Low Cost Hydrogen Production from Biomass Using Novel Membrane Gasification Reactor

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This presentation does not contain any proprietary or confidential information
Overview

Timeline
> Start: ?
> End: ?
> Percent complete: 1%

Budget
> Total project funding: $3,372,126
  –DOE share: $2,697,701
  –Contractors share: $674,425
> Funding received in FY04: $0
> Funding for FY05: $?
Overview (con’t)

Barriers

> Hydrogen Production from Biomass Barrier
  G. Efficiency of Gasification, Pyrolysis, and Reforming Technology

> DOE Technical Target
  – $2.5/kg H₂ for hydrogen from biomass by 2010

Partners

> Arizona State University
> National Energy Technology Laboratory
> Schott Glass North America
> Wah Chang, an Allegheny Technology Company
Project Objectives

> Reduce the cost of hydrogen from biomass to $2.5/kg H₂ by developing an efficient novel membrane reactor combining biomass gasification, reforming and shift reaction in one step

> Develop hydrogen-selective membrane materials compatible with the biomass gasification conditions

> Demonstrate the feasibility of the concept in a bench scale biomass gasifier
Conventional Hydrogen Production from Biomass Gasification

Biomass Syngas Platform

Biomass → Feed preparation → Gasification → Gas cleaning → Syngas

Syngas → Shift reaction → CO₂ removal → PSA → Hydrogen

H₂ From Syngas

Tail gas → Steam or Power generation
Hydrogen Production Cost from Biomass Gasification

Total cost breakdown
- 25% feedstock
- 25% capital
- 50% operation & maintenance

Capital cost breakdown
- 25% biomass feed handling
- 20% gasifier
- 20% air separation
- 20% reforming & separation
- 15% balance of plant
Approach

> Extract hydrogen directly from gasifier using high temperature H$_2$-selective membrane

> Achieve one-step biomass gas reforming, shift and hydrogen separation
Potential Benefits of Membrane Reactor for Hydrogen Production from Biomass

> High H₂ production efficiency:
  - Thermodynamic analysis indicates potentially over 40% improvement in H₂ production efficiency over the current gasification technologies

| Eliminate loss in PSA tail gas
| More CO shift H₂O+CO = CO₂+H₂
| Reform CH₄ CH₄+H₂O = CO+3H₂

> Low cost:
  - reduce/eliminate downstream processing steps

> Clean product:
  - no further conditioning needed, pure hydrogen

> CO₂ sequestration ready:
  - simplify CO₂ capture process

> Power co-generation:
  - utilization of non-permeable syngas
GTI’s Fluidized Bed Gasifier RENUGAS®
Ideal for Membrane Gasification Reactor

Membrane module in this area

STEAM/OXYGEN OR AIR

ASH LOCKHOPPER

BIOMASS FEED

FEED LOCKHOPPER

1st-STAGE CYCLONE

2nd-STAGE CYCLONE

RAW PRODUCT GAS

Disengaging zone

Gasification zone

T: 700~900°C
P: 20~60 atm
H₂, CO, CO₂, H₂O each 15~25%
CH₄: 5~10%
Contaminants
# Advanced Inorganic Membranes for Biomass Gasification Application

<table>
<thead>
<tr>
<th>Mixed proton/electron conducting membrane</th>
<th>Atomic transport dense metallic membrane</th>
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<tbody>
<tr>
<td>Hydrogen at high pressure</td>
<td>Hydrogen at high pressure</td>
</tr>
<tr>
<td>H₂ → 2H⁺ + 2e⁻</td>
<td>H₂ → 2H</td>
</tr>
<tr>
<td>Hydrogen at low pressure</td>
<td>2H⁺ + 2e⁻ → H₂</td>
</tr>
<tr>
<td></td>
<td>H → H⁺</td>
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<td>H → H</td>
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<tr>
<th>Multi-phase ceramic/metal membrane</th>
<th>Dense thin layer on porous support layer</th>
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<tbody>
<tr>
<td></td>
<td>Active H₂ transport layer</td>
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<tr>
<td></td>
<td>Catalytic support layer</td>
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Scope of Work

> Task 1. Membrane material development
  – Subtask 1.1 Ceramic material synthesis and testing
  – Subtask 1.2 Metallic membrane synthesis and testing
  – Subtask 1.3 Multi-phase membrane synthesis and testing
  – Subtask 1.4 Optimization of selected candidate membranes

> Task 2. Gasification membrane reactor process development and economic analysis
Scope of Work (con’t)

> Task 3. Design of membrane module configuration
> Task 4. Membrane module fabrication
> Task 5. Bench scale biomass gasifier design and construction
> Task 6. Testing of a bench scale biomass gasification membrane reactor
Task 1.1 Ceramic Membrane Material Synthesis and Testing
led by Arizona State University

> Proton-conducting material synthesis
  – Powder preparation by citrate method
  – Membrane fabrication by pressing-sintering

> Material characterization
  – Conductivity/flux measurement

> Chemical stability evaluation
  – Compatible to biomass-derived syngas

> Improve hydrogen separation and flux
  – Membrane seal
  – Thin membrane (to 5 micron)
Task 1.2 Metallic Membrane Material Synthesis and Testing

led by NETL

> Verification of sulfur resistance of Pd-Cu alloy membrane
  – No inhibition of H₂ flux for Pd₇₀Cu₃₀ under 1000 ppm H₂S

> Optimization of Pd-Cu alloy compositions
  – With respect to permeability and sulfur resistance

> Effect of non-sulfur contamination on Pd-Cu membrane
  – N, Cl, Na

> Durability test
Task 1.3 Multi-Phase Membrane Material Synthesis and Testing

- Fabricate single-phase ceramic membranes
- Fabricate multi-phase membranes
  - Metal phase to increase electronic conductivity
  - Thin membrane on a support layer
- Conduct permeation and chemical stability testing under simulated biomass syngas conditions
- Incorporate catalyst to the membrane support layer
  - Tar cracking, reforming and shift reactions
Task 1.3 Multi-Phase Membrane Material Synthesis and Testing (Glass-Based)

led by Schott Glass

> Survey of known glass-ceramic compositional families with respect to $\text{H}_2$ permeability

> Material development to evaluate and optimize the prospective materials in the Schott Glass Test Melt facility

> Evaluate using glass as a substrate to incorporate other hydrogen transport materials
Task 2. Membrane Reactor Process Development and Economic Analysis

> Develop membrane permeation model or correlation based on the measured data

> Evaluate overall process performances for hydrogen production from biomass based on different membrane reactor process options

> Perform analysis on process economics

> Provide feedback and targets for the performance and cost of the membrane materials
Task 3. & 4. Design and Fabrication of Membrane Module Configuration

> Conceptual design, tubular, planar, or monolithic
> Modeling approach for sizing
> Sealing development
> Mechanical design
> Assisted by Wah Chang and Schott Glass
Task 5. Bench Scale Biomass Gasifier Design and Construction

- GTI’s RENUGAS® fluidization bed technology
- Make use of components from an existing low pressure unit
- Two to four inches in gasifier diameter
- Oxygen/air blown
- 60 bar and 1000°C
**Task 6. Integrated Testing of Membrane Reactor with Bench Scale Biomass Gasifier**

- Commission the new bench scale gasifier
- Install the membrane module to the gasifier
- Prepare test plan and conduct testing
- Demonstrate technical feasibility of one step hydrogen production from biomass gasifier using membrane reactor

- **Biomass feed:**
  - wood pellet, \( \sim 1 \text{ kg/hr} \)
## Road Map to Successful Membrane Gasification Reactor Technology

<table>
<thead>
<tr>
<th>Membrane Material Development</th>
<th>Membrane Module Development</th>
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<tbody>
<tr>
<td>- Material synthesis</td>
<td>- Design of membrane gasifier configuration</td>
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<td>- Screening and testing</td>
<td>- Large-scale membrane manufacturing</td>
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<td>- Contaminant issues</td>
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<td>- Stability and durability</td>
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<tr>
<th>Membrane Process Development</th>
<th>Membrane Gasifier Scale-up</th>
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<tr>
<td>- Flow sheet development and simulation</td>
<td>- Engineering design</td>
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<td>- Optimize operation conditions</td>
<td>- Bench scale</td>
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<tr>
<td>- Economic analysis</td>
<td>- Pilot unit (GTI’s FlexFuel unit)</td>
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<td>- Prototype demonstration</td>
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Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

> Hydrogen leakage

> Equipment or instrument failure of high temperature and high pressure apparatus (permeation unit, gasifier)
Hydrogen Safety

Our approach to deal with this hazard is:

> Hazard assessment
  – what-if/checklists, hazard and operability studies (HAZOP), failure mode and effects analyses (FMEA), fault tree analyses, and others.

> Risk management plan
  – identify approaches and actions required to mitigate and minimize exposure to identified risks

> Communication plan
  – failure reporting and corrective actions, periodic revision of all safety plans, training, emergency response plan development, and safety-related reporting to the sponsor