2016 NETL CO_2 Capture Technology Meeting

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Creative Oxygen

CO_2 Capture by Cold Membrane Operation with actual power plant flue gas (DE-FE0013163)

August 10th, 2016
T. Chaubey| R&D

Project Organization- DOE NETL Award No. DE-FE0013163

Total Budget : $6.5 MM, DOE Funding - $5.2 MM ; Cost share - $1.3MM

	DOE Share	AL Cost Share
Budget Period 1 (Oct 2013 – June 2015)	$3,283,727	$820,931
Budget Period 2 (July 2015 – Dec 2016)	$1,913,802	$478,450

Period of Performance: 10/01/2013 through 12/31/2016 over 2 Budget Periods

NETL Project Manager: José Figueroa

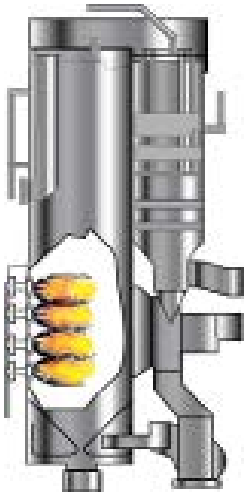
Project Team:

- Air Liquide R&D - Sudhir Kulkarni, David Hasse, Jacob Brumback, Alex Augustine, Dean Kratzer, Ted Li, Madhava Kosuri, Shilu Fu, Gerard Gagliano, Jiefu Ma, Monaca Mcnall, Michael Bennett, Judy Huss, Dennis Calvetti, Robert Sokola, Jean-Pierre Tranier, Robert Gagliano, David Edwards, Ed Sanders, Deborah Hutchinson
- MEDAL/ALAS - Karl Beers, Jean-Marie Gauthier, Alfredo Velasco, Dana Husnay
- E&C – Mike Turney, Paul Terrien
- Parsons - Brad Knutson, Surajit Amrit, Jay Hellinger, Tom Moe, Louis Wheat

- Host site partner – National Carbon Capture Center

Project Summary

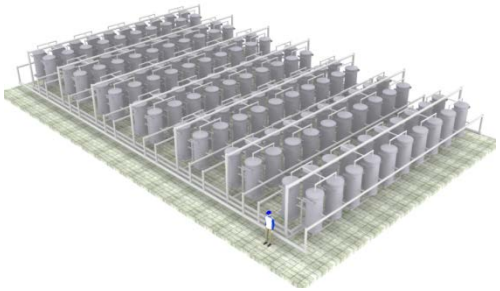
- Air Liquide Hybrid Cold membrane - Liquefaction Process plant for 550 MWe scale



POWER PLANT

Flue Gas

Improved Performance at Cold Condition



COLD MEMBRANE

LIQUEFACTION

CO_2 for sequest. or EOR

- Cold membrane testing at 0.1 MWe with synthetic flue gas (TRL4) in 2012
  - CO_2 Capture Cost estimated at 46-52$/tonne (DOE Target - $40/tonne)
- Current project tested the cold membrane technology at 0.3 MWe scale (TRL5) at National Carbon Capture Center (NCCC)

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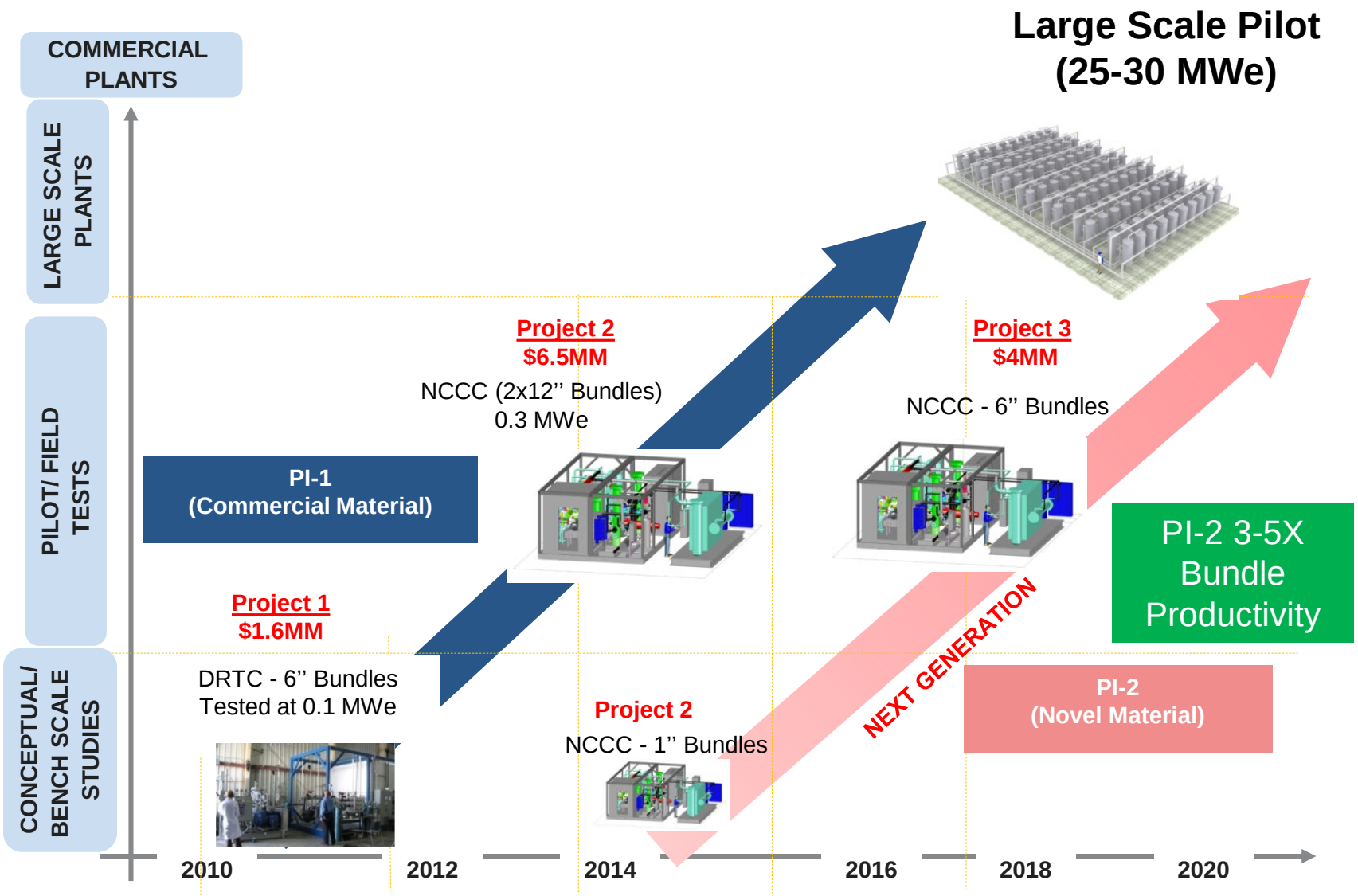
Agenda

- Cold Membrane Technology Roadmap
- Hybrid Cold Membrane Technology
- Project Overview
- Project Progress
  - Field Testing
  - Techno-economic Analysis
  - Next Phase design
- Next Steps

Cold Membrane Technology Roadmap



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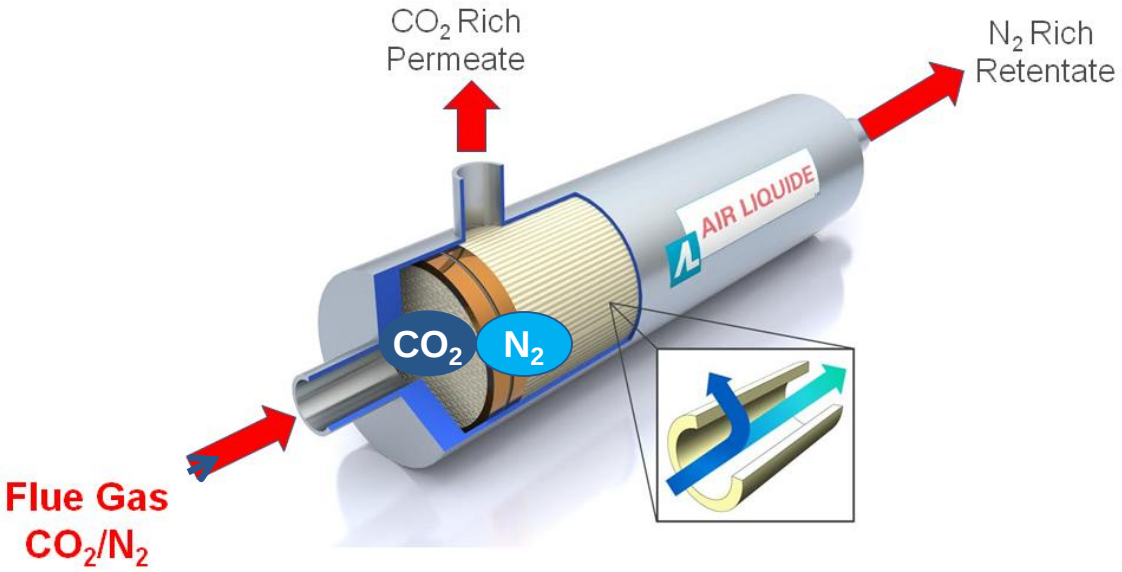
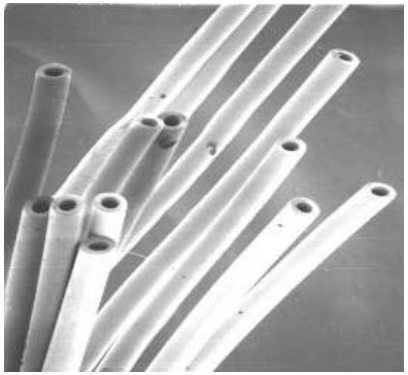
Cold Membrane Process Based on Hollow Fiber Membrane





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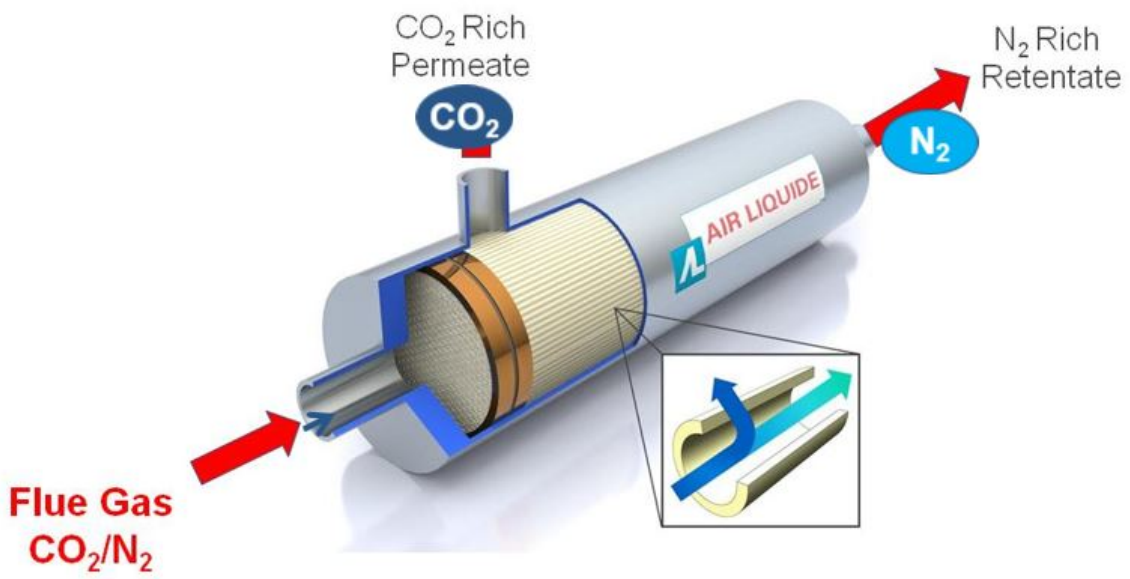
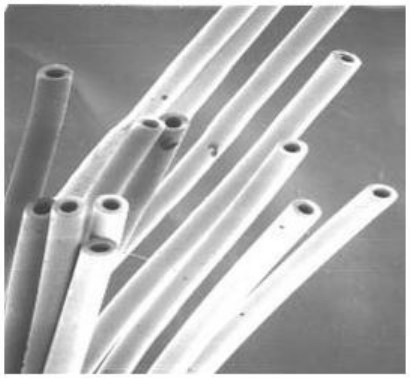
Cold Membrane Process Based on Hollow Fiber Membrane



- Key Parameters for cost effective membrane solution
  - High surface area/volume, good permeability, thin separating layer necessary for high productivity/bundle
  - High selectivity necessary to meet permeate purity specification at 90% CO_2 capture



>5X Surface area/volume compared to spiral membranes.

Cost effective solution at large scale application

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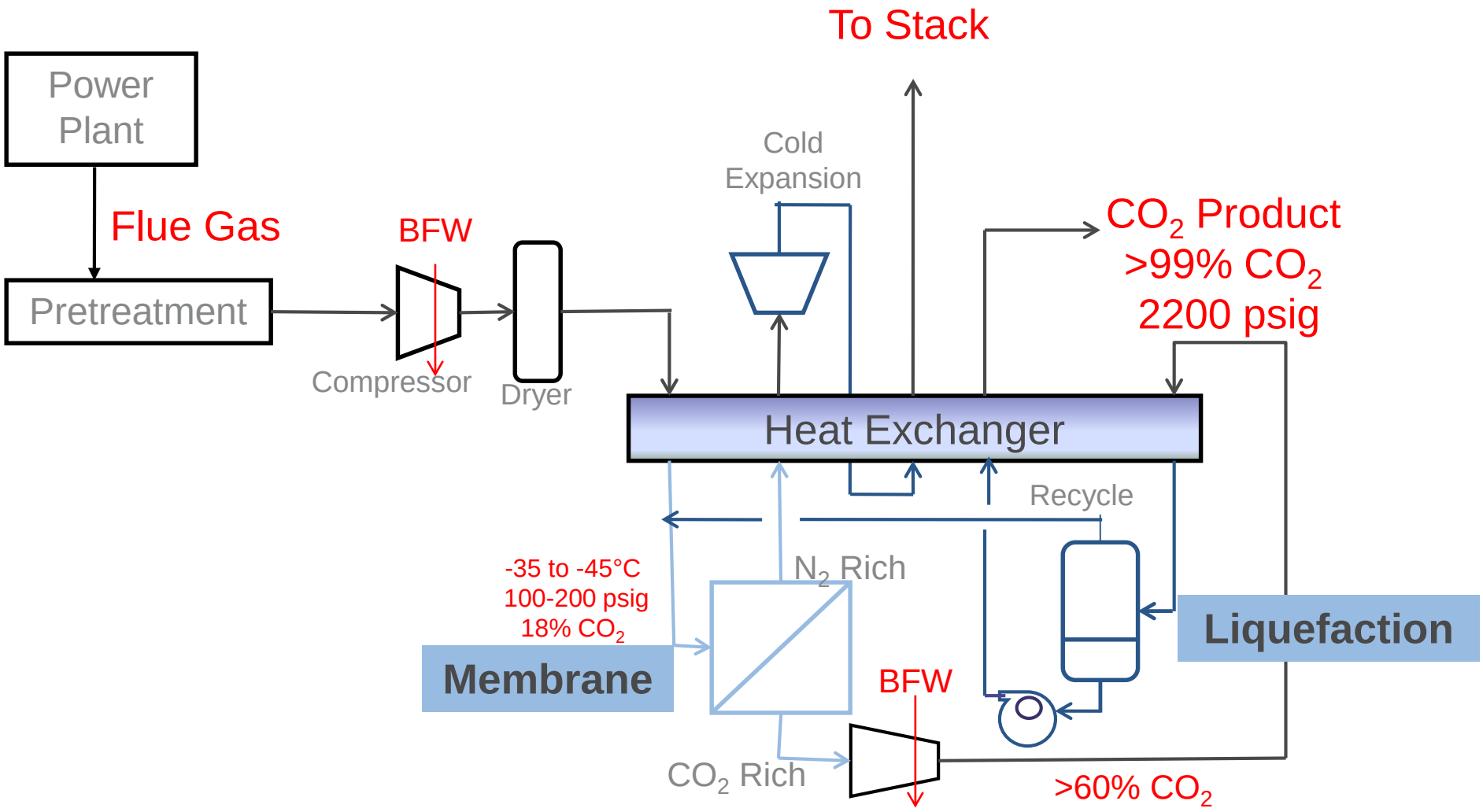
Hybrid Membrane + Liquefaction Configuration



All technology unit operations have now been demonstrated with real flue gas

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Project Overview

Main Tasks	Start	End	Milestones/ Success Criteria	Status
BUDGET PERIOD 1 (BP1) Oct 2013 to June 2015				
PI-1 Optimization & Testing	Oct 2013	March 2014	>30% improvement in bundle productivity	**COMPLETED**
PI-2 Bundle Preparation & Testing	Oct 2013	June 2015	4-5X projected bundle productivity compared to PI-1	**COMPLETED**
Design and fabrication of 0.3 MWe field test unit	Oct 2013	June 2015	Fabrication, installation, acceptance testing	**COMPLETED**
BUDGET PERIOD 2 (BP2) July 2015 to December 2016				
Field Test at NCCC	July 2015	August 2016	500 hours of steady state testing, parametric testing	**Partial Complete**
TEA	July 2015	Dec 2016	$40/tonne CO2 capture cost	**In Progress**
Preliminary design next phase	July 2015	July 2016	Preliminary design and costing of next phase	**In Progress**

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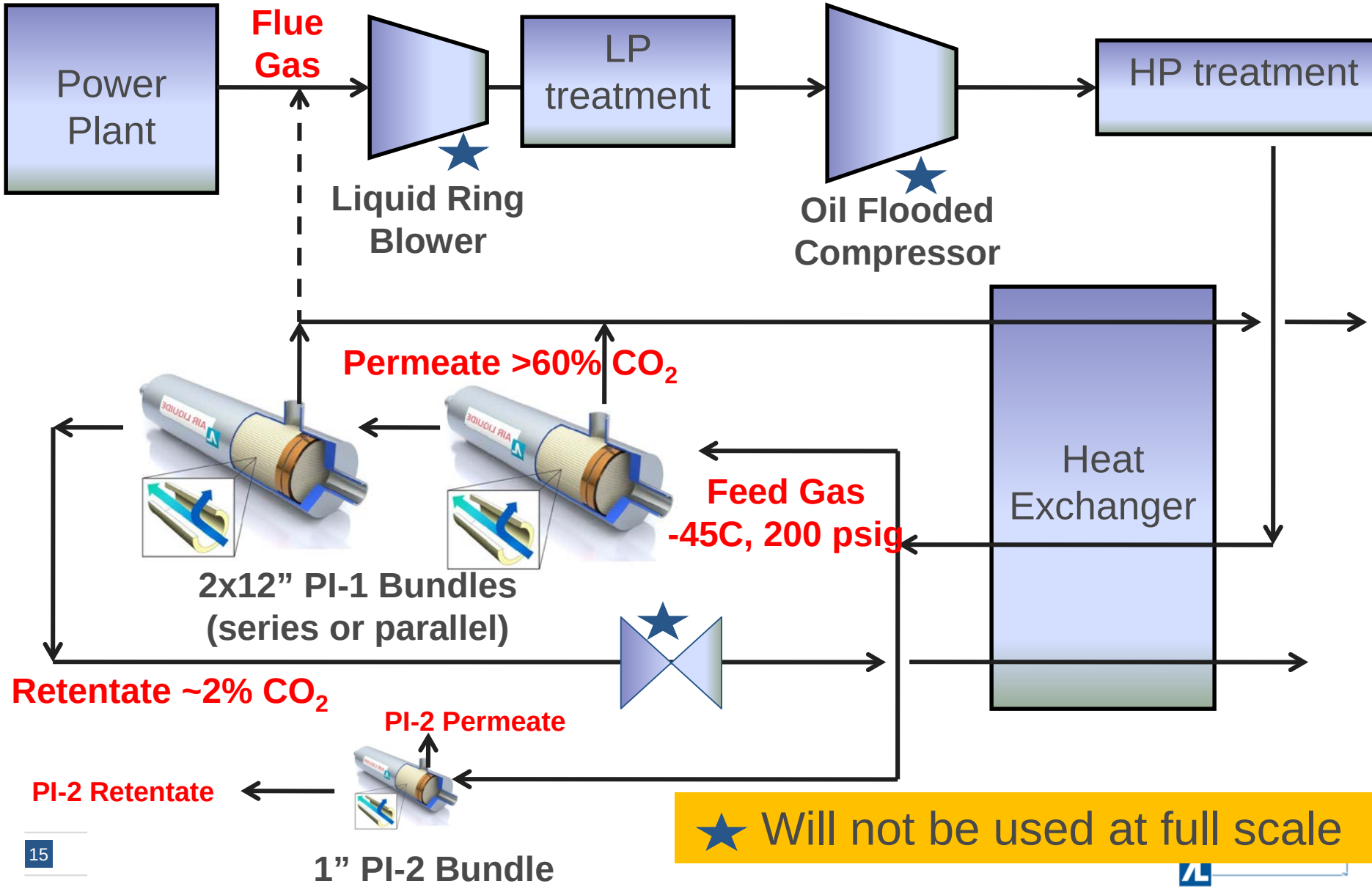
Development Spin Unit at MEDAL

- Development spin unit – representative of commercial spin line
  - Fabricated five 1” bundles in the current project (DE-FE0013163)
  - Will be used for fabricating larger bundles (4 – 6”) in the next project (DE-FE0026422)

Field Testing at NCCC

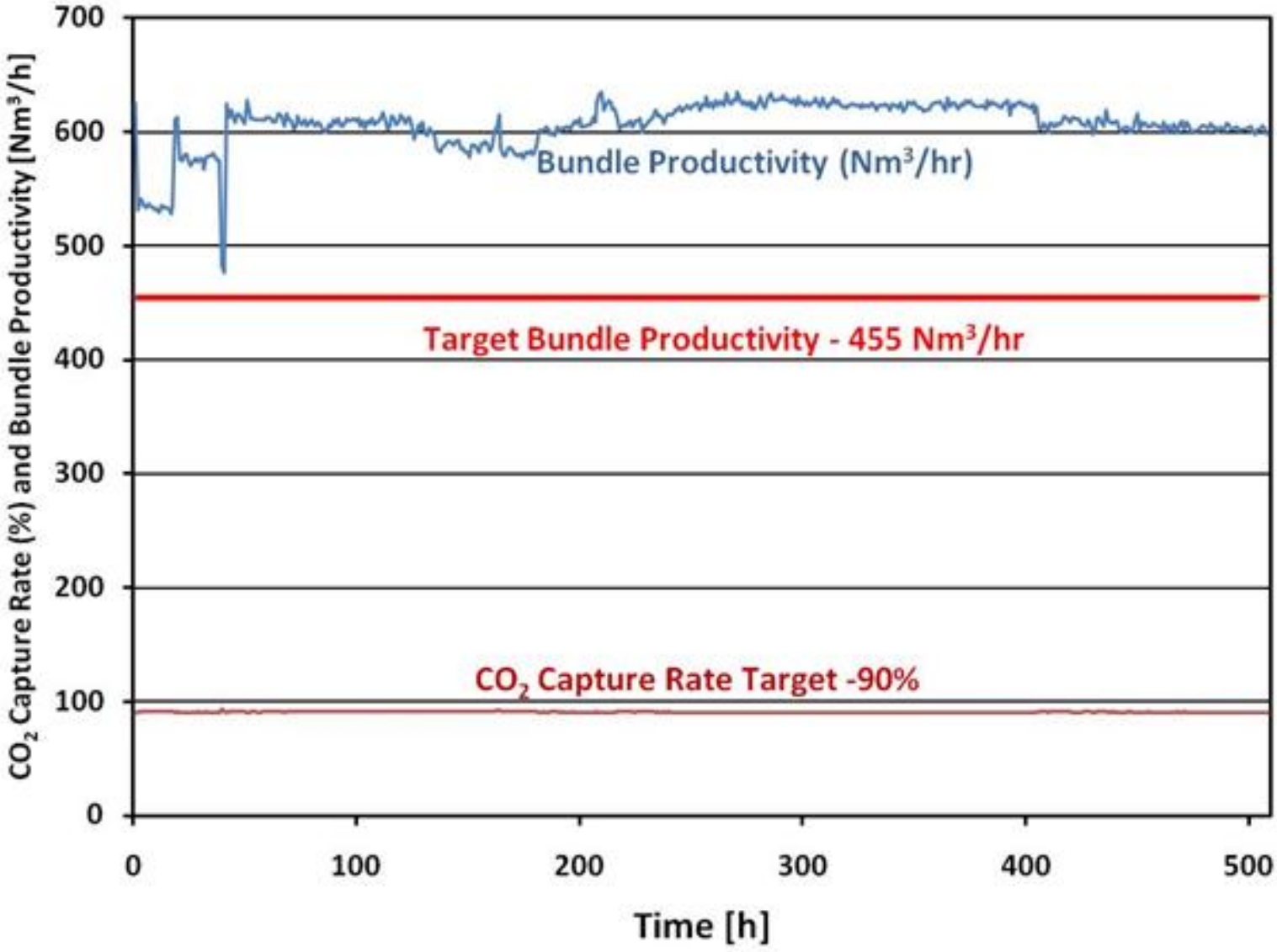
Process Flow Diagram - NCCC



Cold Membrane Skid at NCCC

Air Liquide TEAM AT NCCC

PI-1 Commercial Bundle at NCCC (Steady State 500 hours)



>30% increase than the previous baseline target – resulting in lower capital cost

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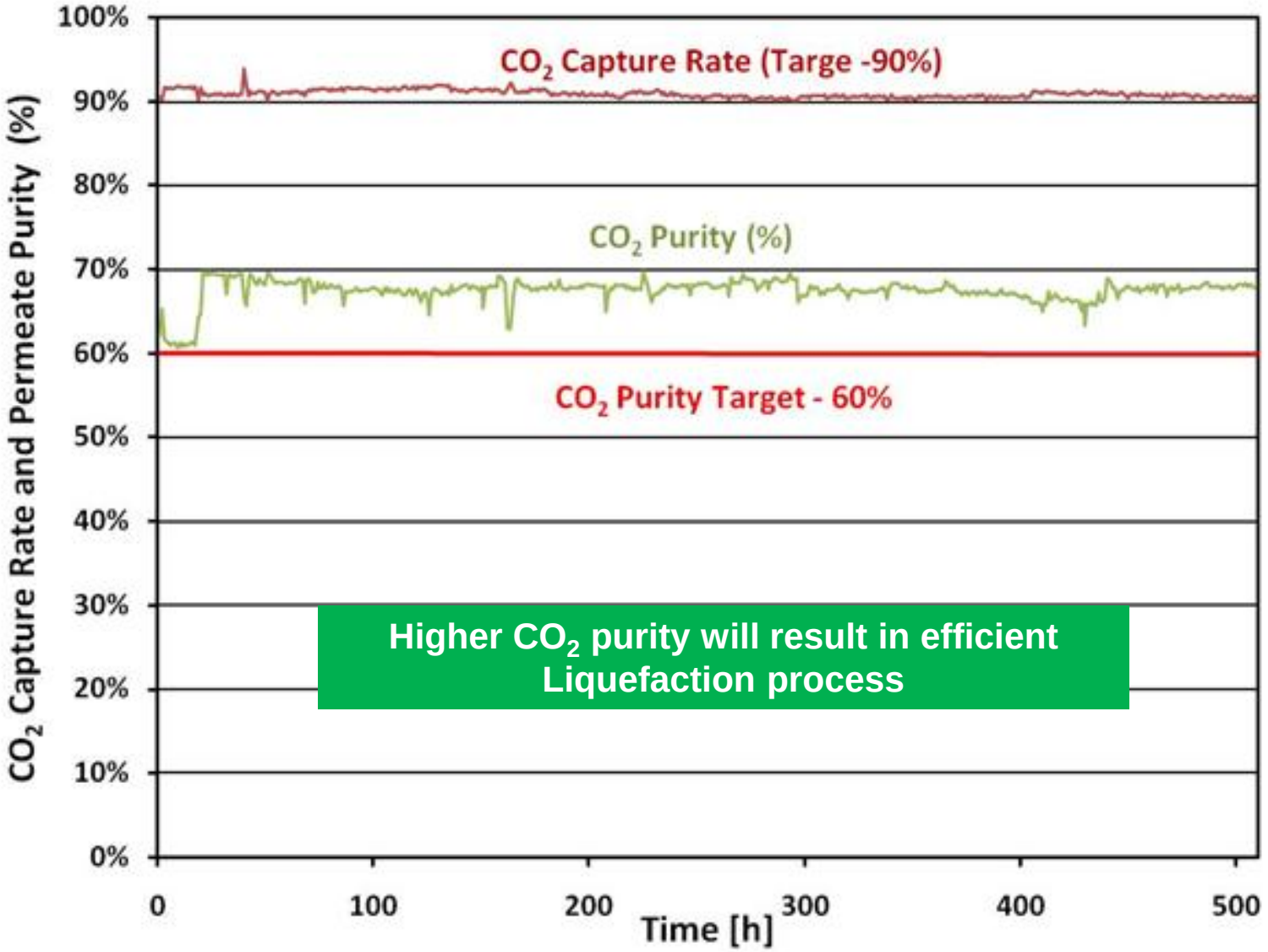
PI-1 Commercial Bundle at NCCC (Steady State 500 hours)



Higher CO_2 purity will result in efficient Liquefaction process

Successful Test Campaign (PO4)!
System running uninterrupted for 17 days

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NCCC - Bundle configurations test

6” versus 12” Bundle

	Capture Rate	Surface area (m^2)	# of Bundles	Bundle Installed Cost	Membrane Cost
12” Bundle	90%	3.7X	Y	2.4Z	2.4YZ
6” Bundle	90%	X	2.5Y	Z	2.5YZ

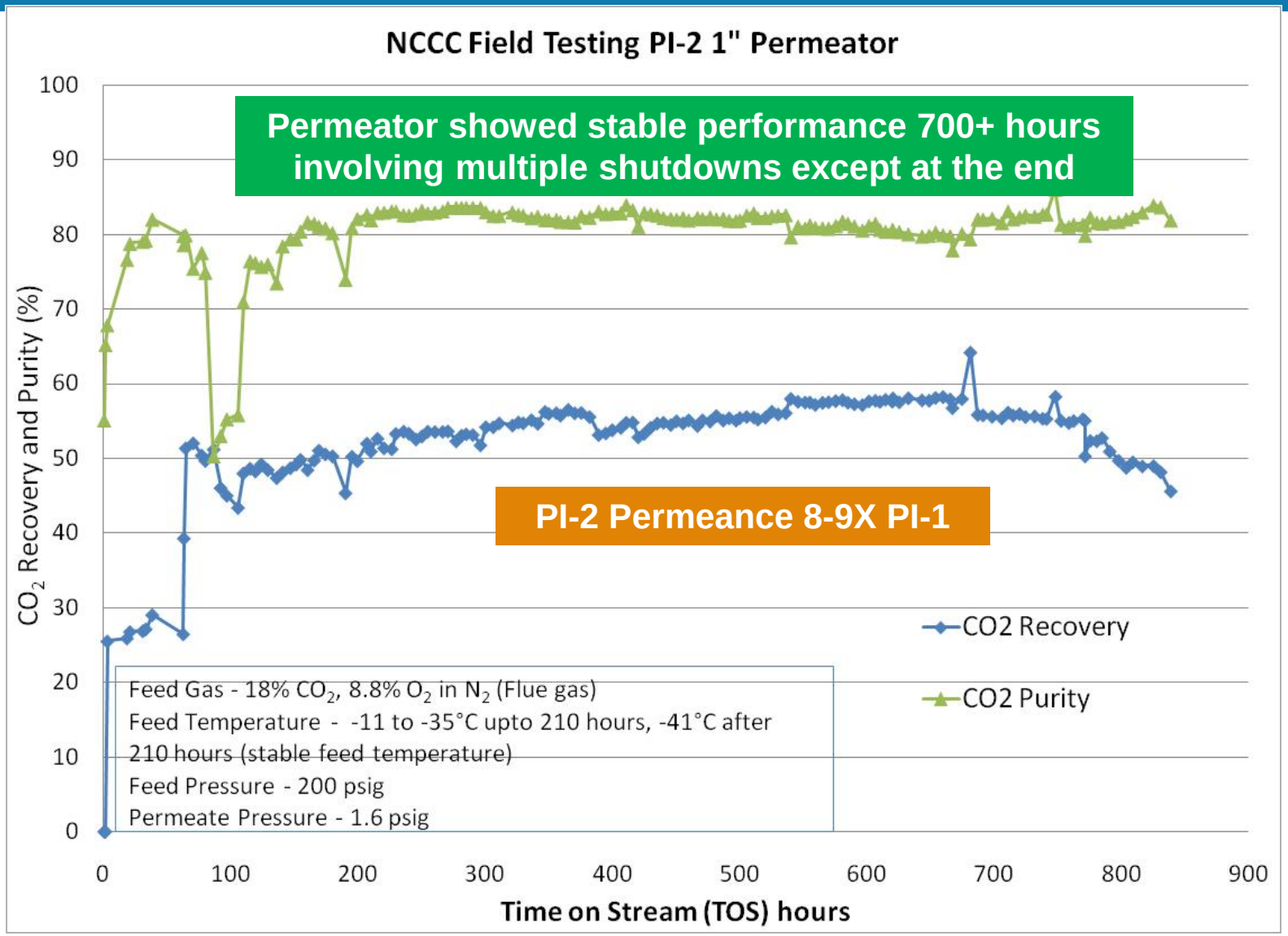
Flue gas (18% CO2) tested at -45°C, 200 psig feed pressure, 1.5 psig permeate pressure

System performance with 6” bundles is better than 12” bundles

Single Bundle versus Two Bundles in series

- Further tests ongoing to test different membrane configurations
  - Based on preliminary results single bundle looks favorable

PI-2 Next Gen Mini-Permeator Tested at NCCC



Permeance loss due to potential contamination towards the end of campaign

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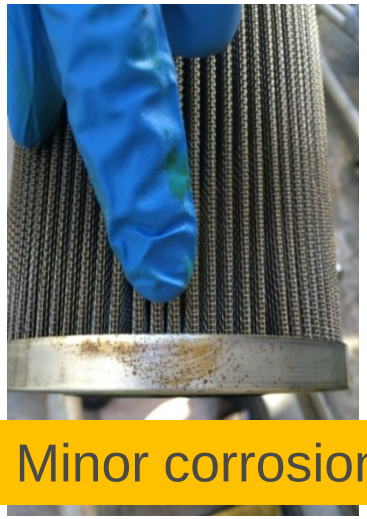
Field test challenges at NCCC

Oil "Flooded" Screw Compressor

- NOx reactions with oil – High acid number resulting in frequent change-out!



Minor corrosion!

Oil "free" compressor will be used for larger systems!

Issues with pre-treatment

- Potential contaminants reaching membrane – Oil, water
  - Decline in PI-1 and PI-2 bundle performance
- Change of adsorbents and Filter media

Oil in knock-out where flue gas exits

Detailed lessons learned list will be prepared and shared!

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Techno-Economic Analysis (TEA) Study

Techno-Economic Analysis (TEA)

- Goal - Carbon capture cost at 90% capture rate from commercial size power plant 550MWe (net) (~12,000 tpd) with EOR grade purity reaching $40/tonne by 2025
- Previous TEA used as basis - Process Updates (OPEX)
  - Air Liquide Engineering and Rotating machinery specialist input
  - Efficiency of rotating machinery updated based on vendor feedback
  - Line segments pressure drops were added
  - Waste heat from the capture process was integrated with power plant to generate Boiler Feed Water (BFW)
  - Motor losses, gear box losses and bearing losses were added
  - Membrane performance updated from field
- Carbon Capture energy consumption kWh/tonne
  - Increased from 255 kWh/tonne to 320-332 kWh/tonne

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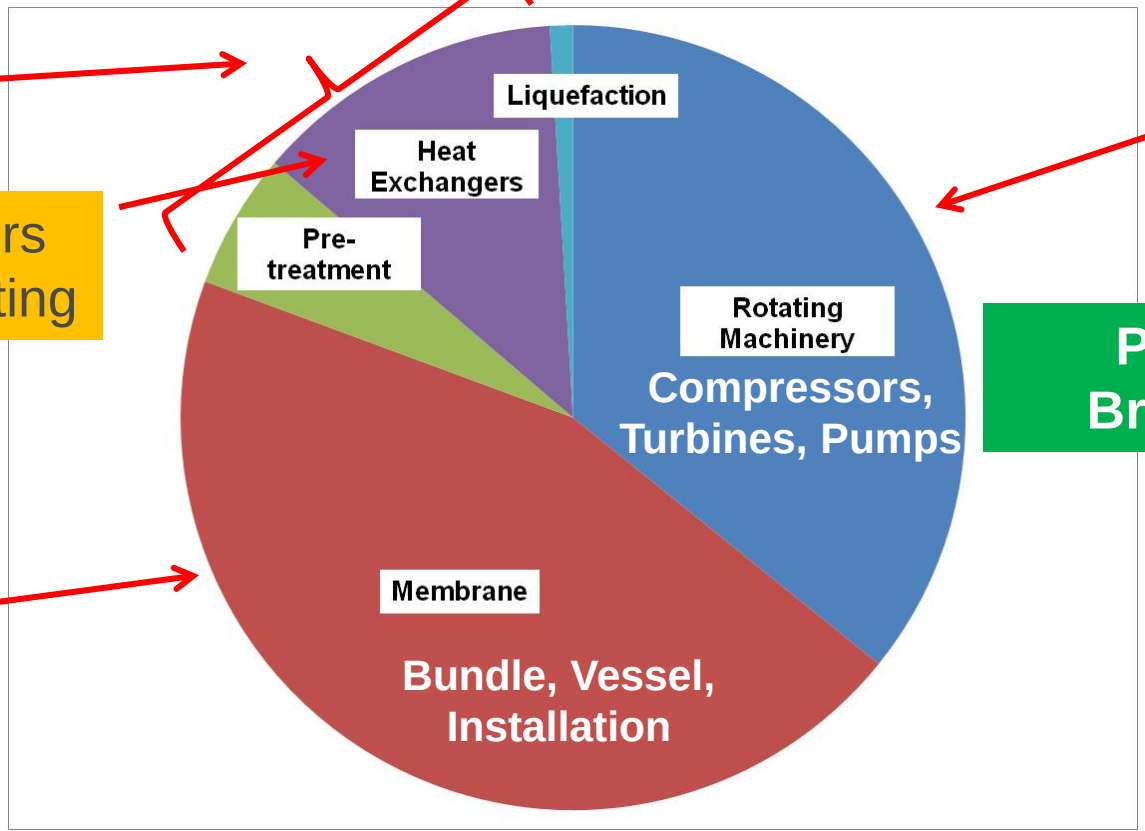
TEA Carbon Capture Capital Cost

- Equipment specific quotes in progress for 80% of cost
- Cost scaled for the rest of the equipments
- Substantial cost reduction by
  - Improved membrane performance
  - Low cost Dryer, Heat Exchangers (vetted by Air Liquide ASU)
  - Low cost Turbine/Compressor by reputable US supplier

Air Liquide Database

Quotes Received

Pending coolers design and costing



PI-1 Cost Breakdown

Quotes Received

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TEA Summary – Budgetary Estimation

	Case 12 (Amine)	2010, DE-FE0004278	12” PI-1 Bundle	6” PI-1 Bundle
		Previous Project	Current Project	
CO_2 Capture Energy Consumption KWh/tonne		255	320-332*	315-327*
Capture Cost FOAK (2011$/tonne CO_2)	56	46-52	42-48*	42-48*

**Preliminary – Pending Parsons validation and cooler design/costing*
Capture Cost +/- 20% on carbon capture cost, Energy Consumption +/-1.5% on rotating machinery

- Further Cost reduction possible
  - PI-2 (higher permeance bundles)
  - Nth of a kind estimate
    - Economy of scale for membrane bundles
  - Simpler pre-treatment

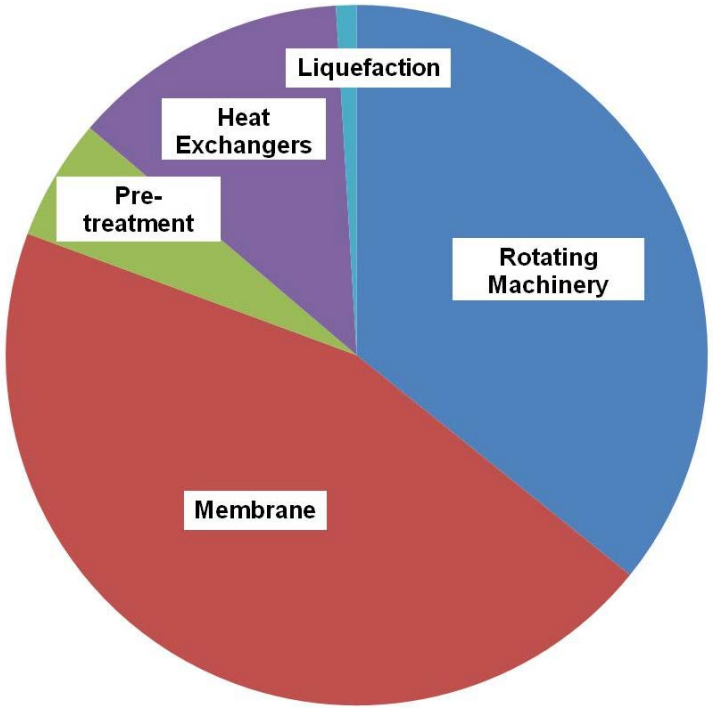
Next Phase Design and Cost

Cold Membrane Development Pathway – Next Phase Options

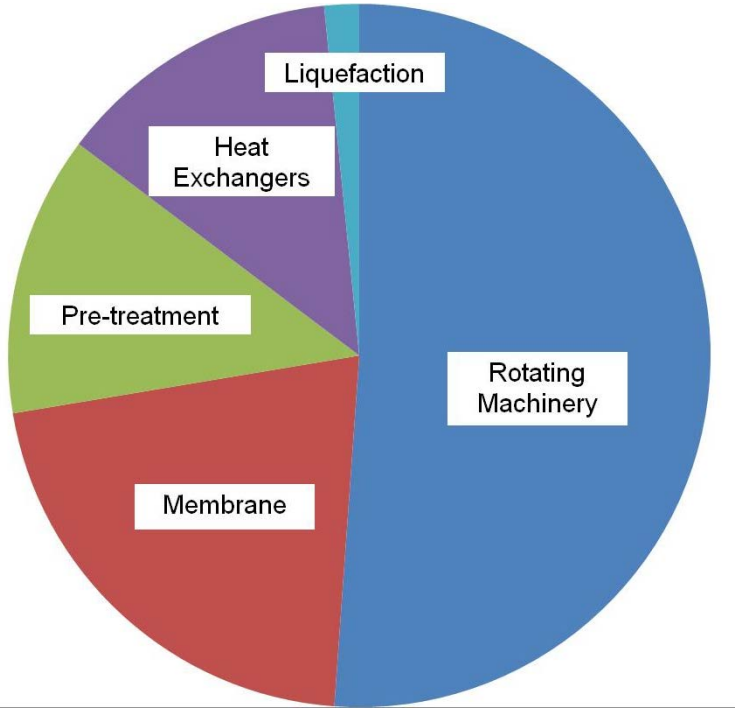
	Coal Fired Flue Gas	Industrial or NG fired flue gas
Source		
Justification	Driven by carbon capture for coal or local demand for CO_2	Driven by market needs for CO_2 and process integration
Commercial scale	~12,000 tpd	~50 – 1000 tpd
Proposed next phase	TRL 7 - 550 tpd (~25-30 MWe)	550 tpd or smaller
Status	• All major components tested at TRL 5-6 scale with flue gas • Preliminary design completed • Major equipment quotes received	Pre-treatment will be different based on source of gas

Capital Cost Breakdown

~12,000 tpd CO_2 plant (TEA Study)



550 tpd CO_2 plant (Next Phase Design Study)



Further membrane bundle cost reduction is essential for larger systems by manufacturing process optimization

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Next Steps

- 0.3 MWe Field testing at NCCC
  - PI-2 Bundle – 1” bundle (90% capture test)
  - Parametric test on PI-1 bundles
- TEA and EH&S analysis for CO_2 capture using cold membrane technology
  - Comparison between different membrane configurations
  - PI-1 versus PI-2 membrane material
- Complete design and cost of next phase of cold membrane technology

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