PROJECT OBJECTIVE - MOTIVATION

Develop a permeate sweep/purge capable full ceramic multiple tube membrane bundle and multi-bundle housing for use at 200 to >350°C at >300 to 1,000 psig.

✓ Critical Technology Gap advanced inorganic membrane Scale-Up in pre-combustion CO_2 capture (and other applications).

✓ This capability is required to achieve the DOE Capture and COE targets.

PRIOR DEVELOPMENT and PROBLEMS

***1st Generation:* "Candle-filter" multiple tube bundle.**

"Candlefilter" Rationale

- Stepping stone from the laboratory to pilot/demonstration scales.
- Wide range of inorganic membranes
- Multiple tube bundles; high surface area.
- High temperature (>500°C); pressure (>1,000psig)
- No module thermal expansion mis-match.

Carbon Molecular Sieve Membrane

Pd-alloy Membrane

"Candlefilter" Problems

- **NOT permeate PURGEABLE.**
- **COMPLEX multi-bundle housing design.**
- **Very LOW module packing density.**
- **NOT viable at Polygeneration scales.**

NaA, NaY, and MFI Zeolite Membranes

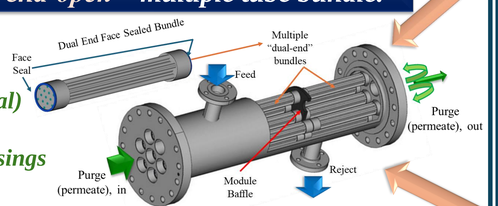
THIS PROJECT and THE SOLUTION

***2nd Generation:* "Dual-end-open" multiple tube bundle.**

Key Concepts

- ✓ *Permeate Purgeable*
- ✓ *Face Seal Capable (v. radial seal)*
- ✓ *High Temperature/Pressure*
- ✓ *Compact Multiple Bundle Housings*
- ✓ *Adaptable to a Wide Range of Advanced Inorganic Membranes*

This Project Focus….Can it be done ???



Solution: "Dual End Open" Multi-tube Membrane Bundle

1. Enables Deep H_2 Recovery = Improved process & capture efficiency.
2. Higher membrane productivity = Lower cost.
3. Face seal capable = Simplified multiple bundle housing design.
4. Face seal capable = Higher packing density.
5. Higher packing density = Improved feed flow distribution; reduced shell side bypass; higher performance.

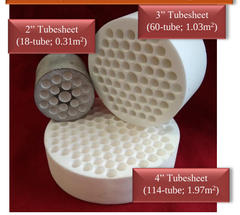
ACCOMPLISHMENTS BP1

✓ Dual End Open Full Ceramic Bundle Development

- ✓ 2" to 4" Diameter Full Ceramic Dual End Bundles
- ✓ Centerline Permeate Takeoff
- ✓ Stable in thousands of thermal/pressure cycles up to 450°C and 800psig

"First-of-its-kind"

- ✓ Full ceramic tubesheet
- ✓ >1,000 °C; >1,800psig
- ✓ Large surface area; compact.

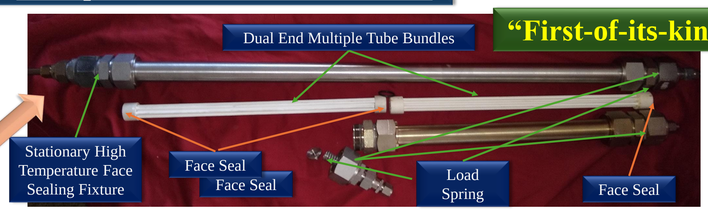


ACCOMPLISHMENTS BP2

✓ Configured with Multiple Bundles per Housing
✓ Series-Parallel Layout, High Packing Density
✓ Permeate Sweep/Purge Capable

➢ Multiple Bundles-in-Series Module

"First-of-its-kind"



➢ Multiple Bundles-in-Parallel Module

"First-of-its-kind"

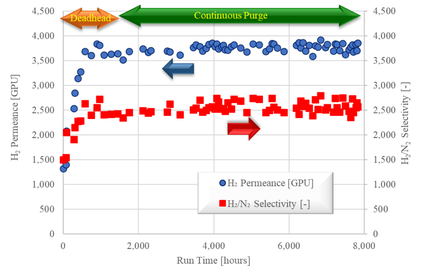
3-Bundle in Parallel Module

Carbon Molecular Sieve Membrane

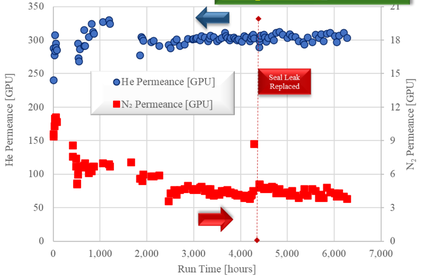
Pd-Alloy Membrane

✓ Excellent Bundle Long Term Performance Stability
✓ Multiple Bundles in Single Module Testing

Membrane: Pd Alloy
Temperature: 320-340°C



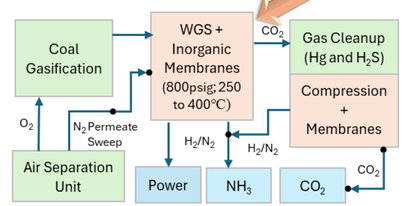
Membrane: 3x CMS
Temperature: 250°C



Polygeneration Concept

- ✓ Coal to Power + NH_3
- ✓ Precombustion CO_2 Capture
- ✓ Inherent high pressure H_2 and CO_2
- ✓ High on-stream factor

Inorganic Membrane Technology (Permeate Purge Capable) Synergizes well with Coal-based Polygeneration + CO_2 Capture



- ✓ Warm gas H_2/CO_2 separation.
- ✓ Minimal pretreatment.
- ✓ CO_2 at Gasifier Pressure.
- ✓ H_2 at ASU N_2 Sweep Pressure.
- ✓ High thermal efficiency.
- ✓ High compression efficiency.
- ✓ Achieves capture targets.
- ✓ Superior Net Power+Chemical Co-production versus baseline.

Polygeneration Plant Performance Summary
AST: Dual Stage Selexol versus MPT: Dual Stage Membrane

Performance Summary	AST	MPT
Combined Gross Power and Chemical Storage	257	264
Total Parasitic Load, MWe	52	52
Combined Net Power and Chemical Storage	205	211
HHV Net Plant Efficiency	38.3%	39.6%

Summary

Successfully developed and performance demonstrated the full ceramic dual end multiple-tube bundle for advanced inorganic membrane scaleup in a permeate purgeable multi-bundle commercially relevant module for high temperature high pressure gas/vapor/liquid separations.

Acknowledgements

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