the Energy to Lead

Post-combustion CO_2 Capture Using PEEK Hollow Fiber Membrane Contactors

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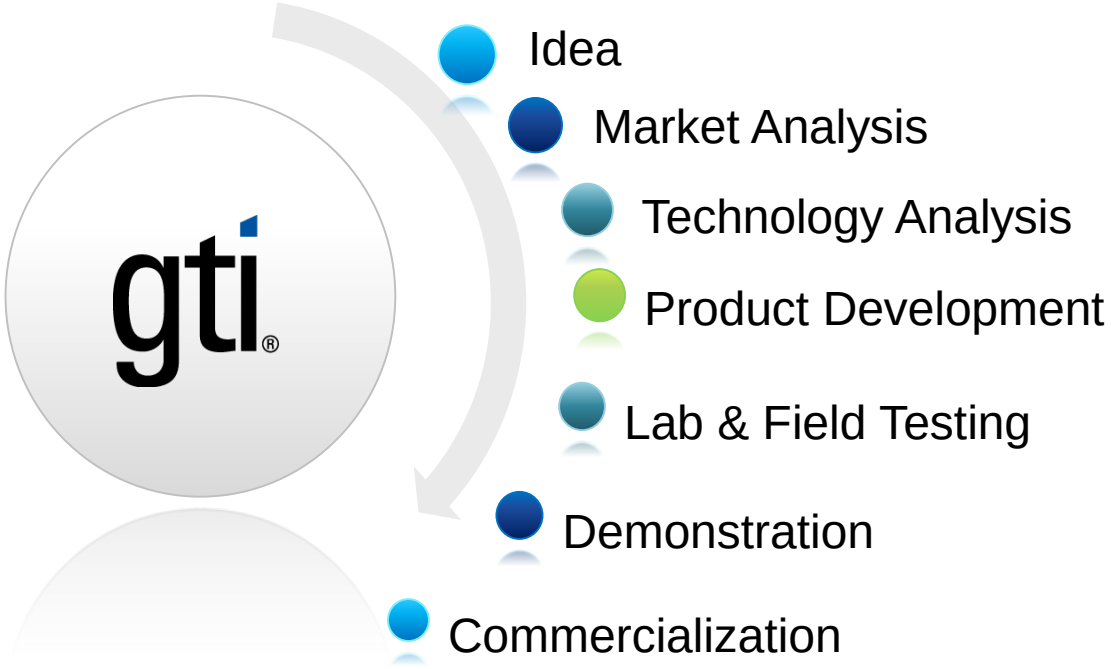
gti PoroGen INNOVATIVE MEMBRANE PRODUCTS

Outline

- Introduction to team members
- Technology overview
- US DOE bench-scale program ($3.8 MM)
- US DOE pilot-scale program ($12.5 MM)

Introduction to GTI

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

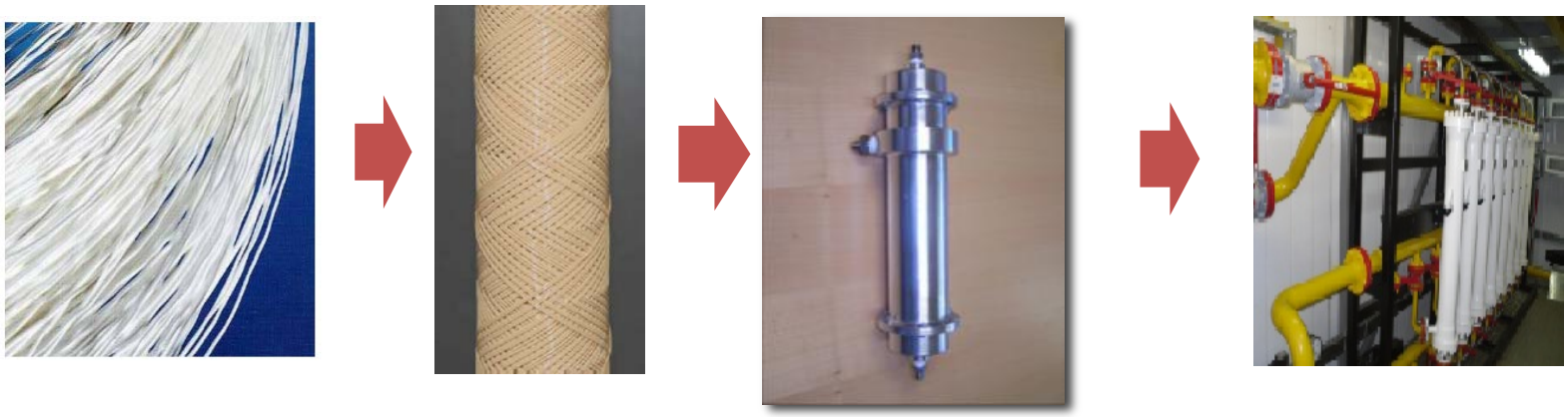


Introduction PoroGen

PoroGen
INNOVATIVE MEMBRANE PRODUCTS

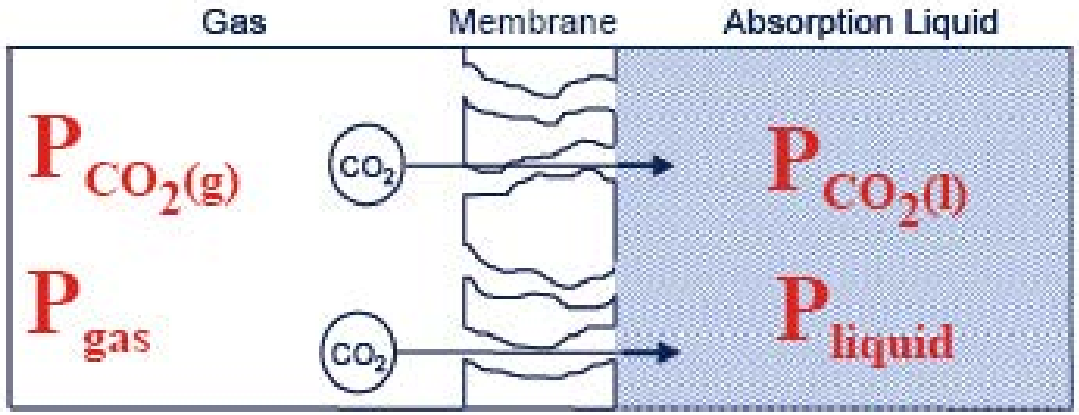
- Materials technology company commercially manufacturing products from high performance plastic PEEK (poly (ether ether ketone))
- Products ranging from membrane separation filters to heat transfer devices

PEEK Fiber + Cartridge + Module = Separation system



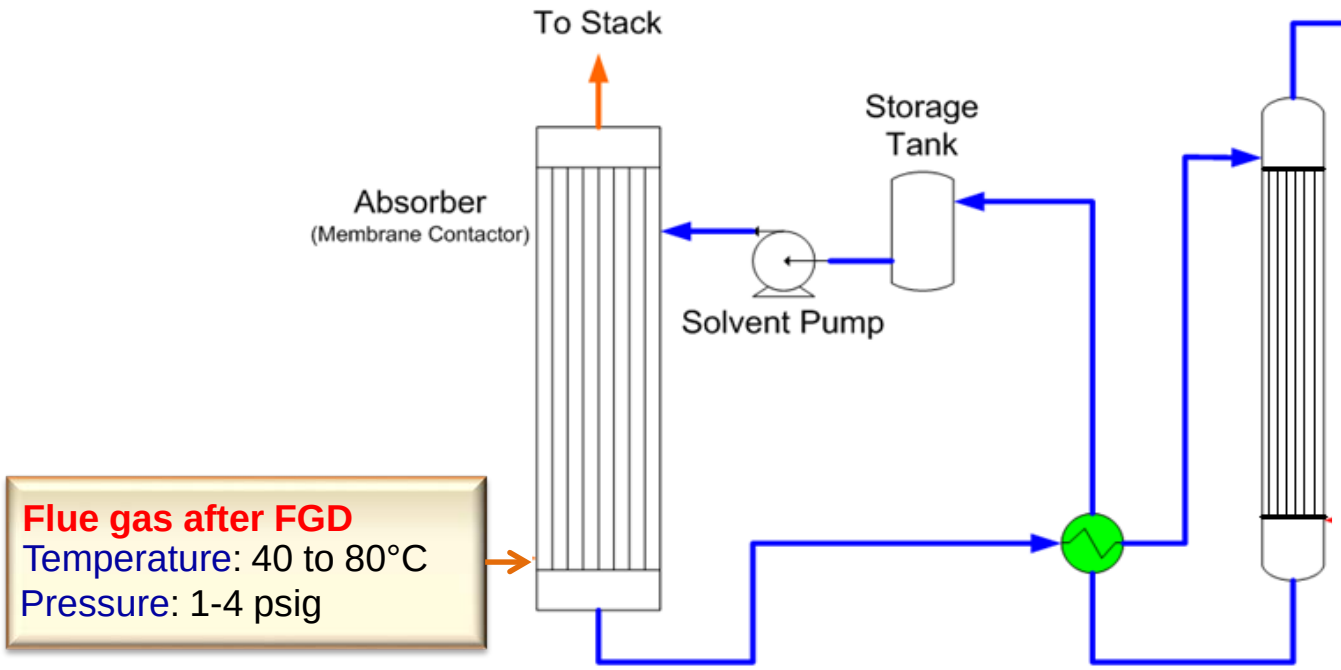
What is a membrane contactor?

- 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 and reacts with the solvent; N_2 does not react and has low solubility in solvent

Process description



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

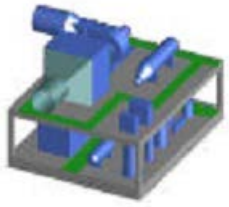
Polymer	Max service temperature (°C)
Teflon™	250
PVDF	150
Polysulfone	160
PEEK	**271**

- 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

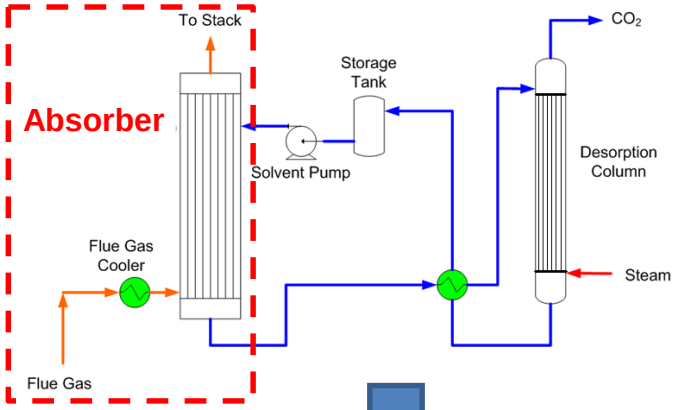
* DOE/NETL Advanced Carbon Dioxide Capture R&D Program: Technology Update, May 2011

Bench-scale development (Oct. 1, 2010 – Dec. 31, 2013): objective and scope

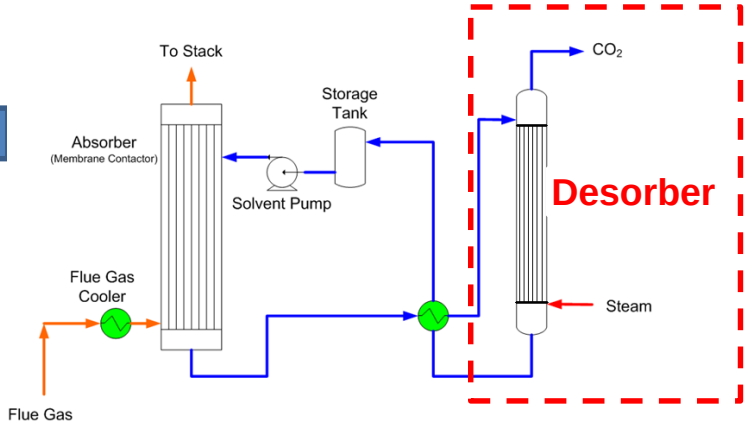
2010

Objective: develop PEEK membrane contactor technology to meet DOE's target of ≥ 90% CO_2 capture in one stage, >95% CO_2 purity, cost <$40/Tonne CO_2 captured

BP1



BP2



BP3

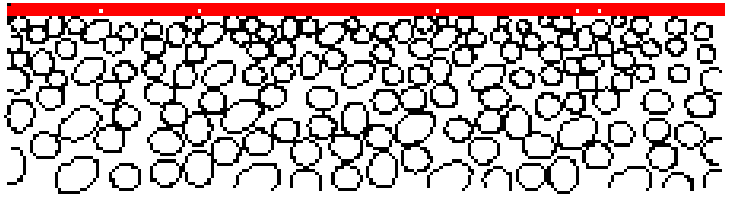
Integrate absorption/regeneration

Field testing

Super-hydrophobic membranes surface

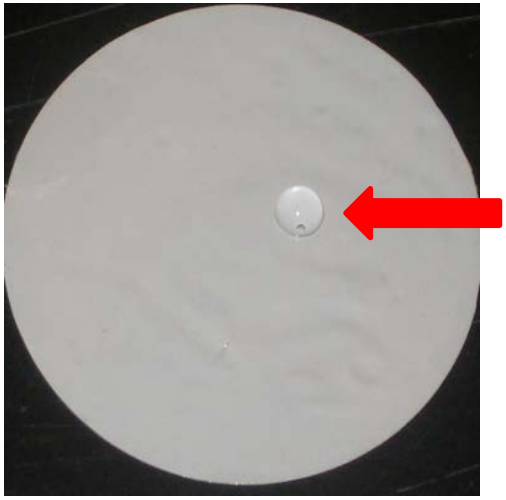
- PEEK composite membrane

Thin layer (0.1 μm) of smaller surface pores



Asymmetric porous structure

- Super-hydrophobic surface not wetted by alcohol

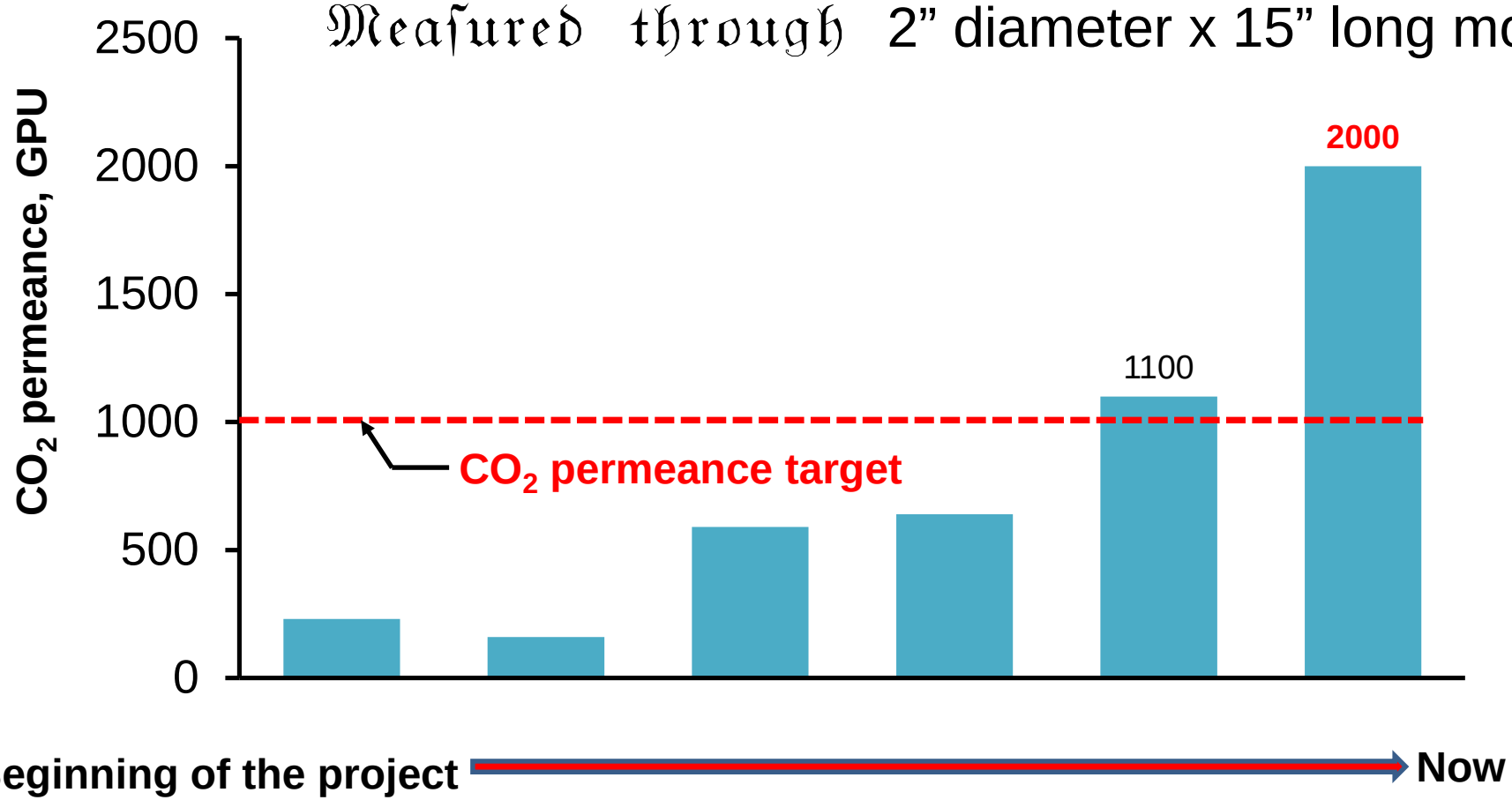


Alcohol droplet

Recent modules achieved 2,000 GPU membrane intrinsic CO_2 permeance

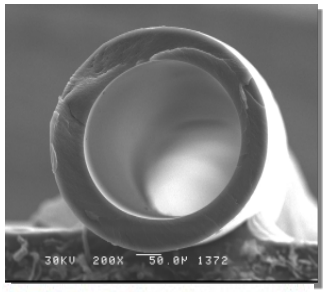
More than 200 modules constructed by PoroGen

Measured through 2” diameter x 15” long module



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

PEEK membrane: from fibers to commercial modules



Hollow fibers

OD: 18 mil

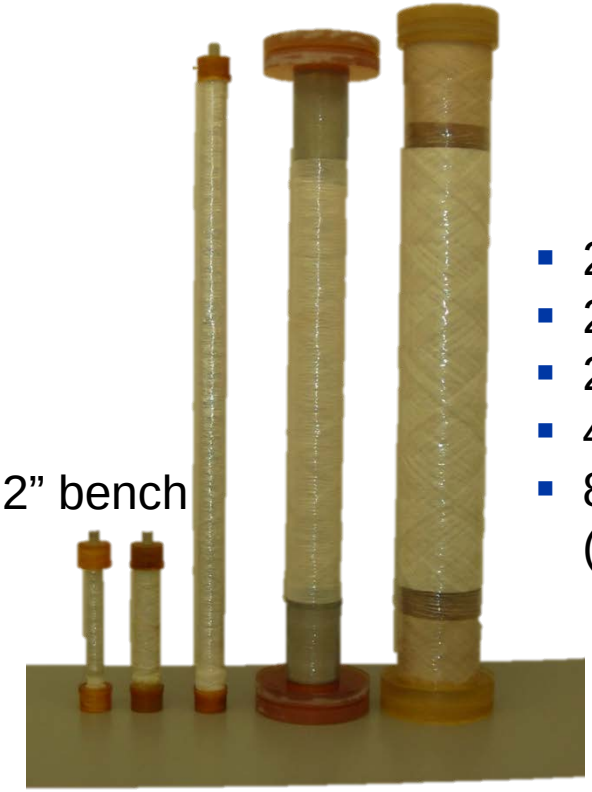
ID: 10 mil

Commercial

8” diameter

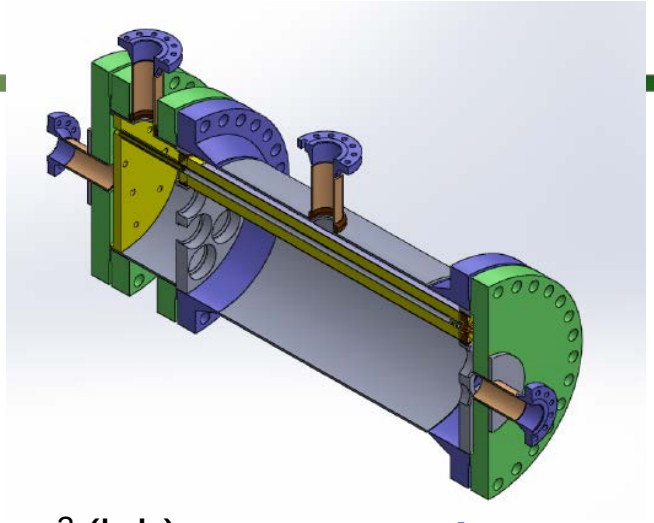
60” long

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

Membrane absorber study in the lab: >140 tests

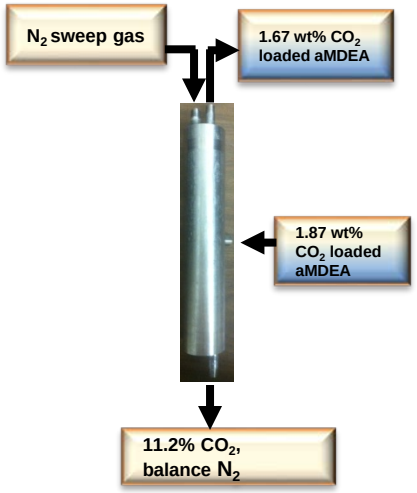
- **Gas feed (bore side)**: simulated flue gas compositions at temperature and pressure conditions after FGD
- **Solvents (shell side)**: aMDEA (40 wt%) and activated K_2CO_3 (20 wt%)
- **BP1 technical goal achieved**

Parameters	Goal	aMDEA	K_2CO_3
CO_2 removal in one stage	≥ 90%	90%	94%
Gas side ΔP, psi	≤ 2	1.6	1.3
Mass transfer coefficient,$(sec)^{-1}$	≥ 1	1.7	1.8

Module for lab testing (∅2” x 15” long, $1m^2$)

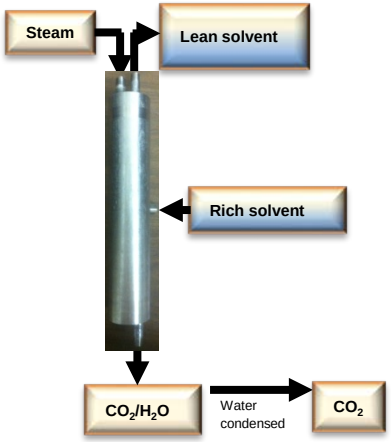
- **Performance not affected by O_2, SOx, NOx contaminants in feed**

Membrane desorber study in the lab: four regeneration modes, > 80 tests



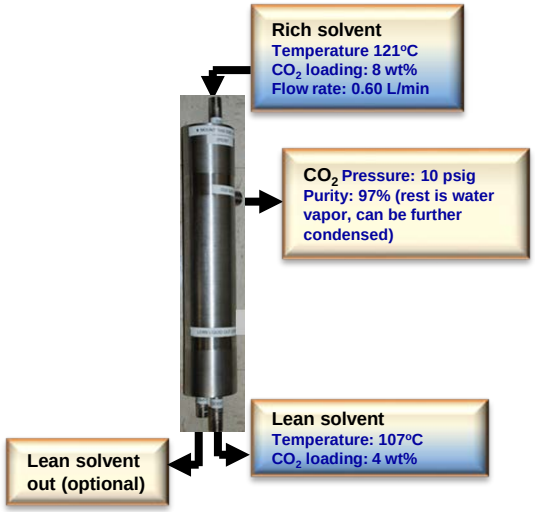
Mode I

- Shakedown
- Hydrophobic
- Shell liquid feed
- N_2 sweep



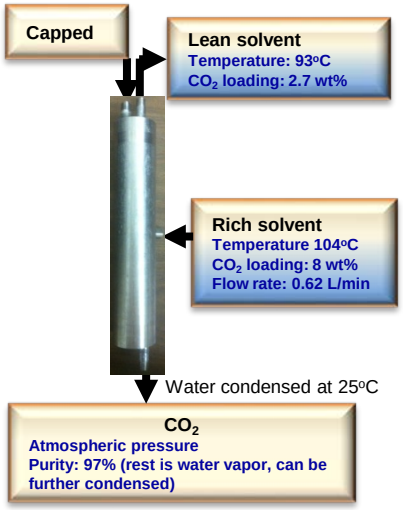
Mode II

- Hydrophobic
- Shell liquid feed
- Steam sweep in bore side



Mode III

- Hydrophilic
- Bore liquid feed
- No sweep in shell side



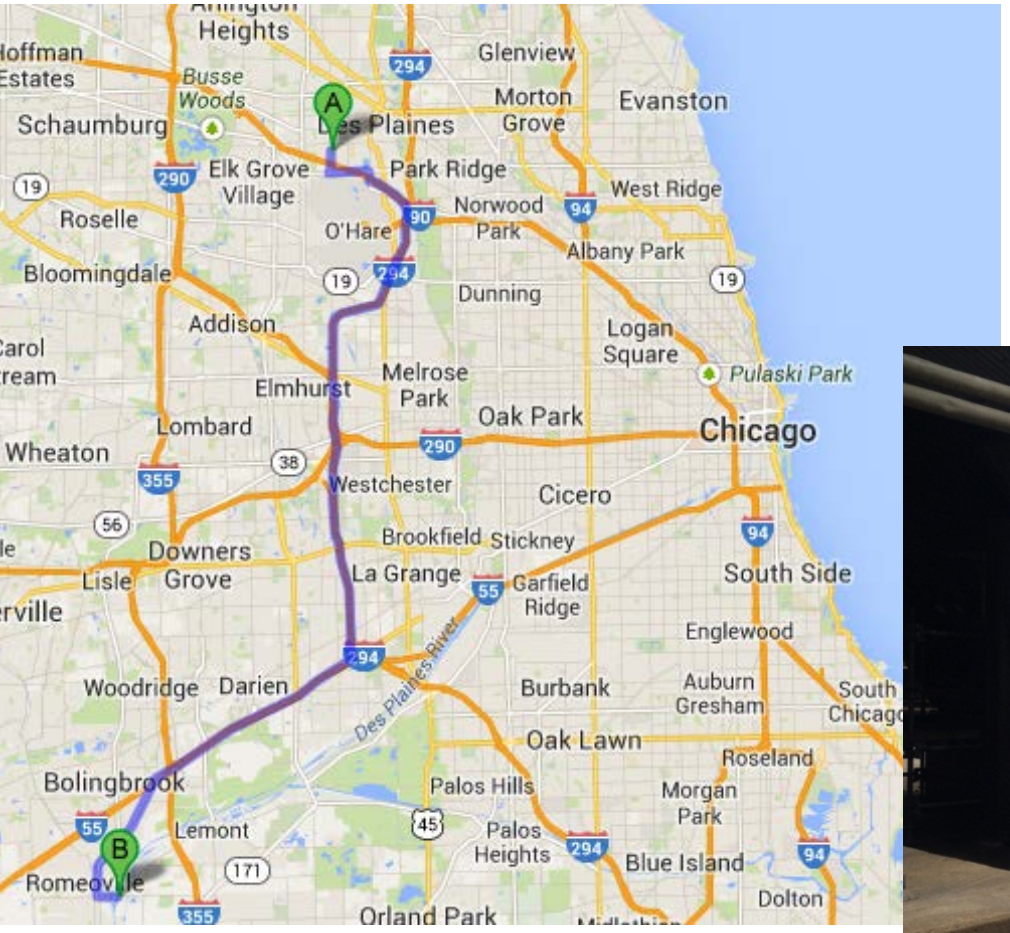
Mode IV

- Hydrophobic
- Shell liquid feed
- No sweep in bore side

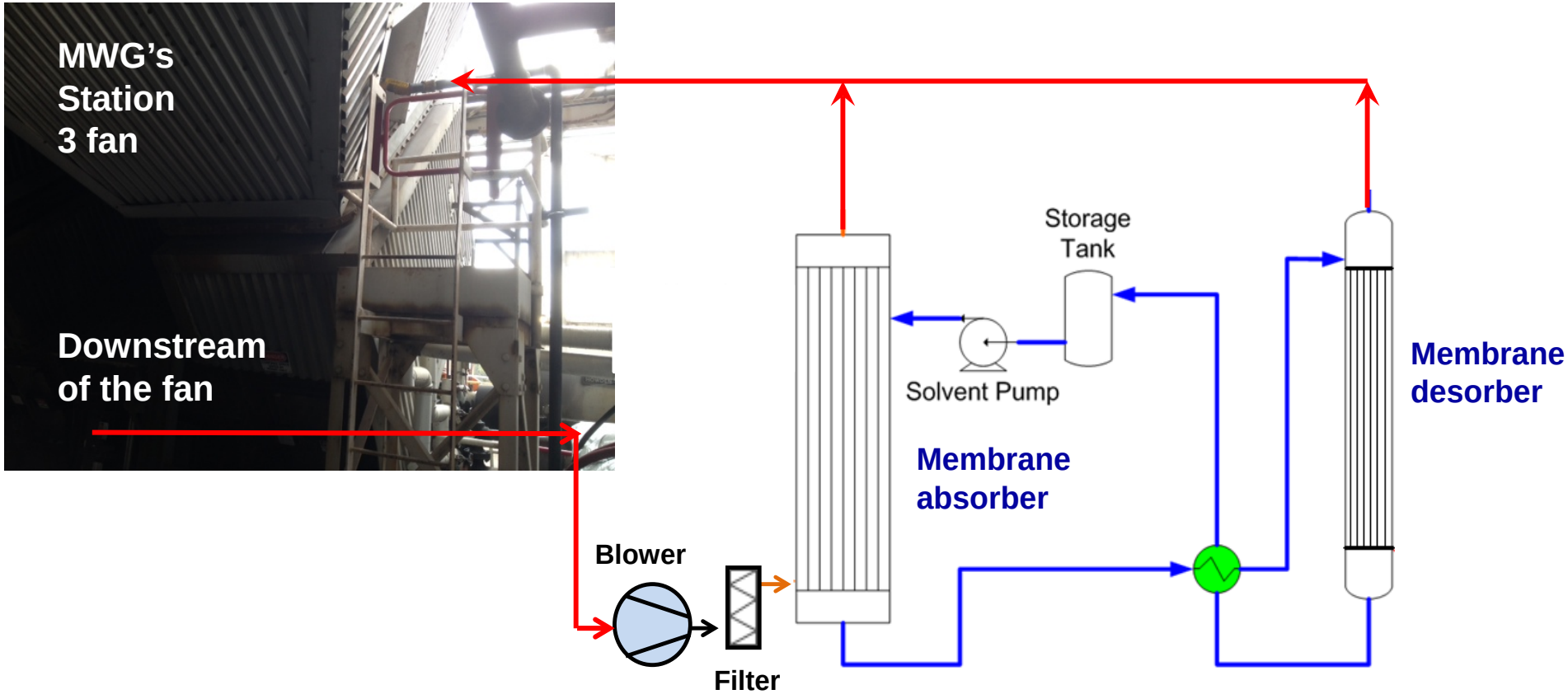
Down selected for Field tests !

Integrated absorber/desorber for field testing

The field site is Midwest Generation, 35 miles from GTI



Process flow diagram

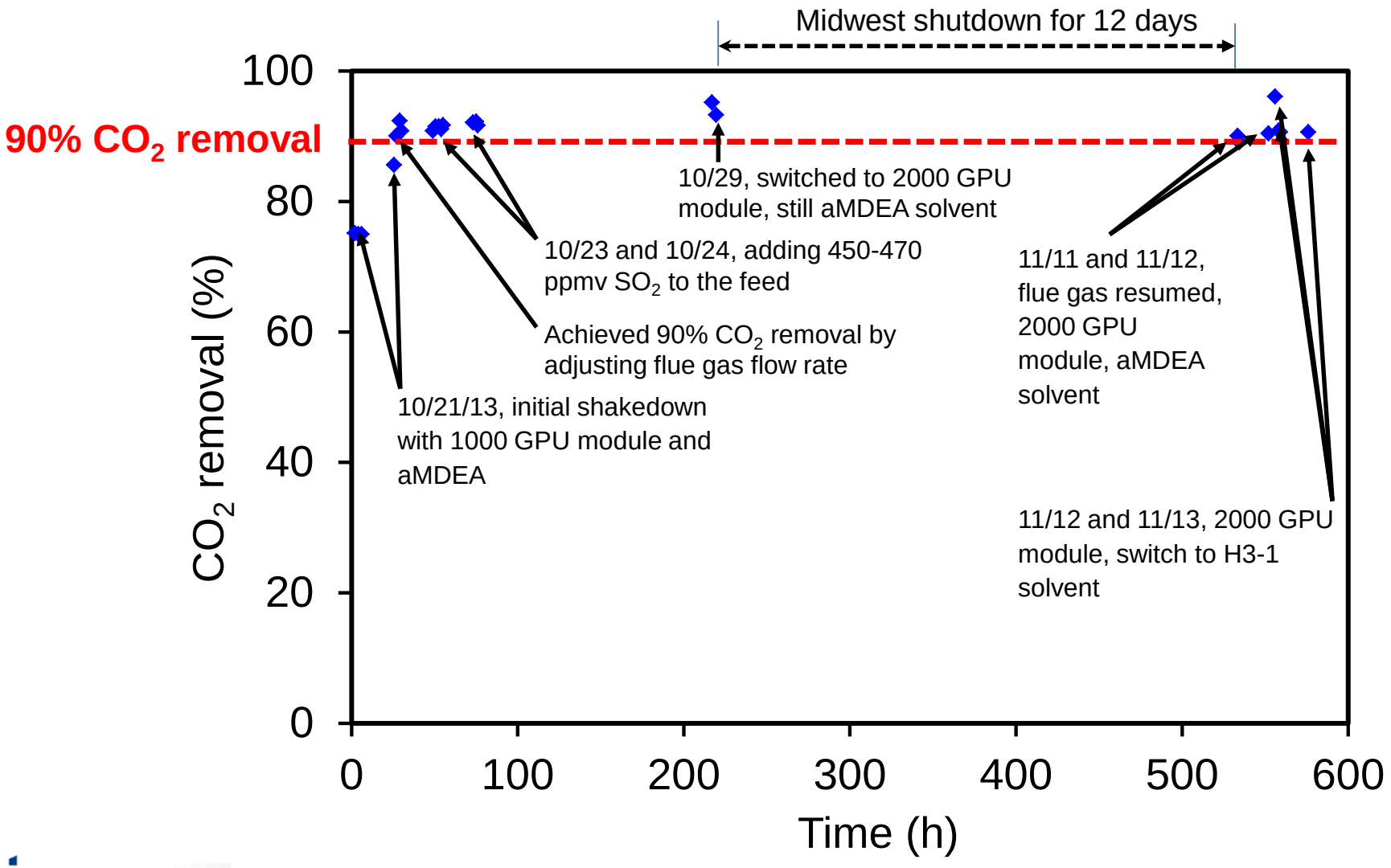


Flue gas composition

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 $(sec)^{-1}$

Pilot Test of PEEK Membrane Contactor Process for Post-combustion CO_2 Capture

DOE Contract No. DE-FE0012829

- **Performance period**: Oct. 1, 2013 – Sep. 30, 2017
- **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 a minimum of two months
- **Goal:** Achieve DOE's Carbon Capture performance goal of 90% CO_2 capture rate with 95% CO_2 purity at a cost of $40/tonne of CO_2 captured by 2025

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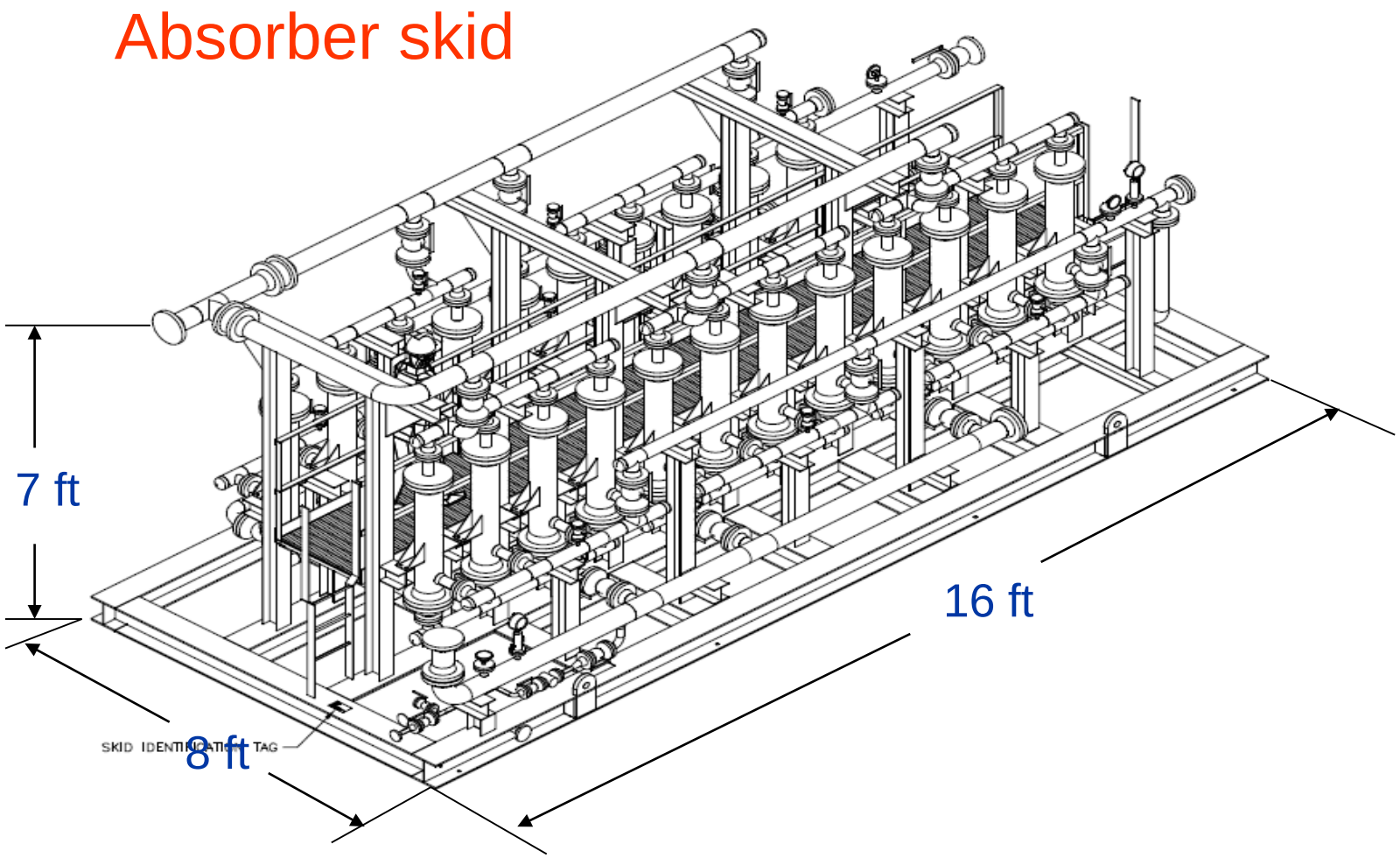
Team member

Member	Specific Project Roles
gti	• Project management and planning • System design and construction • Site preparation and system installation • Pilot test at the NCCC
PoroGen INNOVATIVE MEMBRANE PRODUCTS	• Membrane and module development • Supporting system design and construction
MITSUBISHI HITACHI POWER SYSTEMS	• Advanced solvent (H3-1) development
TRIMERIC CORPORATION	• Techno-Economic Analyses
NCCC	• Site host

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

Conceptual diagram for a 24 module skid for 8-inch diameter modules

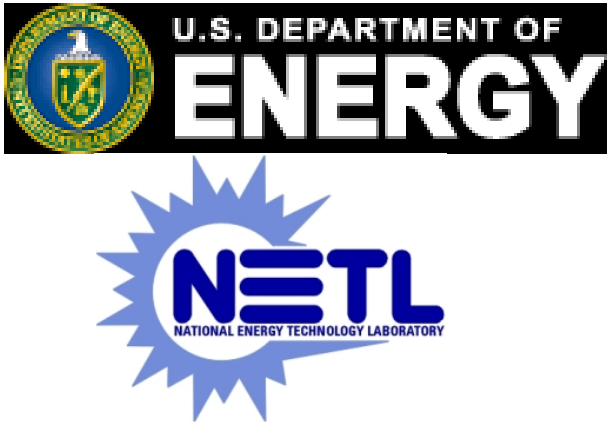


Summary

- Promising technology 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
- Test of advanced solvents planned
- Pilot-scale research program is ongoing

Acknowledgements

- **Financial support**



- **DOE NETL José Figueroa**
- **ICCI Dr. Debalina Dasgupta**