High Temperature Electrolysis for Hydrogen Production

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Materials Innovations in
an Emerging Hydrogen Economy
Hilton Oceanfront
Cocoa Beach, Florida
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High Temperature Electrolysis Plant
$90\% \ H_2O + 10\% \ H_2$  

$25\% \ H_2O + 75\% \ H_2$

**Porous Anode, Strontium-doped Lanthanum Manganite**

**Gastight Electrolyte, Yttria-Stabilized Zirconia**

**Porous Cathode, Nickel-Zirconia cermet**

$2 \ H_2O + 4 \ e^- \rightarrow 2 \ H_2 + 2 \ O^=$

$2 \ O^= \rightarrow O_2 + 4 \ e^-$

$H_2O + H_2 \rightarrow$

$H_2O \downarrow$

$O_2 \downarrow$

$\leftrightarrow O_2$

**Typical thicknesses**

<table>
<thead>
<tr>
<th>Electrolyte-supported</th>
<th>Cathode-supported</th>
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<tbody>
<tr>
<td>0.05 mm</td>
<td>1.500 mm</td>
</tr>
<tr>
<td>0.10 mm</td>
<td>0.01 mm</td>
</tr>
<tr>
<td>0.05 mm</td>
<td>0.05 mm</td>
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<td>1 – 2.5 mm</td>
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Stack Internal Components

Stainless Steel Interconnect Plate

ScSZ Electrolyte

LSM Electrode

10 cm
25-cell stack used in 1000-hour test
Jan. 4 – Feb. 16, 2006

2 x 60-cell stacks tested at Ceramatec, SLC

Initial rate: 1.2 Nm3 H2/hr
final: 0.65 Nm3 H2/hr
2040 hours, ended 9-22-06
>800 hrs in co-electrolysis
High Temperature Electrolysis: from Button Cells to the Integrated Laboratory Scale Experiment

Button cell (2003) 3.2 cm²
10-cell stack (2004) 640 cm²
120-cell half-module (2006) 7,680 cm²

Research Goals:
• Develop efficient solid-oxide electrolysis cells, building on solid-oxide fuel cell research
• Decrease cost, increase durability
• Determine reasons for long-term cell degradation
• Optimize plant designs
• Co-electrolyze CO₂ and steam to CO and H₂
• Develop designs to apply nuclear heat and H₂ to heavy petroleum and oil sand upgrading
• Integrate nuclear energy sources and fossil/biomass carbon sources for hydrocarbon synthesis

CFD and Flowsheet Analyses

Temperature profile of cell
Process Flowsheet for Reactor-driven commercial plant

Integrated Laboratory Scale (operational 8-22-07) 720 cells, 3 modules (2008) 46,080 cm²
ILS Piping and Instrumentation
Comparison of nominal and extreme design cases.

<table>
<thead>
<tr>
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<th>Nominal Case</th>
<th>Extreme Design Case</th>
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<tbody>
<tr>
<td>ASR (ohm cm²)</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Current Density (A/cm²)</td>
<td>0.25</td>
<td>0.37</td>
</tr>
<tr>
<td>Per-cell Voltage, (V)</td>
<td>1.283</td>
<td>1.283</td>
</tr>
<tr>
<td>Electrolysis Power (kW)</td>
<td>14.54</td>
<td>21.8</td>
</tr>
<tr>
<td>Hydrogen Production Rate (NL/hr)</td>
<td>4735</td>
<td>7103</td>
</tr>
</tbody>
</table>
Assembled ILS Components
High-Temperature Electrolysis
Integrated Laboratory Scale Experiment July 16, 2007
ILS Module Installation
ILS Module Installation
Start of Testing

Initial operations began Aug 24, 2007
Module testing began Sept 24, 2007
**ILS Module Sweep Data**

![Graphs showing Stack Operating Voltage (V), Stack Internal Temperatures (°C), ASR, Polarization Curve, Stack #1, Top, Stack #2, Top, Stack #3, Top, Stack #4, Top, Shunt Current (A), Average ASR ~ 2.38 Ωcm², H₂ Production Rate (slpm), Dew Point Temperature (°C), Inlet Dew Point T (°C), Outlet Dew Point T (°C), and Shunt Current (A).]
Overall ILS Data

One additional experimental problem:

Bias voltages arising from intra-stack instrumentation

Not a problem for short stacks

Next iteration – separate DAC for intra-stack instrumentation
Syntrolysis: Co-Electrolysis of CO₂ and Steam to produce CO and H₂ (synthesis gas)

\[ 2 \text{H}_2\text{O} + \text{CO}_2 \rightarrow 2\text{H}_2 + \text{CO} + 1.5 \text{O}_2 \]

(demonstrated 2006 and 2007 at INL and Ceramatec)

Application: Carbon-neutral Production of Synthetic Diesel and Jet fuels via the Fischer-Tropsch process

\[ n\text{CO} + (2n+1)\text{H}_2 \rightarrow C_n\text{H}_{2n+2} + n\text{H}_2\text{O} \]

using CO₂ from biomass sources and nuclear heat/electricity
INL Coelectrolysis Experiment
Conclusions

• Conventional electrolysis is available today
• High temperature electrolysis is under development and will be more efficient
• HTE Experimental results from 25-cell stack, 2x60-cell half-module and 4x60-cell full module, fabricated by Ceramatec,
  – Hydrogen production greater than 800 normal liters/hour was achieved in the half-module test for 2040 hours
  – The Integrated Laboratory Scale experiment operated with one module in Sept-Oct 2007, producing a maximum of 2.0 Nm³/hr and an average of ~0.85 Nm³/hr for 420 hours
• In the near-term hydrogen from nuclear energy will be used to upgrade crude and later to synthesize conventional gasoline and diesel fuel from renewable carbon sources
• In the long-term pure hydrogen from nuclear energy will power vehicles directly through fuel cells