the Energy to Lead

PEEK Hollow Fiber Membrane Contactor (HFMC) Process for CO_2 Capture

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Outline

- Introduction to team members
- Technology overview
- Field testing in a coal-fired power plant
- Feasibility of CO_2 capture for natural-gas power plants using HFMC

Introduction to GTI and PoroGen

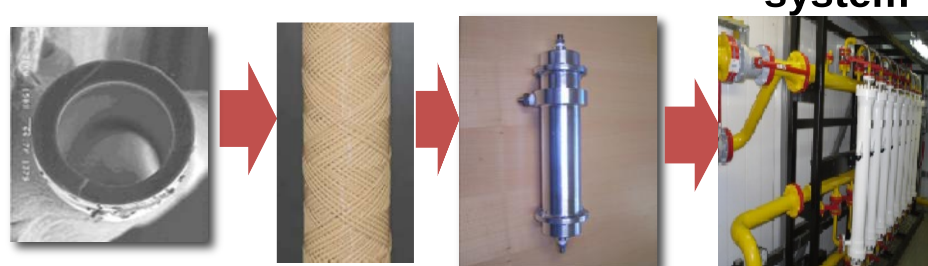
gti

- **<u>Not-for-profit</u>** research company, providing energy and natural gas solutions to the industry since 1941
- **<u>Facilities</u>**: 18 acre campus near Chicago, 28 specialized labs

PoroGen
INNOVATIVE MEMBRANE PRODUCTS

- Materials technology company commercially manufacturing products from high performance plastic **<u>PEEK</u>** (poly (ether ether ketone))
- **<u>Products</u>**: membrane separation filters to heat transfer devices

PEEK Fiber + Cartridge + Module = Separation system



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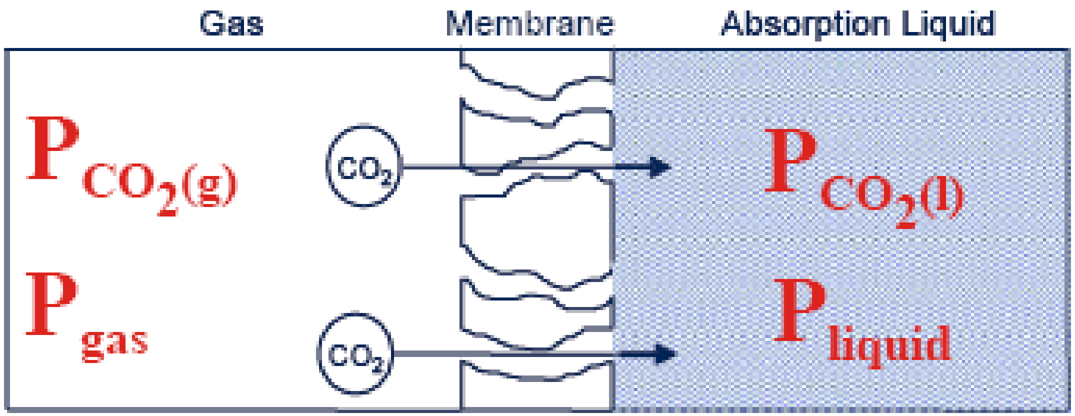
What is a membrane contactor?

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

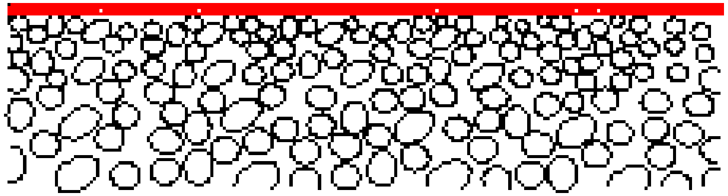


- Membrane does not wet out in contact with liquid
- **<u>Separation mechanism</u>**: CO_2 permeates through membrane, reacts with the solvent; N_2 does not react and has low solubility in solvent

Super-hydrophobic membranes surface

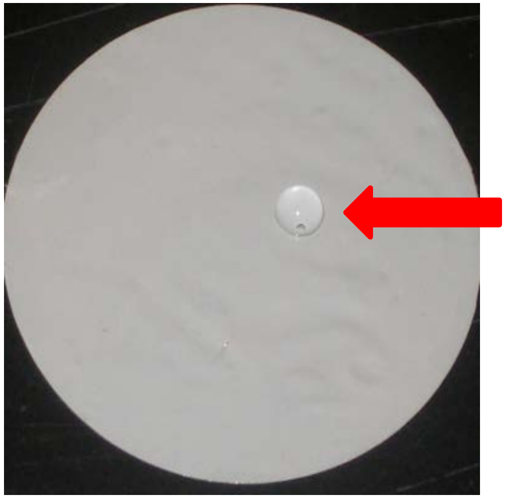
- PEEK composite membrane

Thin layer (0.1 μm) of smaller surface pores



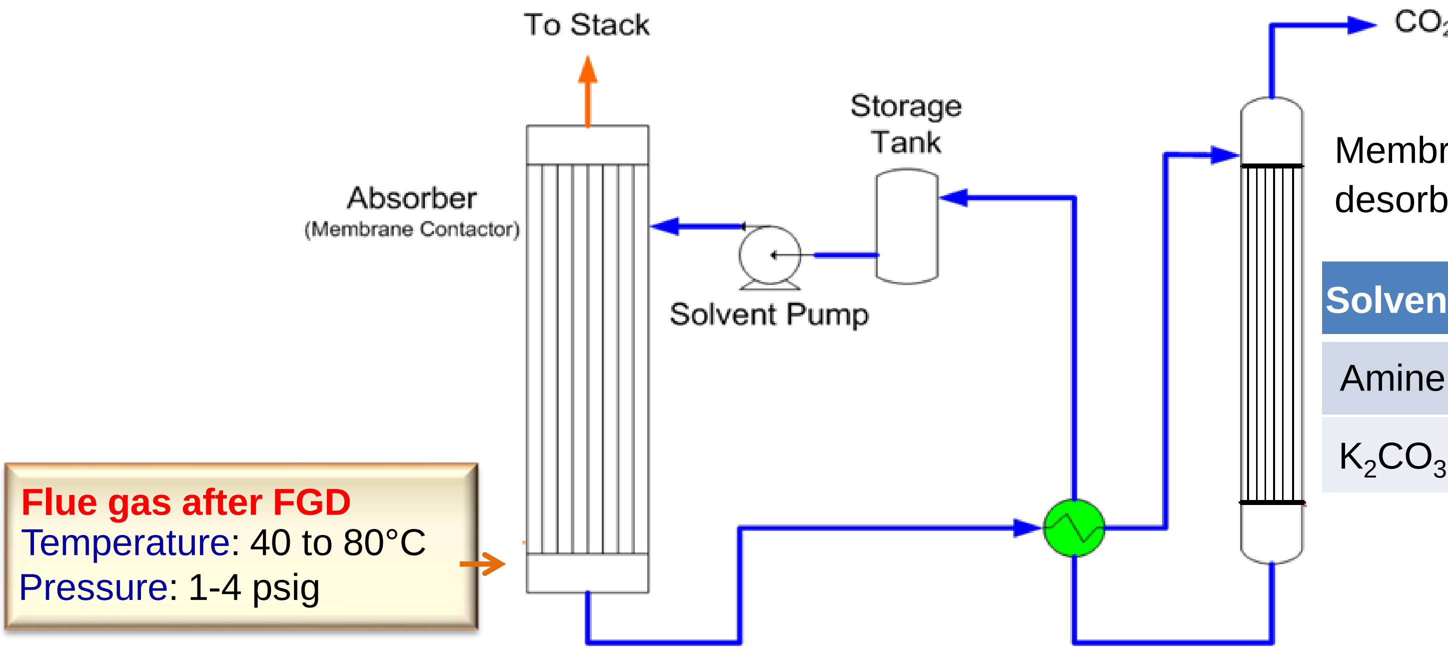
Asymmetric porous structure

- Super-hydrophobic surface not wetted by alcohol



Alcohol droplet

Process description



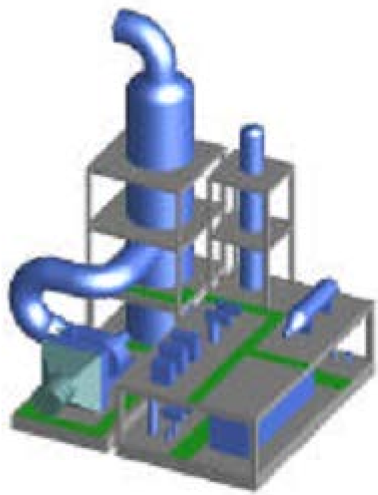
Solvent	T (ºC)	P (psig)
Amine	~120	1-50+
K_2CO_3	~120-150	1-50+

Polymer	Max service temperature (°C)
Teflon™	250
PVDF	150
Polysulfone	160
PEEK	**271**

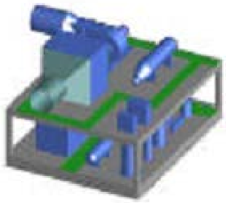
- The PEEK hollow fibers exhibit exceptional solvent resistance: exposure of fibers to MEA solution (30%) for 1,500 hours at 120 °C had no adverse effect on the mechanical properties or gas transport

Membrane contactor advantages as compared with conventional absorbers

Gas-liquid contactor	Specific surface area, (cm^2/cm^3)	Volumetric mass transfer coefficient, $(sec)^{-1}$
Packed column (Countercurrent)	0.1 – 3.5	0.0004 – 0.07
Bubble column (Agitated)	1 – 20	0.003 – 0.04
Spray column	0.1 – 4	0.0007 – 0.075
Membrane contactor	**1 – 70**	**0.3 – 4.0**



Conventional Amine Scrubber Column



Membrane Contactor

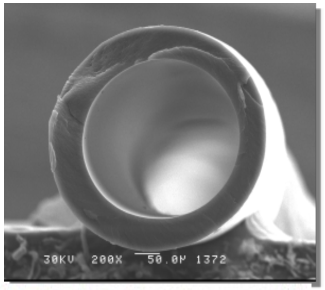
* Olav Falk-Pedersen, Developments of gas/liquid contactors, GRI contract 8325, December, 2002.

Membrane contactor for flue gas CO_2 capture compared to conventional membrane process

Membrane technology	Need to create driving force?	CO_2/N_2 selectivity (α)	Can achieve >90% CO_2 removal and high CO_2 purity in one stage?
Conventional membrane process	Yes. Feed compression or permeate vacuum required	Determined by the dense "skin layer", typically $\alpha = 50$	No. Limited by pressure ratio, multi-step process required*
Membrane contactor	No. Liquid side partial pressure of CO_2 close to zero	Determined by the solvent, $\alpha > 1000$	Yes

* DOE/NETL Advanced Carbon Dioxide Capture R&D Program: Technology Update, May 2011

PEEK membrane: from fibers to commercial modules



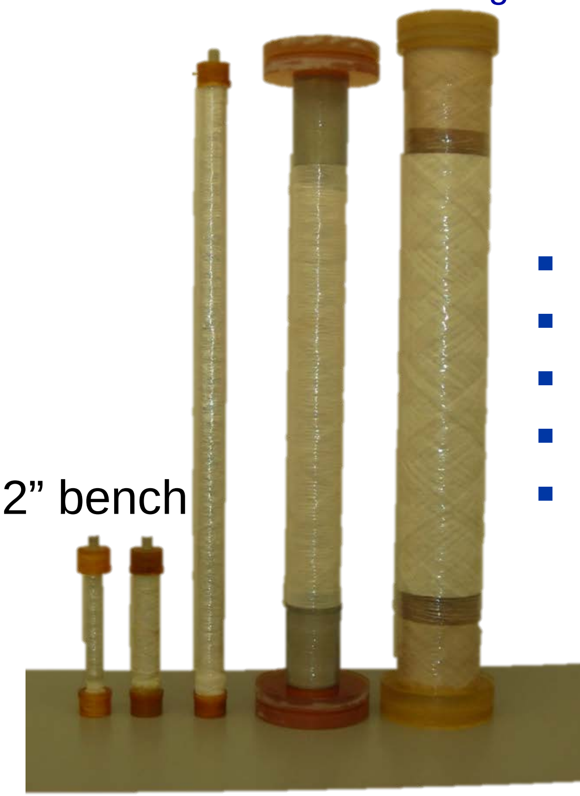
Hollow fibers

OD: 18 mil
ID: 10 mil

Commercial

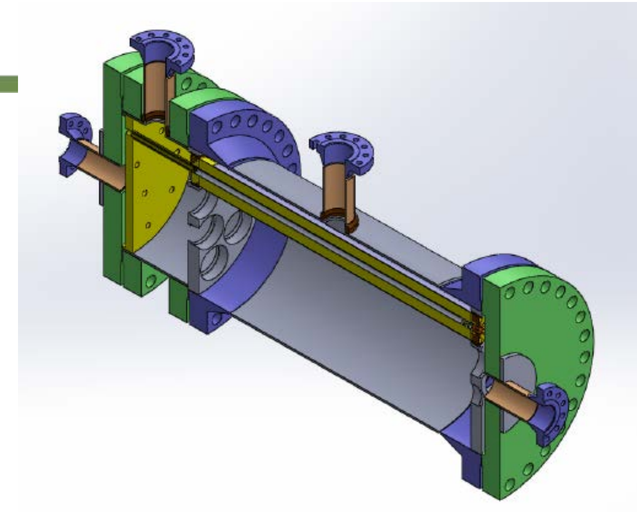
8” diameter
60” long

2” bench



Module scale-up from bench to commercial

- 2” bench – 0.12 m^2 (lab)
- 2” bench – 0.5 m^2 (lab)
- 2” bench – 3 m^2 (lab)
- 4” field – 15 m^2 (field)
- 8” commercial – 60 m^2 (pilot-scale)



Housing

Module in housing

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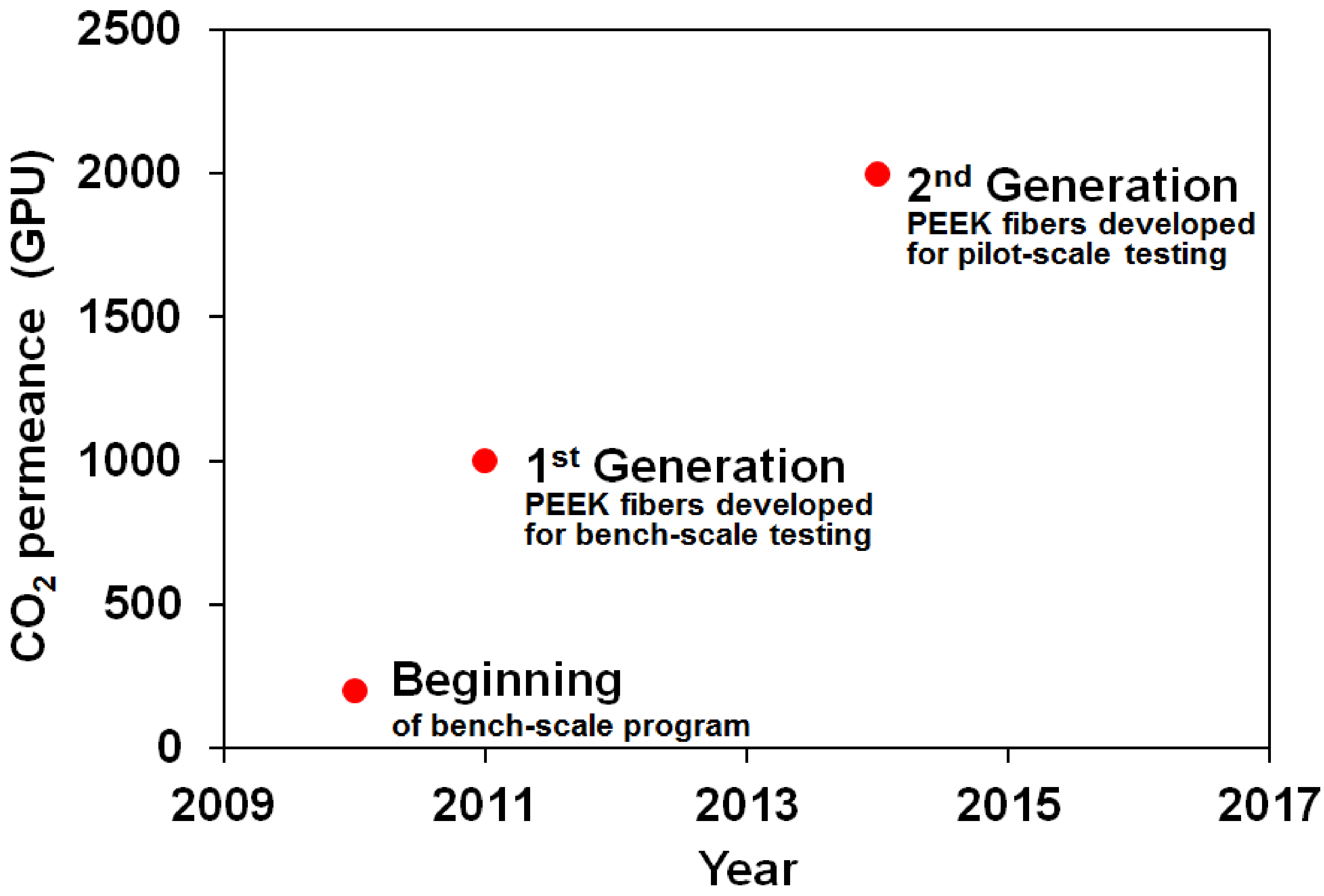
Recent modules achieved 2,000 GPU membrane intrinsic CO_2 permeance



1 GPU = 1×10^6 cm^3 (STP)/cm^2 • s • cmHg

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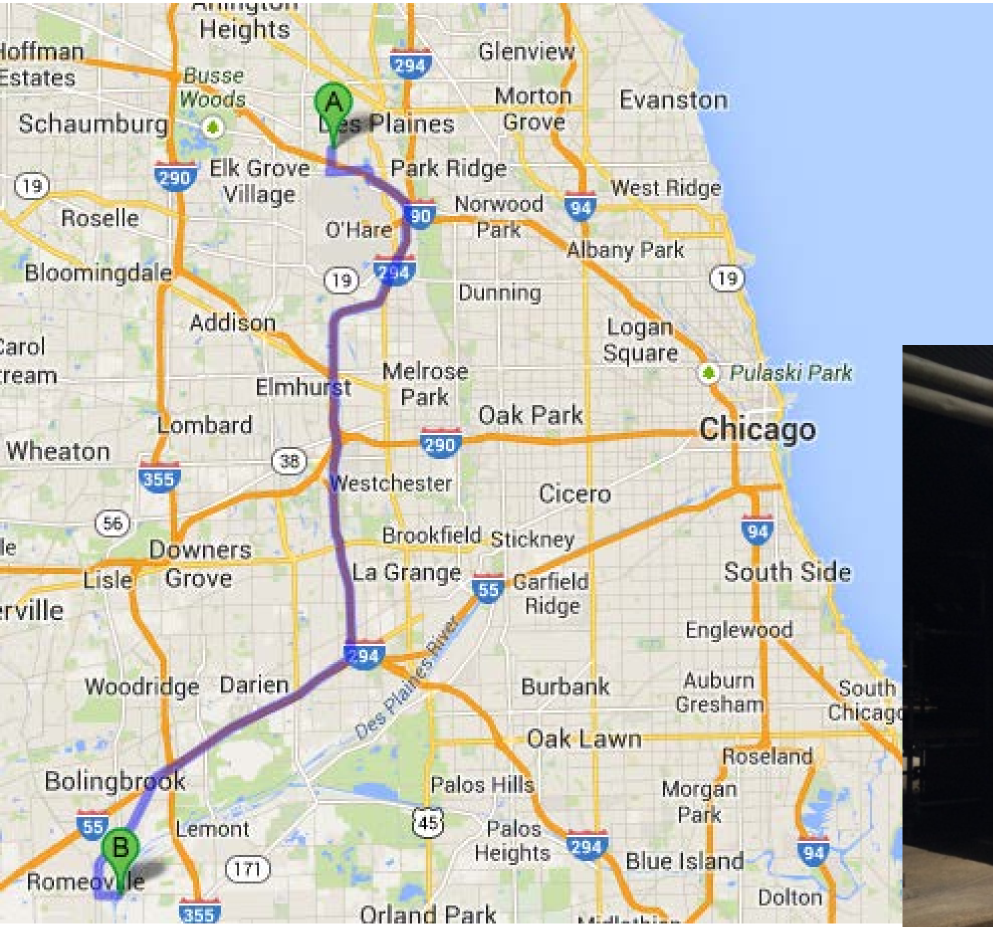
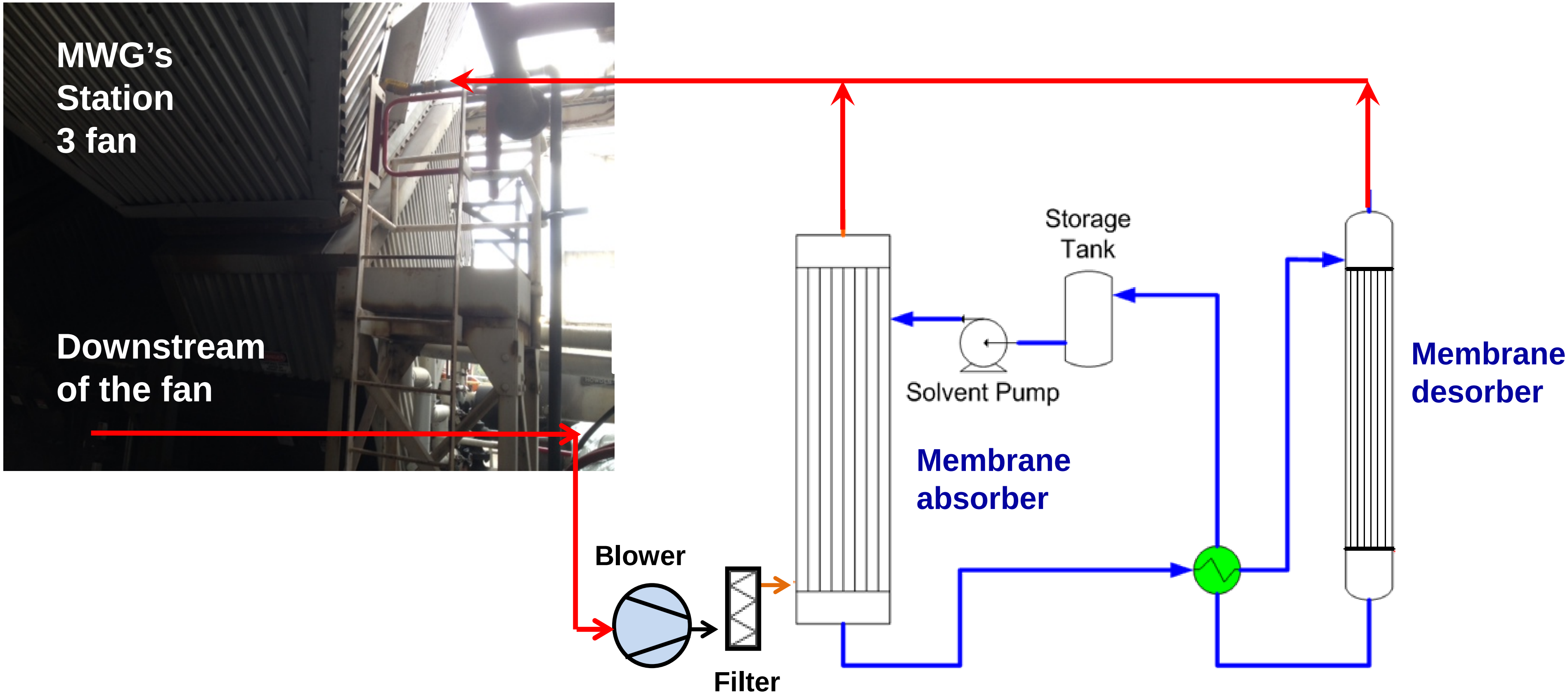
Integrated absorber/desorber testing at the field



Testing site: Midwest Generation, 35 miles from GTI

Process flow diagram

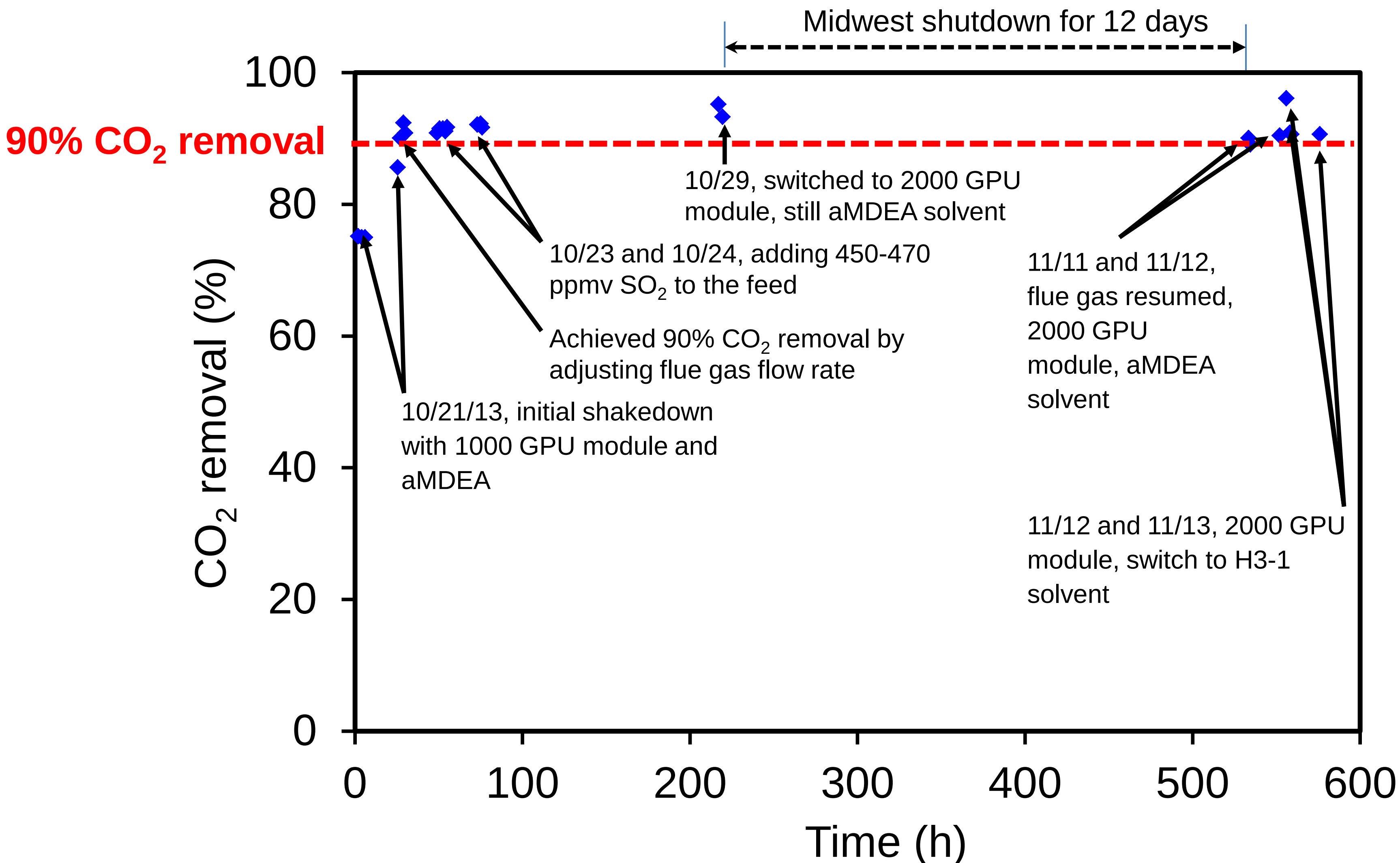


Flue gas composition

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	

Relative humidity: 39% at 130°F

Field test results with aMDEA and H3-1 solvents



Membrane contactor field performance: mass transfer coefficient for absorption 1.2 $(sec)^{-1}$

aMDEA solvent

Total gas flow rate, L(STP)/min	CO_2 removal, %	Volumetric mass transfer coefficient, $(sec)^{-1}$
245	93.2	1.2

Mass transfer coefficient for conventional contactors: 0.0004-0.075 $(sec)^{-1}$

Preliminary Techno-Economic Analysis (TEA)

TRIMERIC CORPORATION

Item	Unit	DOE Case 12	HFMC with aMDEA	HFMC with H3-1
LCOE - No TS&M	mills/kWh	137.3	127.1	120.1
Increase in LCOE - No TS&M	%	69.6%	57.0%	48.4%
Cost of CO_2 Capture - No TS&M	$/tonne	**56.47**	**47.53**	**41.89**

TS&M: Transportation, Storage, and Monitoring

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Five-year DOE pilot-scale project ongoing

- **Performance period**: Oct. 1, 2013 – June 30, 2018
- **Total funding**: $12,544,638
- **Objectives**:
  - Build a 1 MW_e equivalent pilot-scale CO_2 capture system (20 ton/day) and conduct tests on flue gas at the 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**:

gti PoroGen TRIMERIC CORPORATION NCCC

NCCC= National Carbon Capture Center (Southern Company, Wilsonville, AL)

Feasibility of CO_2 capture for natural gas power plants using HFMC

Impact of adding CO_2 capture system to NGCC power plants in California

- Plant capital cost is ~ doubled
- Cost of electricity increased by ~41-53%
- Plant net output reduced by 14-16%
- Cost of CO_2 capture is \$66-99/ton CO_2
- Plant land area available at plant is limited

Technical and Regulatory Analysis of Adding CCS to NGCC Power Plants in California, Prepared for Southern California Edison Company by CH2M Hill, Nov. 2010

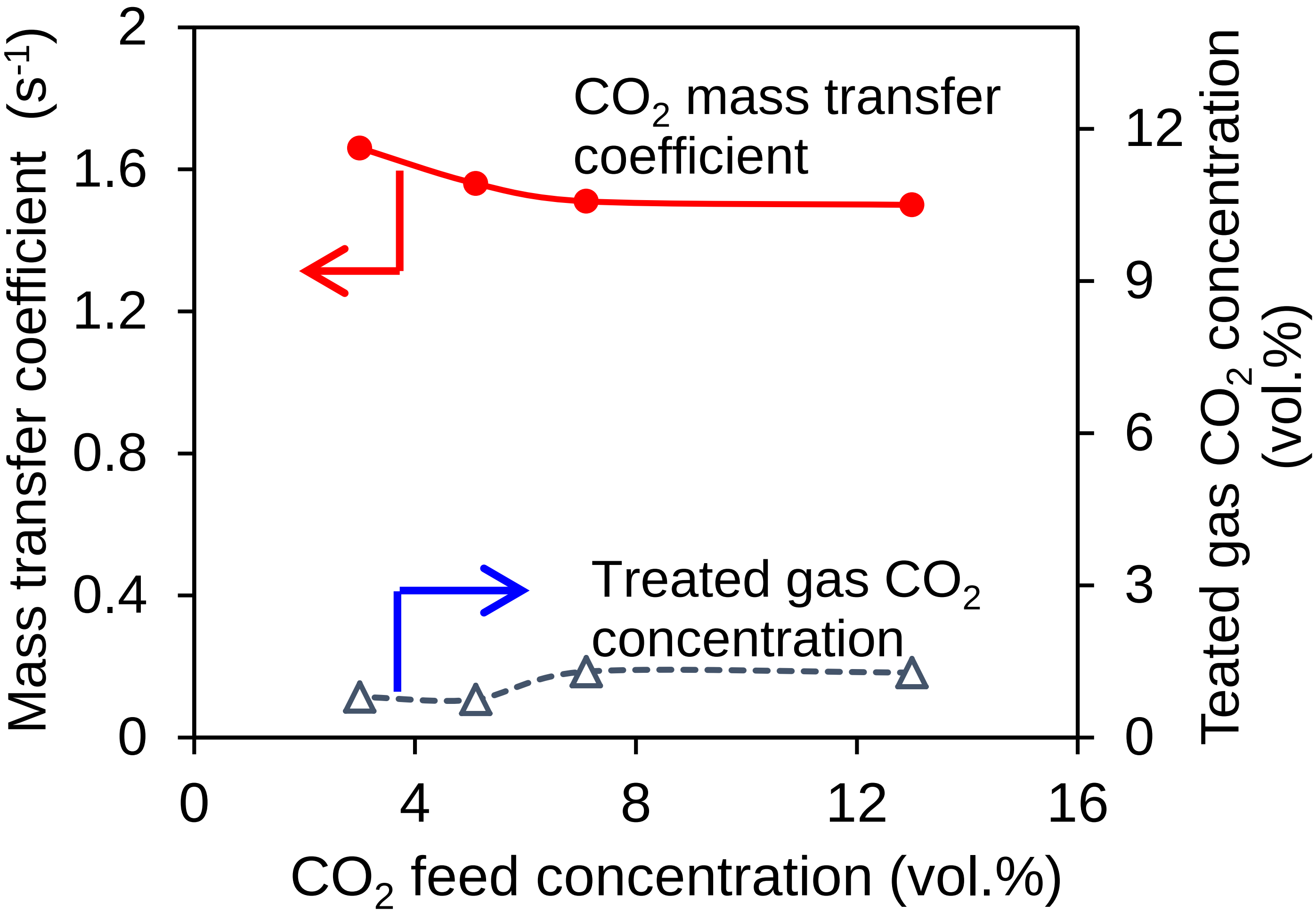
Natural gas flue gas has lower CO_2, higher O_2 than coal flue gas, which is not a problem for HFMC

	Coal-fired	NGCC-fired
Plant Size, MW_e	550	474
Flue Gas Rate, kgmole/hr	102,548	113,831
CO_2, vol.%	13.5	**4**
H_2O, vol.%	15	9
O_2, vol.%	2	**12**
N_2, vol.%	68.5	74
CO_2 captured, Tonne/hr	550	183

Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity Revision 2a, September 2013, **DOE/NETL-2010/1397**

PEEK HFMC is effective for low CO_2-concentration feeds, conditions encountered in NGCC

Lab testing data for 2-inch module



Summary

- PEEK HFMC: promising based on field tests
  - ≥ 90% CO_2 removal in one stage
  - Mass transfer coefficient of 1.2 $(sec)^{-1}$, which is over one order of magnitude greater than conventional contactors
- Costs ~16-26% lower than DOE benchmark technology
- Pilot development for coal-fired flue gas ongoing
- HFMC provides additional savings for promising solvents, as well as a much smaller equipment size
- HFMC works well at lower CO_2 partial pressures, conditions that match those of the NGCC flue gases.

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