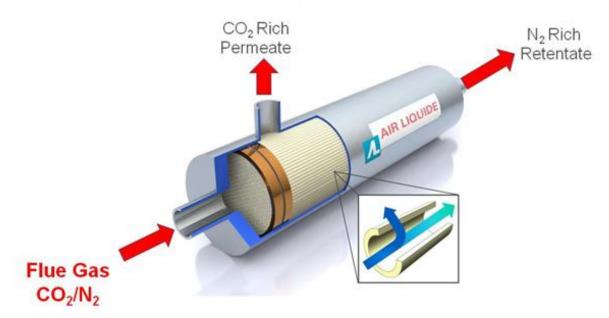


Bench Scale Testing of Next Generation Hollow Fiber Membrane Modules (DE-FE0026422)



Shilu Fu

Research Scientist shilu.fu@airliquide.com

Carbon Management Technology Conference 2017

Houston, TX

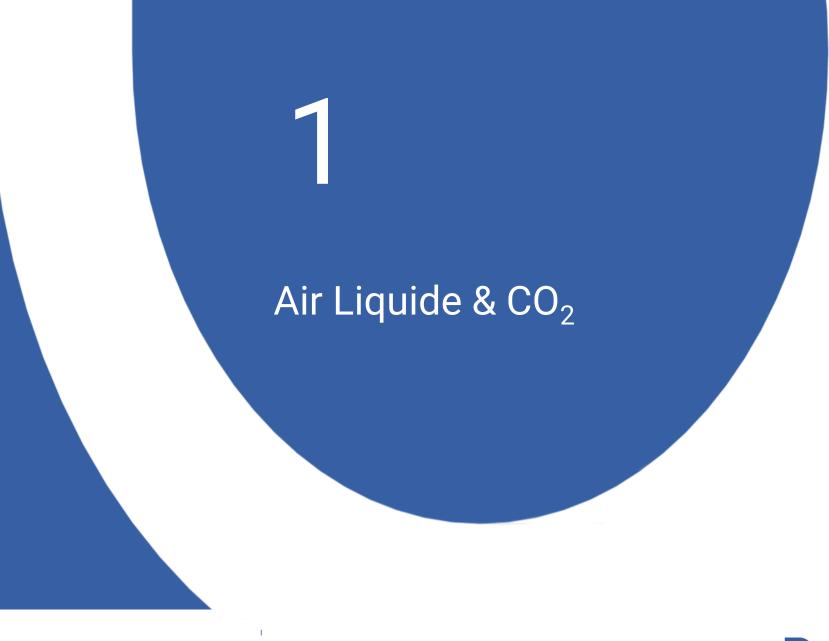
Agenda

1. Air Liquide & CO₂

2. Project Overview

3. Current Technology Status







Air Liquide & CO₂

Market position

- CO₂ as a product 24 CO₂ plants in US
- Huge potential market in EOR application

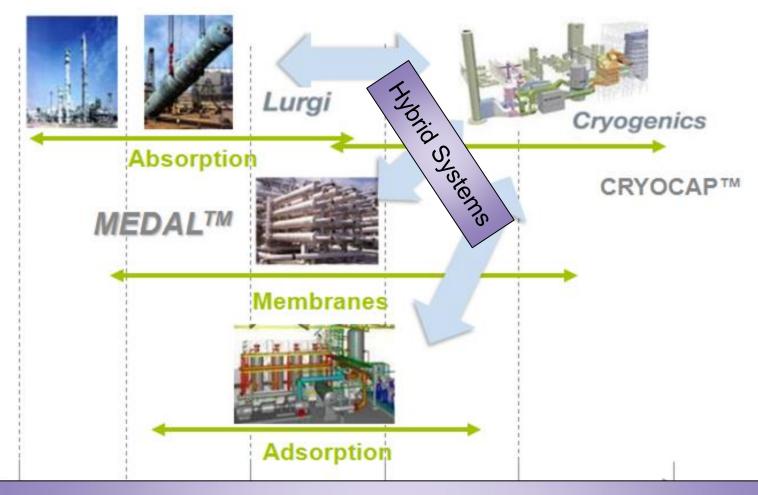
Air Liquide Cryocap™: new range of products for this market

- Cryocap™ H₂: CO₂ capture during Hydrogen production
- Cryocap[™] Oxy: CO₂ capture with Oxycombustion
- Cryocap™ NG: CO₂ capture from Natural Gas
- Cryocap™ Steel: CO₂ removal from Steel Production

provider



Air Liquide - CO₂ separation solution provider



Utilizing all existing techniques for the whole range of CO₂ feed and product purities from any CO₂ source

Large Air Liquide CO₂ Projects

TOTAL Lacq - FRANCE (2010) CO₂ Free Steam Generation

30 MWth oxy-combustion boiler apture & storage (rs, O₂, CO₂ dryer

Cold membrane project

Vilsonville, AL (2015)
National Carbon Capture Center

0.3 MWe PC air-combustion CO₂ separation and release *AL scope*: field test unit

FUTUREGEN 2.0 – USA

Clean coal power plant

~165 MWe Oxy-coal Power plant with CO₂ capture for CCS

AL scope: ASU_CPU& mixer

Torrens Island Power-AUSTRALIA (2017) CO2 Utilization

140TPD CO2 Capture from gas fired Turbine for Food and Beverage Industry

AL scope: ASU, CPU

AIR LIQUIDE Port-Jérôme, FR (2015)
Cryogenic CO2 capture on SMR H2
CO2 capture for liquid production
AL scope: investment including
CPU & Membrane

Oxycombustion for cement

Industrial Cement plant with CCS feasibility study AL scope: ASU & CPU study

ULCOS Florange - FRANCE Low CO2 Steelmaking

Industrial blast furnace with CO₂ capture & storage AL scope: ASU & CPU study

CIUDEN – SPAIN (2011/2012) Carbon Capture test facility

20 MWth PC & 30 MWth CFB oxy-combustion boilers AL scope: CPU ENDESA - SPAIN
Clean coal power plant

300 MWe Oxy-coal Power plant with CO₂ capture for CCS AL scope: ASU FEED

Callide Oxyfuel – AUSTRALIA (2012) Clean power pilot plant

30 MWe coal oxy-combustion boiler with CO₂ partial capture and storage

AL scope: ASU, CPU

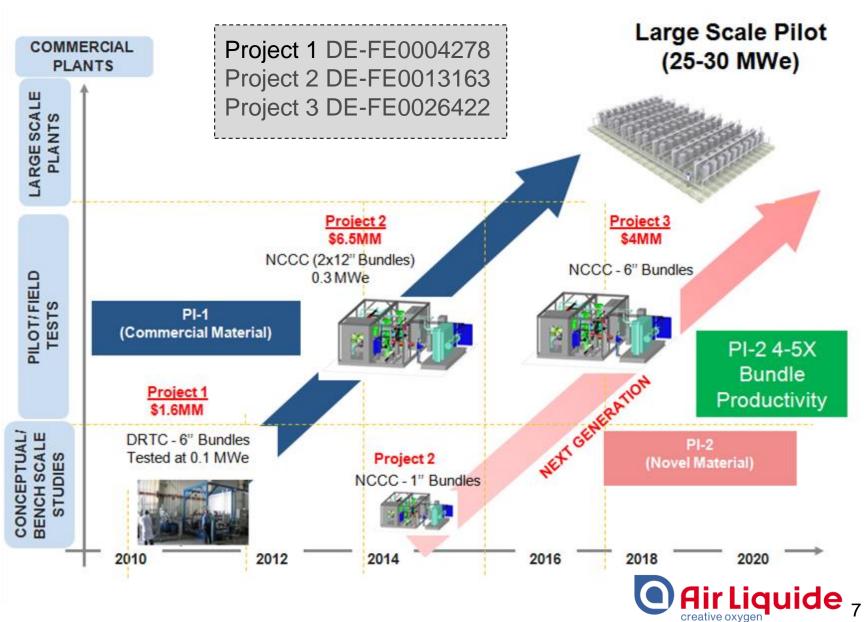
Power/steam

Industrial

R&D



Cold Membrane Technology Roadmap



Project Overview



Project Overview: CO₂ capture by cold membrane

Project target: CO₂ capture from coal fired power plant flue gas with AL cold membrane technology at \$40/tonne:

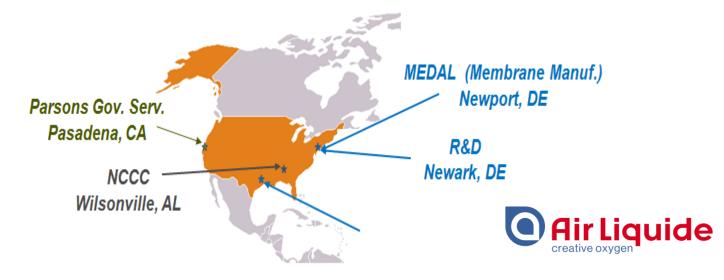
Total Budget: \$4.0MM, DOE Funding - \$3.0MM, AL Cost Shares - \$1.0MM *Period of Performance:* 10/01/2015 through 12/31/2018 over 2 budget periods

	Expenditures
Budget Period 1 (Oct 2015- June 2017)	\$1,600,000
Budget Period 2 (Jul 2017- Dec 2018)	\$2,370,000

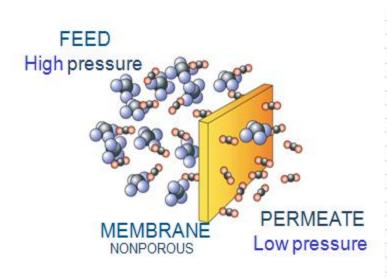
NETL Project Manager: José Figueroa

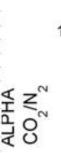
Project Partners: ALAS (membrane scale-up and manufacturing), NCCC (field

testing), E&C (engineering cost analysis), Parsons (TEA review)

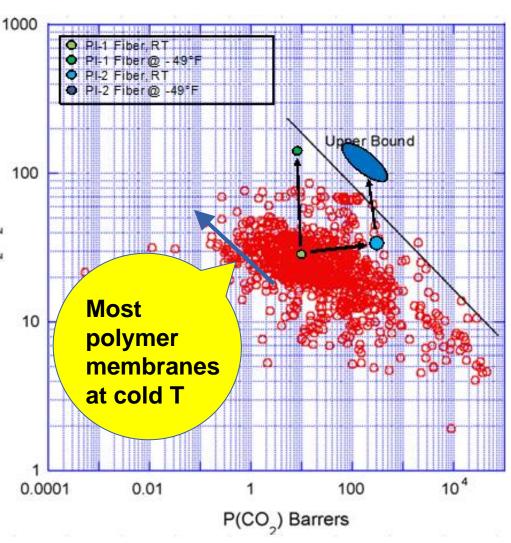


Motivation: Membrane? Why cold? Why PI-2





- Why cold? -- improve selectivity
- ★ Discovered by Air Liquide R&D in 2008: Improved CO₂ selectivity at T below ambient
- Why PI-2? -- improve productivity
- ★ 4-5 X higher CO₂ productivity





Air Liquide Capture Technology Summary

- Air liquide hybrid cold membrane liquefaction process
- Novel cold membrane technology
- Well established liquefaction



Synthetic flue gas at 0.1 MWe (TRL4) bench scale skid



Actual flue gas from coal fired power plant at 0.3 MWe (TRL5) field test unit at NCCC

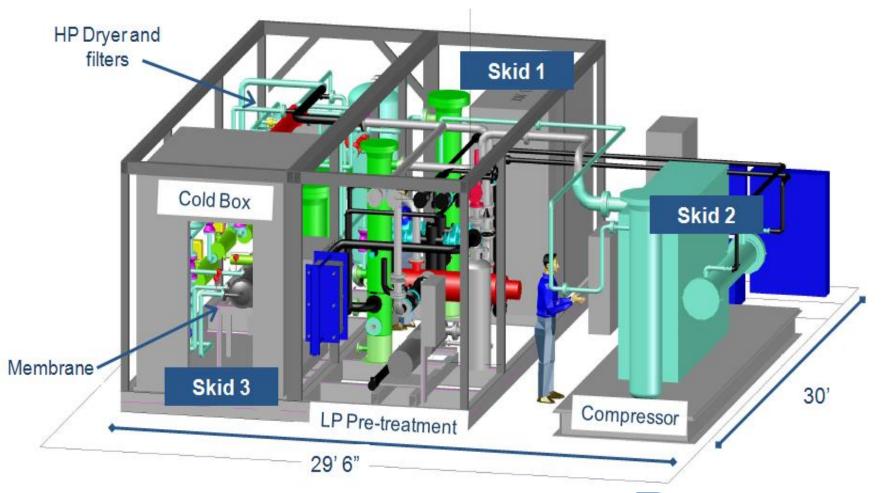
Synthetic flue gas testing

0.1MWe (TRL 4) bench scale skid



Actual flue gas testing at NCCC

0.3MWe (TRL 5) field test unit



Actual flue gas testing at NCCC

0.3MWe (TRL 5) field test unit



3

Current Technology Status



Membrane bundles - lab scale to commercial scale

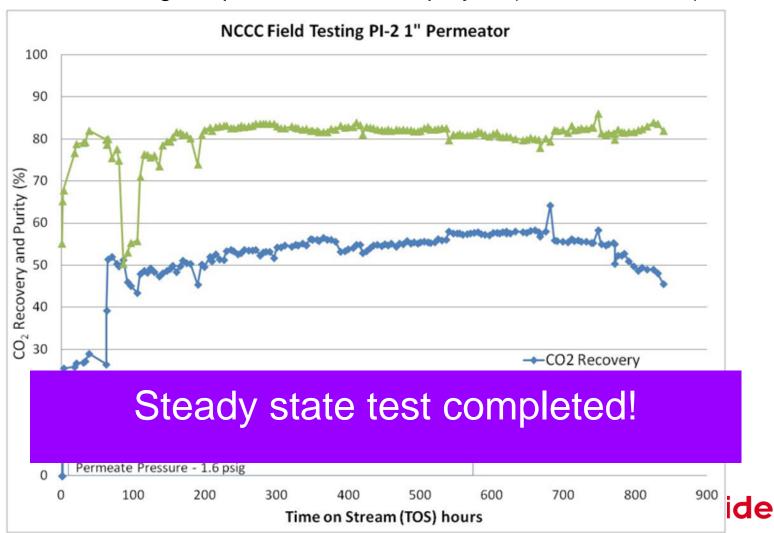
		Diameter in. (mm)	Length ft. (m)	Fiber Count	
Mi	ini permeator	0.25 - 0.5" (6.4 - 12.7)	0.5-2.8 (0.15085)	<1000	
	Permeator	1" (25.4)	1.6 (0.5)	2 – 20x	
	Prototype Permeator	2.5" (63.5)		10 – 100x	
R	&D prototype bundle	4" (101.6)	2.8 (0.85)	100 – 400x	
(0	6" bundle commercial)	6" (152.4)		200 - 1000x	
	12" bundle commercial)	12" (304.8)		500 - 4000x	





PI-2 1" mini permeator tested at NCCC (2016)

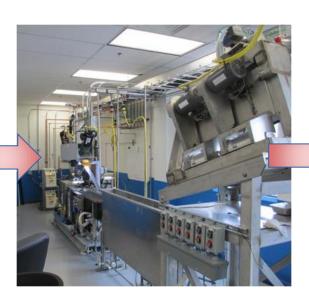
- ★ Testing for viability of PI-2 membrane in treated flue gas service
- ★ Tested during the previous DOE-AL project (DE-FE0013163)



Design/Manufacture 4" PI-2 Bundles (2017)







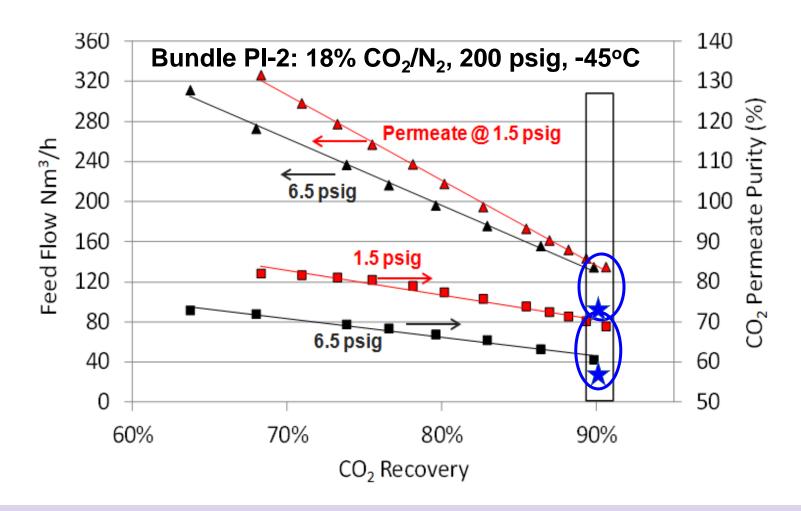
DSU unit Multi-filament spin line



Two prototype bundles

Development spin unit (DSU) - representative of commercial spin line

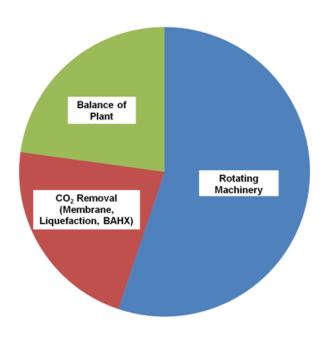
4" Bundles tested with synthetic flue gas



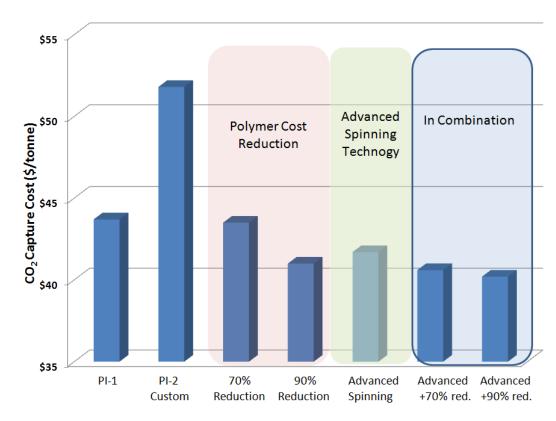
★ Exceeding the project target: > 90 Nm³/h feed at 90% CO₂ recovery, >58% CO₂ purity

Ongoing & future work

Reducing CO₂ capture cost with PI-2:



Projected 12" PI-2
bundle cost breakdown
(TEA study from Project 2)



- ★ Reduced costs moving from lab production to bulk production
- **★** Advanced vs. traditional membrane formation method

Ongoing & future work

Field test of 6" PI-2 bundle at NCCC



Summary

- ★ Air Liquide is utilizing all existing techniques for the whole range of CO₂ feed and product purities from any CO₂ source
- ★ Exceeding the project target: > 90 Nm³/h feed at 90% CO₂ recovery, >58% CO₂ purity
- ★ Getting ready for the 0.3 MWe field test of 6" PI-2 bundle



Acknowledgement / Disclaimer

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- NCCC: Frank Morton, Tony Wu
- Air Liquide: Rob Gagliano, Alex Augustine, Trapti Chaubey, Sudhir Kulkarni, Dave Hasse, Mike Bennett, Dean Kratzer, Jean-Marie Gauthier, Ted Li, Judy Huss, Randy Hutchison, Mike Turney
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