Oxygen Transport Membrane Based OxyCombustion for CO_2 Capture from Coal Power Plants

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Outline

- **Background**
  - Oxy-Fuel Combustion
  - Oxygen Transport Membrane (OTM)
- **Proposed Concept**
- **Project status**
- **Summary**

Technology Solutions for Clean Energy

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Clean Coal for Power Generation

Clean Coal Options	Praxair Technologies
IGCC with CO_2 Capture	Oxygen Supply Syngas Processing
Oxy-Coal Combustion	Oxygen Supply CO_2 Capture Oxy-Coal Burners High Temperature Coatings Oxygen Transport Membrane
Flue Gas Scrubbing	O_2 Tolerant Amine System

Praxair Is Well Positioned To Provide Technology Solutions For All CO_2 Capture Options

Related Praxair Capabilities

Expertise In Handling CO_2

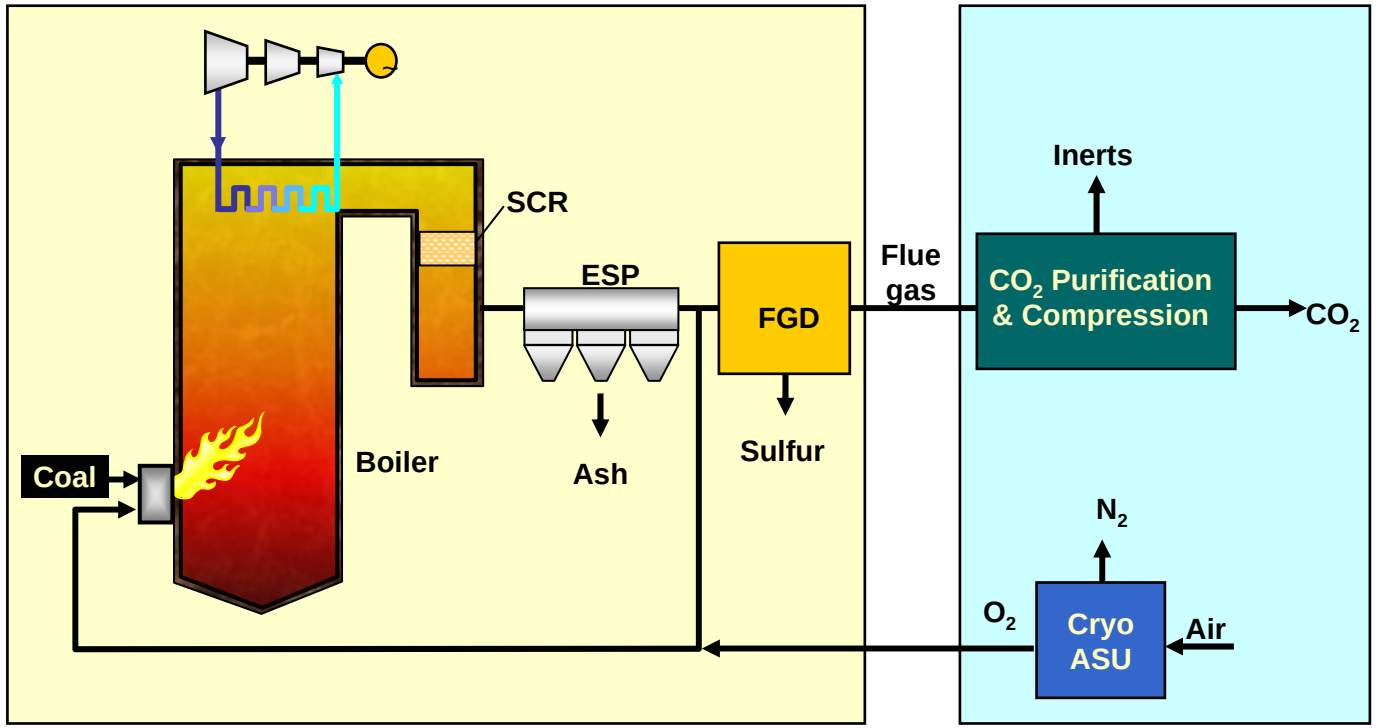
- Separation
- Compression
- Transportation
- Pipelines

Enhanced Oil Recovery

Carbon Sequestration

Seeper Trace™ To Monitor Sequestered CO_2

Conventional Oxy-Fuel Process



- Oxygen supplied from cryogenic ASU
- Flue gas recirculation for temperature control
- 3% O_2 in wet flue gas
- Suitable for retrofit and CO_2 capture ready designs

Need for New Oxy-Fuel Technology

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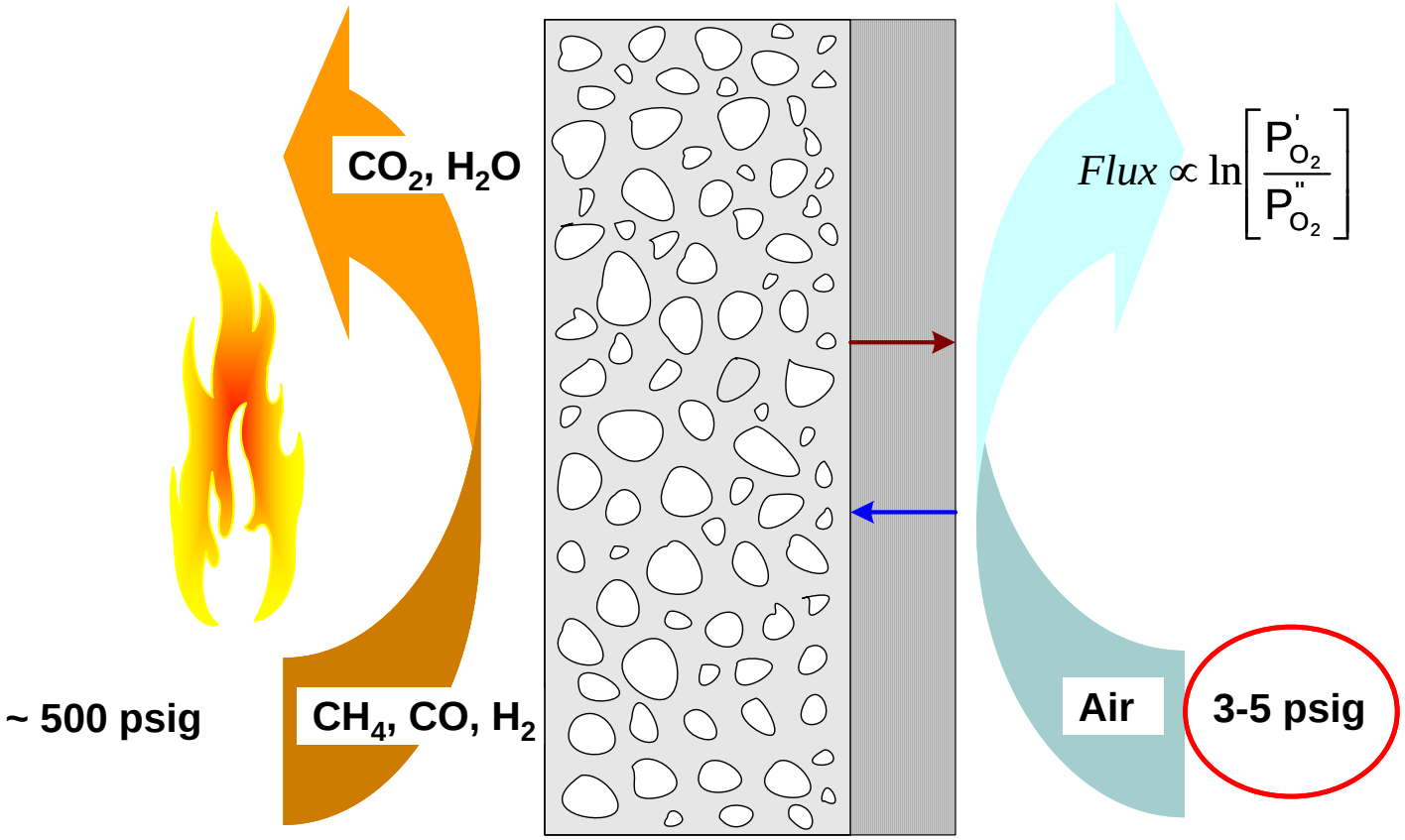
- Conventional oxy-fuel process (cryogenic ASU) will have a large energy penalty for capturing CO_2
  - 15 – 20% of power output is consumed by cryogenic ASU
  - ~10% for compressing and purifying CO_2
- Cryogenic ASU technology is mature
  - Improvements likely to be incremental
- Need for a technology that makes a step-change improvement in efficiency
- Praxair's advanced boiler technology has a potential to reduce power consumed in air separation by >75%

Oxygen Transport Membrane (OTM)



Oxy-Fuel Combustion Without Producing Oxygen

Praxair OTM Process for CO_2 Capture

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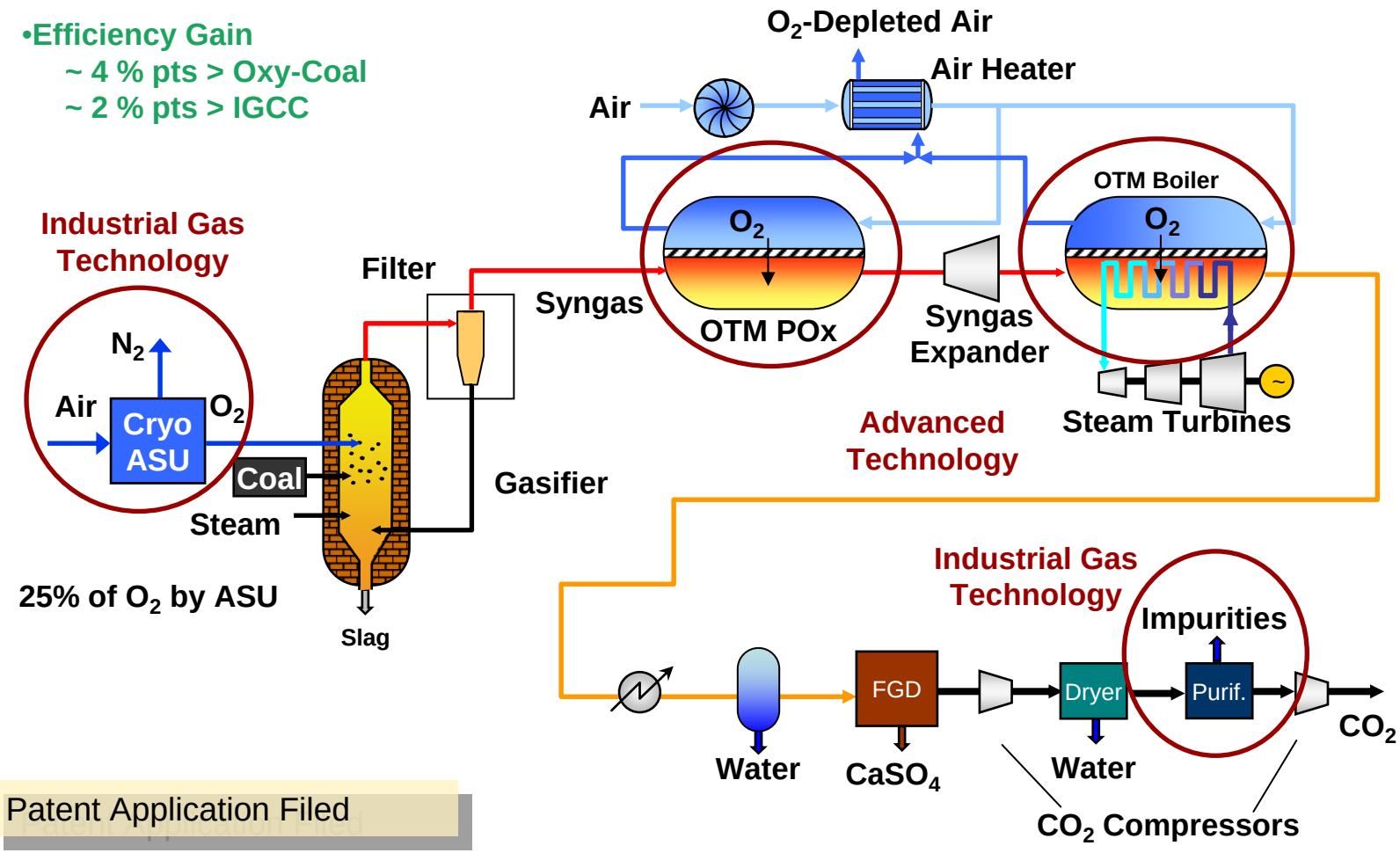
Recent DOE award to Praxair

- **Efficiency Gain**
  - ~ 4 % pts > Oxy-Coal
  - ~ 2 % pts > IGCC



Patent Application Filed

Preliminary Performance Comparison

	Air Fired PC Boiler	Oxy-PC with CO_2 Capture	OTM Process with CO_2 Capture
Net Output, MWe	600	600	600
Efficiency % HHV	39.1%	29.9%	34.5%
CO_2 Emissions, t/MWh	0.88	0.12	0.016
Purity of Captured CO_2 %		96%	96%
% CO_2 Captured		90%	98.4%

OTM Oxy-Fuel plant shows 4.6 point increase in efficiency as compared to cryogenic Oxy-Fuel PC Power Plant w/CO_2 Capture

OTM Program Status

- Completed proof-of-concept testing with Natural Gas in 2006
- Entered into new Cooperative Agreement with DOE in 2007
  - 3 year project
  - $8.4 MM (65% or $5.4 MM Cost share from DOE)
- Phase 1 (2007-2008)
  - OTM development (Oxygen flux, strength and reliability)
  - Down-select process integration cycle for coal power plant
- Phase 2 (2009)
  - Scale-up OTM size to that required for pilot testing
  - Basic engineering design and cost of pilot plant
  - System and economic analysis

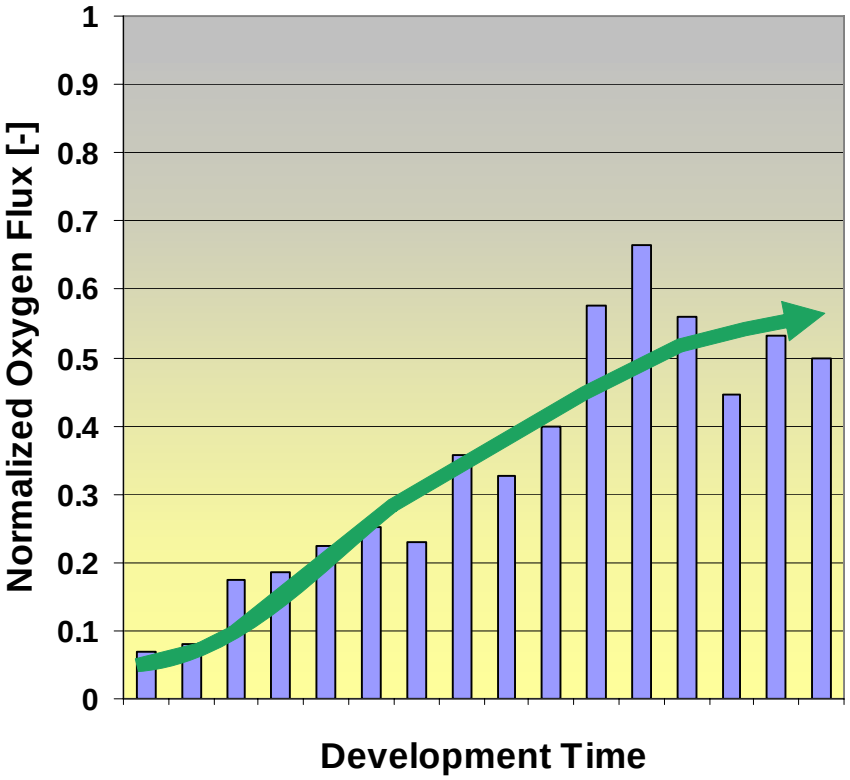
Development Partners

- **Utah Clean Coal Center (UC^3, Salt Lake City, Utah)**
  - Exposure of oxygen transport membranes to actual coal combustion environment
  - Obtain basic understanding of coal combustion with oxygen supplied by oxygen transport membranes in fluidized bed reactor

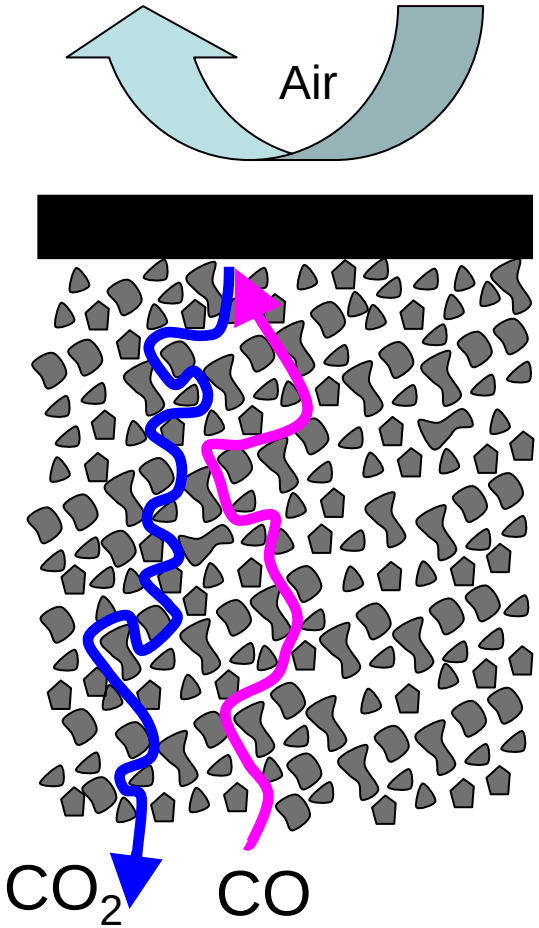
- **Ceramic Technology for Clean Energy (ENrG, Inc., Buffalo, NY)**
  - Advanced porous support
  - Manufacturing process development

Membrane Development Status

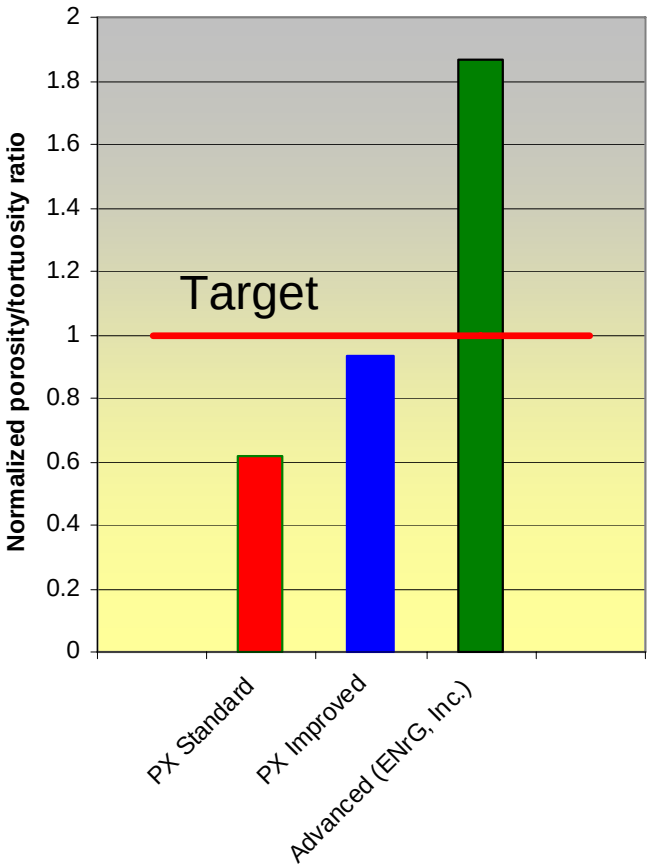
- Demonstrated robust materials system
- Thousands of hours cumulative testing with no mechanical failures
- Demonstrated thermal shock and chemical shock resistance
- Working to increase oxygen transport rates whilst maintaining mechanical reliability



OTM Porous Support

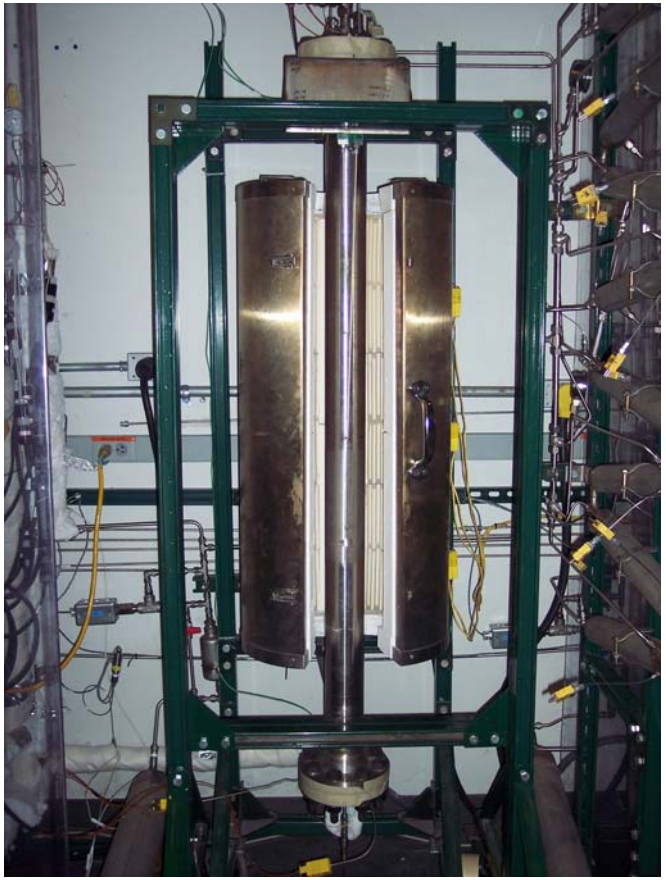


$$Flux \sim \frac{1}{t}\frac{\varepsilon}{\tau}$$



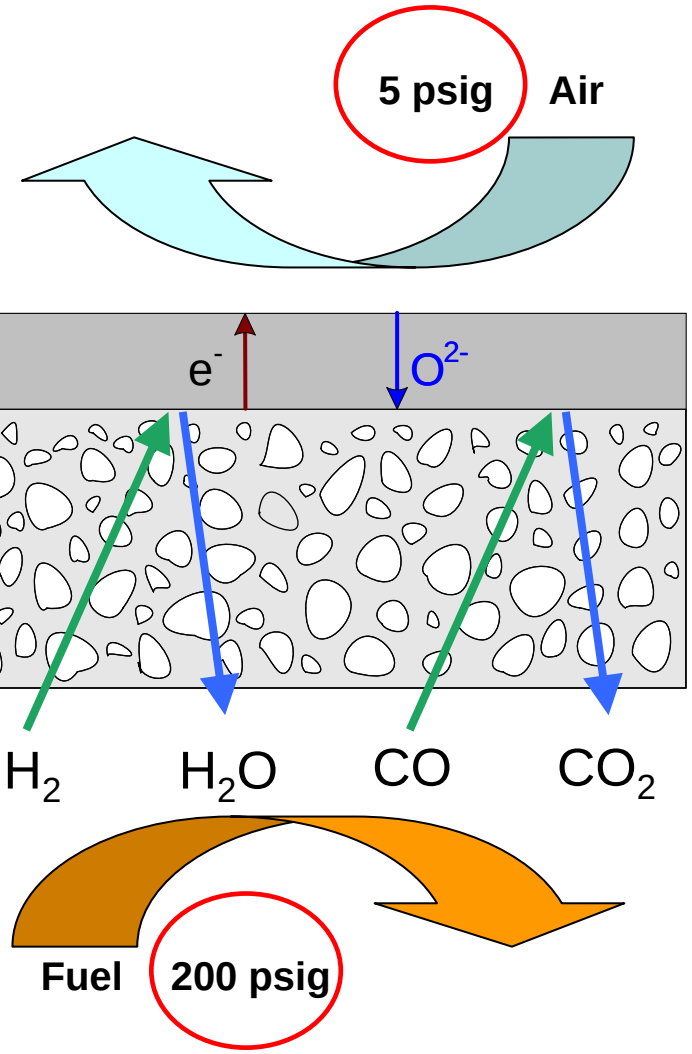
OTM Test Facilities

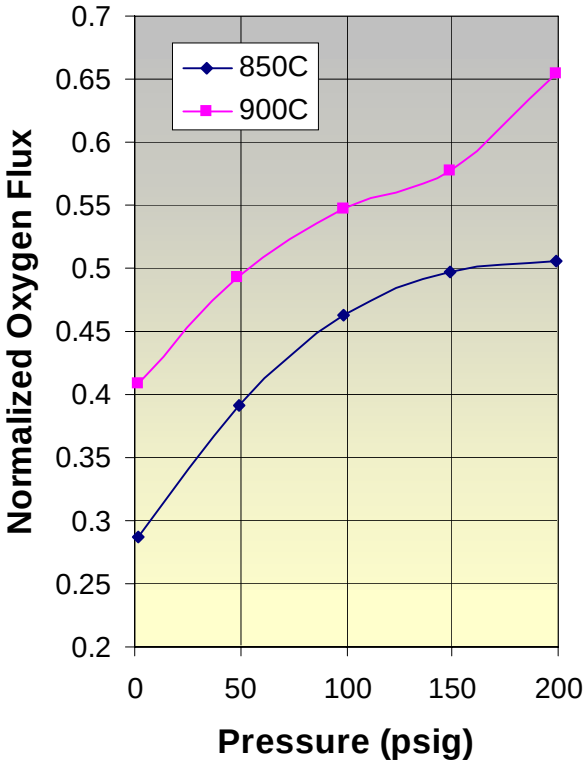
- **Partial oxidation reactor**
  - High pressure fuel
  - H_2S/COS containing syngas
- **OTM boiler**
  - Low pressure fuel
  - Complete combustion
- **Reactor for Coal Combustion**
  - Low pressure fuel
  - Direct exposure to coal



Partial Oxidation Reactor

$$Flux \sim \ln\left(\frac{P_{O_2}'}{P_{O_2}''}\right)$$





Summary

- **Step-change technology**
  - **Power cost associated with ASU reduced by 70-80%**
  - **Current estimates show 4 to 5 point efficiency increase compared to Oxyfuel PC with CO_2 capture**

- **Significant challenges**
  - **Achieving high oxygen flux through OTM whilst maintaining reliability**
  - **Stability of membranes with respect to coal impurities (extent of clean-up required not yet quantified)**
  - **Design and engineering of a large scale OTM boiler**
  - **Cost of heat recovery cost from oxygen depleted air stream**
  - **Commercial stepping stones on the way to coal power plants**

- **Current phase 2007 – 2009 is focused on membrane performance and process integration**

Thank you.

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