# Assessment of a Metal Membrane for an IGCC Power Plant (A TEA Exemplar)

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# Example Case

- Objective: Assess a novel technology using the QGESS technology
- Novel technology: Precious metal hydrogen membrane in an IGCC plant using a GE gasifier
- Background on precious metal membrane:
  - Generally Palladium, although other metals can be used to enhance performance and life
  - Transfers hydrogen via ion mechanism resulting in infinite selectivity
  - Costly
  - Operates at process temperature
  - Required technologies and process modifications include:
    - Sulfur removal
    - Nitrogen diluent is used as sweep gas
    - $CO_2$ purification

# Technology Analysis Plan

- Example Objective: Determine and quantify the key parameters that effect COE in a IGCC plant; aspirational R&D targets will be used.
- Reference case is case GE example with capture from the Bituminous Baseline[1]
    - Justification: The GE example provides the lowest COE gasification plant with capture and implementing this technology will show a further reduction in COE
- Integration plan:
    - Removal of Selexol $CO_2$ removal section
    - Utilize turbine diluent Nitrogen as sweep gas for the permeate side
    - $CO_2$ requires drying and perhaps further purification
    - Lower $CO_2$ compression requirements
- Additional Purposed TEA: high temperature desulfurization
    - Justification: Membrane operates at process temperature – benefit could be realized by maintaining syngas temperature
    - Implement RTI's warm gas cleanup train
    - Advanced technology tested at TECO 50 MWh scale

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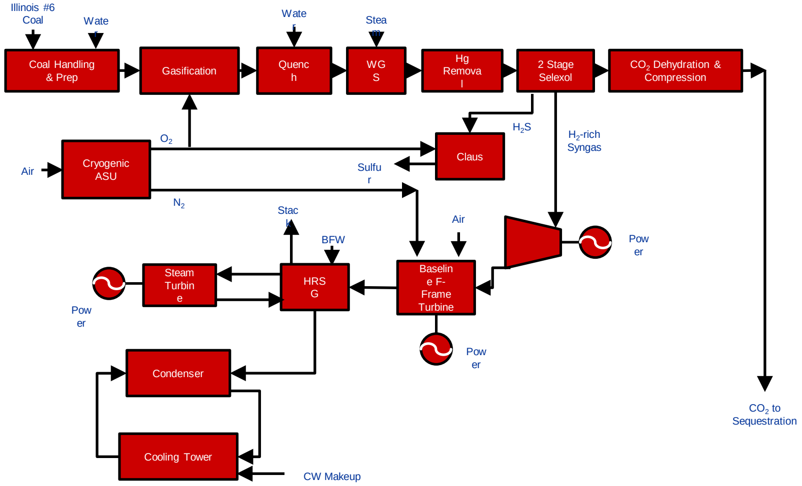
*1. Bituminous Baseline Volume 1 Rev. 2a*

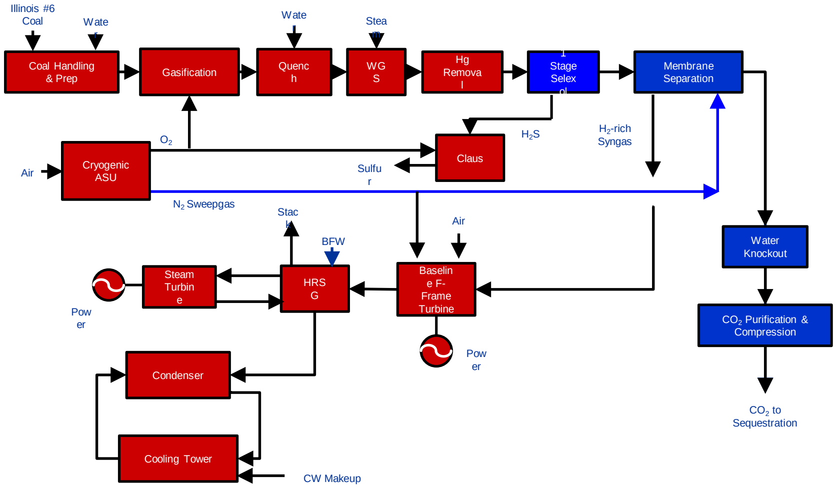
# Evaluated Cases

## Reference Case from Baseline

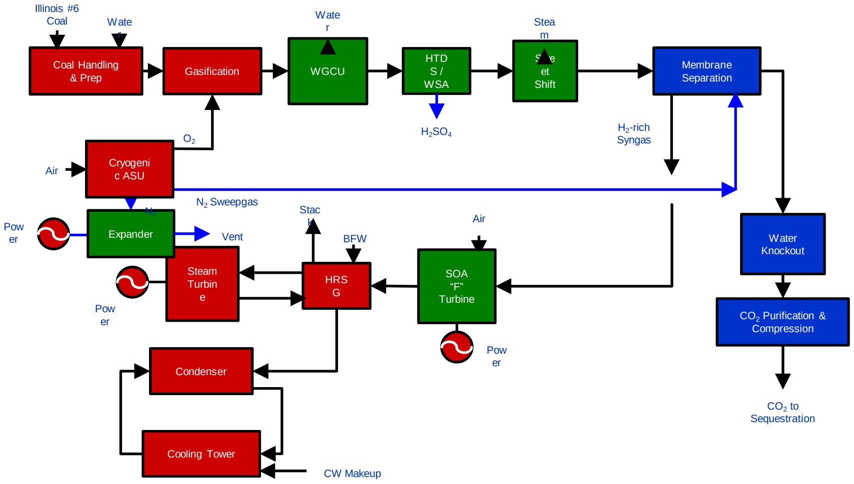


| Case | Baseline (Reference) | Case Study | |
|---|---|---|---|
| | | Case 1 | Case 2 |
| Technology Combinations | | | |
| $CO_2$ Removal | Selexol | Metal Membrane | |
| Sulfur | Selexol | | WGCU |

## Metal Membrane



## Metal Membrane & WGCU



# Technology Analysis Plan

- **Design Basis: Key assumptions**
  - Programmatic goal or targets
  - Note what scale current technology is at and relate to experimental data.
    - how reasonable assumption are
    - contingency
- **Purposed sensitivity studies**
  - Membrane permeance (flux)
  - Membrane service life
  - Capital cost of the precious metal membrane
- **Expected deliverables**
  - Presentation and report outlining results
  - Net power generation and efficiency
  - TPC and COE
  - Sensitivity results

## Key assumptions

| Hydrogen Membrane Parameter | Value | Implication if target not achieved | Potential of not achieving target |
|---|---|---|---|
| Permeance (lb-mole/ft$^2$-hr-psi$^{1/2}$) | 0.14 | Lower flux = increased membrane surface area, higher costs | High |
| Permeance degradation | 10-20% | Potentially lower service life | Moderate |
| Service life (years) | 3 | Greater replacement rate, increased O&M | High |
| Hydrogen recovery (%) | 90 | Increased fuel loss and lower efficiency | Moderate |
| Hydrogen selectivity (%) | 100 | Impure fuel to the turbine | Low |
| Effectiveness factor | 0.85 | Increased membrane area | Low |
| Bare erected cost (\$/ft$^2$) | 800 | Increased capital cost | Moderate |
| Replacement cost (\$/ft$^2$) | 400 | Increased O&M cost | Moderate |

# Performance Model

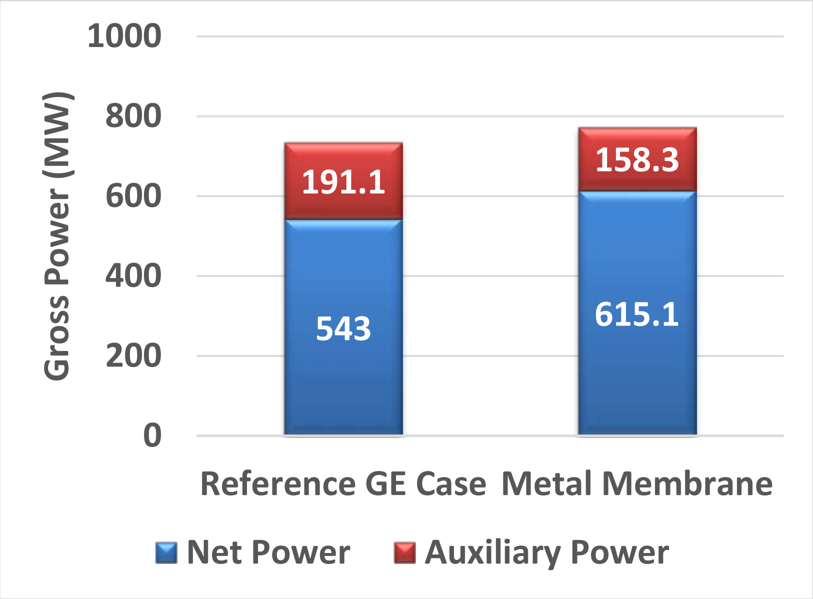
1. ASPEN Plus model for reference case
2. Proposed integration plan carried out to implement membrane
3. WGCU train was integrated into model

- High level plant wide results shown here
- Report should have significantly greater detail

| Parameter | Reference GE Case | Precious Metal Membrane Case |
|---|---|---|
| Turbine Power (MWe) | 464.0 | 464.0 |
| Fuel Gas Expander (MWe) | 7.0 | N/A |
| Steam Turbine Power (MWe) | 264.0 | 309.4 |
| Gross Power Produced (MWe) | 734.0 | 773.4 |
| Coal Handling | 0.5 | 0.5 |
| Coal Milling | 2.3 | 2.3 |
| Recycle Slurry Pump | 0.2 | 0.3 |
| Slag Handling | 1.2 | 1.2 |
| Air Separation Unit Auxiliaries | 1.0 | 1.0 |
| ASU Main Air Compressor | 67.3 | 66.4 |
| Oxygen Compressor | 10.6 | 10.7 |
| Nitrogen Compressor | 35.6 | 30.7 |
| $CO_2$ Compressor | 31.2 | 17.3 |
| Regeneration Air Compressor | N/A | 4.8 |
| Tail Gas Recycle Blower | 1.8 | 0.2 |
| WSA Air Blower | N/A | 4.3 |
| Cooling Tower Fans | 2.4 | 2.0 |
| Feedwater Pumps | 4.2 | 5.7 |
| Condensate Pumps | 0.3 | 0.3 |
| Circulating Water Pumps | 4.6 | 3.9 |
| Selexol Unit Auxiliaries | 19.2 | N/A |
| Gas Turbine Auxiliaries | 1.0 | 1.0 |
| Steam Turbine Auxiliaries | 0.1 | 0.1 |
| Claus Plant Auxiliaries | 0.3 | N/A |
| Miscellaneous Balance-of-Plant | 3.0 | 3.0 |
| Transformer Losses | 2.9 | 2.8 |
| Auxiliary Power Use (MWe) | 191.0 | 158.3 |
| Net Power (MWe) | 543.0 | 615.1 |
| As-Received Coal Feed (lb/hr) | 487,005 | 497,708 |
| Net Heat Rate (Btu/kW-hr) | 10,459 | 9,439 |
| Net Plant Efficiency (% HHV) | 32.6 | 36.2 |
| Net $CO_2$ Emissions ($lb/kW\text{-}hr_{net}$) | 0.206 | 0.102 |
| Simple Cycle Efficiency (%) | 42.4 | 41.1 |
| Steam Cycle Efficiency (%) | 42.4 | 39.3 |

# Performance Model Results (Example)

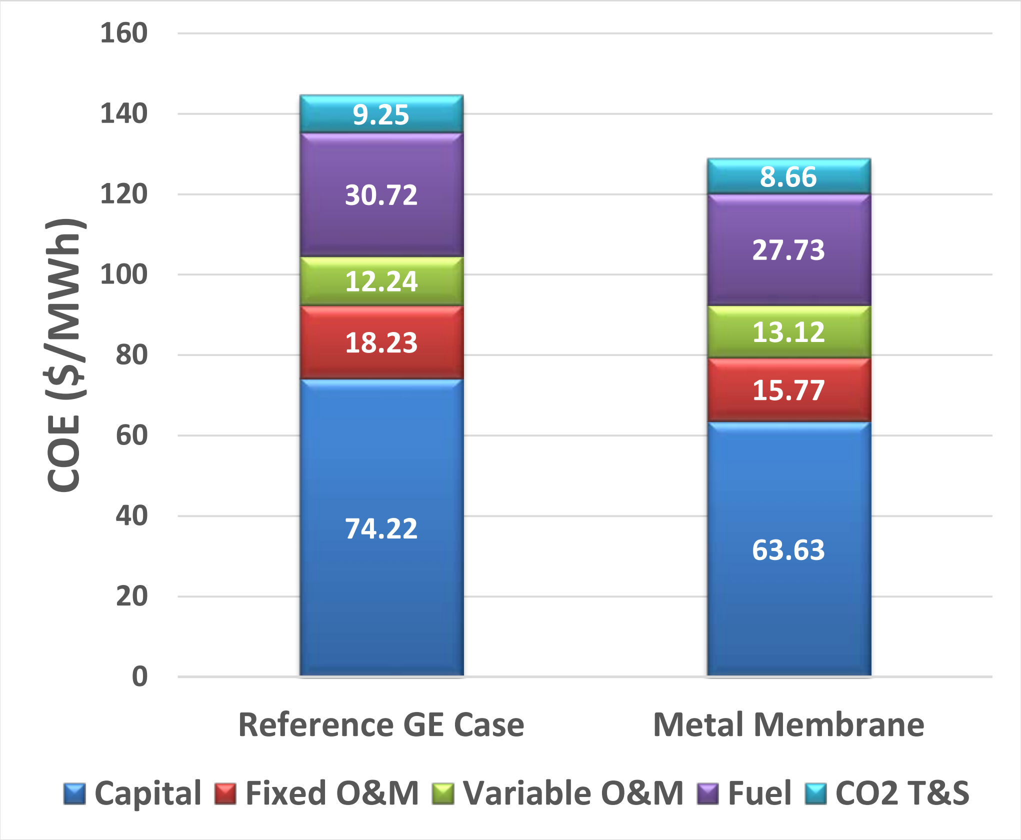
- No fuel gas expander in this case
- Steam turbine power increases by 48 MW by eliminating the Selexol and SWS reboilers. Syngas moisture is condensed, which contributes to steam turbine power
- Auxiliary power decreases by 30 MW
  - $N_2$ compressor load decreases by 5 MW from reduced fuel valve pressure drop
  - $CO_2$ pressures from auto-refrigeration are at greater pressure than from Selexol, decreasing $CO_2$ compressor load by 14 MW
  - 2nd generation technology differences further reduce auxiliary power load by 10 MW
- Plant efficiency increases by 3.5 percentage points, from 32.6% to 36.1%



# Cost Model Results

## COE Comparison

- Basis: Membrane replacement is based on 3-year service life and cost of $400/ft$^2$
- Capital cost and fixed O&M cost are 13%lower
- 8% increase in variable O&M cost
  - dominated by membrane replacement cost
  - Trona and ZnO chemical
- 10% decrease in fuel cost reflects increase in net power generation
- Overall, COE decreases from $135/MWh to $120/MWh (w/o T&S) in the precious metal membrane case. Primary factors contributing to the decrease are:
  - Increased net power generation
  - reduced $CO_2$ compressor cost

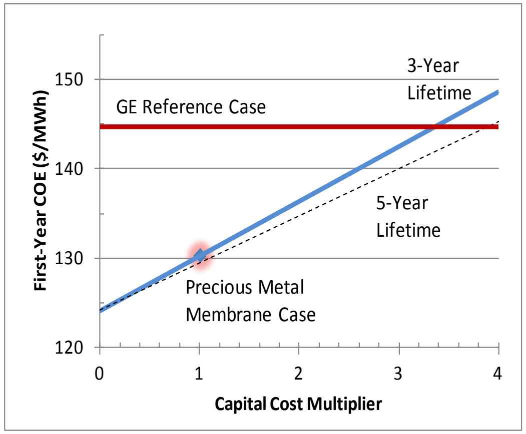


# Sensitivity Analyses

## Sensitivity to Capital Cost and Service Life

- Both capital cost and membrane replacement cost are multiplied by the cost factor
- If the cost of the membrane exceeds 315% of its design basis cost, this technology loses its economic advantage over the low-cost GE reference case
- If service life increases to 5 years, the precious metal membrane increases its economic advantage

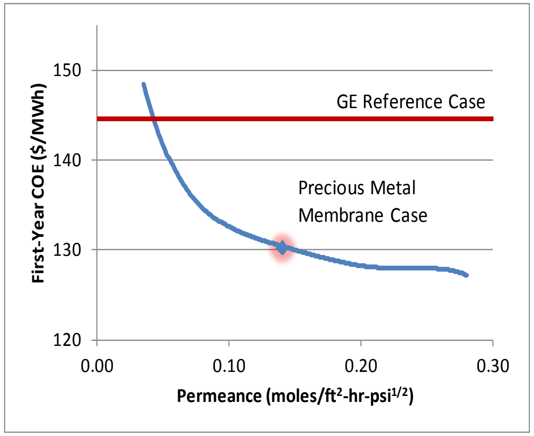
The metal membrane loses its economic advantage if capital cost increases



## Sensitivity to Permeance

- Membrane surface area is strongly tied to permeance
- Membrane cost (and COE) increase sharply as permeance falls below 0.10 moles/ft$^2$-hr-psi$^{1/2}$
- Precious metal membrane case does not lose its economic advantage until permeance drops below 0.04 moles/ft$^2$-hr-psi$^{1/2}$

Membrane cost and COE are highly sensitive to permeance



# Summary

- Condensation of moisture from non-permeate stream contributes to steam turbine power generation. Increase in dilution $N_2$ for fuel decreases the reduction in $N_2$ compressor load
- Fuel valve pressure drop of 50 psi reduces $N_2$ compressor load
- 72 MW increase in net power generation results in 3.5 percentage point increase in efficiency
- Due to high cost of membrane, decrease in gas cleanup cost account is minor
- 13% reduction in TPC is due to 2nd generation technologies and increase in net power generation
- COE decreases by 10% relative to the low-cost GE reference case
- High cost of membrane material makes COE very sensitive to capital equipment cost, service life, and permeance