



Hydrogen Production through SMR with CCS

2021 ARPA-E Methane Pyrolysis Annual
Program Review Virtual Meeting

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January 12, 2021

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Agenda

- 1 Air Liquide and CCS
- 2 SMR with CCS Options
- 3 Port-Jerome Demonstration
- 4 Hybrid Technologies



Air Liquide and CCS

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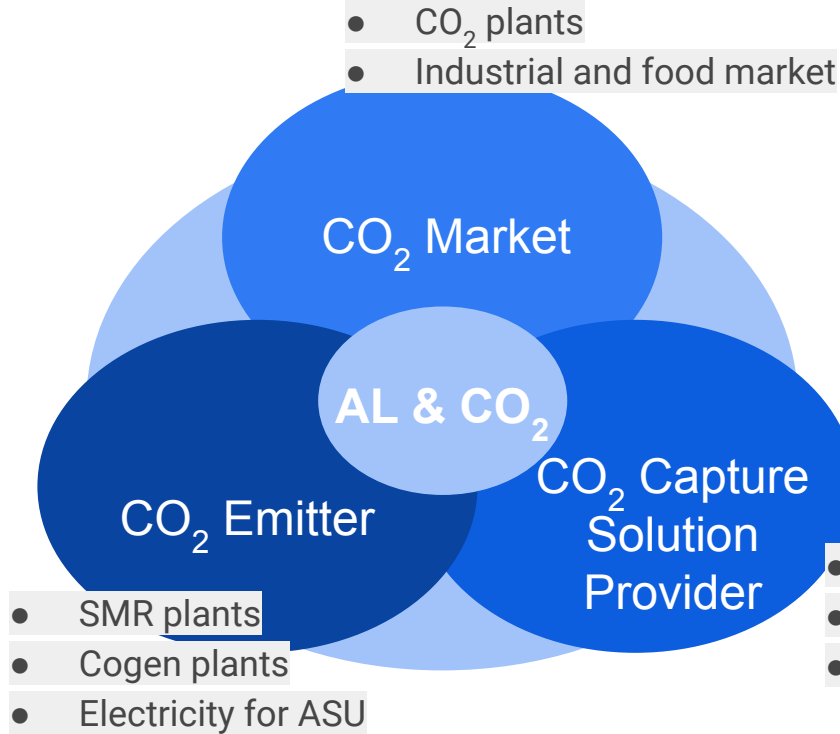
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Air Liquide and CCS



Committed to reducing carbon intensity by 30% by 2025

SMR with CCS Options

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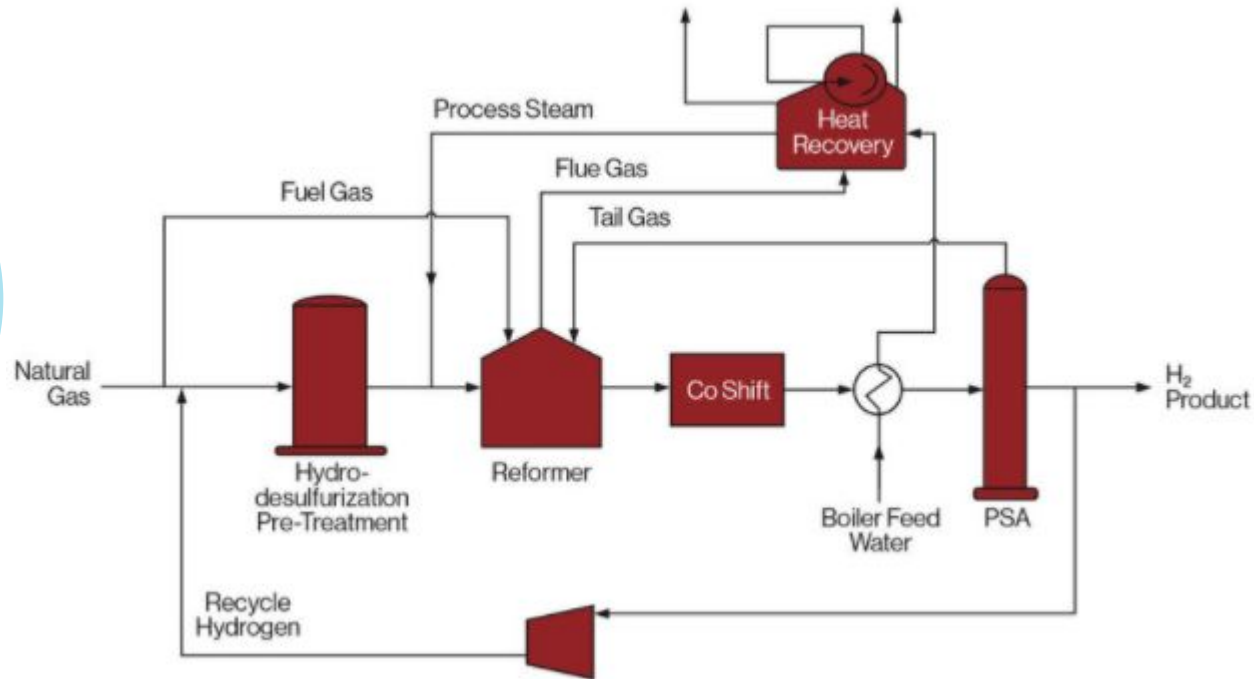
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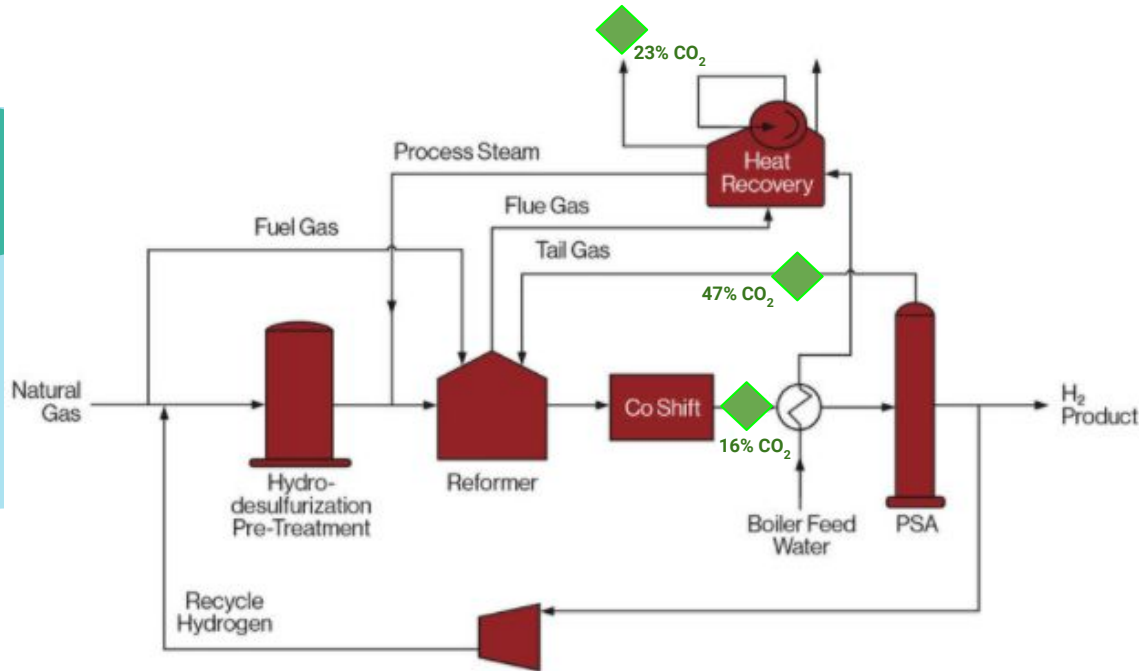
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H₂ Production through SMR



H₂ Production through SMR



CO₂ can be captured at three locations

The flue gas is 23% CO₂ with nitrogen, but the other two locations are CO₂ with hydrogen

◆ CO₂ capture points and concentrations



Port-Jerome Demonstration

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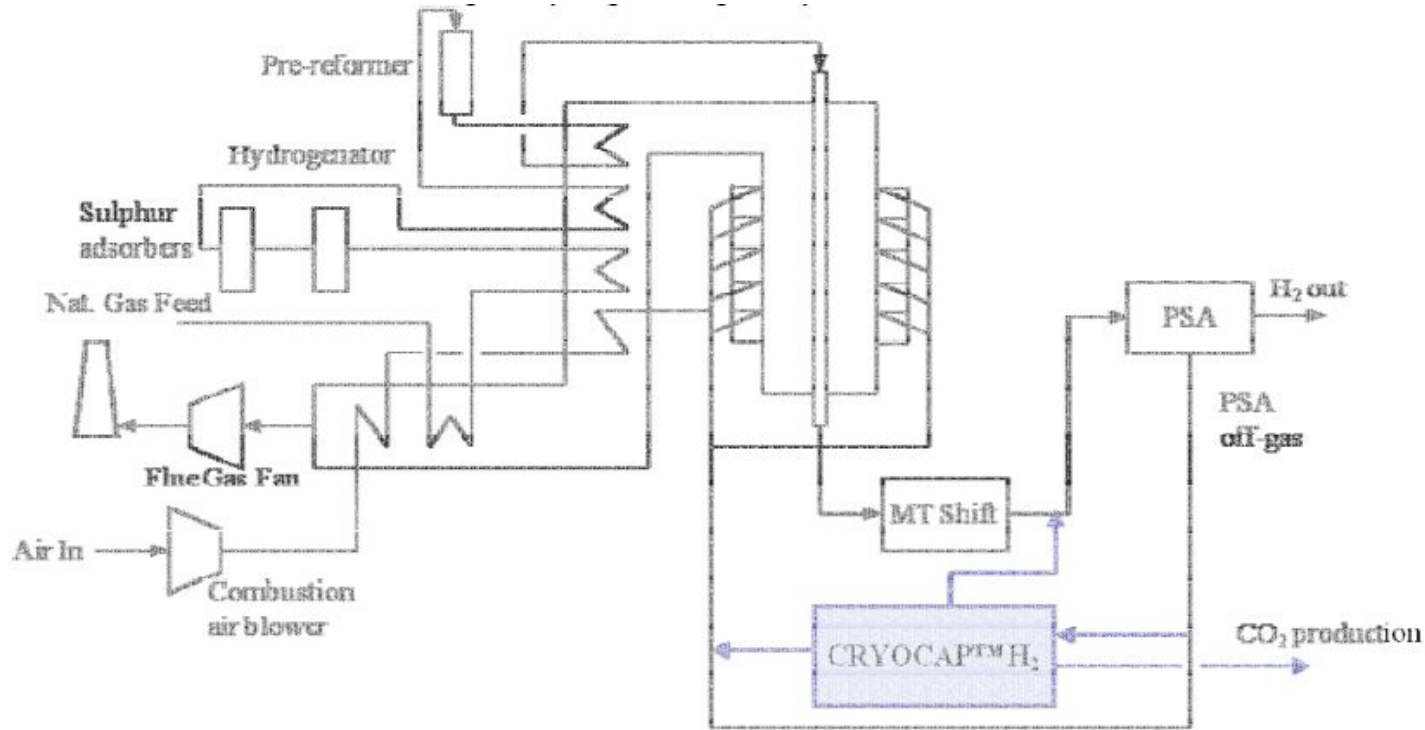
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Commercial Scale Demonstration at Port-Jérôme SMR

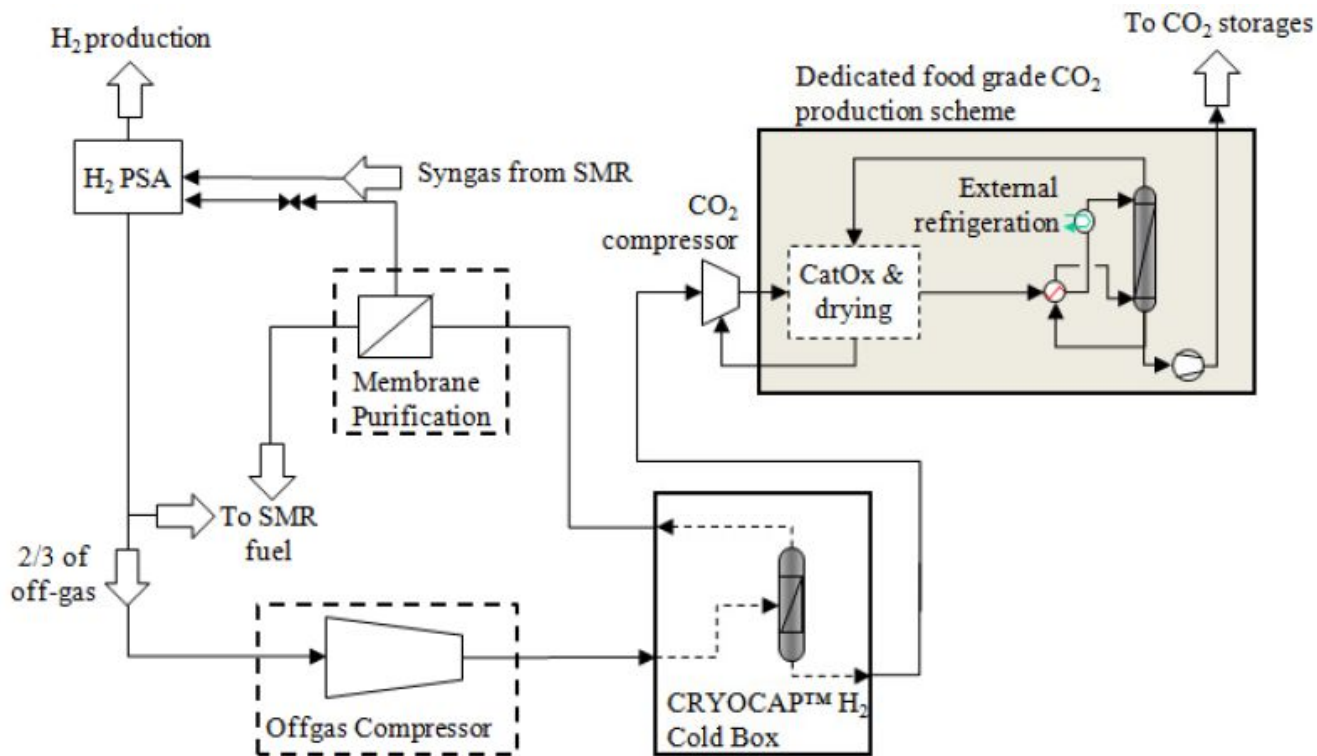


This Cryocap™ unit has an annual capture capacity of **100 000 tonnes of CO₂** at this site.

Simplified Scheme at Port-Jerome



Process Flow Diagram



Commercial Operation

Increased H₂ production coupled with industrial scale CO₂ production

Case	SMR only	SMR + CRYOCAP™ H ₂ <i>Partial CO₂ capture (Port-Jérôme unit)</i>	SMR + CRYOCAP™ H ₂ <i>Full CO₂ capture</i>
H ₂ production	47 000 Nm ³ /hr	50 155 Nm ³ /hr	52 480 Nm ³ /hr
Additional H ₂ production	-	+7%	+12%
H ₂ recovery from PSA offgas	0%	87%	87%
Overall H ₂ recovery from syngas	88.0%	93.9%	98.3%

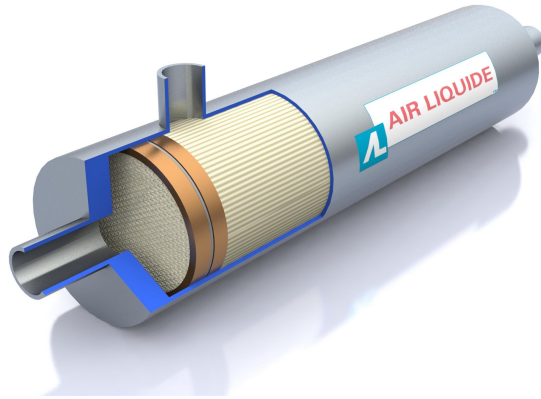


Hybrid Technologies

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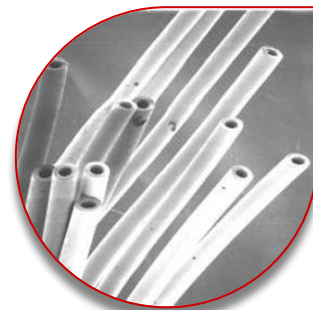
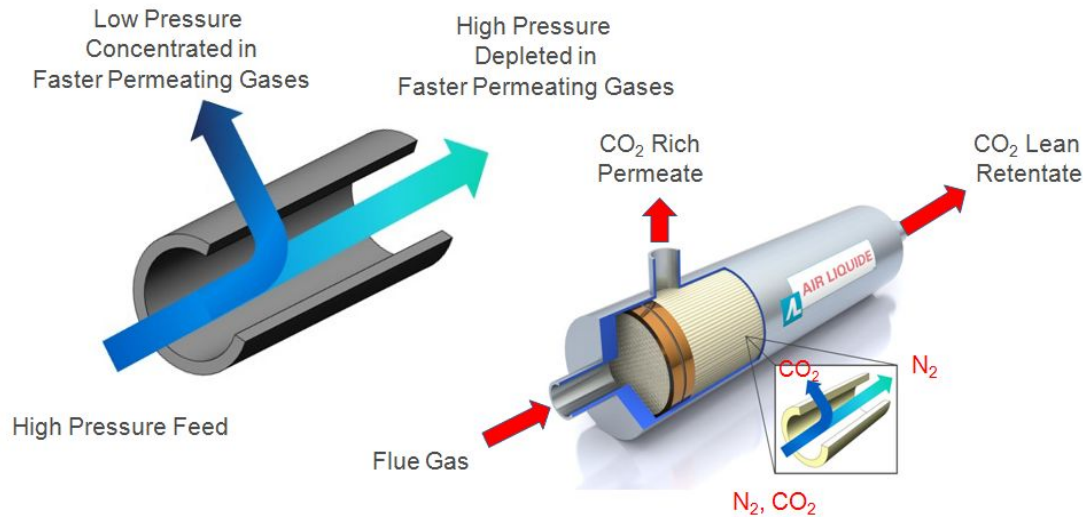
Hybrid Systems

- Cryogenic solutions have two advantages:
 - High purity of the CO₂
 - Liquid CO₂ Product



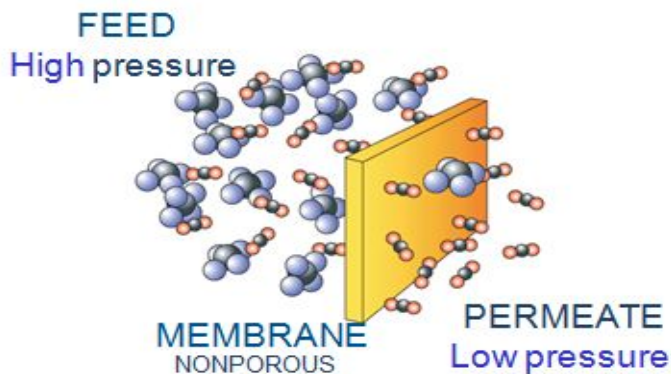
- Hybridization of the process to achieve high recovery of CO₂
- Recovery with PSA or Cold Membranes

Hollow Fiber Membranes

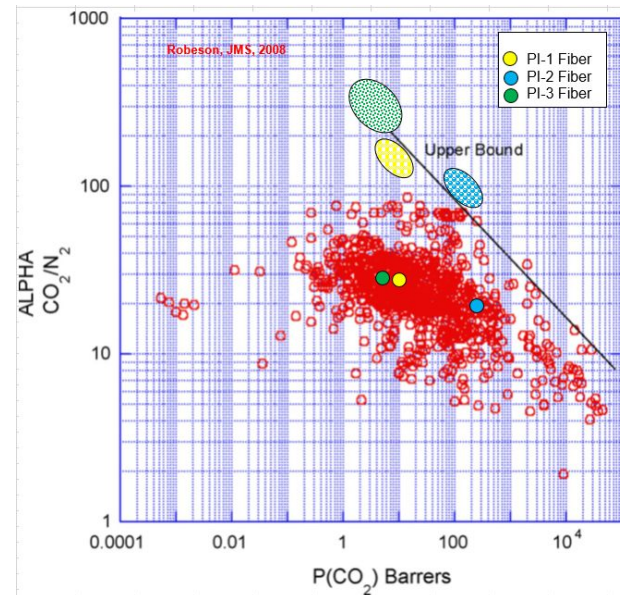


Hollow fibers allow low cost manufacture of membranes with high surface area per unit volume. Large natural gas installations have been installed at membrane costs of $\sim \$20/\text{m}^2$.

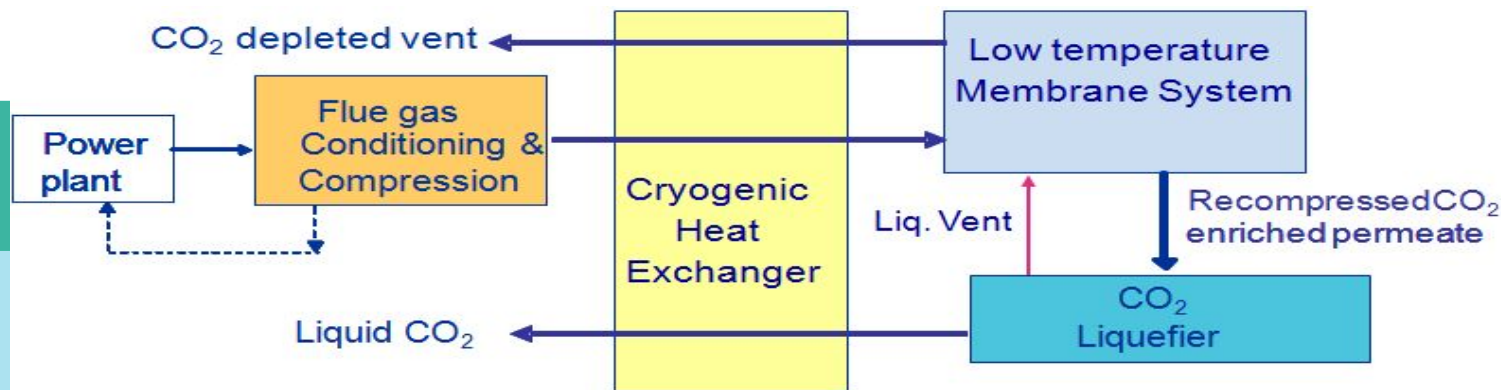
Air Liquide Cold Membrane Technology



- **Why Cold? -- Improve selectivity without loss of productivity**
 - Discovered by Air Liquide R&D in 2008: Improved CO₂ selectivity at T below ambient
- **Why PI-2? -- Improved productivity lowers cost**
 - 4-5 X higher CO₂ productivity/bundle

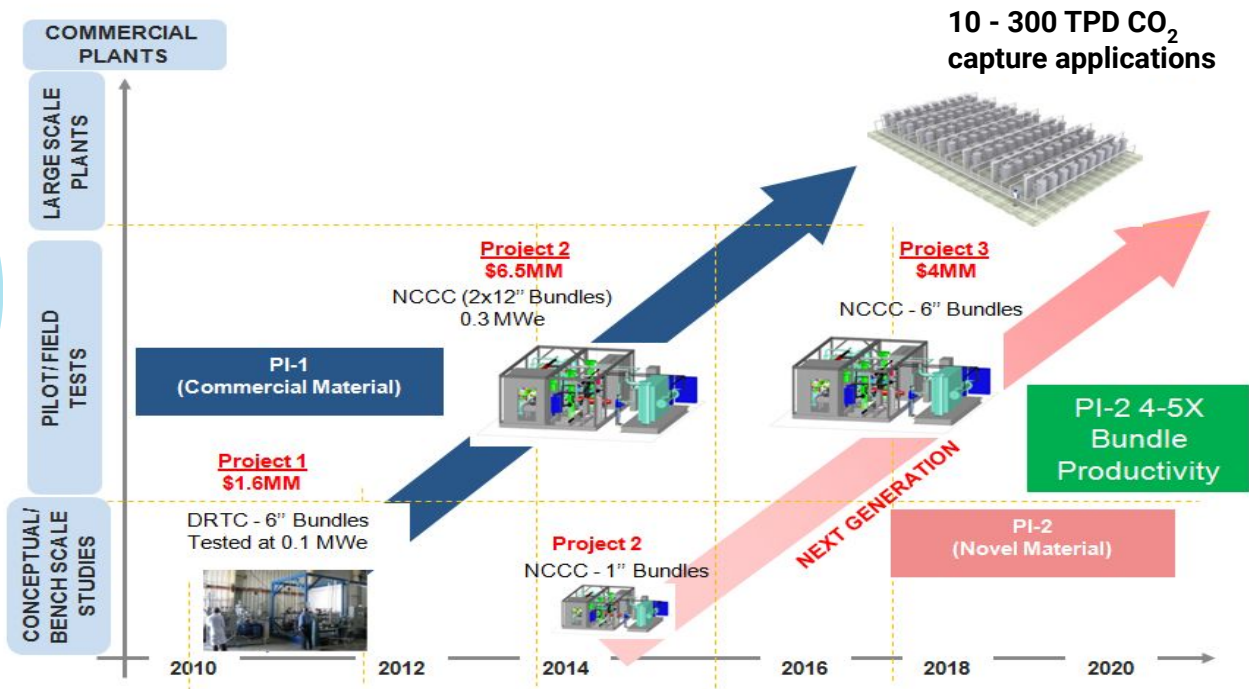


Cold Membrane Process



- Pre-concentration of CO₂ by highly selective membrane before liquefier
- Energy integration between membrane/liquefier through heat exchange
- Efficient recovery of compression energy
- Direct production of liquid CO₂
- High purity suitable for EOR / sequestration / consumer applications

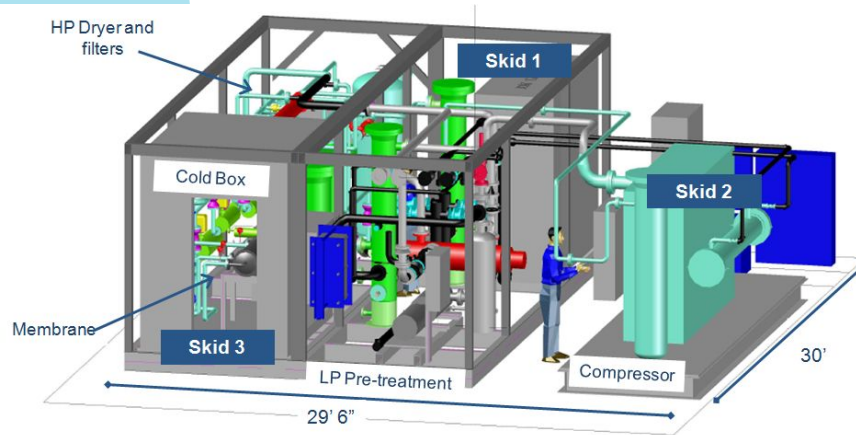
DOE Funded Projects Timeline



Flue Gas Testing - Coal Plant flue gas

0.3MWe / 6 TPD CO₂ (TRL-5) field test unit at the NCCC (Wilsonville, AL)

3,000+ Hours operation PI-1
3,000+ Hours operation PI-2



Summary

- SMR with CCS :
 - Cryocap™ H₂ → Increase in H₂ production while also capturing CO₂
 - Hydrogen production increase ranges from 10 to 15%
 - Partial capture at 60+% CO₂ recovery
 - Hybrid Process can capture 90+% of CO₂ from SMR Flue gas
 - Cold Membrane technology can be implemented in SMR

We are thankful to DOE for a decade of successful partnership with cold membranes

- ❖ US DOE: Andrew O’Palko, Sheldon Funk, José Figueroa
- ❖ NCCC Team: Frank Morton, Tony Wu, Graham Bingham
- ❖ Air Liquide: Dave Hasse, Dennis Calvetti, Gerard Gagliano, Trapti Chaubey, Tim Poludniak, Judy Huss, Raja Swaidan, Pierre-Philippe Guerif and Chendhil Periasamy
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