the Energy to Lead

# Pilot-Scale Development of a PEEK Hollow Fiber Membrane Contactor Process for Post-Combustion $CO_2$ Capture

**DOE Contract DE-FE0012829**

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NETL $CO_2$ Capture Technology Meeting

August 8-12, 2016

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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<br>• Process design and testing |
| AIR LIQUIDE Advanced Business & Technologies, ALaS, PoroGen Innovative Membrane Products PEEK inside | • Membrane and module development |
| Trimeric Corporation | • Techno-Economic Analyses (TEA) |
| NCCC | • Site host |

# Timeline and scope

Oct. 2013

**BP1: Design of the pilot-scale system**

Nov. 2015 →

**BP2: Lab testing, skid construction**

Dec. 2016 →

**BP3: System installation and parametric testing**

Oct. 2017 →

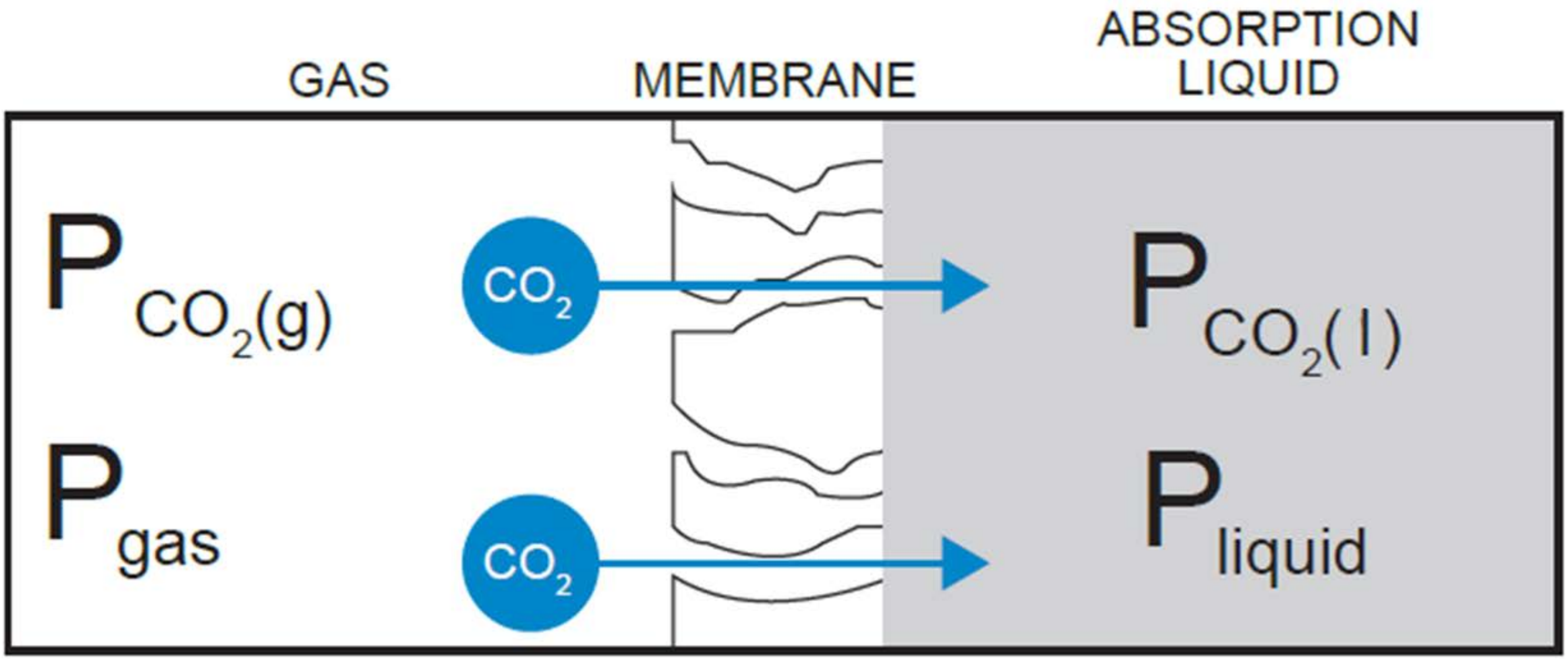
**BP4: Continuous tests and TEA**

June 2018

- **Currently in BP2**:
  - Funding: DOE: \$5.6MM; Cost share: \$1.0MM
  - Delivery: 0.5 $MW_e$ (10 tonne/day) pilot plant

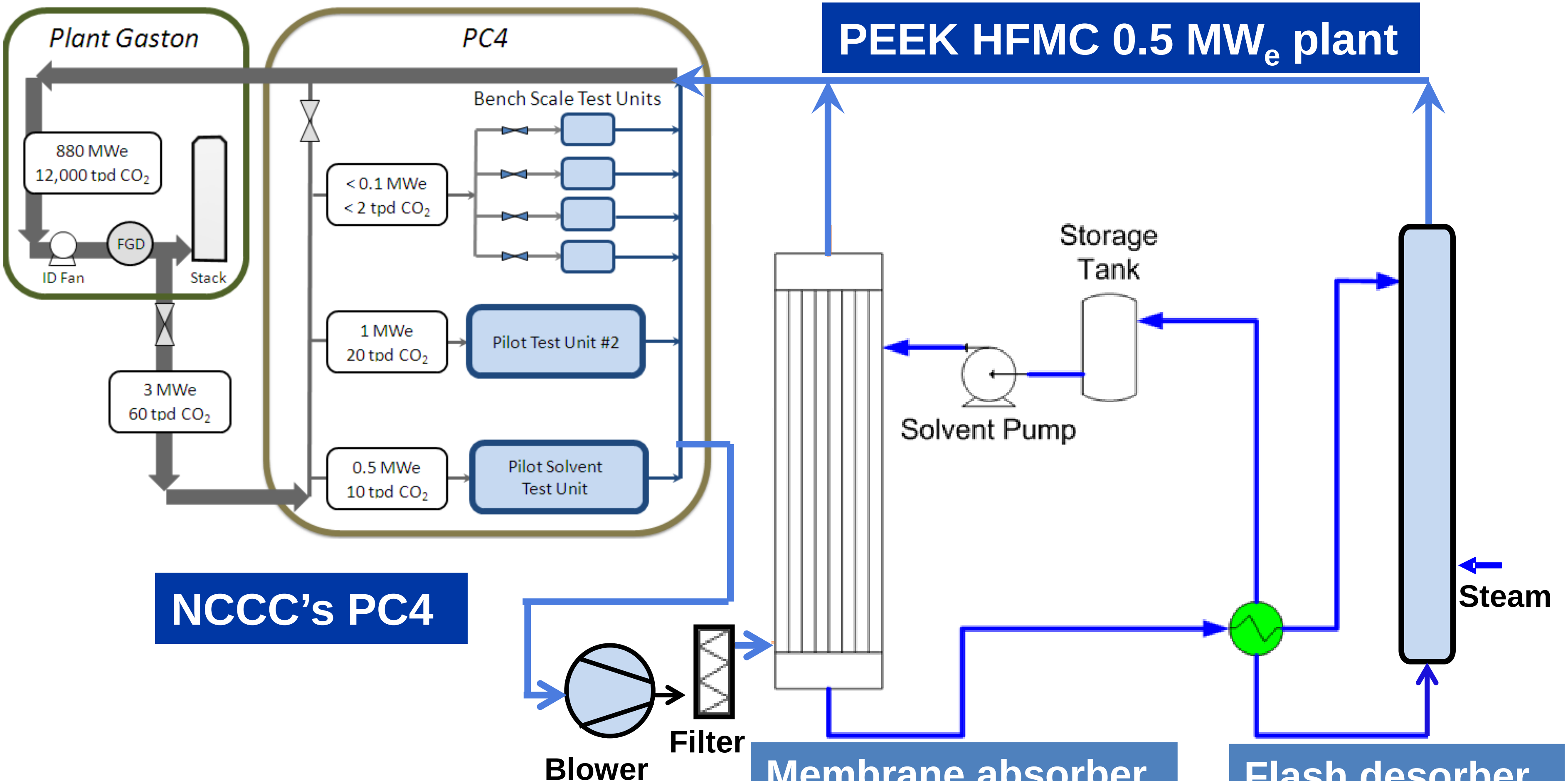
# What is a membrane contactor?

- 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

# Process description




**Membrane absorber**

| Solvent | T (ºC) | P (psig) |
|---|---|---|
| Amine | ~40 | 1-5 |

**Flash desorber**

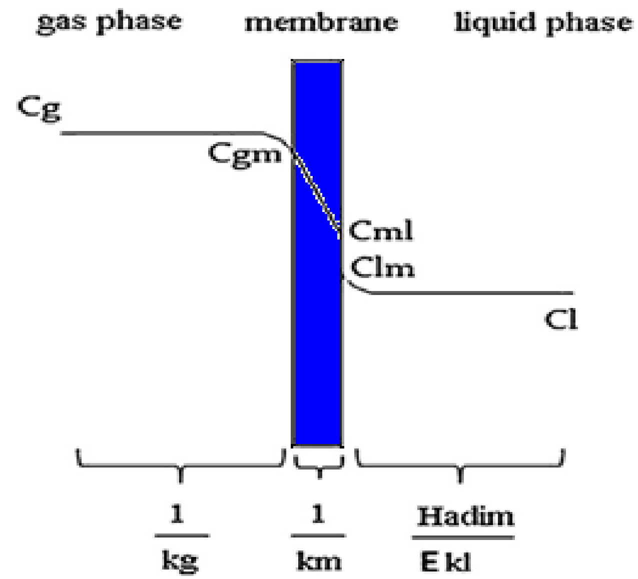
| T (ºC) | P (psig) |
|---|---|
| ~130 | 1-50 |

PEEK = polyether ether ketone

HFMC = hollow fiber membrane contactor

# Technical challenges of applying HFMC to existing coal-fired plants

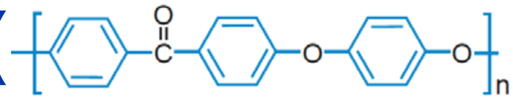
- **Performance** – Overall mass transfer resistance consists of three parts
  - Minimize each resistance
- **Durability** – Long-term membrane wetting in contact with solvent may affect performance
  - Make membrane surface super hydrophobic
  - Improve membrane potting to provide good seal between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

**GPU**= **G**as **P**ermeation **U**nit

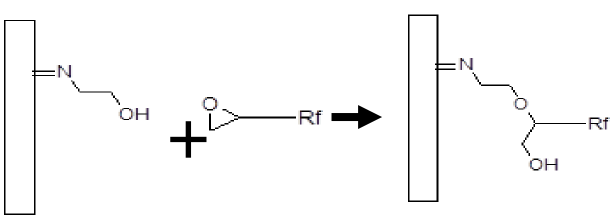
# PEEK (  ) membrane characteristics

- Exceptional thermal & mechanical resistances

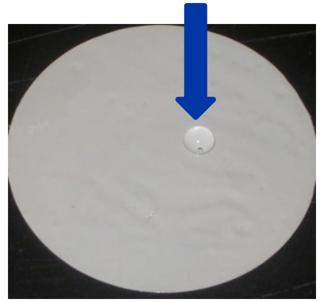
| Polymer | Tensile modulus (GPA) | Tensile strength (MPa) | Max service temperature (°C) |
|---|---|---|---|
| Teflon™ | 0.4-0.5 | 17-21 | 250 |
| PVDF | 0.8 | 48 | 150 |
| Polysulfone | 2.6 | 70 | 160 |
| **PEEK** | **4** | **97** | **271** |

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

- Surface modified to be super hydrophobic




Ethanol



Hydrophilic **Hydrophobic**

- 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



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# 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 | $/tonne | 56.47 | 47.53 |

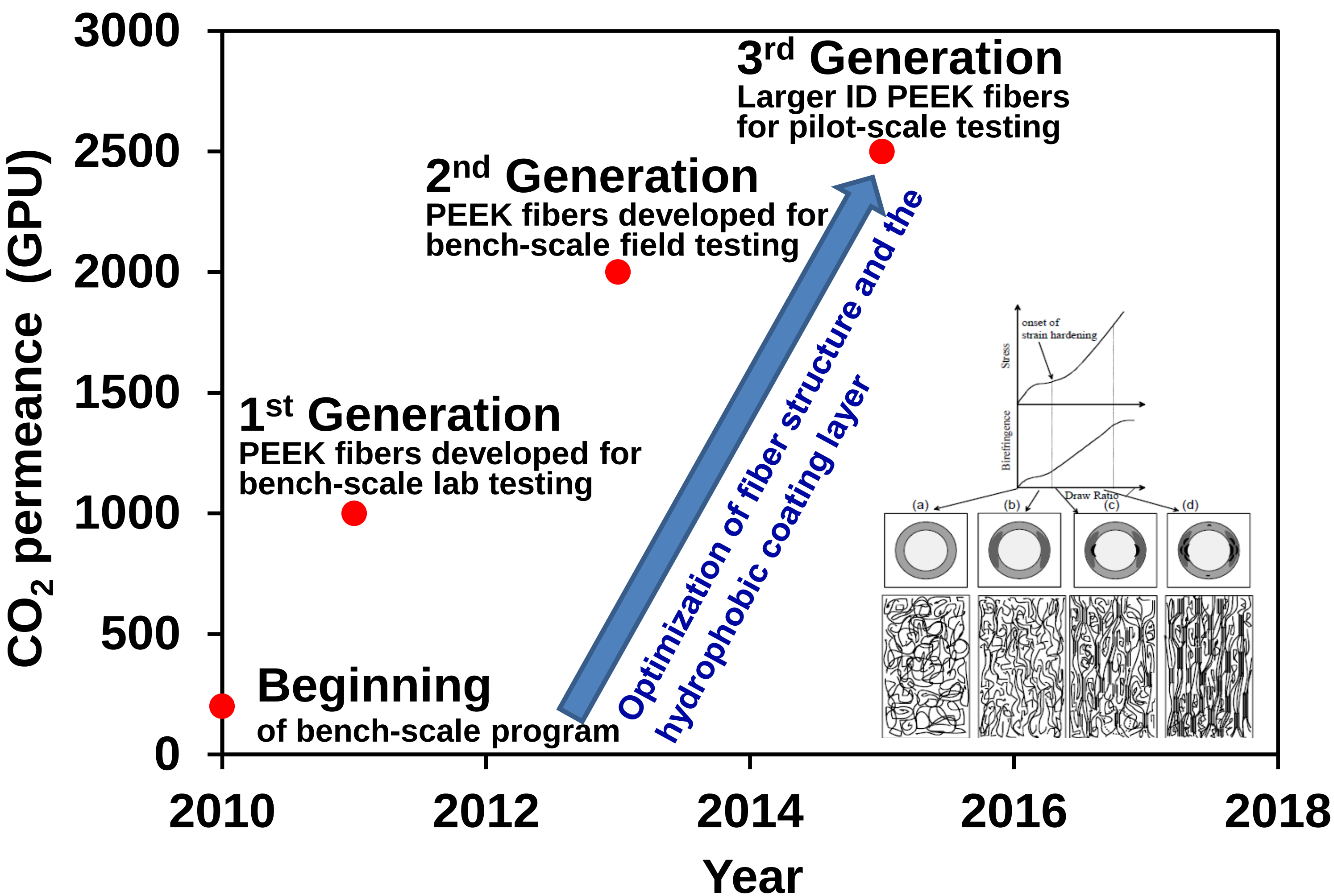
* Bench-scale field tests with 4-inch-diameter module and aMDEA solvent : mass transfer coefficient of 1.2 $(sec)^{-1}$ at 93.2% $CO_2$ removal

| 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 = A**ctivated **m**ethyl**d**i**e**thanol**a**mine

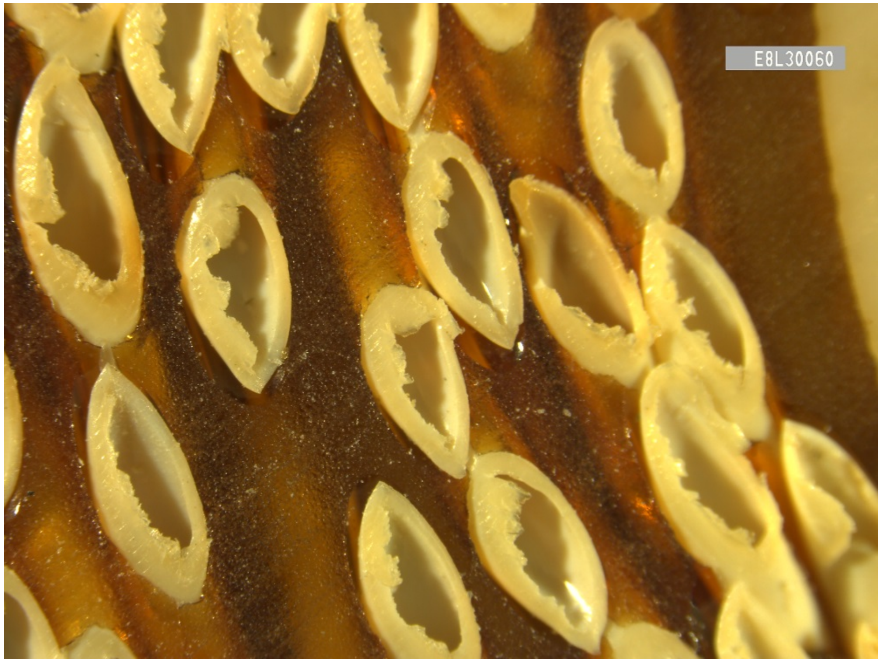
**LCOE = Levelized Cost Of Electricity**

# Intrinsic $CO_2$ permeance of the PEEK fiber improved to 2,500 GPU




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

# Delamination of the fiber/epoxy interface observed during startup/shutdown tests, membrane potting improved recently

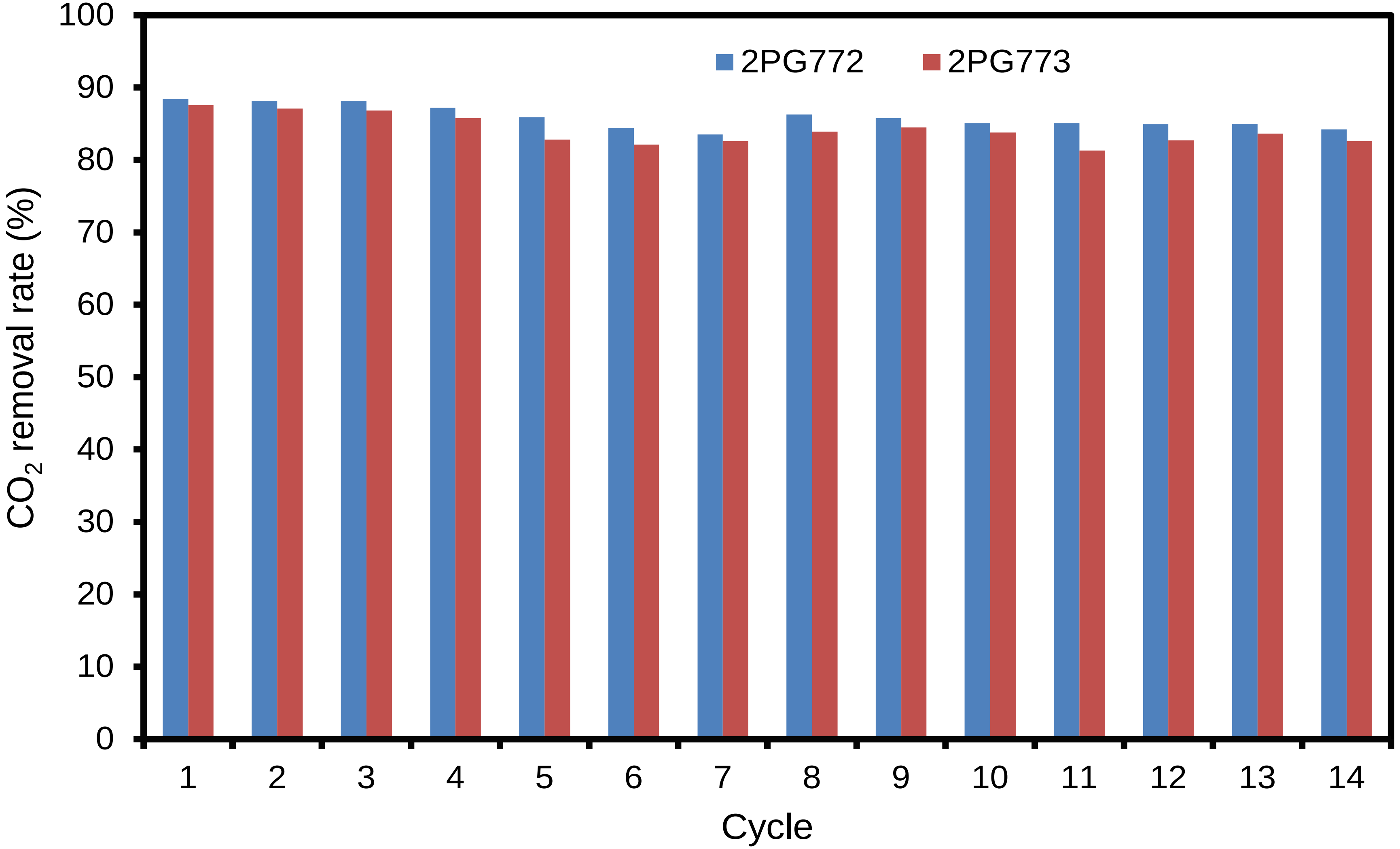




**Old modules**: clear color differentiation between the epoxy and the fiber; the epoxy surrounds the fiber rather than infusing into the fiber.

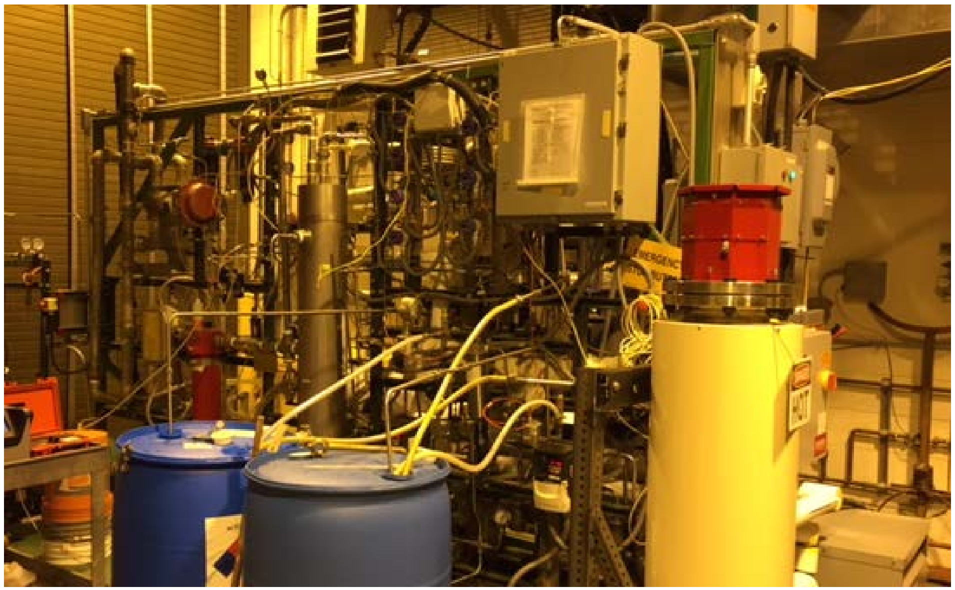
**Recent modules**: fibers and epoxy are the same color; epoxy penetrated into the wall of the fibers

# Recent modules showed good startup/shutdown stability



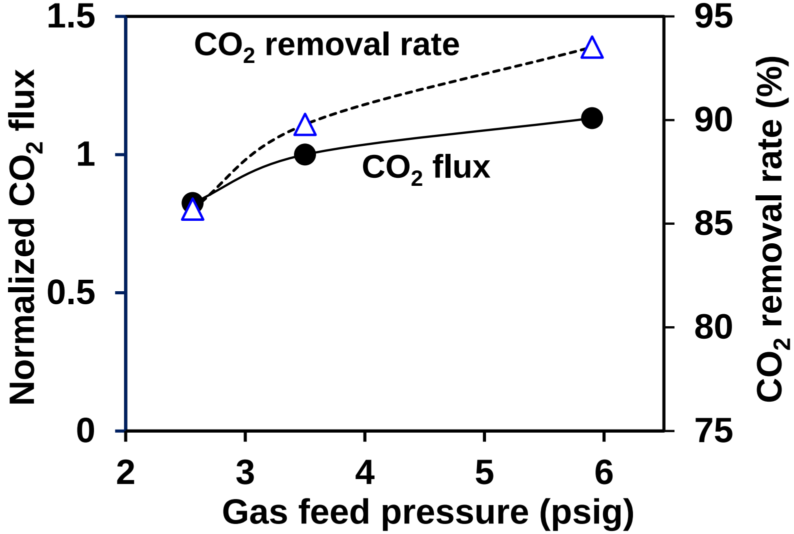
# Module scaled to 8-inch, which was tested at GTI with aMDEA solvent using air/$CO_2$ mixed gas as feed

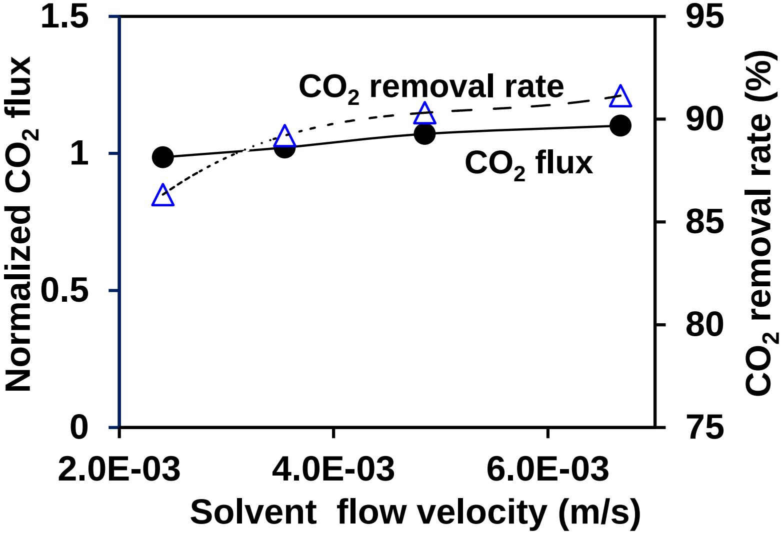
4 inch 8 inch

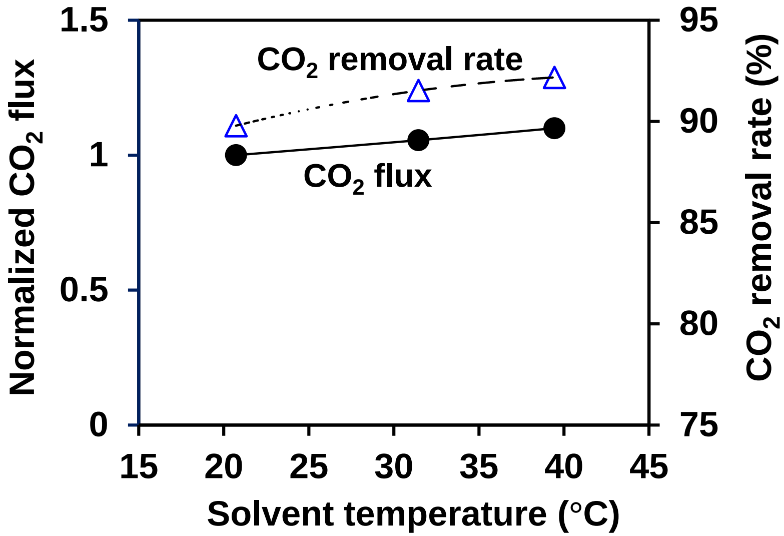


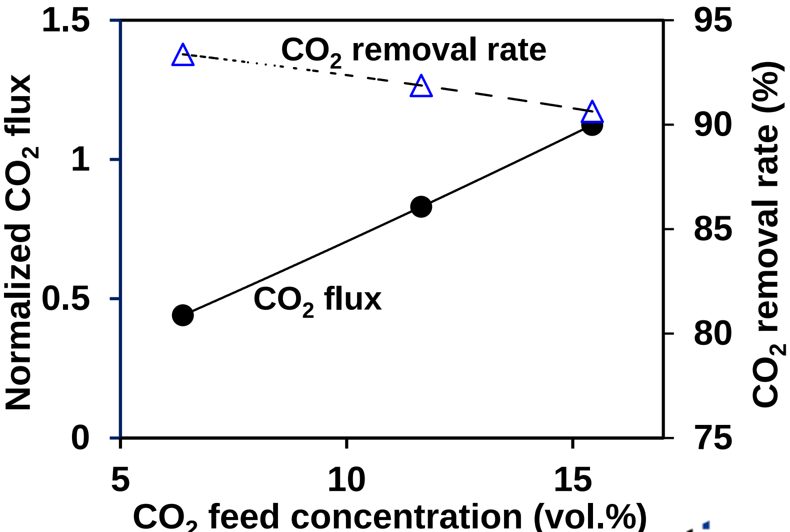

**Improved mass transfer coefficient of 2.0 $(sec.)^{-1}$ obtained**

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





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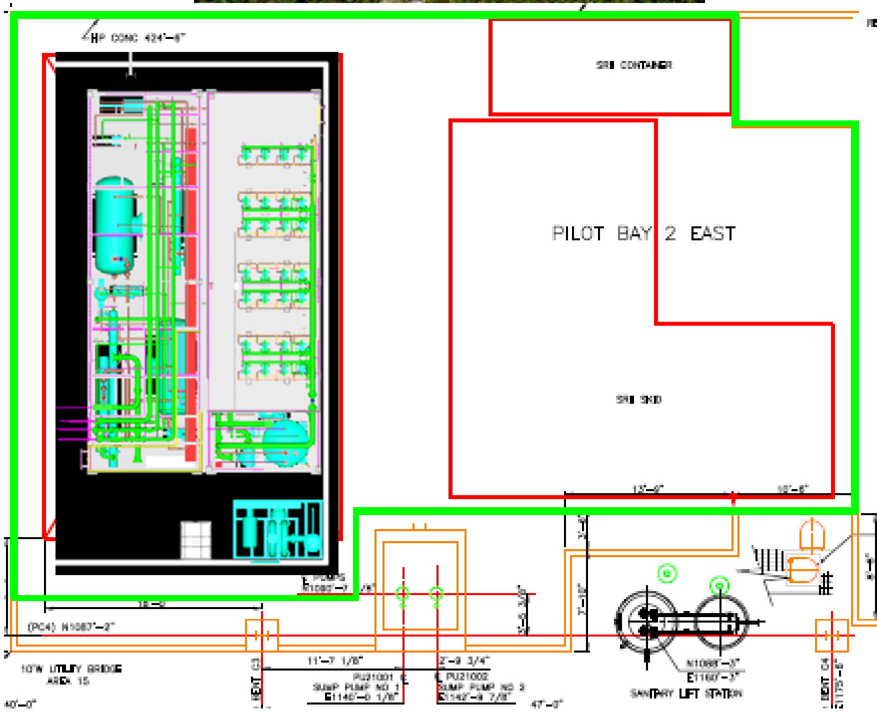
# Planning tests at the NCCC

- EPIC System was down selected from five bidders to construct the 0.5 $MW_e$ plant due to their:
  - Reasonable bid in terms of costs and technical approaches
  - Experience at NCCC
  - Modular construction experience
  - Experience with membrane skid design
- Detailed engineering and HAZOP completed
- Testing site (Pilot Bay 2 West) and layout of skids determined



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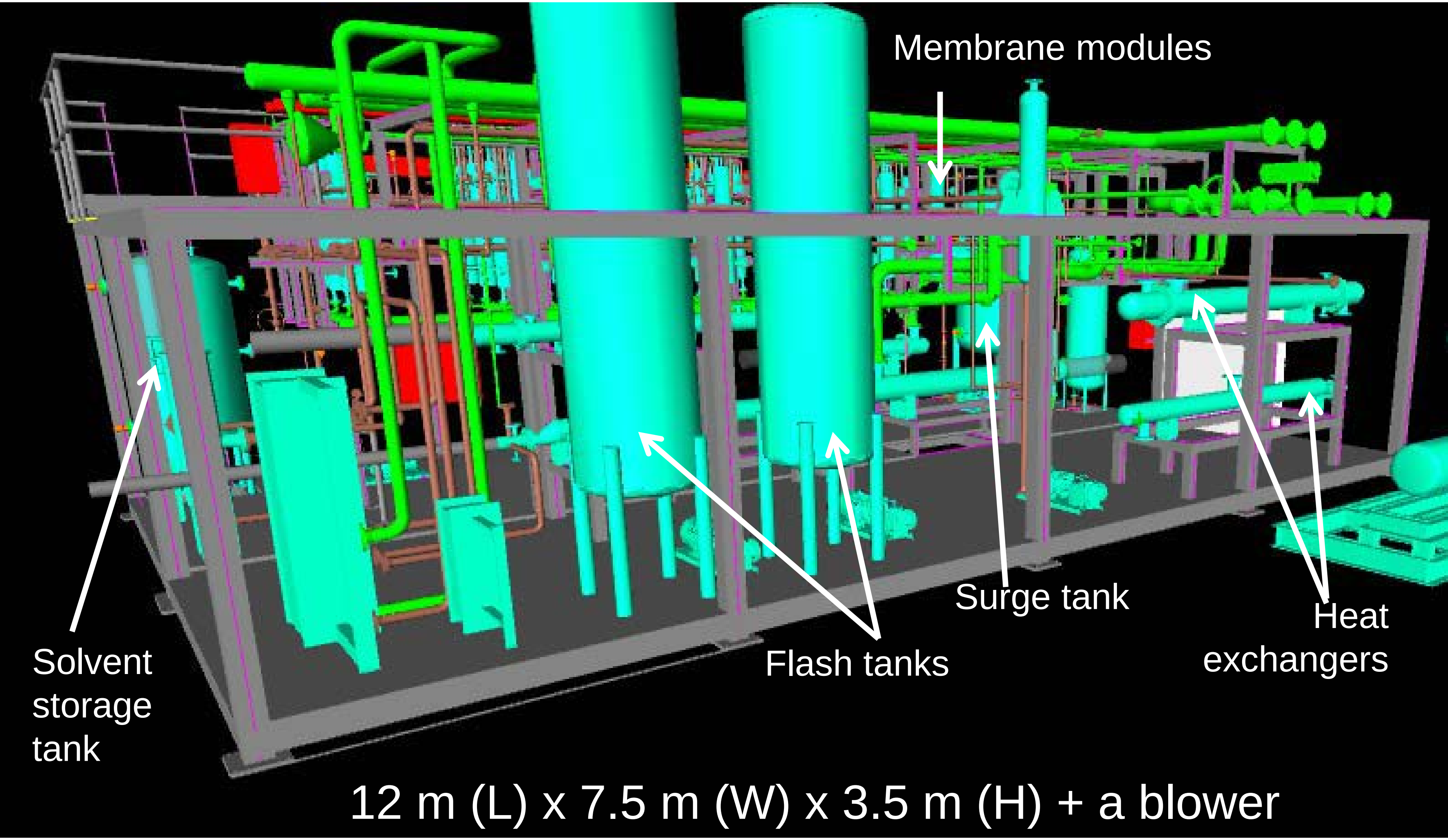
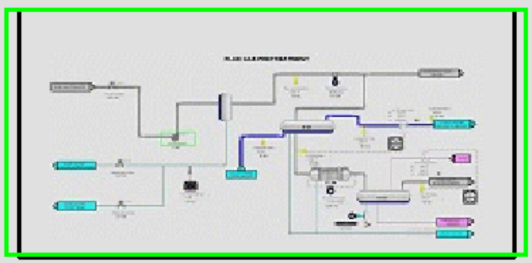
# Pilot plant for 0.5 $MW_e$ (10 tonne/d) $CO_2$ capture

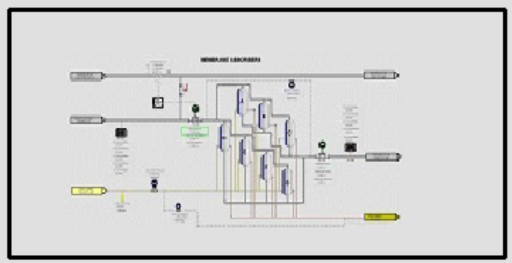


# Plant is under construction

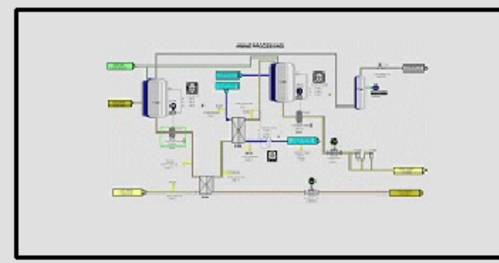
**Skids: frames complete, all equipment received, components are being installed**



FLUE GAS PRETREATMENT

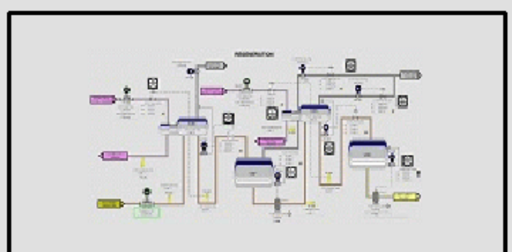


MEMBRANE ABSORBERS

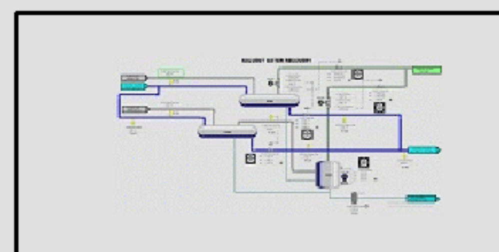


AMINE PROCESSING

**Control system: 75% complete**



REGENERATION



SOLVENT WATER RECOVERY

# BP2 milestones and overall testing schedule

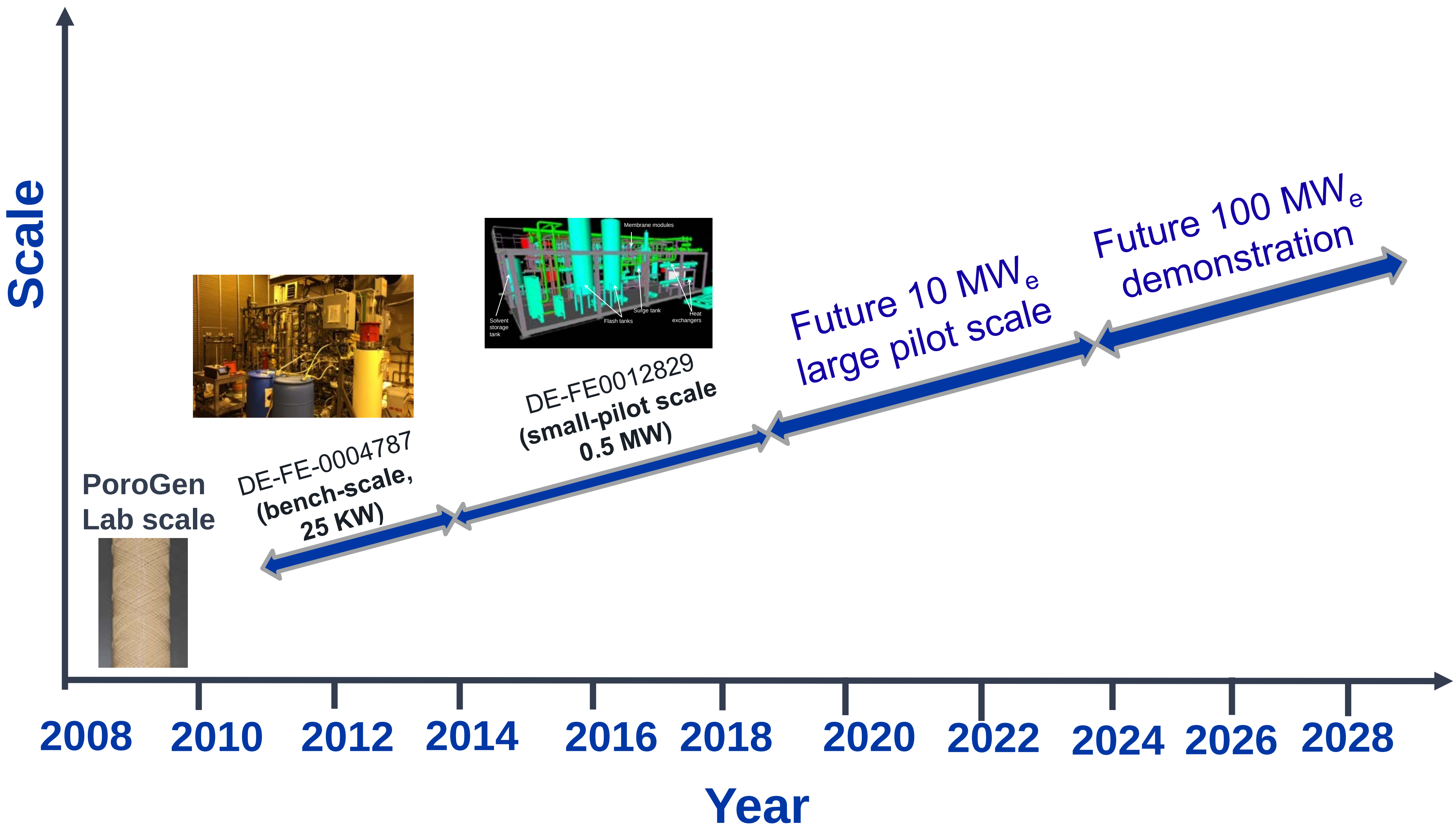
| Milestone No. | Milestone Description | Planned Completion | Actual Completion |
|---|---|---|---|
| 1 | Submit Budget Period 1 Report | 11/30/15 | 12/23/15 |
| 2 | Complete 8-inch module fabrication | 12/31/15 | 10/09/15 |
| 3 | Technical information for 8-inch module delivered | 01/31/16 | 01/28/16 |
| 4 | Complete initial solvent process determination | 02/29/16 | 02/25/16 |
| 5 | Achieve ≥90% $CO_2$ removal, contactor mass transfer coefficient ≥1.7 $(sec)^{-1}$ in 8-inch modules | 04/30/16 | 03/31/16 |
| 6 | Complete procurement for the 0.5 $MW_e$ system | 05/30/16 | 04/30/16 |
| 7 | Complete construction of the 0.5 $MW_e$ pilot system | 09/30/16 | EPIC scheduled to complete by 9/30/16 |

## Overall testing schedule at NCCC

Plant fabrication and acceptance testing completed → Plant delivered to NCCC → Installation/ shakedown completed → Parametric testing completed → Long-term testing completed

| Plant fabrication and acceptance testing completed | Plant delivered to NCCC | Installation/ shakedown completed | Parametric testing completed | Long-term testing completed |
|---|---|---|---|---|
| Sept. 2016 | Dec. 2016 | March 2017 (PO-6) | Sept. 2017 (PO-7) | March 2018 (PO-8) |

# PEEK HFMC-based technology development path



# Summary

- Preliminary TEA: PEEK HFMC costs 16% less than Case 12, can be furthered reduced by improving contactor performance
- Intrinsic $CO_2$ permeance of the fiber improved to 2,500 GPU
- Wicking of solvent at fiber/epoxy interface observed during startup/shutdown tests, membrane potting improved recently
- Module scaled to 8-inch diameter, lab tests showed mass transfer coefficient of 2.0 $(sec)^{-1}$ with aMDEA solvent
- EPIC System was selected to construct the 0.5 $MW_e$ plant
- Detailed engineering and HAZOP completed
- Pilot plant construction to be completed by 9/30/16, testing at NCCC planned

# Acknowledgements


- **Financial support**

JIP Partners

ALaS

- **DOE NETL José Figueroa**