the Energy to Lead

Pilot Test of a Nanoporous, Super-hydrophobic Membrane Contactor Process for Post-combustion CO_2 Capture

DOE Contract No. DE-FE0012829

S. James Zhou, Shiguang Li, Travis Pyrzynski, and Howard Meyer, *GTI*
Yong Ding and Ben Bikson, *PoroGen*
Katherine Searcy, *Trimeric*

NETL CO_2 Capture Technology Meeting
June 23-26, 2015

gti PoroGen INNOVATIVE MEMBRANE PRODUCTS

Introduction to GTI and PoroGen

gti

- Not-for-profit research company, providing energy and natural gas solutions to the industry since 1940s
- Facilities
  - 18 acre campus near Chicago
  - 200,000 ft^2, 28 specialized labs

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

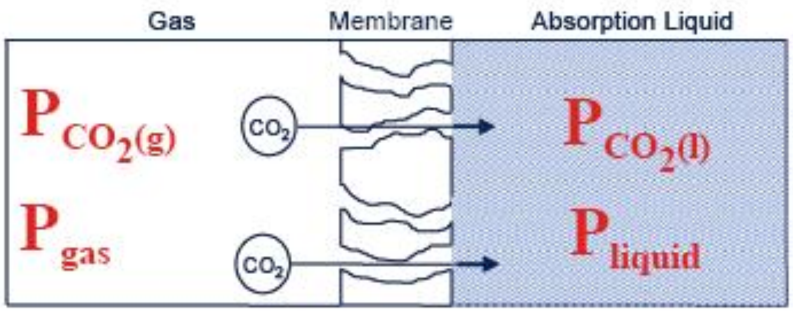
Project overview

- **Performance period**: Oct. 1, 2013 – June 30, 2018
- **Total funding**: $12.5 MM (DOE: $10MM, Cost share: $2.5MM)
- **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
PoroGen	• Membrane and module development
Trimeric Corporation	• Techno-Economic Analyses (TEA)
NCCC	• Site host

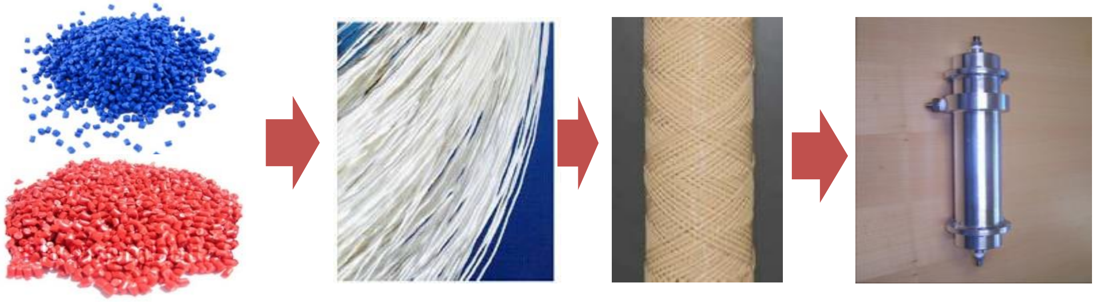
What is a membrane contactor?

- High surface area membrane device that facilitates mass transfer



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

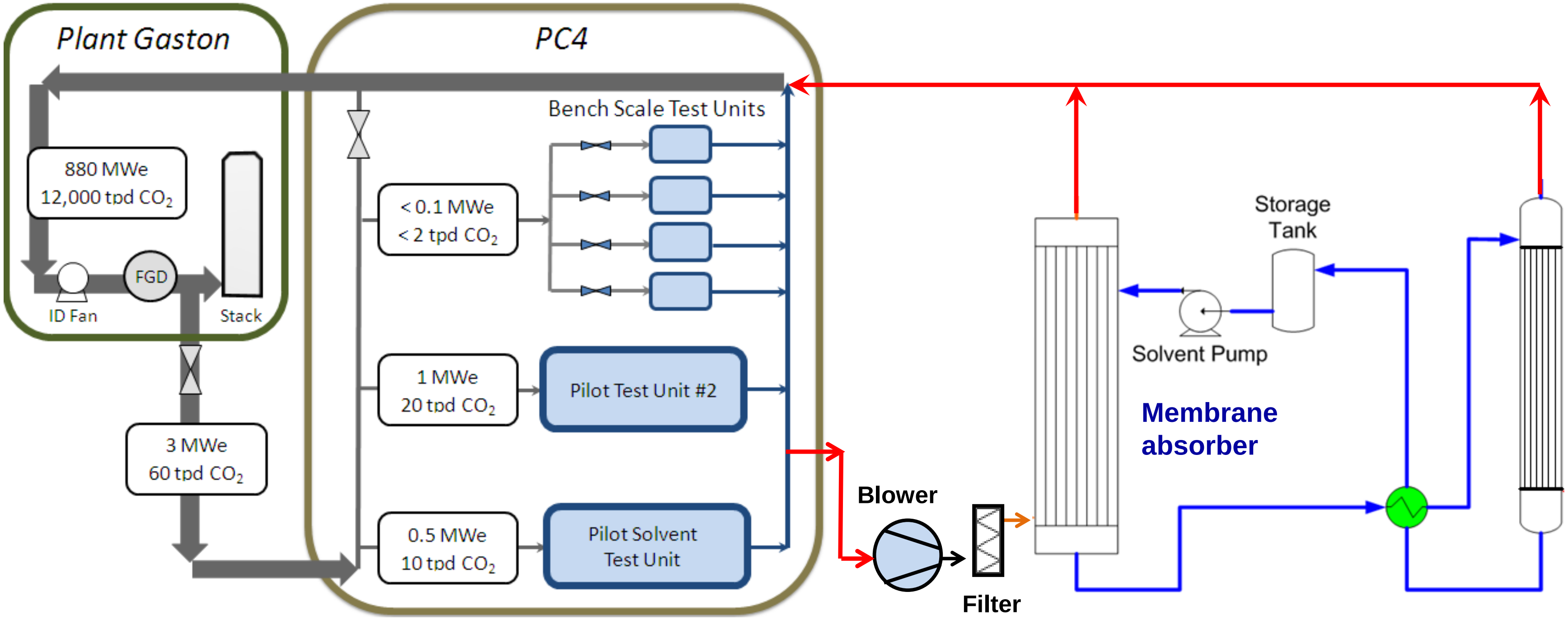
Polymer	Max service temperature (°C)
Teflon™	250
PVDF	150
Polysulfone	160
PEEK	**271**



PEEK= Polyether ether ketone

HFMC= Hollow Fiber Membrane Contactor

Process description



NCCC's PC4 **HFMC plant**

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/sweep gas required	Determined by the dense “skin layer”	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, α > 1000	Yes

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

Technical and economic challenges of applying membrane contactor to existing PC plants

- **Performance**
  - Maximize overall mass transfer coefficient to reduce absorption system size
- **Durability** – Long-term membrane life in contact with solvent
  - Improve membrane hydrophobicity
- Contactor **scale-up** and **cost reduction**
  - Make larger diameter module, module packaging to reduce cost

Timeline and scope

Oct. 2013

BP1: Design of the pilot-scale system

July 2015

BP2: Lab testing, Skid construction

July 2016

BP3: System installation and shakedown

July 2017

BP4: Parametric and continuous tests

June 2018

- **Current BP1 scope:**
  - Preliminary TEA and EH&S study
  - Bench-scale testing in support of the pilot-scale design
  - Design and costing of the pilot plant

gti PoroGen INNOVATIVE MEMBRANE PRODUCTS

Preliminary Techno-Economic Analysis completed in September 2014

- Preliminary TEA was based on bench scale field test results at Midwest Generation's (IL) coal fired power station
  - Flue gas feed

Feed 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, trace elements	

  - Mass transfer coefficient of 1.2 $(sec)^{-1}$ achieved with aMDEA solvent at 93.2% CO_2 removal

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

Preliminary TEA shows HFMC technology with aMDEA solvent can cost 25% less than DOE Case 12

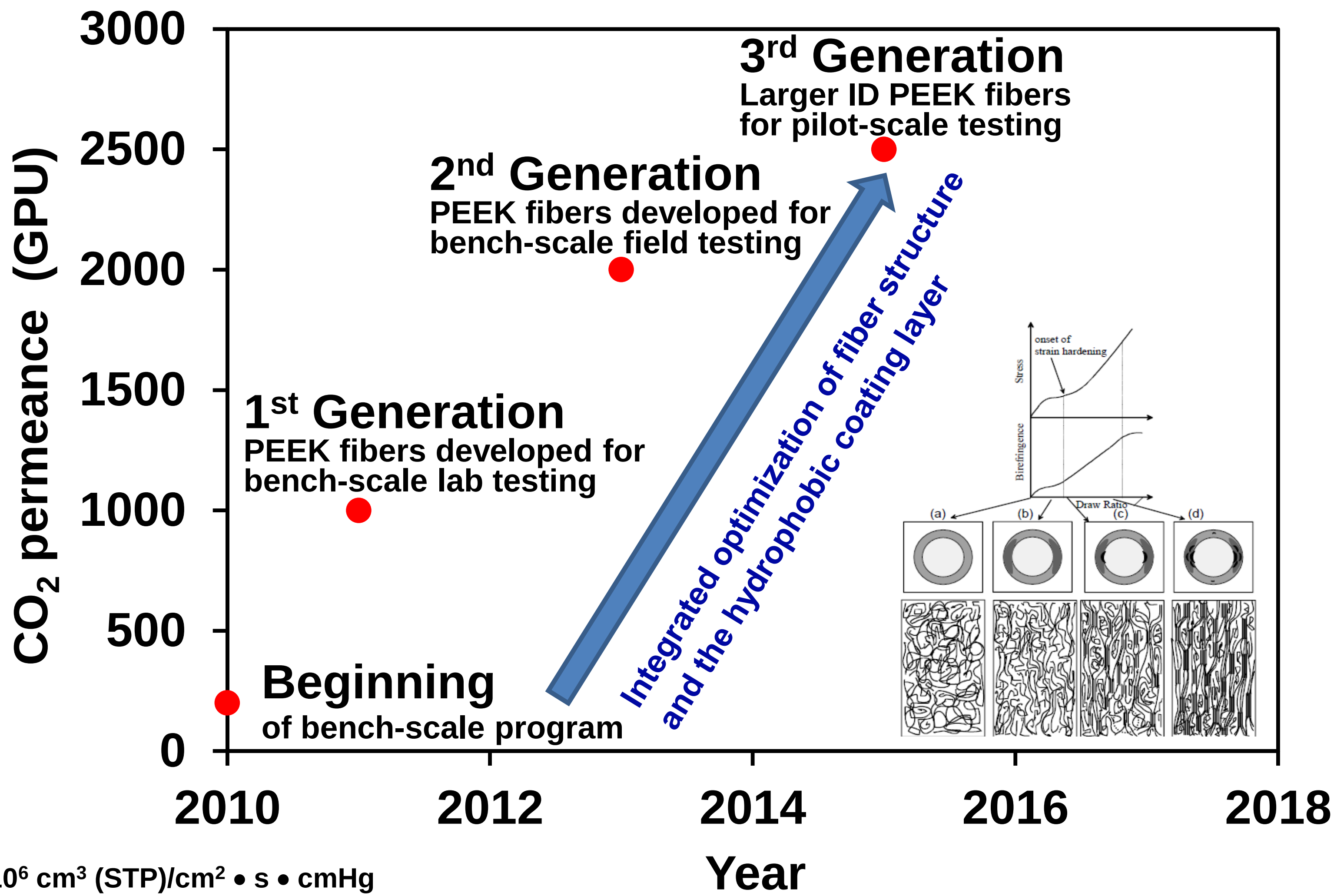
Mass transfer coefficient target of the current pilot program: **1.7** sec^{-1}

Item	Unit	DOE Case 12	Bench scale field test data	Target mass transfer coefficient achieved
LCOE - No TS&M	mills/kWh	137.3	127.1	122.1
Increase in LCOE - No TS&M	%	69.6%	57.0%	50.9%
Cost of CO_2 Capture - No TS&M	$/tonne	56.47	47.53	42.48

LCOE = Levelized Cost Of Electricity

TS&M = Transportation, Storage and Monitoring

PEEK membranes continue to improve, larger inner diameter fibers with high CO_2 permeance developed



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

gti PoroGen INNOVATIVE MEMBRANE PRODUCTS

New larger ID fibers have intrinsic CO_2 permeance as high as 2,600 GPU, surpassing our target of 2,000 GPU

- Achieved in January 2015 with testing conditions:
  - 2-inch diameter modules
  - Pure CO_2 gas
  - ~3 psig feed pressure
  - Room temperature (22 °C)

Cartridge No.	Number of fibers	Active fiber area (cm^2)	Pure CO_2 permeance (GPU)
2PG-664	448	3,161	2,580
2PG-665	448	3,161	2,500

Why larger inner diameter (ID) fibers?

- During bench-scale field test, pressure drop (ΔP) between flue gas Inlet and outlet was 5 psi
- Current pilot program target: decrease ΔP to ≤ 2 psi because the lower the ΔP the more saving on operating costs
- The Hagen–Poiseuille equation: ΔP very sensitive to ID

$$\Delta P = \frac{8Q\eta L}{\pi \cdot r^4}$$

  - *Q:* volumetric flow rate, η: absolute viscosity of the fluid, *L:* length of the hollow fiber, and *r:* radius of the hollow fiber
- Fiber ID is being increased from 13 mil to 20 mil

The 2,500 GPU 20-mil-ID-fiber module showed high CO_2 capture performance in contactor mode

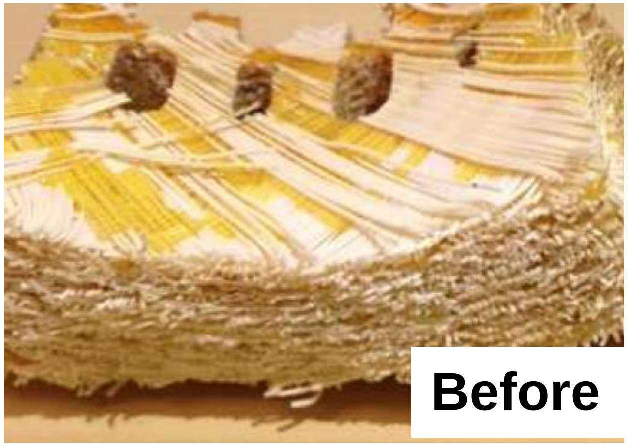
- aMDEA solvent
- 90% CO_2 removal

	Mass transfer coefficient, $(sec)^{-1}$	gas-side ΔP, psi
Tested in 2-inch module	1.6	0.28

Predicted ΔP for 8-inch module: 0.74 psi

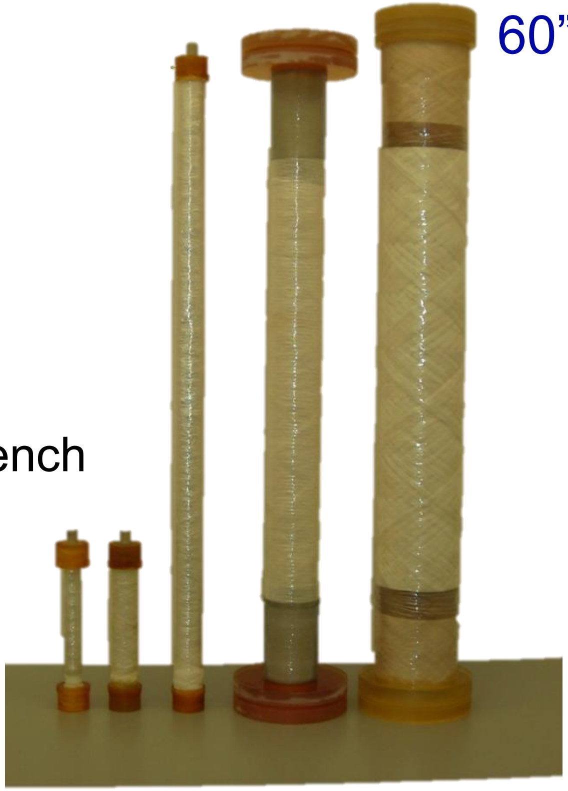
Material compatibility confirmed/resolved before module scale-up

- No problems with O-ring seals were noted through tests of multiple 2-inch diameter modules
- Resolve tubesheet adhesion issues



- No wet out of hydrophobic membrane surface after long-term operation based on single-gas CO_2 permeation measurements before and after contactor testing

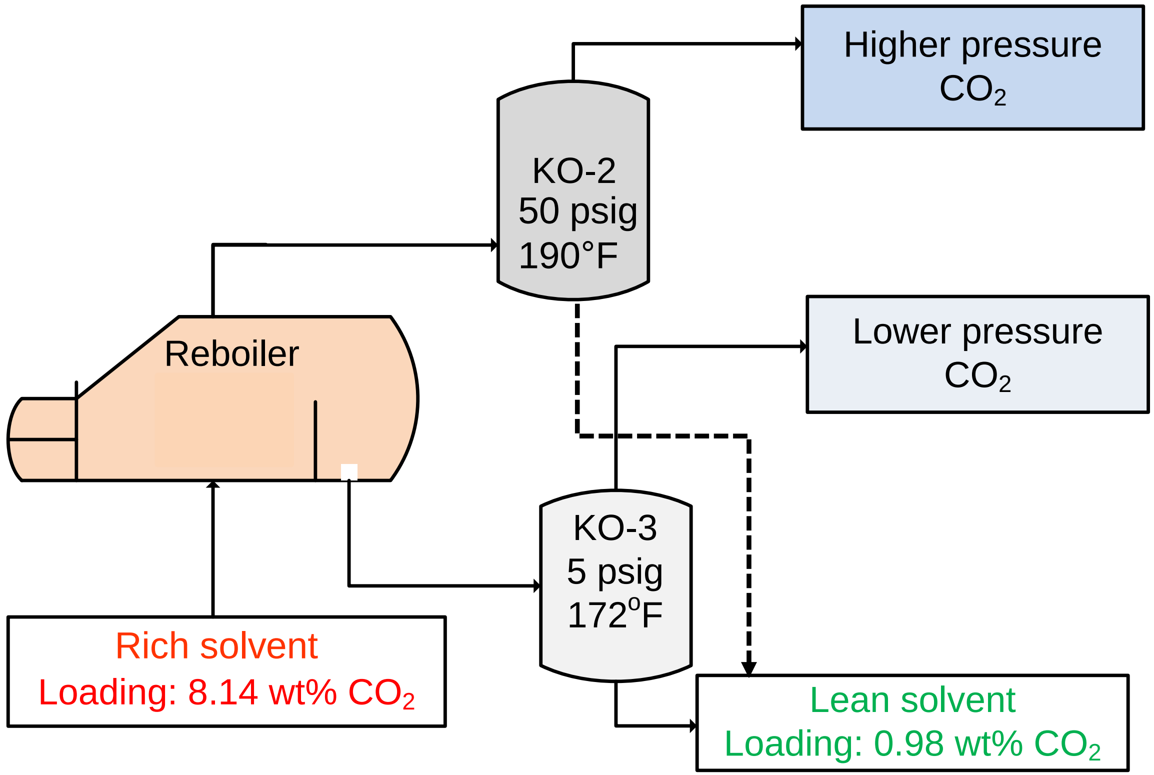
Membrane module scaled to 8-inch diameter



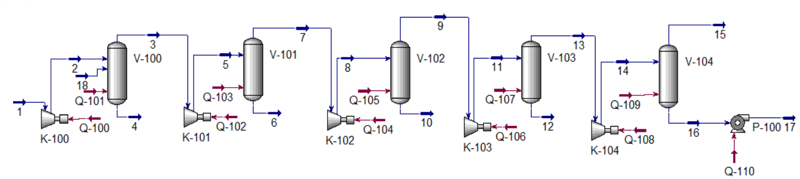
8-inch module constructed

Measured intrinsic CO_2 permeance for the 8-inch module: 2,300 GPU

New regeneration process developed from process modeling during TEA study, validated by lab testing



- One stage of high pressure flash combined with one stage of low pressure flash
- Power required for compression can be reduced by as much as 20%



gti PoroGen INNOVATIVE MEMBRANE PRODUCTS

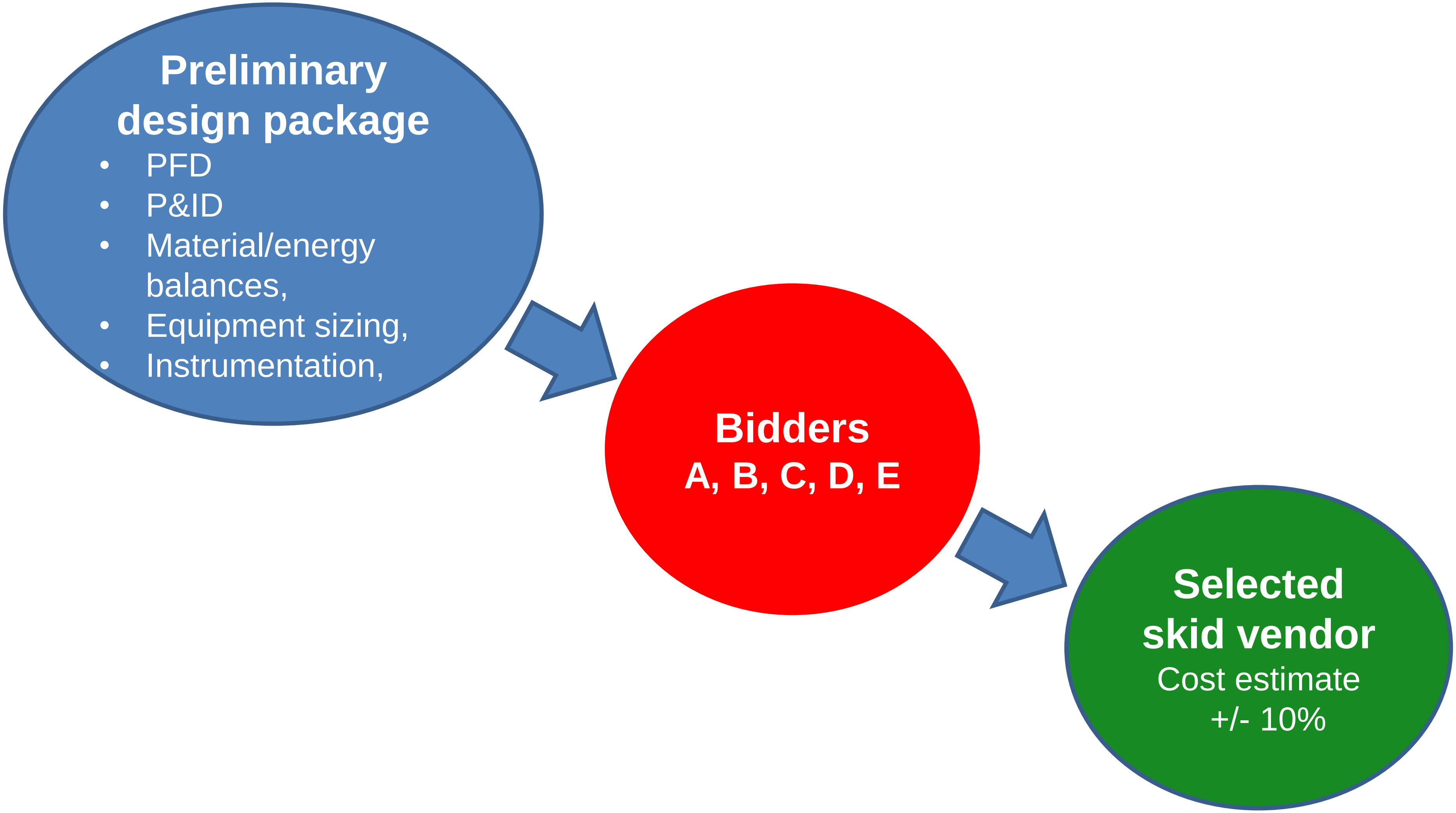
Pilot plant design

- **Design bases:**
  - Bench scale PFD, P&ID and testing results
  - Process modeling
    - **Mass and energy balances**
    - **Equipment sizing**
    - **Process conditions**

Preliminary design completed, HAZOP reviewed at NCCC in February 2015

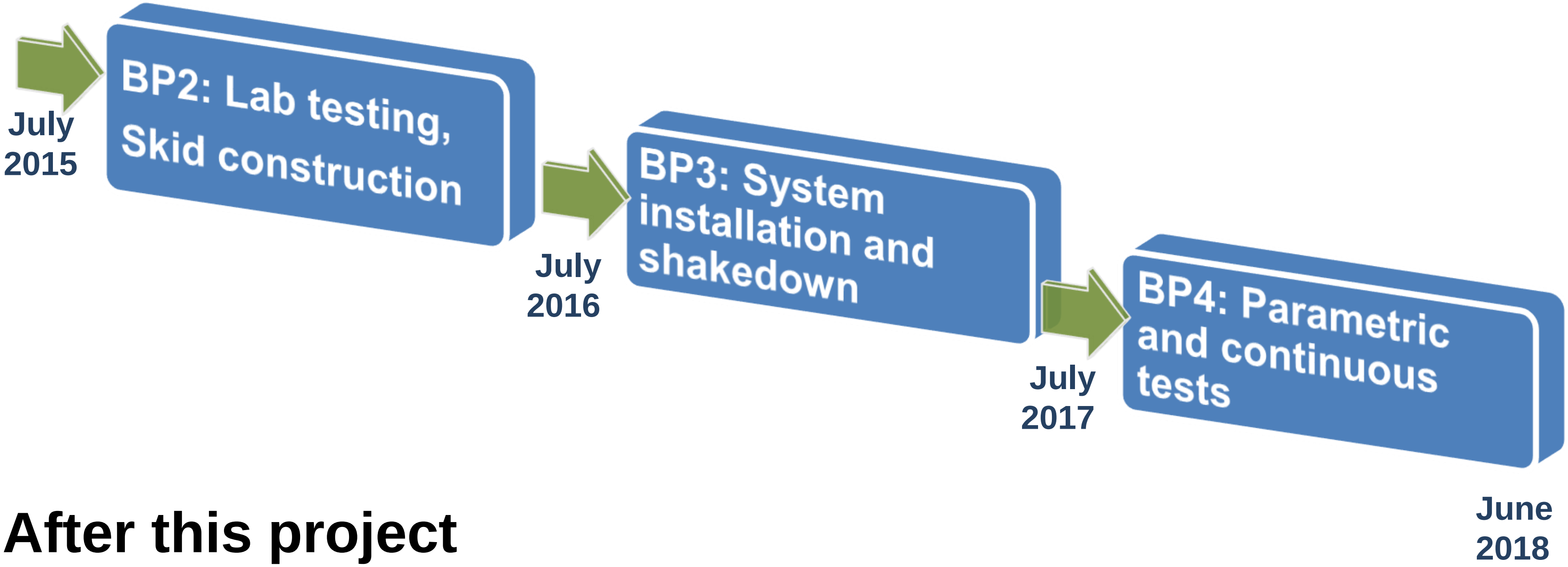
- **Major HAZOP review outcome**
  - No “show-stopper” or “major” modifications were identified
  - Valuable insights from NCCC engineers → revised design

Revised design package sent to bidders, one will be selected to construct the plant



Plans for future testing/development/commercialization

- **In this project**



- **After this project**

Time	Development	CO_2 capture, Ton/day
By 2018	0.5 MWe pilot scale (in progress)	10
By 2022	10 - 25 MWe demonstration	200 - 500

Summary

- PEEK HFMC: promising based on bench-scale 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
- Pilot-scale development in progress
  - TEA: projected costs 25% lower than benchmark technology
  - PEEK membranes continue to improve, new developed larger ID fibers showed high CO_2 permeance and low pressure drop
  - Module scaled to 8-inch diameter with CO_2 permeance of 2,300 GPU
  - New regeneration process designed and validated experimentally
  - Design and costing near completion

Acknowledgements

- **Financial support**

JIP Partners

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