

Award: DE-FE0026422



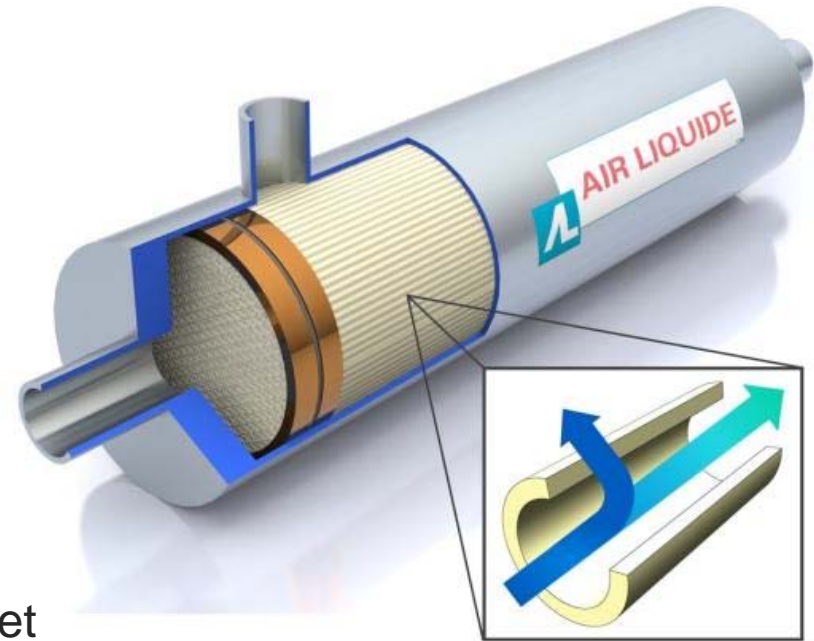
Project Kick-off: Bench Scale Testing of Next Generation Hollow Fiber Membrane Modules

November 6, 2015

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S. Kulkarni, E. Sanders, D. Kratzer, G. Gagliano | R&D
J.-M. Gautier | MEDAL**

Outline

- Air Liquide Overview
 - Background
 - PI-2 over the years
 - Cold membrane concept
 - Process & economics
 - Project details
 - Summary / Objectives
 - Schedule
 - Task summary
 - Discussion/thoughts
- Budget
 - Risks/Mitigation



Air Liquide: Key Information



A world leader in industrial and medical gases

> 50,000 employees

\$17.5 billion sales (2014)

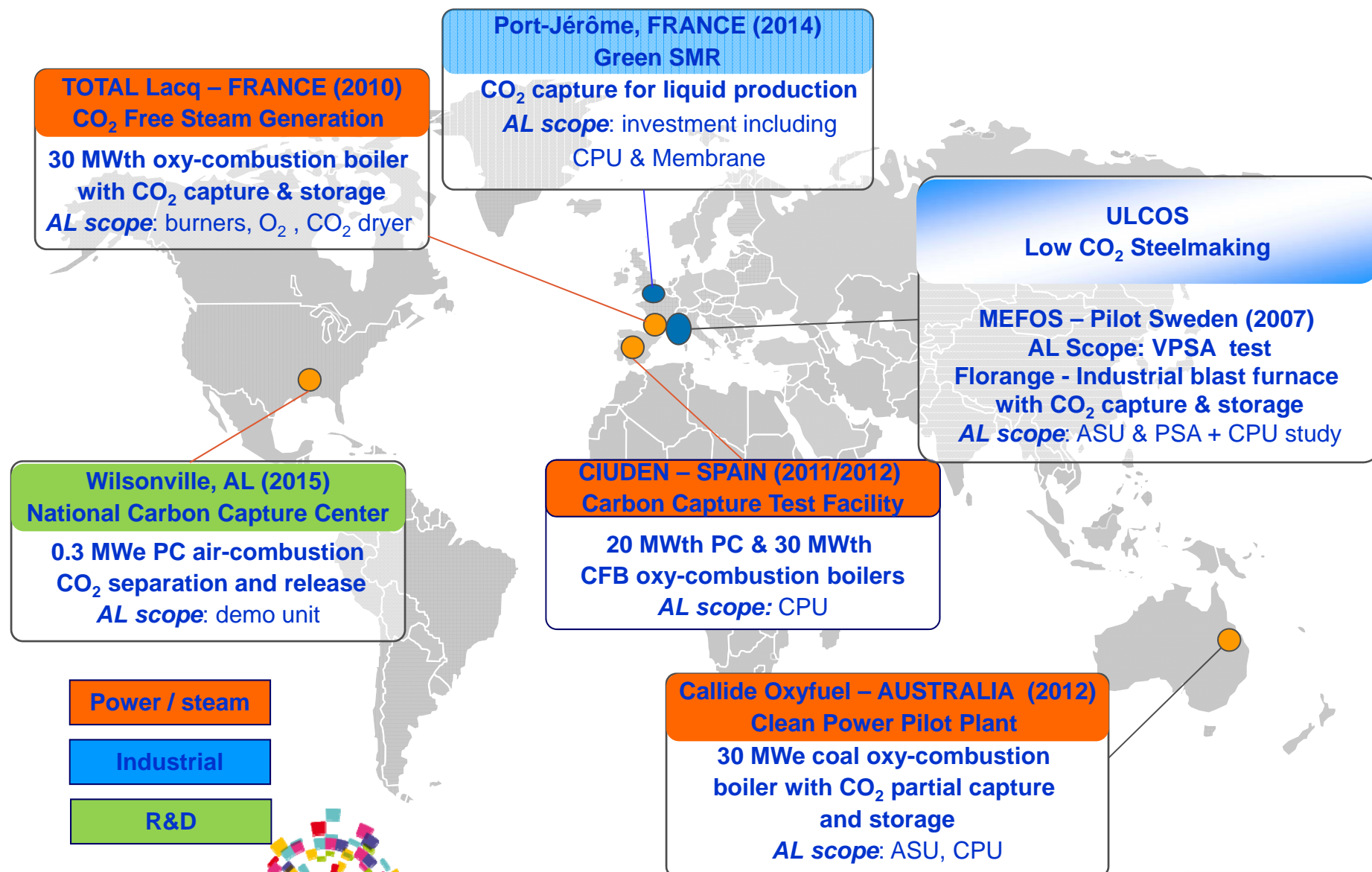


Proposed new technology develops upon AL strengths

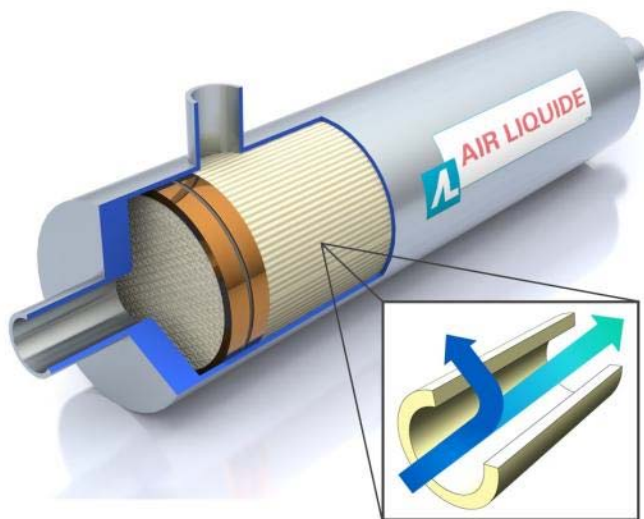
- Air Liquide core expertise in gas separation, cryogenics and gas handling
- MEDAL – Established membrane manufacturer for N₂ and CO₂ applications



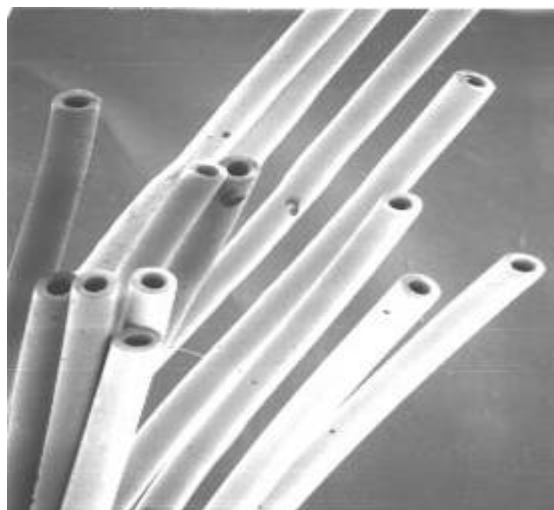
Air Liquide: CO₂ Capture Demonstration Projects



Air Liquide: MEDAL Membrane Manufacturing



- Membrane fiber and module manufacturing since 1988
- Over 20 engineered systems for CO₂ separation, largest up to 590,000 Nm³/h
- High surface area per volume (up to 13,000 m²/m³)
- Low cost (~\$20/m²)



Background/Previous Work

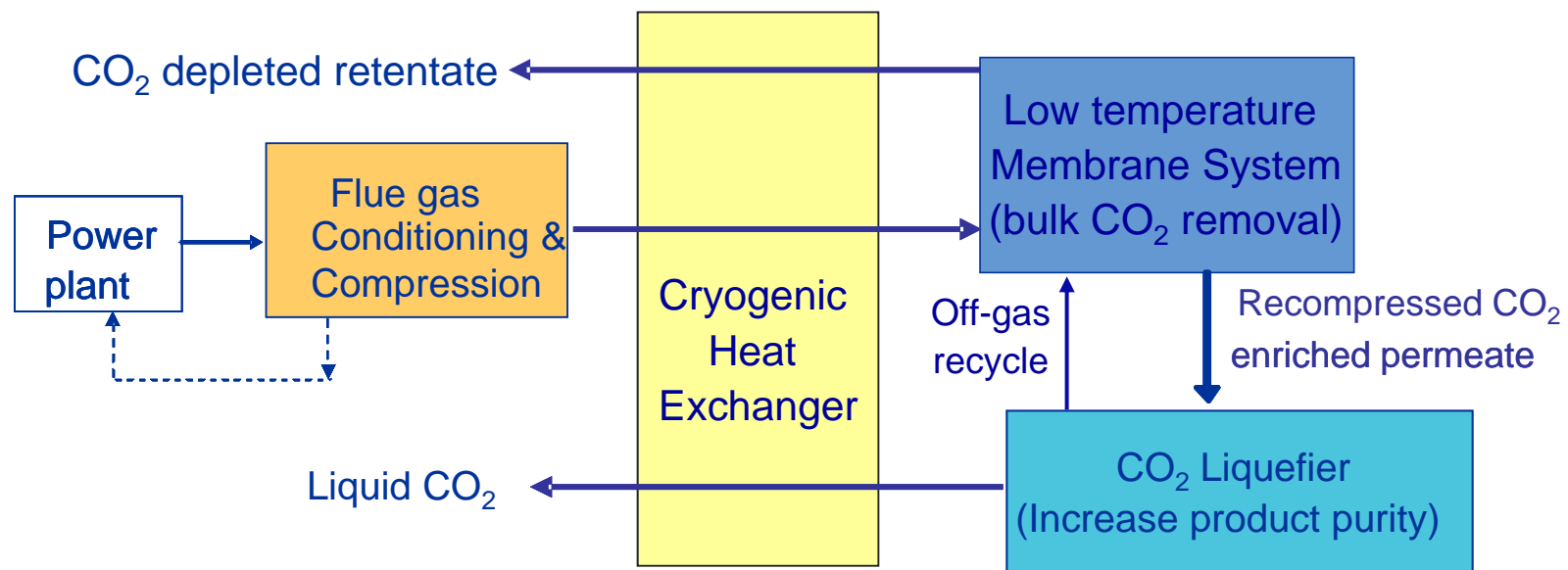
■ 2010 – 2012 DOE: DE-FE0004278

■ Cold membrane hybrid process

■ TRL 4 (PI-1)

■ Techno-economic analysis

- Energy recovery by turbo-expand and cold production
- Energy integration
- BFW generation
- Pumping liquid CO₂



Background/Previous Work

■ 2010 – 2012 DOE: DE-FE0004278

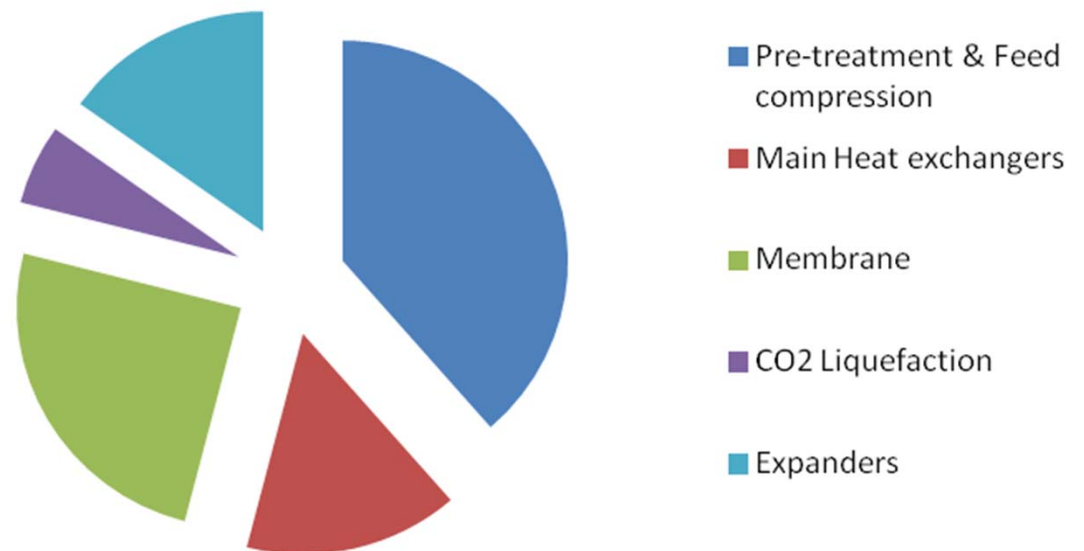
- Cold membrane hybrid process
- TRL 4 (PI-1)
- Techno-economic analysis

Projected CO₂ capture cost 46 -52\$/ton
(DOE Target – 40\$/ton of CO₂)

Areas of improvement:

- Reduce membrane cost –
improve membrane performance
- Reduce pre-treatment /
compression costs, **lower operating pressure**

Relative equipment costs



Background/Previous Work

■ 2013 – 2016 DOE: DE-FE0013163

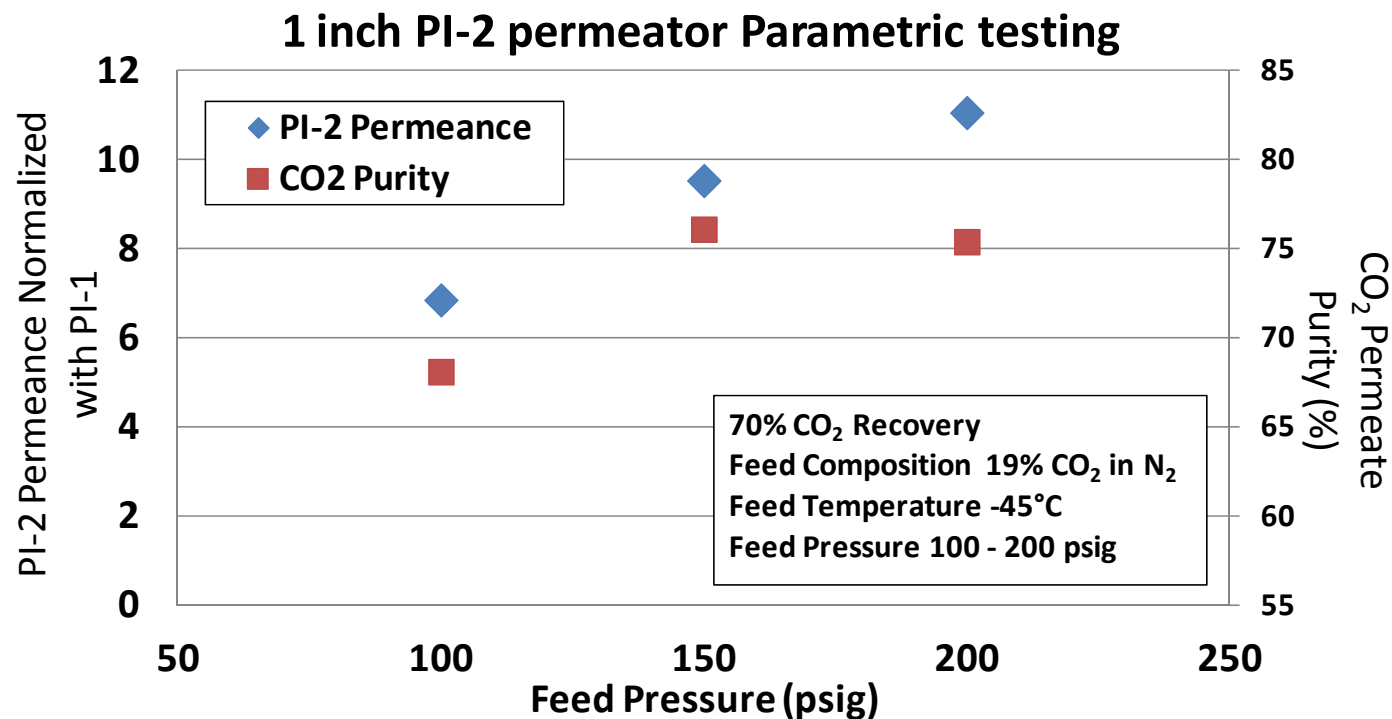
■ 1" PI-2 modules

■ 2x12" PI-1 bundles, real flue

■ TRL 5 (PI-1), TRL 4 (PI-2)

- Lab-scale spinning methodology

- 1" modules (500 fibers) achieving good performance



Background/Previous Work

- 2013 – 2016 DOE: DE-FE0013163

- 1" PI-2 modules (13 – 25 Nm³/h)

- 2x12" PI-1 bundles, real flue

- TRL 5 (PI-1), TRL 4 (PI-2)

- 0.3 MWe unit currently in commissioning at NCCC



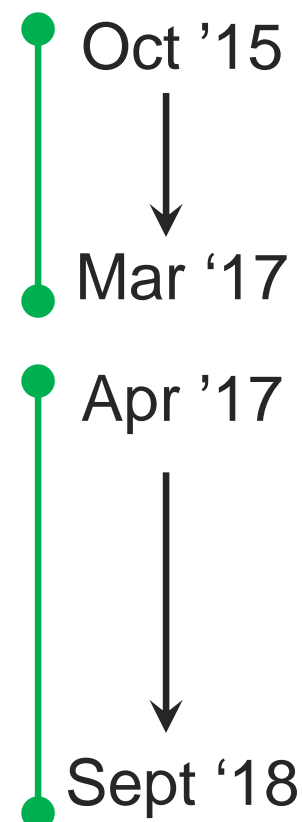
2015 – Current Project DE-FE0026422



Project Summary & Objectives

■ Objectives (Success Criteria):

- Design/manufacture 4" bundle(s) reaching >90 Nm³/h feed @ 90% CO₂ recovery, >58% CO₂ purity
- Identify other hybrid processes with possibility of economic feasibility
- Design/manufacture 6" bundle(s) reaching >400 Nm³/h feed @ 90% CO₂ recovery, >58% CO₂ purity (manufacture at least one 12" bundle)
- Field-test 6" bundles at 0.3 MWe scale with real flue gas at NCCC
- Techno-economic analysis achieving >90% CO₂ capture at a cost of electricity 30% less than DOE baseline



Total Budget - \$3.98 MM (25% cost share), 9.4 man-years total
Partners – DRTC, MEDAL, and Parsons



Project Schedule & Planning

ID	Task Name	Start	Finish	COST	2016				2017				2018					
					Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	
1																		
2	Task 1. Project Management and Planning	Thu 10/1/16	Sun 9/30/17	\$71,730														
7	Task 2. Prototype PI-2 Bundle Manuf Setup	Thu 10/1/16	Thu 3/31/17	\$100,667														
10	Task 3. Prototype PI-2 Bundle Prep and Testing with Sim Flue	Fri 1/1/16	Sat 12/31/16	\$321,667														
15	Task 4. Commercial PI-2 Bundle Preparation (6")	Fri 7/1/16	Fri 3/31/17	\$163,667														
18	Task 5. Acid Gas Contaminant Testing	Sat 10/1/16	Fri 3/31/17	\$10,000														
19	Task 6. Hybrid Process Analysis for CO2 Capture	Fri 7/1/16	Fri 3/31/17	\$30,000														
20	Task 7. 0.3 MWe Field Test Unit Safety Review	Sat 10/1/16	Fri 3/31/17	\$25,000														
21	BUDGET PERIOD 2	Sat 4/1/17	Sun 9/30/18															
22	Task 8. Commercial PI-2 Bundle Testing	Sat 4/1/17	Fri 12/29/17	\$595,500														
27	Task 9. Cold Membrane Field Testing	Sat 4/1/17	Sun 9/30/17	\$559,770														
34	Task 10 Techno-Economic Analysis	Sat 4/1/17	Sun 9/30/17	\$127,394														
40	Task 11 EH&S analysis	Sun 4/2/18	Sun 9/30/18	\$20,000														



Project Milestones

BP #	Expected	Milestone
BP1	03-31-2016	Milestone C. Complete prototype manufacturing setup and initiate 4" bundle fabrication
	12-31-2016	Milestone D. Complete prototype bundle testing: >90 Nm ³ /hr productivity @ 18%CO ₂ , 16 bar, 90% CO ₂ recovery, and >58% CO ₂ permeate composition
	03-31-2017	Milestone E. Complete verification of PI-2 flue gas contaminant testing
	03-31-2017	Milestone F. Complete hybrid process analysis comparing different applicable process schemes
GO/NO-GO Decision		
BP2	03-31-2018	Milestone G. Complete PI-2 commercial bundle fabrication and testing: >400 Nm ³ /h productivity @18%CO ₂ , 16 bar, 90% CO ₂ recovery, and >58% CO ₂ permeate composition
	01-31-2018*	Milestone H. Complete installation and commissioning of the 0.3 MWe field-test unit at NCCC
	09-30-2018*	Milestone I. Complete 0.3 MWe field-testing including parametric testing and at least 500 hours for one membrane
	09-30-2018*	Milestone J. Techno-economic analysis of CO ₂ capture at 550 MWe net AFPC plant using cold membrane technology
	09-30-2018*	Milestone K. Environmental, Health, and Safety analysis of cold membrane technology at full scale

*contingent upon host-site availability



Budget Projection

	Budget Period 1 (Oct 2015 – Mar 2017)		Budget Period 2 (Apr 2017 – Sept 2018)		Total
	DOE Share	Cost Share	DOE Share	Cost Share	
Air Liquide R&D	\$1,434,244	\$358,561	\$1,394,312	\$599,279	\$3,786,396
MEDAL	\$52,000	\$13,000	\$24,000	\$6,000	\$95,000
Parsons			\$95,444		\$95,444
Total	\$1,486,244	\$371,561	\$1,513,756	\$605,279	\$3,976,840
Cost Share	80%	20%	71%	29%	

Budget was modified following discussions with DOE:

- + FTU Decommissioning (\$42,000)
- + Final BP2 meeting (\$1,485)

AL agreed to cover cost adders such that DOE cost share was not impacted



Project Risks / Mitigation Strategies

	Project Risks	Mitigation Strategy
1.	MEDAL resource availability due to shutdowns or production quotas	Construction of a dedicated spin line for fiber production
2.	Small scale custom polymer quality may be non-uniform	Development of good specifications and communication with vendors
3.	High cost of custom polymer synthesis	Multiple suppliers will be approached and evaluated
4.	Bundle non-ideality flow effects may be more significant with higher productivity fiber	Employ learning from previous CFD work
5.	Field-test equipment corrosion/failure during storage	Adherence to equipment storage recommendations by manufacturers
6.	Field-test schedule relying on NCCC availability	Frequent communication and coordination



Task 1. Project Management

- Maintain updated Project Management Plan, Statement of Project Objective, and Budget files
- Periodic project updates to DOE Project manager – **José Figueroa**
- Monthly invoicing
- Quarterly progress reports
- Present results to partners and public:
 - NCCC bi-annual review
 - CO₂ capture conferences
 - One external conference (probably NAMS)



Task 2. PI-2 Manufacturing Setup

■ Development Spin Unit

- Construction currently proceeding, ready January 2015!



- Start spinning for project February 2016

- 10+ spins by June

■ PI-2 polymer procurement

- ~30 lbs needed during 2016

- Established vendor – 5 lb batches @ Initial cost

- New vendor – in discussions, 5 lb batches @ 77% cost reduction

- Develop more suppliers



Tasks 3 - 4. PI-2 Bundle Preparation & Testing

■ Task 3. Prototype bundles (4")

■ Polymer specification development: MW, solubility, stability

■ Fiber manufacturing development

■ Qualify on air

■ Fabricate \longleftrightarrow $\xrightarrow[\text{x10}]{\text{Iterative}}$ \longrightarrow ■ CO₂/N₂ at sub-ambient

Performance Target:
>58% CO₂ purity @ 90% recovery, 90 Nm³/h feed (18% CO₂)

■ Task 4. One commercial bundle (6") – on manufacturing spin-line

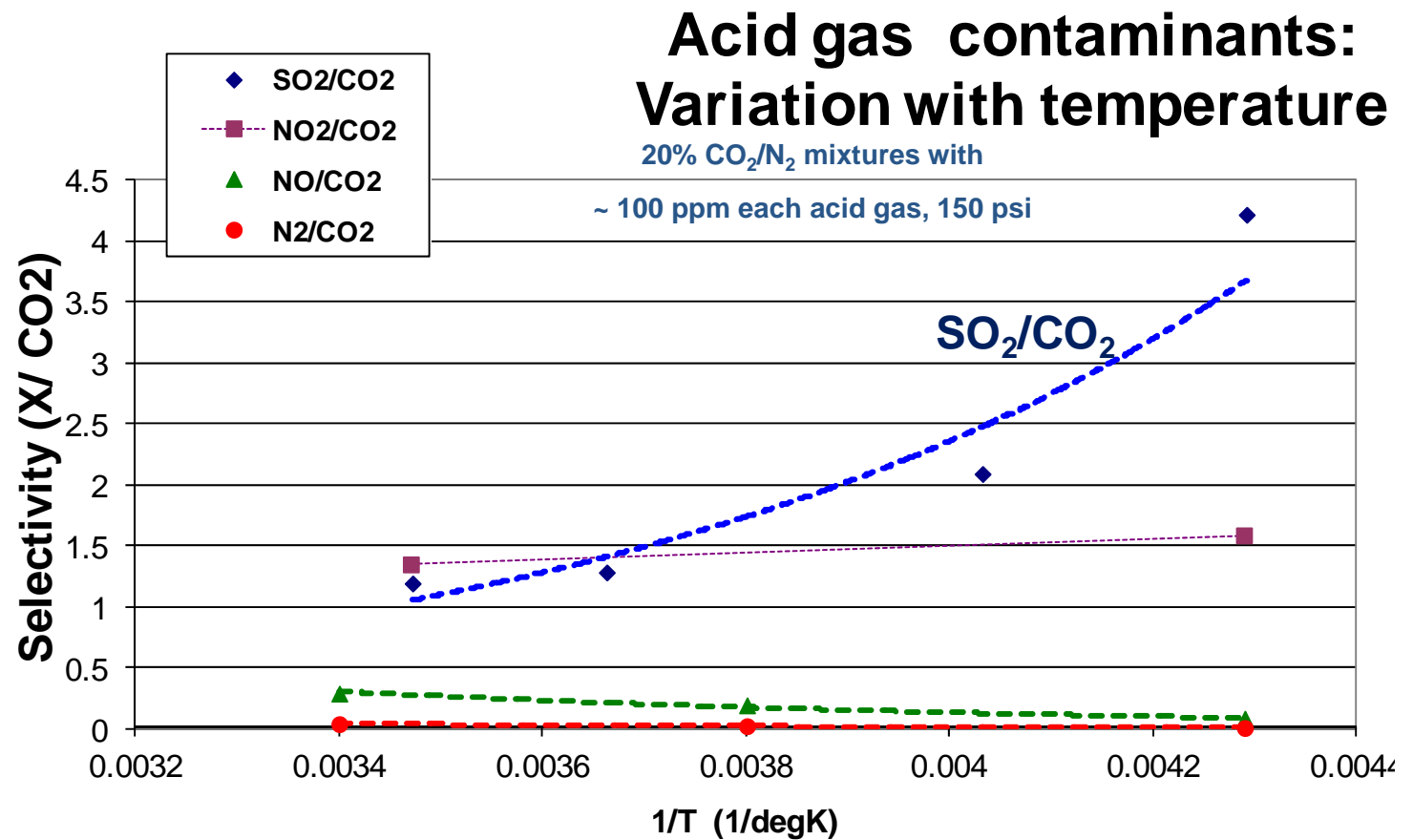
■ Fabricate \longrightarrow $\xrightarrow{\text{Just 1}}$ ■ Qualify on air

■ SF₆ leak test



Task 5. Acid Gas Contamination Testing

- Tolerance to NO_x and SO_x
 - Mini-permeators in lab setup
 - NO , NO_2 , and SO_2 (100 ppmv)



Task 6. Hybrid Process Analysis Using Cold Membranes

Standard Scheme Modifications:

- BFW vs energy recovery
- Lower operating pressure



Modify existing model



Feedback/brainstorming
by E&C and team



Options for TEA

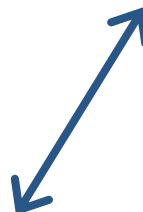


Hybrid Schemes:

- Lower membrane recovery with PSA
- Couple to NGCC system



Basic engineering design
via HYSYS (new model)



Task 7. Field Test Unit Safety Review & Prep

■ Overhaul 0.3 MWe Field-Test Unit

- Equipment storage
- Detailed design for new location (at NCCC) foundation, piping, electrical, etc.
- Revise HAZOP documents if necessary



BUDGET PERIOD 2

Apr 2017 – Oct 2018 (18 months)



Task 8. PI-2 Bundle Preparation & Testing (6 - 12")

MEDAL production floor (36-hole unit)



- Manufacture 3 – 5 bundles (6")
 - Fiber consistency?
 - Damage from handling?
 - Manufacture at least one 12" bundle
- Iterative*
- Qualify on air
 - CO₂/N₂ at sub-ambient



Task 9. Cold Membrane Field Testing

- Minor changes to equipment, replacement of any corroded or worn parts
- Detailed engineering design for installation
- Transport, installation & commissioning
- Field-test with 6" bundles
- Decommissioning & transport



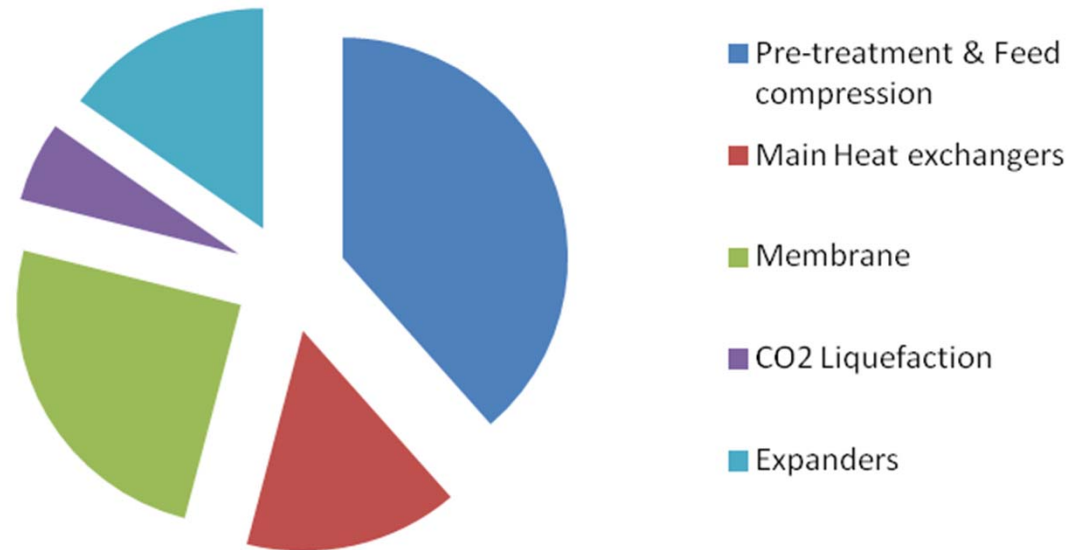
0.3 MWe Field-Test Unit at NCCC, Pilot Bay 3
(DE-FE0013163)



Task 10 - 11. TEA and EH&S

- Equipment cost estimates
 - Impact of reduced membrane size/cost
 - Alternate process configurations
- Process simulation (OPEX)
 - Impact of improved membrane performance
 - Energy management/efficiency
- Validation by Parsons
- Environmental, Health, and Safety impacts from proposed tech

Relative equipment costs



TEA Conclusions
(DE-FE0004278)



Progress To-Date

- Award documents signed: SOPO, Class Pat. Waiver
- Internal project kick-off meeting
- Visited NCCC for field-test unit scheduling
 - Tentatively scheduled for Sept-2017, targeting PO8 campaign
 - Use of same Pilot Bay 3 simplifies installation
 - Project schedule subject to NCCC field testing availability
- Multiple quotes for 15 gal mixer (large polymer dope batches)
- Preliminary lab work towards fiber manufacturing methodology



Acknowledgements

- US DOE: José Figueroa, Sheldon Funk
- NCCC: Frank Morton, Tony Wu
- Parsons: Mark Breor, Brad Knutson
- Air Liquide: Rob Gagliano, Sudhir Kulkarni, Trapti Chaubey, Ed Sanders, Dave Hasse, Dean Kratzer, Dave Edwards, Jean-Marie Gautier
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