Recovery Act: Oxy-Combustion

Oxygen Transport Membrane Development

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| Phase 1 | 05/07 – 12/09 | OTM integrated coal power plant  
Advanced oxy-combustion cycle  
Process economic evaluation  
Membrane performance improvement |
|---------|---------------|---------------------------------------------------------------------|
| Phase 2 | 01/10 – 6/12  | OTM integrated coal power plant  
Advanced oxy-combustion cycle  
Scale-up membrane technology  
Equipment design for pilot demonstration |
| Phase 3 | 10/10 – 09/15 | Industrial Applications  
ARRA funding  
OTM integrated process for conversion of natural gas to syngas  
160,000 scfh syngas demonstration  
OTM modules qualified for scale-up and larger demonstration projects |
Principle of Operation

Air < 5 psi

\[ \text{O}_2 + 4e \rightarrow 2\text{O}^{2-} \]

Fuel Gas > 100 psi  Heat

Process Fluid

Gas separation layer

Oxy-Combustion Without Producing Oxygen
OTM Power Cycle

OTM Technology
70% of O₂ requirements

550 MWₑ net Plant

Cryogenic Technology
30% of O₂ requirements

US Patents 7,856,829 & 8,196,387
Equipment Design

- Basic design of pilot units and cost estimate with scaling factors completed
- 5 tpd O2 partial oxidation unit
- 7.5 MWth boiler
- Scaling factors established
- Concepts used to cost large scale equipment
- Update to power cycle economics
- Allowable membrane cost to meet DOE cost of electricity targets
OTM Testing with Coal Gas Fuel

Praxair Hot Oxygen Burner for Coal Syngas

OTM Coal Gas Reactor University of Utah

Coal Feeder

Syngas Flame

HOB Coal Gasifier
OTM Testing with Coal Gas Fuel

- Tests with 25/75 mixtures of Utah/PRB and 50/50 mixtures of Illinois/PRB
- No filter between HOB and OTM reactor
- Large build-up of ash on surface OTM tube
- Coatings inside tube are protected by substrate
- Significant corrosion of metal parts in furnace
- No reaction found in post-test analysis

<table>
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<tr>
<th>Coal Type</th>
<th>LOD (105°C)</th>
<th>Ash (705°C)</th>
<th>C</th>
<th>H</th>
<th>N</th>
<th>S (by diff)</th>
<th>Volatile Matter</th>
<th>Fixed Carbon</th>
<th>HHV (BTU/lb)</th>
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</thead>
<tbody>
<tr>
<td>Utah</td>
<td>3.18</td>
<td>8.83</td>
<td>70.6</td>
<td>5.41</td>
<td>1.42</td>
<td>0.53</td>
<td>13.21</td>
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<td>Illinois</td>
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<td>7.99</td>
<td>64.67</td>
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<td>3.98</td>
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<td>PRB*</td>
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<td>0.23</td>
<td>34.11</td>
<td>33.36</td>
<td>38.01</td>
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</tbody>
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*North Antelope Powder River Basin
Applications

- **OTM Boiler**
  - Steam and Power with CCS
  - Process heaters
  - Long term applications

- **OTM Autothermal Reformer**
  - Syngas for liquid fuels and chemicals
  - Low H2O/C ratio
  - Near term applications

Heat transfer from OTM to process fluid is key to all applications
OTM Autothermal Reformer Process

- Oxidize recycled syngas with OTM
- Steam and CO\textsubscript{2} reforming in separate catalyst section
- Improved coking resistance of feed stream
- Reactive fuel drives high oxygen flux without a catalyst
- Requires good thermal integration between catalyst and OTM
Development of robust test methodologies is critical

- Large sample size and long times for success based testing with confidence
- Engaged consultant with proprietary techniques
- Initial focus on membrane, seal and identification of other high risk areas
Test Infrastructure
Preliminary Results from Commercial Scale Cost Study

- Comparison of conventional process to OTM process
  - 5,000 bpd syncrude from natural gas feedstock
- Conventional process technology
  - Syngas island: SMR + H2 membrane
  - FT island: Microchannel FT reactors
- Developed detailed process models to evaluate operating performance
- Working to establish cost targets for critical components based on capital estimates of flow sheets

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Benefits of OTM Based Process Over Conventional Process</th>
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</thead>
<tbody>
<tr>
<td>CO2 emissions (lb CO2/bbl product)</td>
<td>70% lower</td>
</tr>
<tr>
<td>Gas conversion (scf/bbl)</td>
<td>23% lower</td>
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Development Roadmap

Cost, Performance, Reliability & Life
Acknowledgements

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