

Carbon Capture utilizing Hybrids: Membrane and Liquefaction

AIChE Carbon Management Technology
Conference

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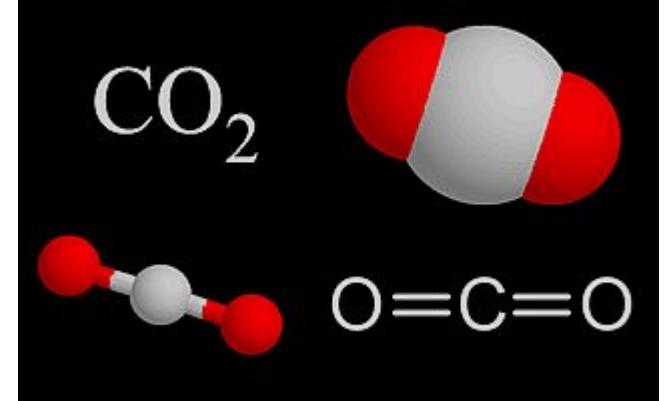
CMTC Houston Texas • July 2019

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Commercial Membrane Hybrid Solutions for CO₂ Separations

1. Cold Membranes for Air Fired flue gas
2. Cryocap Oxy for Oxy Fired flue gas
3. Cryocap CO₂ for Steam Methane Reforming



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Why Do We Need Hybrids?

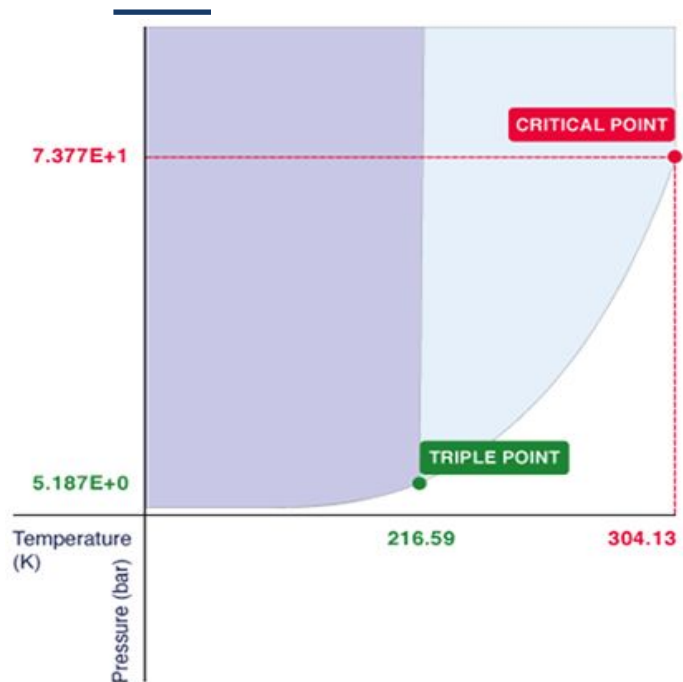
Cryogenic Separation of CO₂

CO₂ Distillation at low pressure at -100 °C

- Estimated cost of capture ~ \$20/tonne
- Why don't we use this?



The Problem with CO₂



Triple Point prevents liquefaction at low pressures

- Temperature
- 56.56 °C
- Pressure
5.1867 bar
- Recovery is low without high pressure

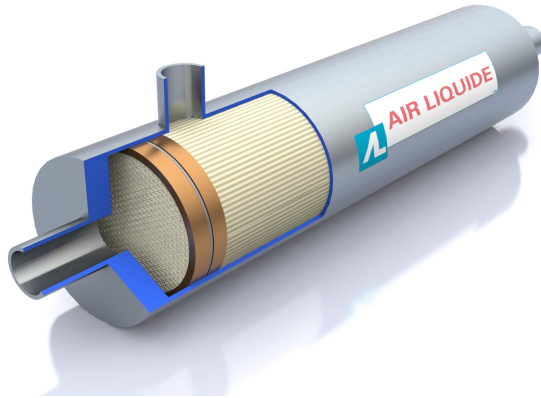
The Problem with Membranes

Purity Specifications of minor components are difficult to reach

Parameter	Limit	Requirement for EOR Pipeline
Temperature	<35°C (95°F)	Transportation pipeline specification
Pressure	152 barg (2200 psig)	Transportation pipeline specification
CO ₂	>95% vol	Minimum miscible pressure for enhanced oil recovery (EOR)
N ₂	<4% vol	Minimum miscible pressure for EOR
H ₂ O	dew point <-40°C (-40°F)	Transportation pipeline corrosion / hydrate formation
O ₂	<40 ppmv	Transportation pipeline corrosion
CO	<0.1% vol	Safety and corrosion

Advantages of a Hybrid System

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



- Membranes have two advantages
 - High recovery of CO₂
 - Simplicity of operation

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Cold Membrane System

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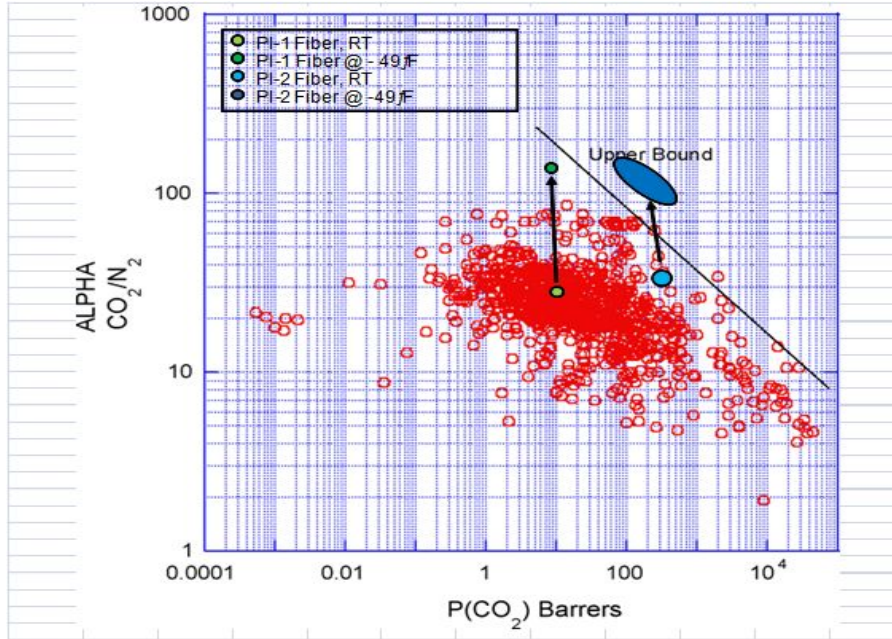
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Title Membrane Hybrid Solutions



Various polyimides respond favorably to cold temperature operation



Robeson, JMS, 2008

$$\Delta E_p = \Delta E_D + \Delta H_S$$

Three polyimides extensively studied:
Varying polymer free-volume, plasticization tendency, chain stiffness and CO_2 affinity

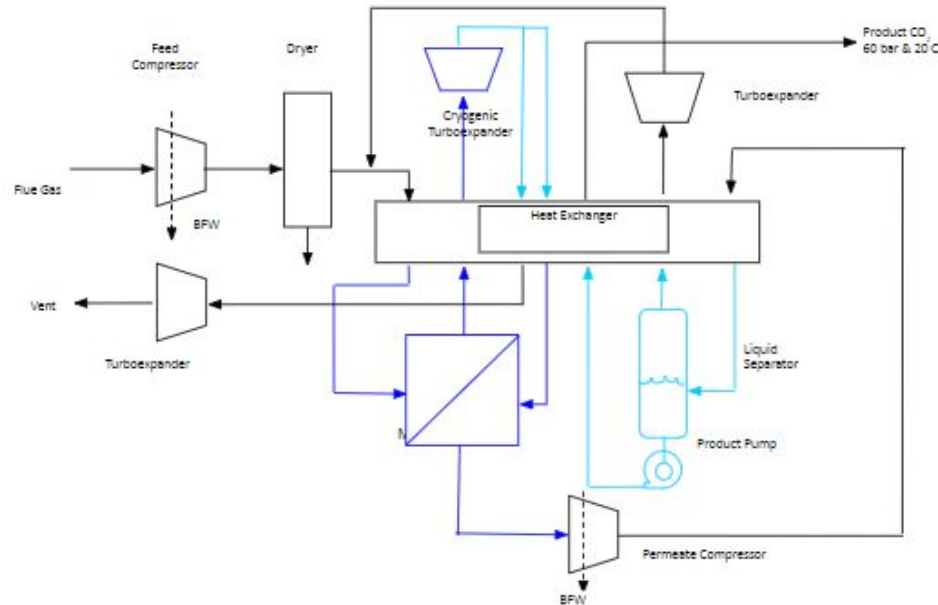
Cold Membrane is a Hybrid System



- Highly selective membrane followed by condensation
- Incondensable stream recycled back at pressure to the membrane
- Liquid product pumped to final pressure

[Energy Procedia](#)
[Volume 37](#), 2013, Pages
993-1003

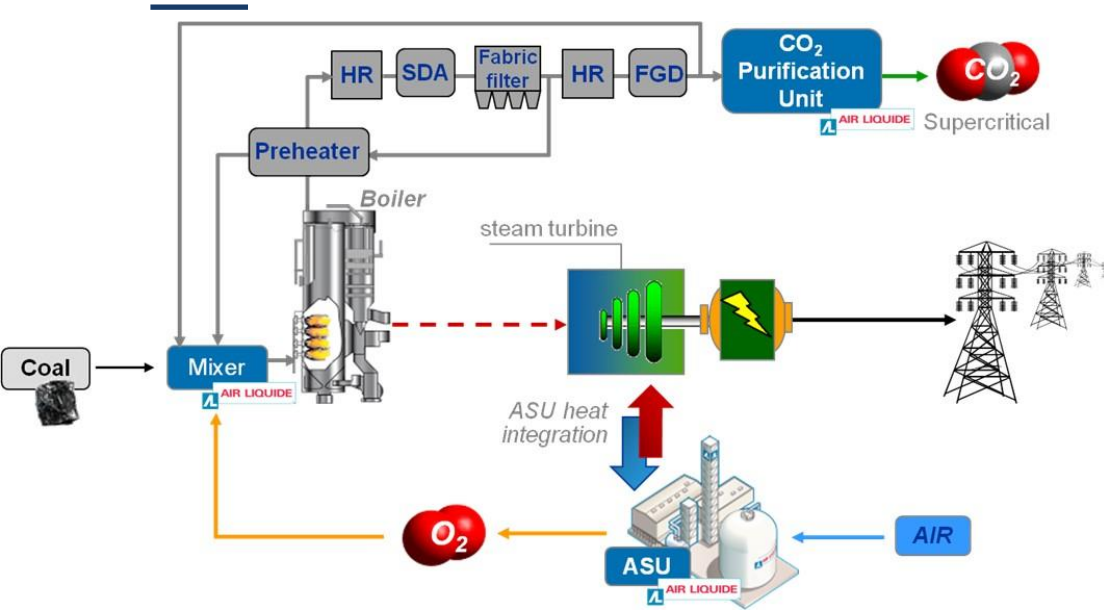
Highly Selective Membrane followed by condensation



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Carbon Dioxide Cryogenic Processing unit (CPU)

Design for Oxy Combustion of Coal



Liquefaction with membrane
recycle of non condensables

[Energy Procedia](#)

[Volume 63](#), 2014, Pages 342-351



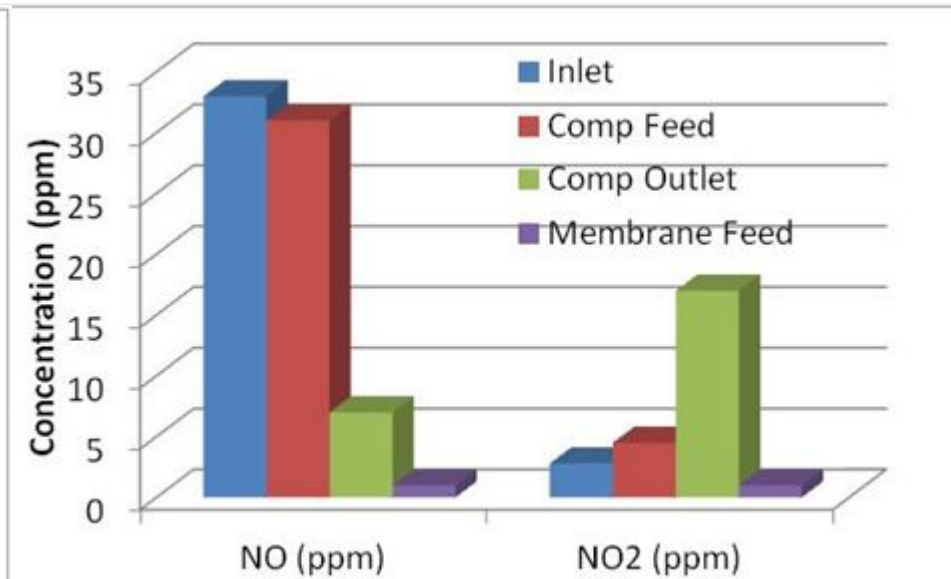
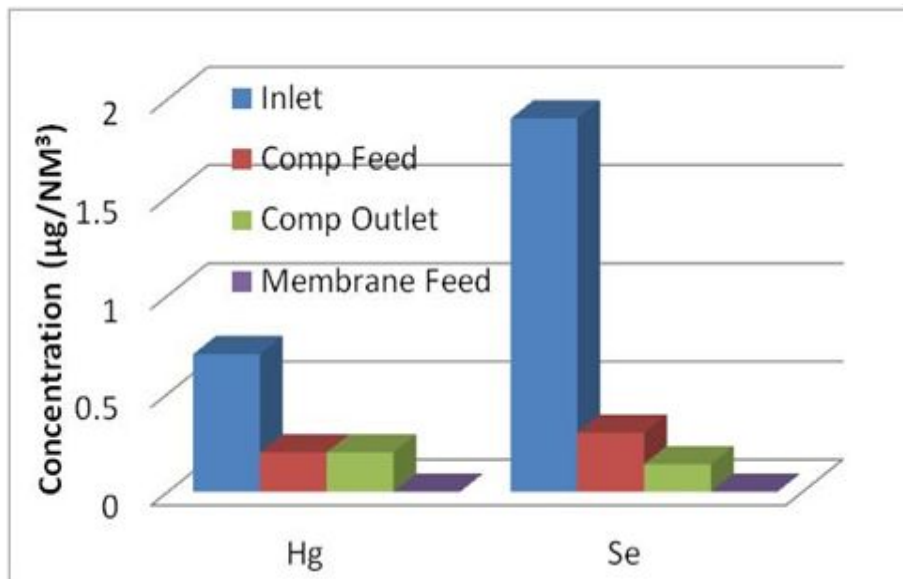
Optimization

- At low concentrations of CO₂, a cold membrane solution is preferred
- At high concentrations of CO₂, a Cryogenic Processing Unit is preferred

For coal fired power production, the costs are roughly equal if the cost of oxygen production is included (and changes of the DOE calculation factored in)

Technology	Cost of CO ₂ (\$/tonne)	Year
Cold Membrane	39	2017
Oxy Coal	38	2013

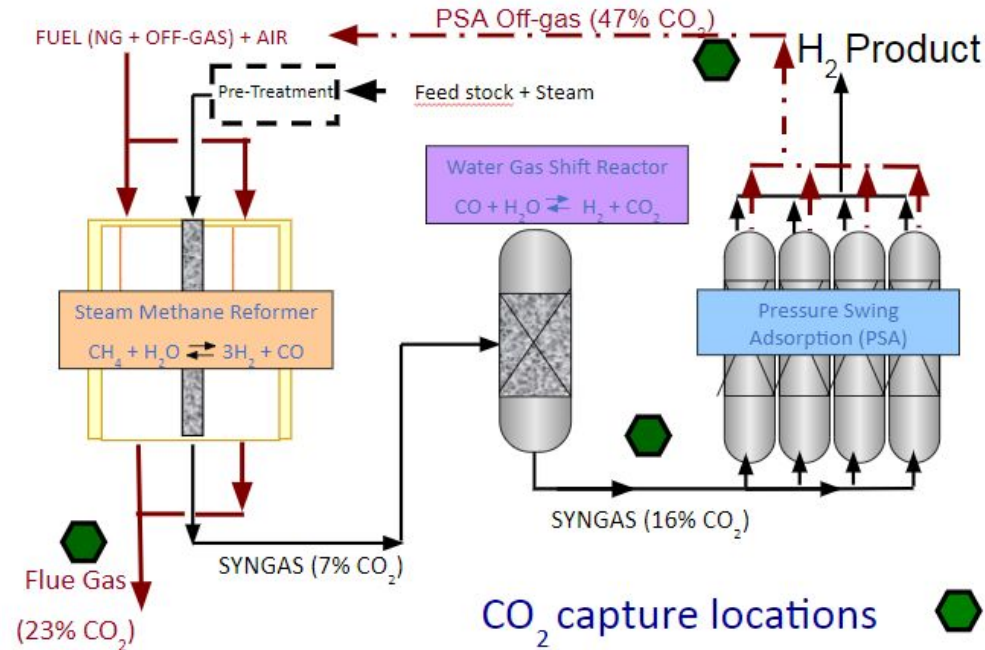
Reduction of Other Impurities



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Steam Methane Reforming

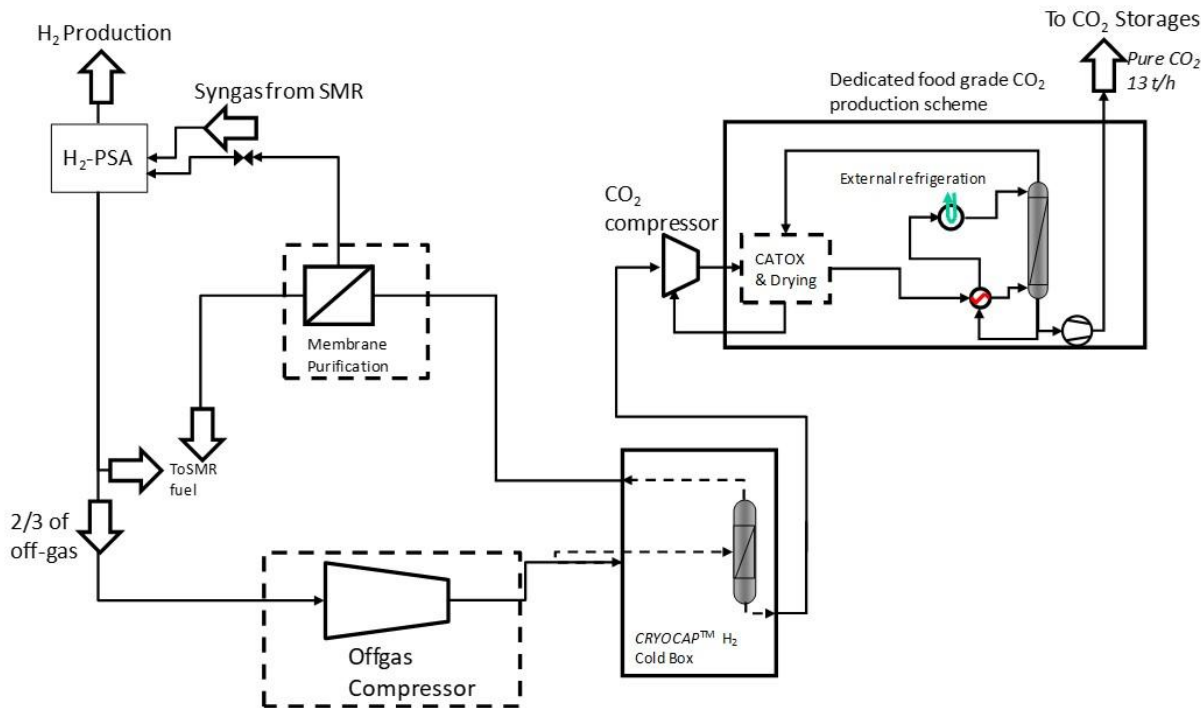
Steam Methane Reforming is Special Case



CO₂ can be captured at three locations

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

Hybrid Solution for Capture after Pressure Swing Adsorption



1st Carbon dioxide is removed by condensation

2nd Hydrogen is recycled with a membrane

Commercial Scale Demonstration at Port-Jérôme SMR



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

[Energy Procedia](#)

[Volume 114](#), July 2017, Pages 2682-26

Advantages of the Hybrid System

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%

Increased H₂ production coupled with industrial scale CO₂ production

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