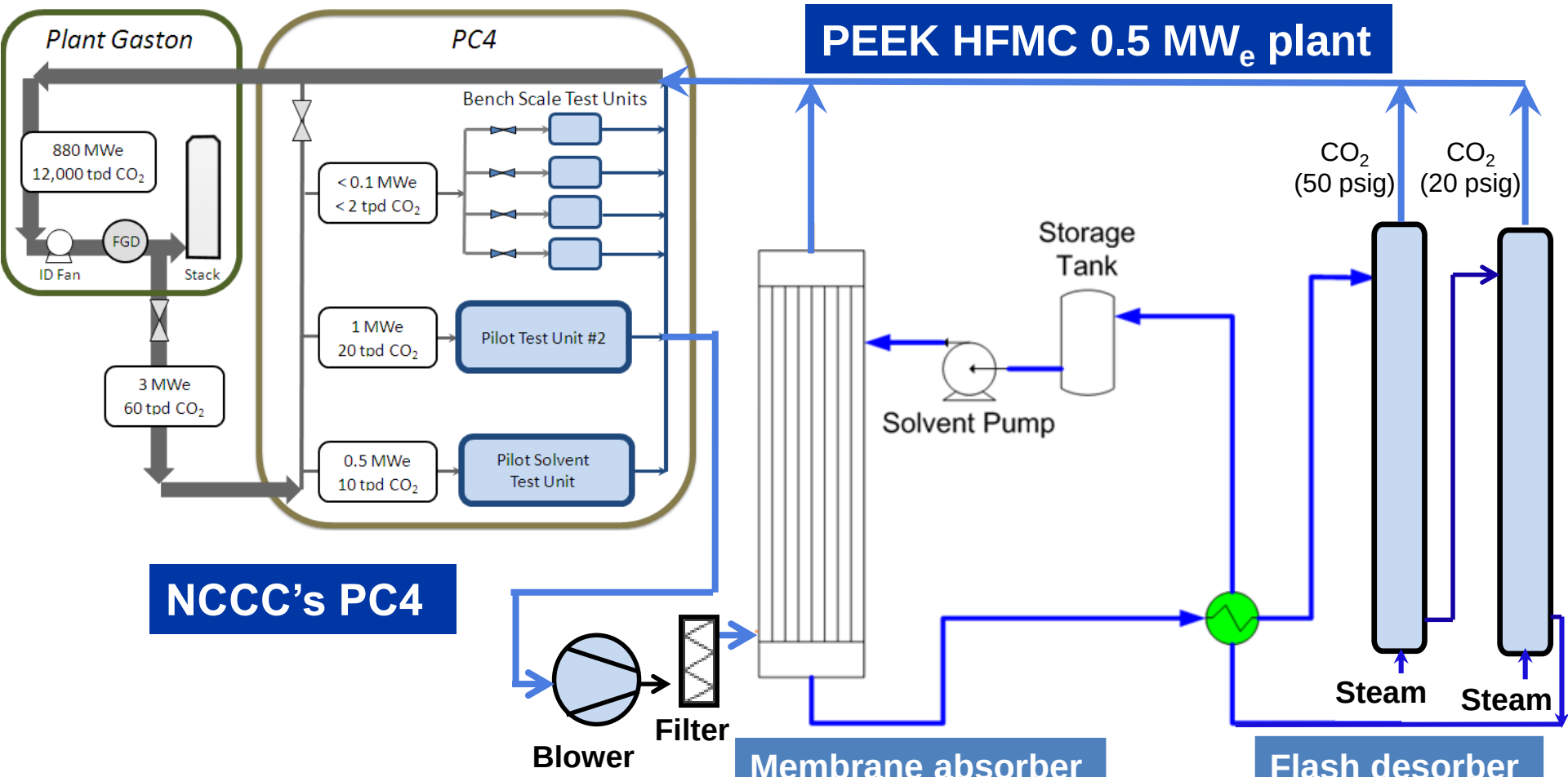
What is a membrane contactor?

- 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
- **<u>Separation mechanism</u>**: CO_2 permeates through membrane, reacts with the solvent; N_2 does not react and has low solubility in solvent

Process description



Membrane absorber	
T (°C)	P (psig)
40-60	1-10

Flash desorber	
T (°C)	P (psig)
~130	1-50

PEEK = polyether ether ketone

HFMC = hollow fiber membrane contactor

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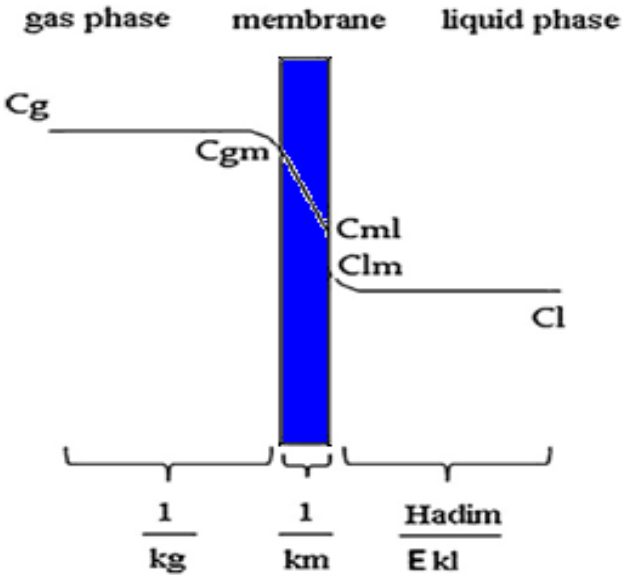
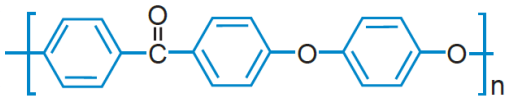
Technical challenges of applying HFMC to existing coal-fired plants

- **Performance** – Overall mass transfer resistance consists of three parts
  - Minimize each resistance
- **Durability** – Long-term membrane wetting in contact with solvent may affect performance
  - Make membrane surface super hydrophobic
  - Improve membrane potting to provide good seal between the liquid and gas sides
- **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

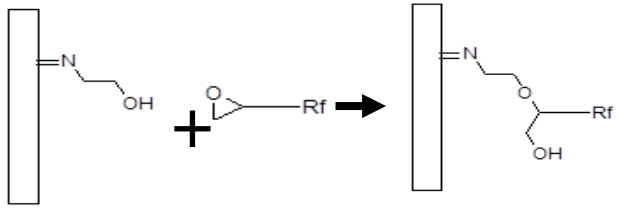
PEEK () membrane characteristics

- Exceptional thermal & mechanical resistances

Polymer	Tensile modulus (GPA)	Tensile strength (MPa)	Max service temperature (°C)
Teflon™	0.4-0.5	17-21	250
PVDF	0.8	48	150
Polysulfone	2.6	70	160
PEEK	**4**	**97**	**271**

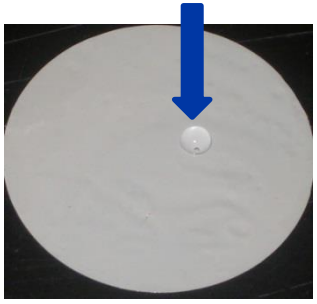
- Good chemical resistance to amine
  - Exposure of fibers to MEA solution (30%) at 120°C for 1,500 hours had no adverse effect on the mechanical or gas permeation properties

- Surface modified to be super hydrophobic

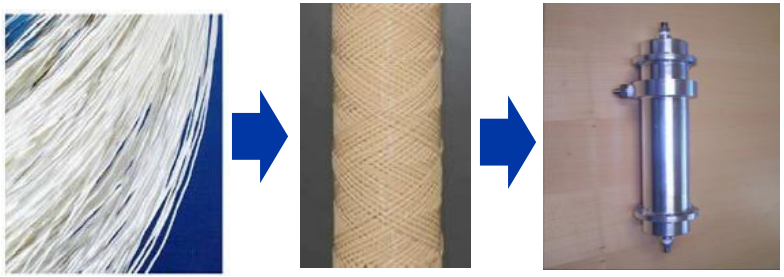


Hydrophilic ⟹ **Hydrophobic**

Ethanol



- Hollow fibers with high CO_2 flux, and thus high packing density and small equipment size



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Feasibility established via testing of 2-inch-diameter modules in the lab (DE-FE-0004787)

- Testing conditions: simulated flue gas compositions close to temperature and pressure conditions after FGD
  - Solvent: activated methyldiethanolamine (aMDEA)
  - Modules: two inchers that can be linearly scaled up

ø2” x 15” long, 0.12-0.75 m^2

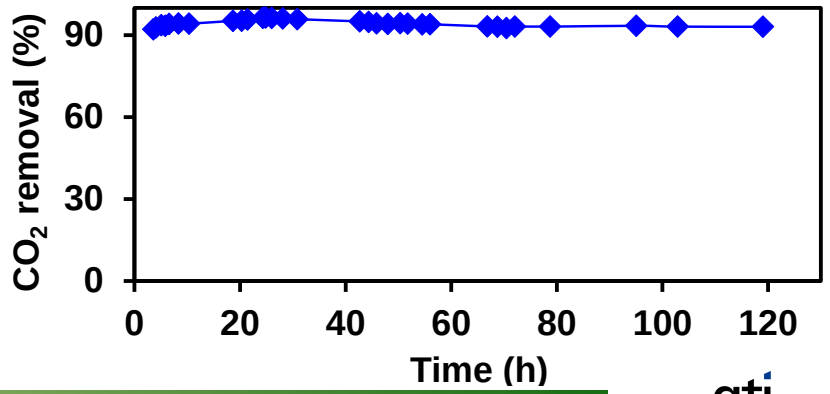
- Mass transfer coefficient over 10x greater than conventional contactors

Parameters	Value
CO_2 removal in one stage	90%
Mass transfer coefficient, $(sec)^{-1}$	1.7

conventional contactors: 0.0004-0.075 $(sec)^{-1}$

- CO_2 removal rate not affected by SO_2 (145 ppmv), NO_2 (66 ppmv), O_2 contaminants
  - Compared to conventional amine scrubber, 15% less of the inlet SO_2, and 9% less of the inlet NO_2 were absorbed; formation of heat-stable salts would be reduced when using PEEK HFMC

- Stable performance obtained with greater than 90% CO_2 removal rate



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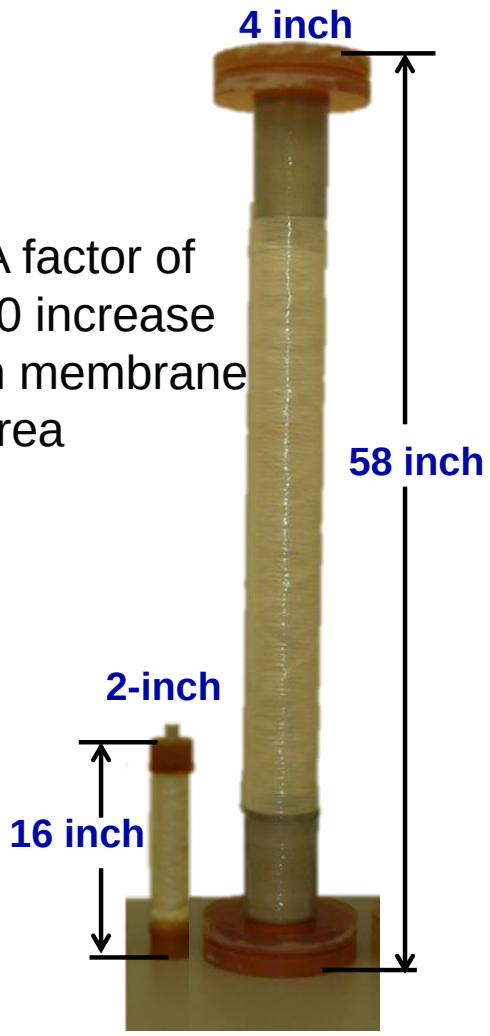
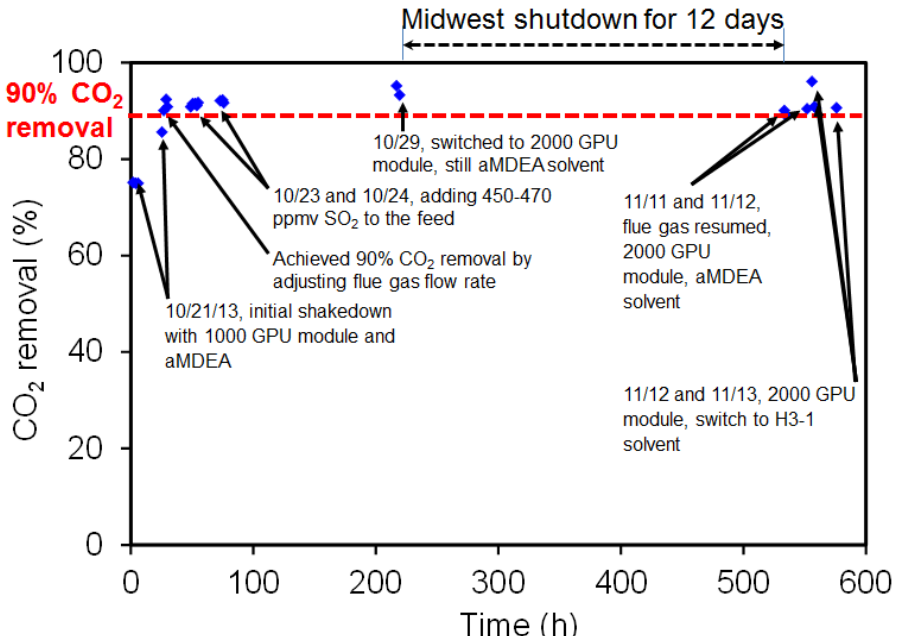
Module scaled to 4” diameter with a successful field testing at Midwest Generation (DE-FE-0004787)



A factor of 90 increase in membrane area

Flue gas composition

Element	Concentration
CO_2	7.4-9.6 vol%
NO_x	40-60 ppmv
SO_2	0.4-0.6 ppmv
CO	100-600 ppmv
O_2	8.5-11 vol%
Balance: N_2 , water vapor and trace elements	



Preliminary TEA based on bench-scale field tests: HFMC costs 16% less than Case 12

Item	Unit	DOE benchmark technology amine plant (Case 12)	PEEK HFMC field test data*
Increase in LCOE	%	69.6	57.0
Cost of CO_2 capture	2011$/tonne	56.47	47.53

* Bench-scale field tests with 4-inch-diameter module and aMDEA solvent : mass transfer coefficient of 1.2 $(sec)^{-1}$ at 93.2% CO_2 removal

R&D strategy to meet DOE's cost target ($40/tonne by 2025)	
Increase mass transfer coefficient from 1.2 to 2 $(sec)^{-1}$	$42.48
Advanced solvents/new regeneration process design	< $40.00

aMDEA = Activated **m**ethyl**die**thanol**a**mine

LCOE = Levelized Cost Of Electricity

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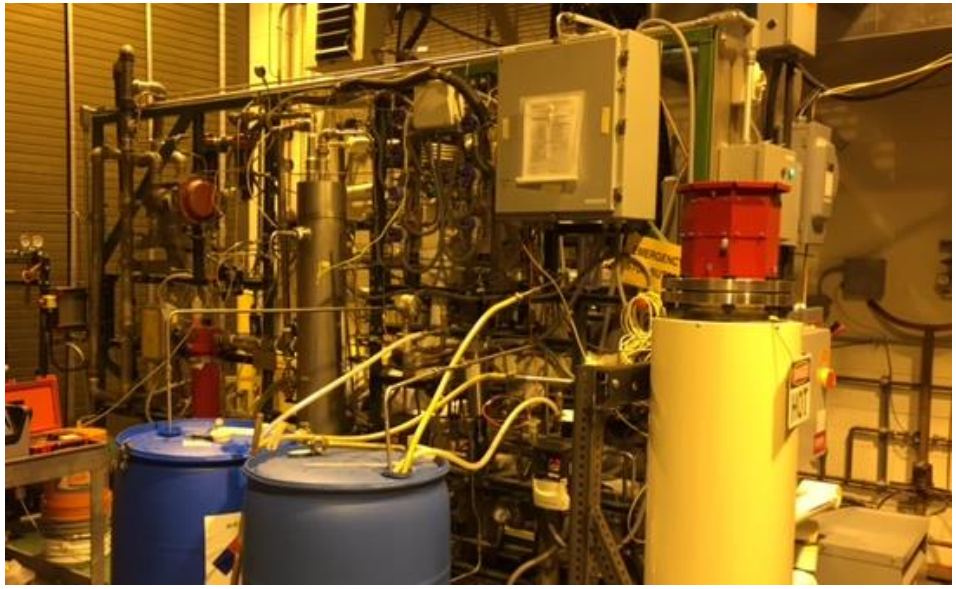
Module scaled to 8-inch, which was tested at GTI with aMDEA solvent using air/CO_2 mixed gas as feed

4 inch 8 inch



- 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

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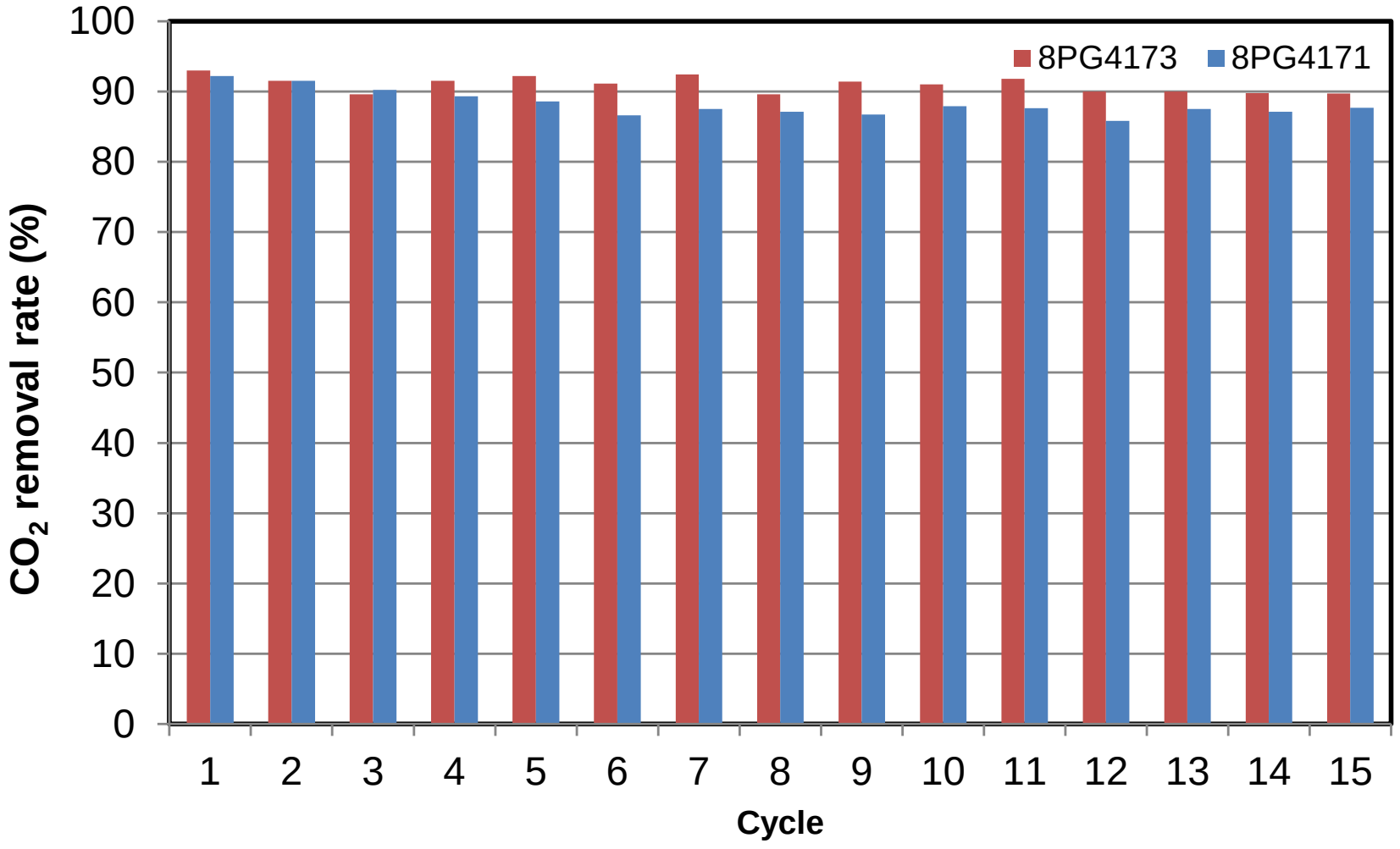
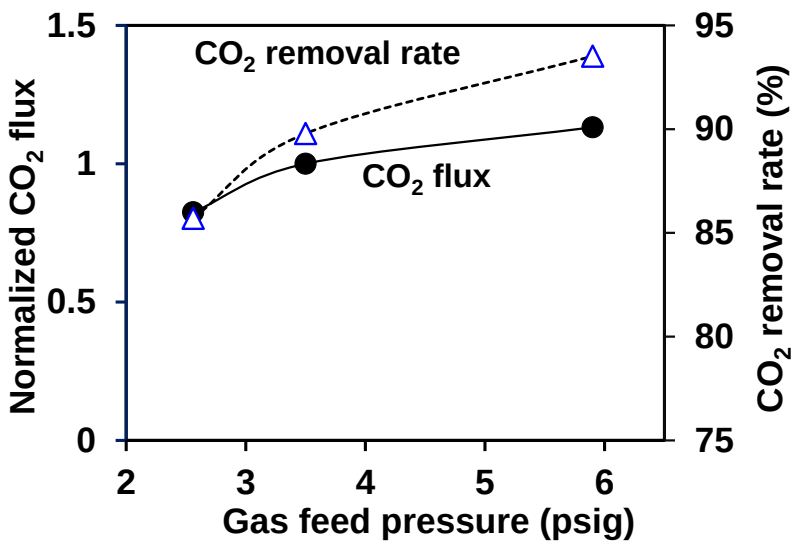
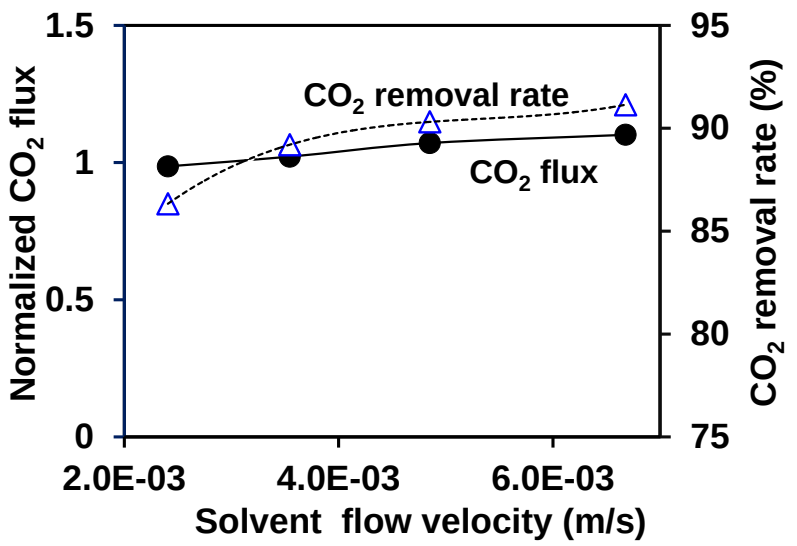
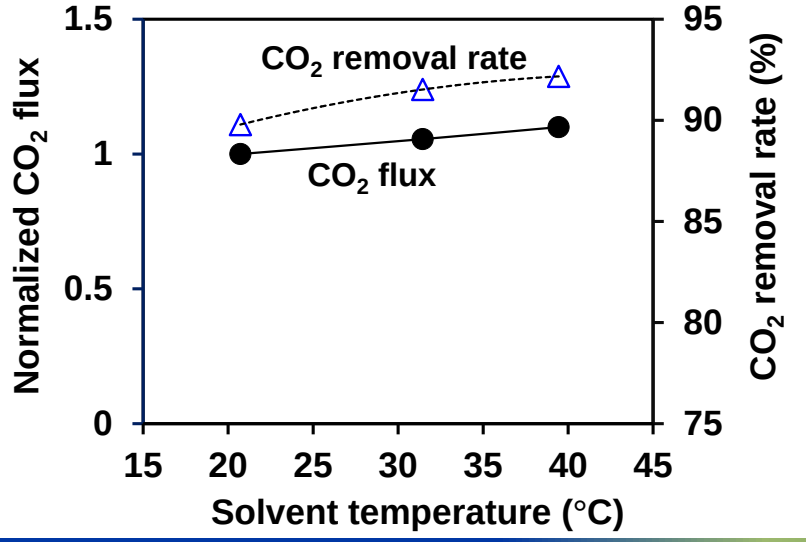
Good startup/shutdown stability validated for 8-inch module; membrane fabrication reproducible

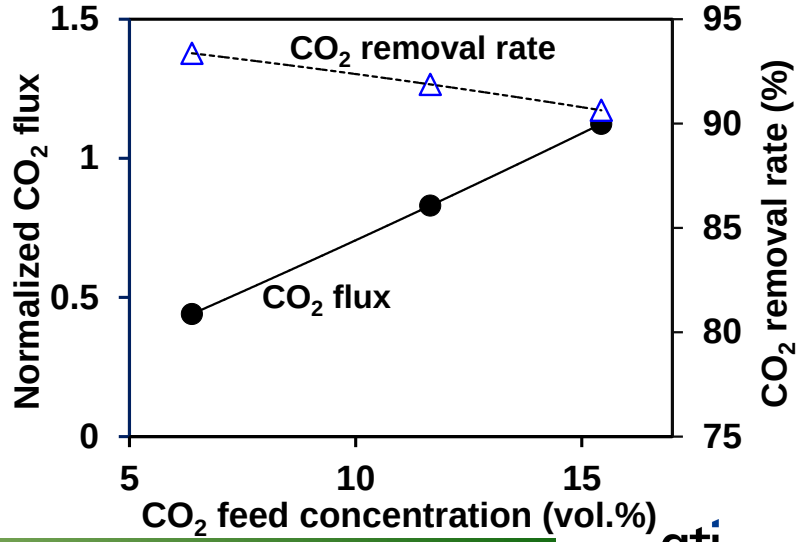


Lab parametric tests: CO_2 flux and capture rate increase with increasing feed pressure, solvent velocity and temperature

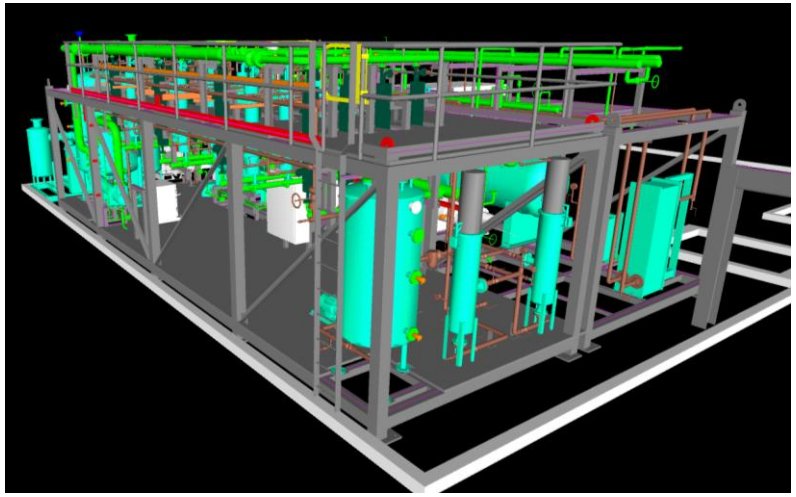








Construction of a 0.5 MW_e pilot plant for testing at the NCCC



3D model

Plant constructed

Successful FAT

Plant shipped to NCCC

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Pilot plant installed at the NCCC

12 m (L) x 7.5 m (W) x 3.5 m (H)

Pilot plant installed at the NCCC

12 m (L) x 7.5 m (W) x 3.5 m (H)

7 clusters of membrane modules

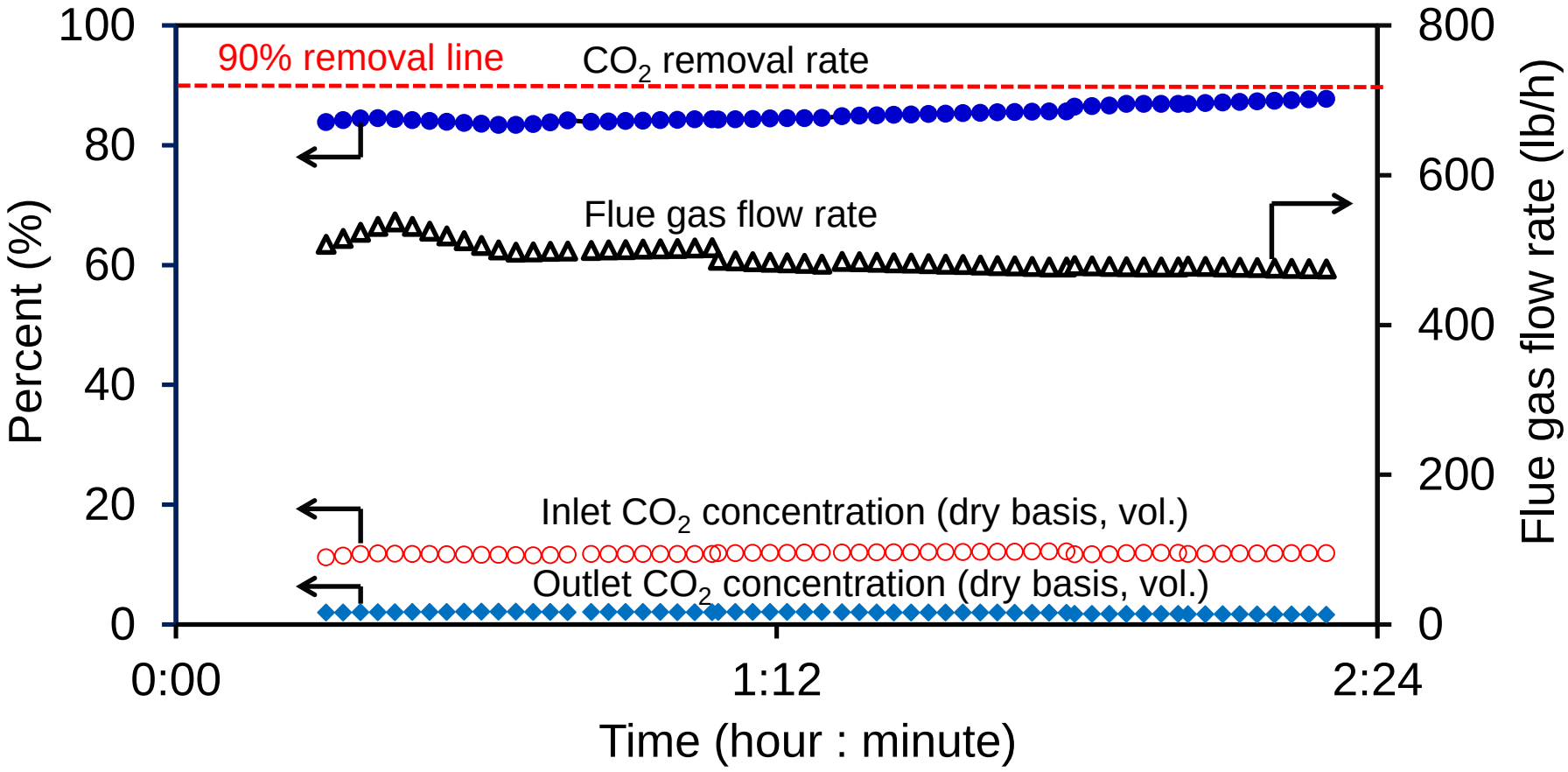
We are conducting parametric testing with one cluster (4 modules)

NCCC PSTU system (0.5 MW_e)

GTI HFMC system (0.5 MW_e)

Early testing results with real flue gas at NCCC indicate DOE's technical target can be achieved

- **CO_2 removal rate:**



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

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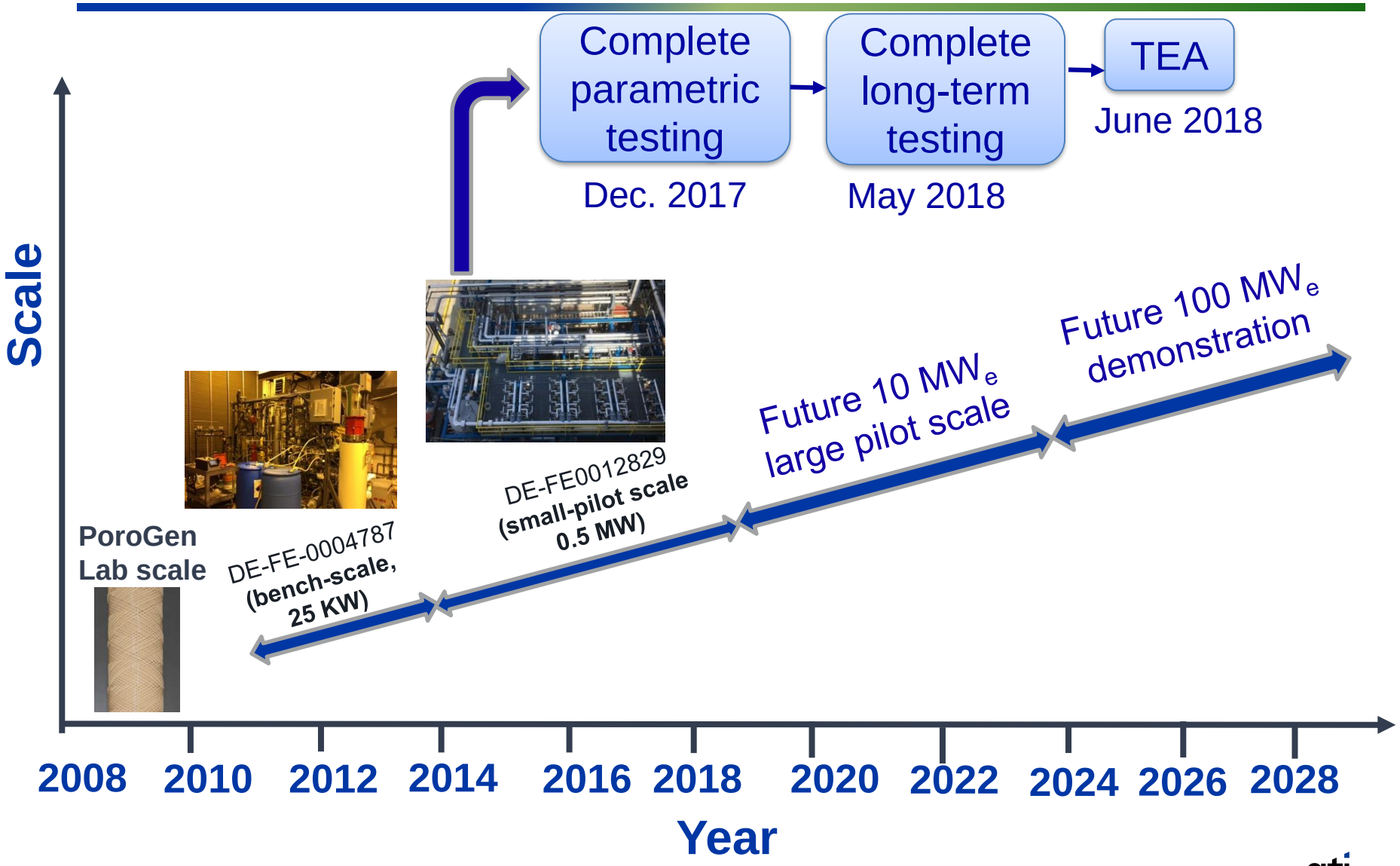
PEEK HFMC-based technology development path



Summary

- Preliminary TEA based on bench-scale field testing: PEEK HFMC costs (in 2011$) 16% less than DOE Case 12, can be further reduced by improving contactor performance
- Commercial 8-inch-diameter membrane modules with intrinsic CO_2 permeance of 2,000 GPU fabricated for pilot scale testing
- 0.5 MW_e pilot plant designed, constructed, installed, and being tested at NCCC
- Early testing results indicate DOE's technical target can be achieved

Acknowledgements

- **Financial and technical support**

U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

Contract DE-FE0012829

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JIP Partners

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- **DOE NETL José Figueroa**
- **Southern Company Services (NCCC)**

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