

# Carbon Capture utilizing Hybrids: Membrane and Liquefaction

AIChE Carbon Management Technology  
Conference

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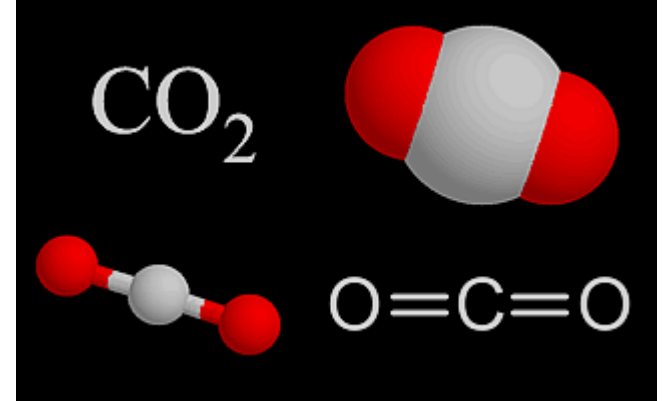
David Hasse • Department PE&C



# Commercial Membrane Hybrid Solutions for CO<sub>2</sub> Separations

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1. Cold Membranes for Air Fired flue gas
1. Cryocap Oxy for Oxy Fired flue gas
1. Cryocap CO<sub>2</sub> for Steam Methane Reforming



# 1

## Why Do We Need Hybrids?

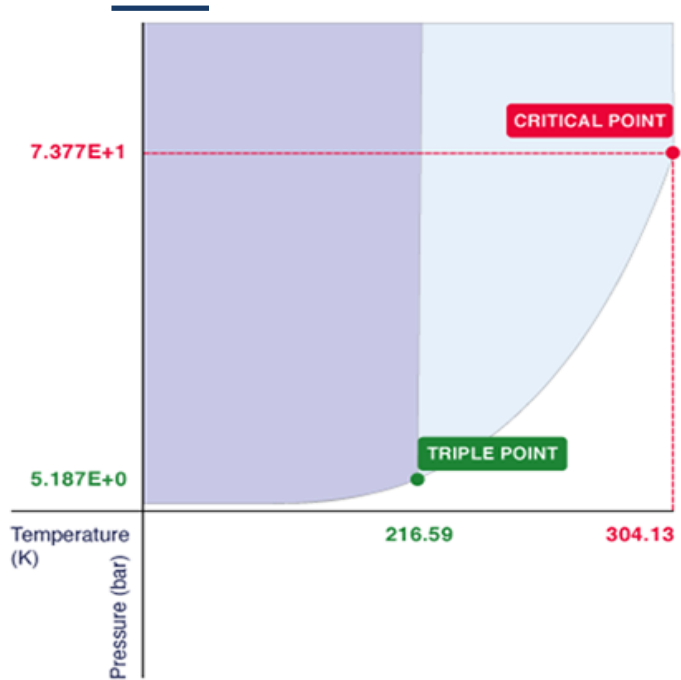
# Cryogenic Separation of CO<sub>2</sub>

## CO<sub>2</sub> Distillation at low pressure at -100 °C

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



# The Problem with CO<sub>2</sub>



Triple Point prevents liquefaction at low pressures

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

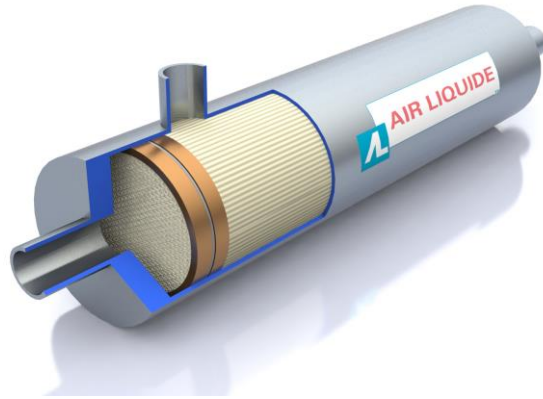
# The Problem with Membranes

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 <sub>2</sub>	>95% vol	Minimum miscible pressure for enhanced oil recovery (EOR)
N <sub>2</sub>	<4% vol	Minimum miscible pressure for EOR
H <sub>2</sub> O	dew point <-40°C (-40°F)	Transportation pipeline corrosion / hydrate formation
O <sub>2</sub>	<b>&lt;40 ppmv</b>	<b>Transportation pipeline corrosion</b>
CO	<0.1% vol	Safety and corrosion

# Advantages of a Hybrid System

- Cryogenic solutions have two advantages
  - High purity of the CO<sub>2</sub>
  - Liquid CO<sub>2</sub> Product



- Membranes have two advantages
  - High recovery of CO<sub>2</sub>
  - Simplicity of operation

# 2

## Cold Membrane System

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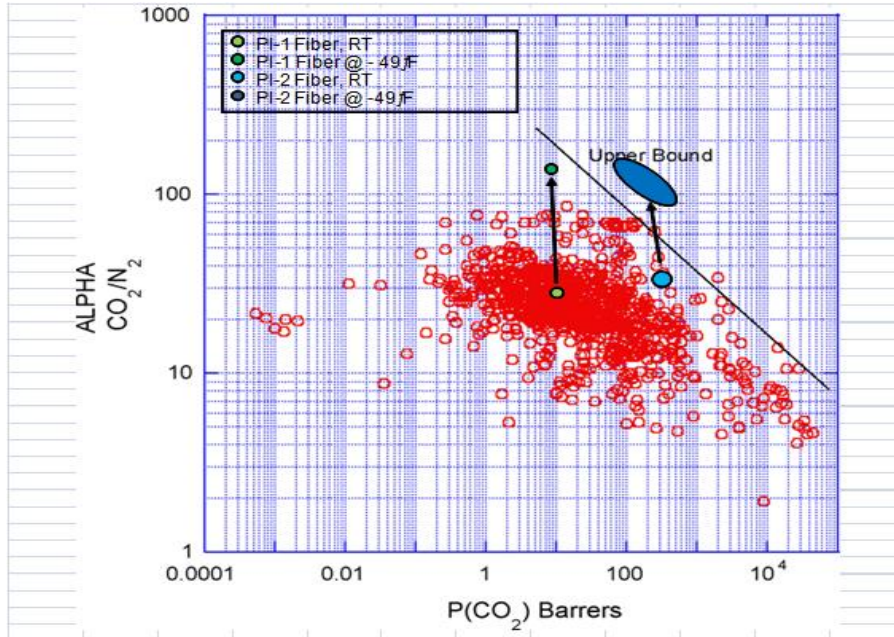
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# Various polyimides respond favorably to cold temperature operation



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  $\text{CO}_2$  affinity

# Cold Membrane is a Hybrid System

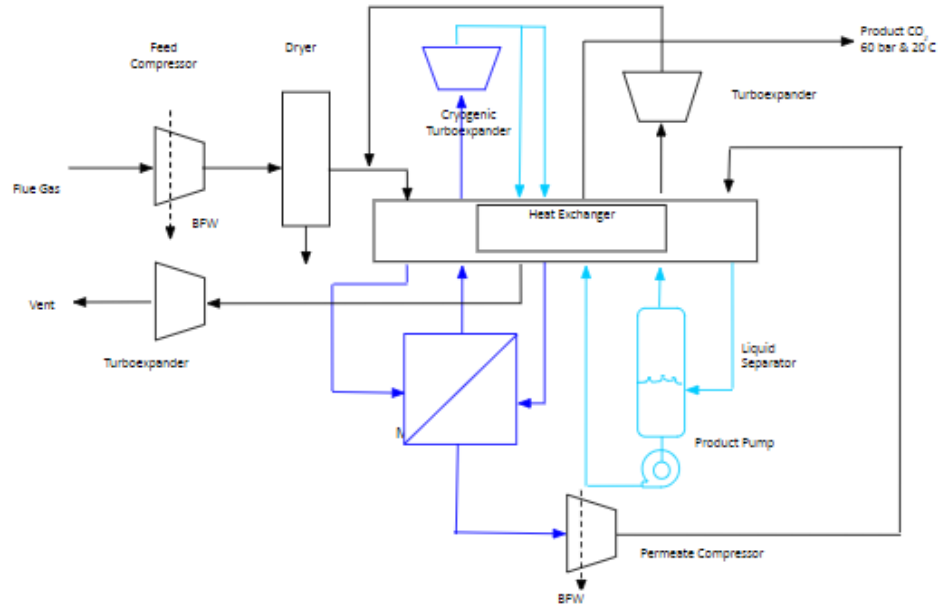


- Highly selective membrane followed by condensation
- Incondensable stream recycled back at pressure to the membrane
- Liquid product pumped to final pressure

[Energy Procedia](#)

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

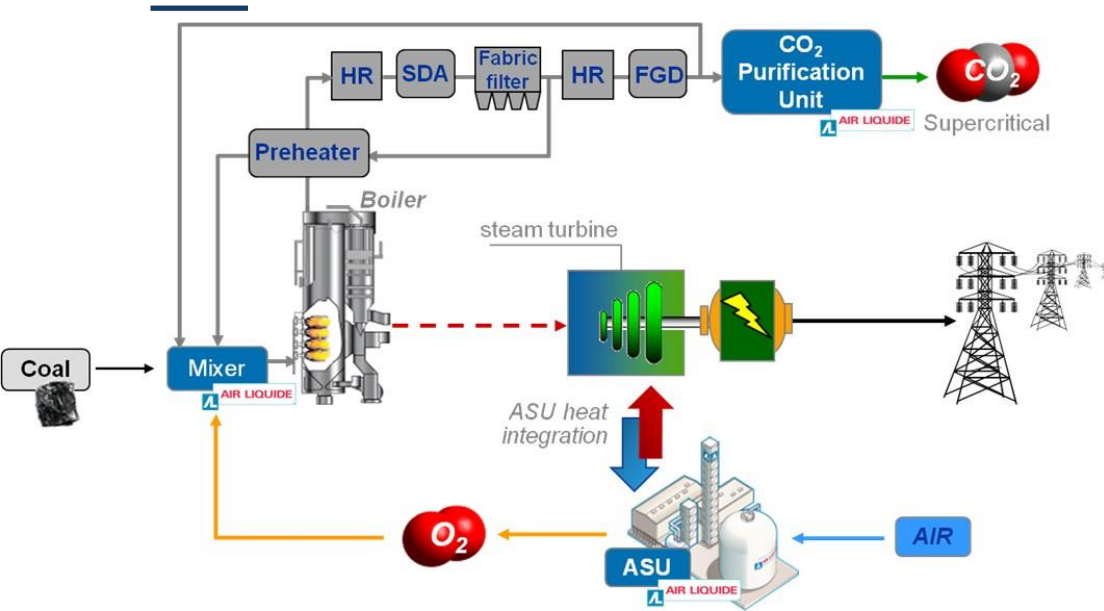
# Highly Selective Membrane followed by condensation



# 3

## Carbon Dioxide Cryogenic Processing unit (CPU)

# Design for Oxy Combustion of Coal

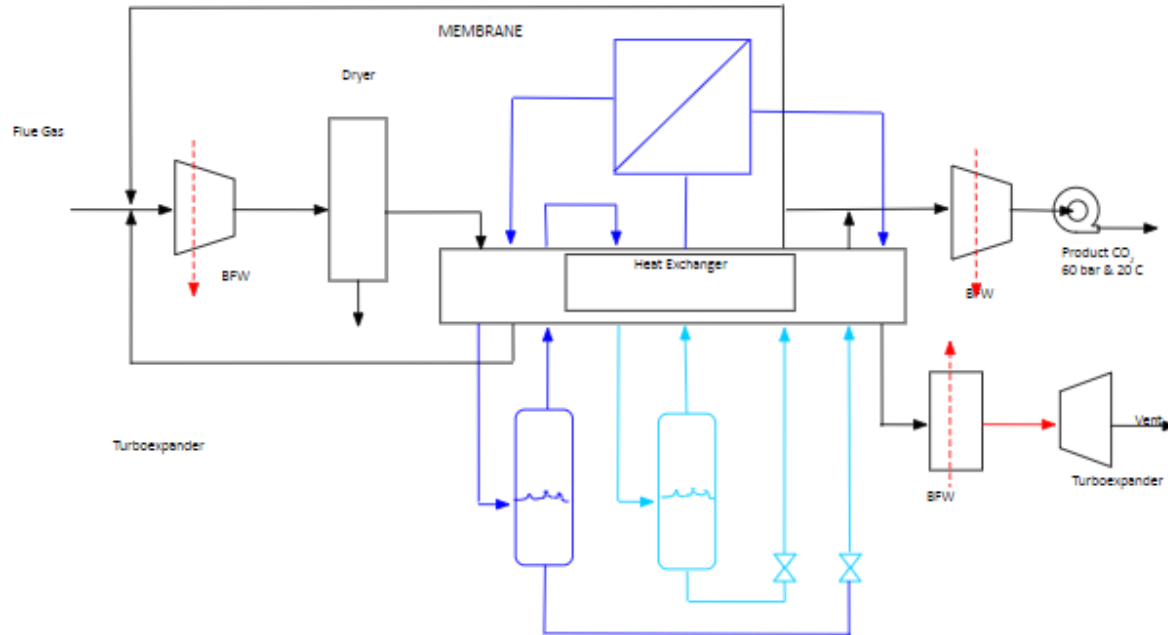


Liquefaction with membrane recycle of non condensables

[Energy Procedia](#)

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

# CPU Process: Condensation before Membrane Separation



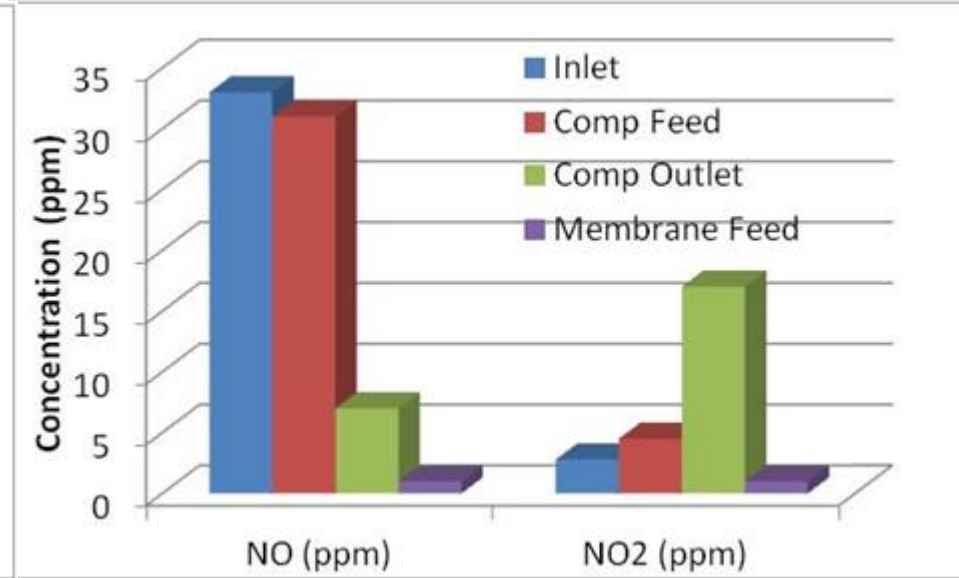
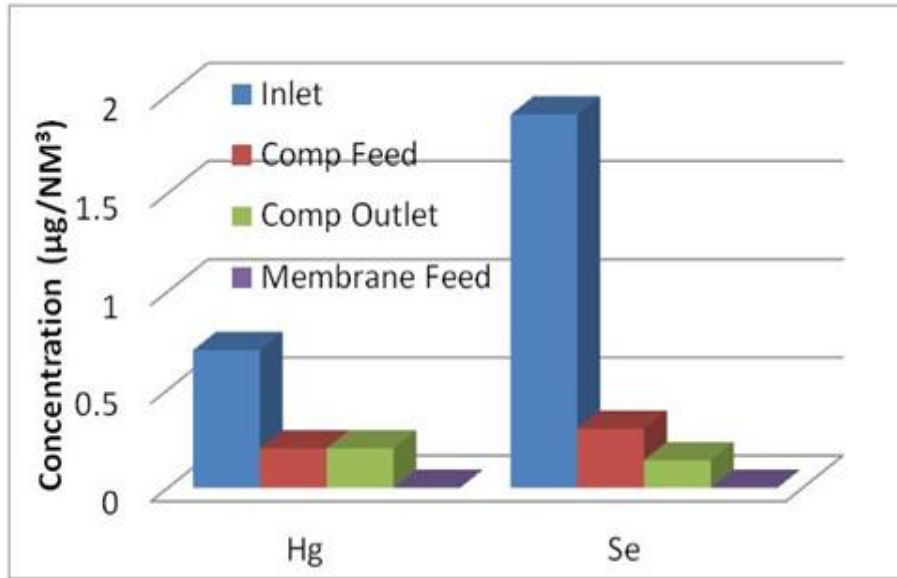
# Optimization

- At low concentrations of CO<sub>2</sub>, a cold membrane solution is preferred
- At high concentrations of CO<sub>2</sub>, 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 <sub>2</sub> (\$/tonne)	Year
Cold Membrane	39	2017
Oxy Coal	38	2013

# Reduction of Other Impurities

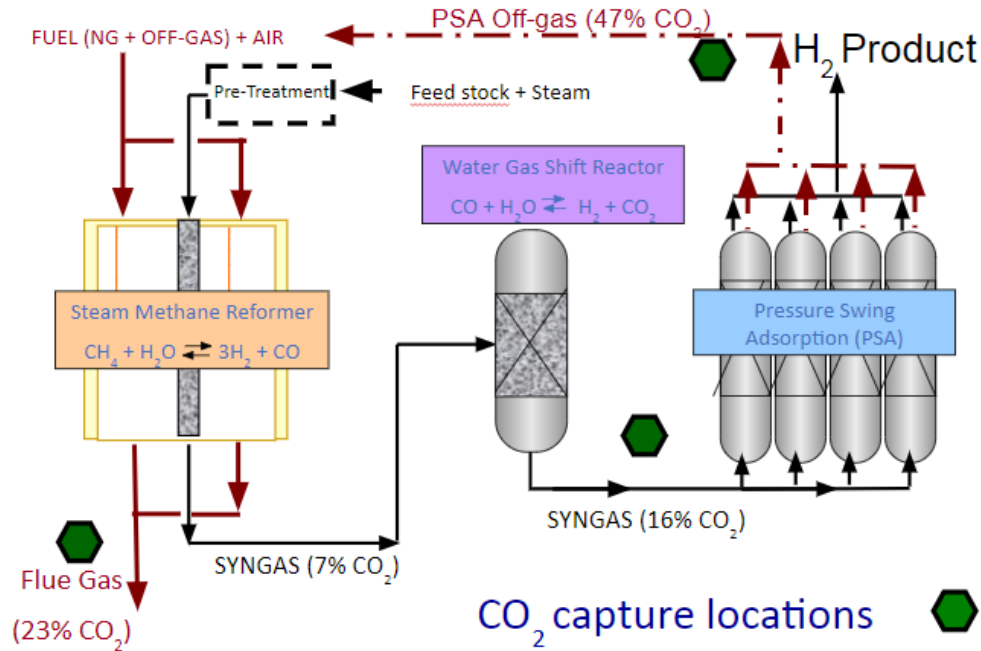




# 3

## Steam Methane Reforming

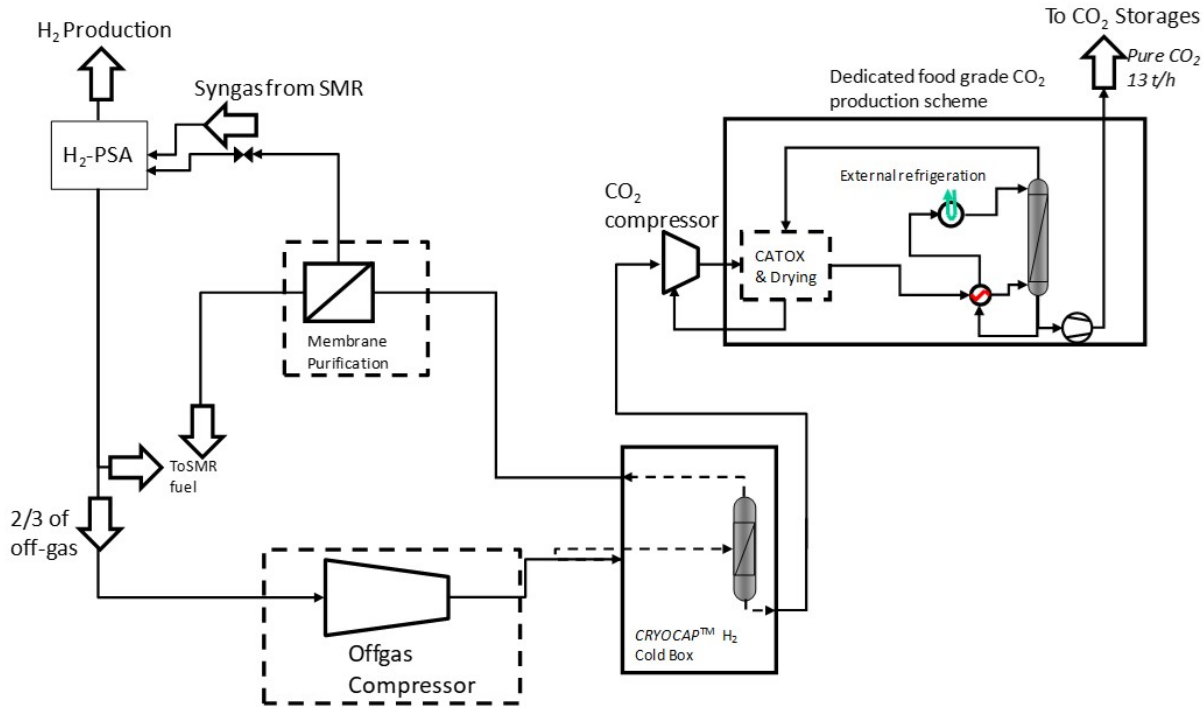
# Steam Methane Reforming is Special Case



CO<sub>2</sub> can be captured at three locations

The flue gas is CO<sub>2</sub> with nitrogen, but the other two locations are CO<sub>2</sub> 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 CO<sub>2</sub>** at this site.

[Energy Procedia](#)

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

# Advantages of the Hybrid System

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

Increased H<sub>2</sub> production coupled with industrial scale CO<sub>2</sub> production

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