Direct Coal Power Generation
Using
Liquid Tin Anode Fuel Cell

9th Annual SECA Workshop
Pittsburg, PA

August 7, 2008
Liquid Tin Anode Direct Coal Fuel Cell

Background

• How it Works
• Technology Experience
• Direct JP-8

Power Gen Applications

• Potential Benefits
• Challenges
• Experimental Work
• Development Activities
CellTech Technology: Liquid Tin Anode

Tin is Ideal Anode
✓ Low Cost
✓ Non-toxic
✓ Not harmed by sulfur, carbon
✓ Wide industrial application

Sn(l) + 2 O^{2-} = SnO_2 + 4 e^-
SnO_2 + C(s) = 2 CO_2(g) + Sn

2 Patents
10 Applications
Liquid Tin Anode: Experience

• Strong DoD support (Direct JP-8, portable)
  – 4X power density increase demonstrated in 2007
    • Additional 6X possible
  – Fundamental, Cell & System development support
• 1 kW Natural Gas prototype operated 2000 hrs
• EPRI Direct Coal and Biomass
  – Direct Coal experimental evaluation
  – Short term, no detectable contaminants in tin
Direct JP-8 Conversion

Gen 3.0
Developed 2005-6:
For DARPA/MISER
Direct Waste Plastic
Conversion

Gen 3.1
Developed 2007-8:
For DARPA/ARMY
Direct JP-8
Conversion
4x reduction

Top View
Cross Section

Separator
Liq Tin (500 micron)
Electrolyte
Cathode

CellTech Power
Fuel Cells for Real Fuels
250 Watt JP-8 Fuel Cell Generator Concept

System Specifications
250 Watt DC or AC output
12 kilogram dry weight
20 liter volume
1 week operation on 5 gallons of JP-8
LTA- SOFC Direct Coal
Use existing Gen 3 Architecture

Cell Cross Section

Stack
Tin Reactor Flowsheet with CCS

- CO₂ Capture & Compression
- H₂O Removal (optional)
- Sulfur Removal
- CO₂ Capture & Compression
- H₂O Removal (optional)
- Sulfur Removal
- Ash
- Spent Fuel Recycle
- Nitrogen Bleed
- Coal
- Tin Reactor 900-1000°C
- Oxygenated Tin (0.1~0.2 wt% O)
- LTA
- Recuperator
- Air
- Spent Air
- Power

CellTech Power
Fuel Cells for Real Fuels
Tin Reactor Flowsheet with CCS
CellTech Direct Coal: Potential

- Near 100% CO₂ capture
- Similar capital cost to conventional coal
- Lower efficiency penalty for CO₂ capture
- Scalable for early biomass markets (1 MW range)

Direct Coal - Major Challenges

**Cell/Stack**
- Impurities
- Cell Scale-up
- Power density
- Cathode improvement
- Longevity

**System**
- Molten Metal Anode Chemistry
- Molten Tin Processing
- 100% Fuel Utilization
- Electrical Isolation
- Tin Circulation

DOE Programs

DoD Programs

Collaboration
Direct Coal Experimental Efficiency Evaluation

Batch mode, single cell

<table>
<thead>
<tr>
<th></th>
<th>Bio-char Univ of Hawaii</th>
<th>Coal Pulverized East/West</th>
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<tbody>
<tr>
<td>Net power measured at test stand load</td>
<td>34%</td>
<td>37%</td>
</tr>
<tr>
<td>IR and Air Corrected</td>
<td>67%</td>
<td>&gt;57%</td>
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*Without correction for fuel utilization*
Direct Coal Experimental Contaminate Evaluation

<table>
<thead>
<tr>
<th>Contaminants of Interest</th>
<th>Procedure</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (As)</td>
<td>Batch mode</td>
<td></td>
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<tr>
<td>Chromium (Cr)</td>
<td>Coal in tin reactor 1000° C</td>
<td>Contaminants of interest below detectable limits</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>Coal reacted to completion</td>
<td></td>
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<tr>
<td>Niobium (Nb)</td>
<td>100 hr test</td>
<td></td>
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<tr>
<td>Selenium (Se)</td>
<td></td>
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<tr>
<td>Tantalum (Ta)</td>
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<td>Tellurium (Te)</td>
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<td>Tungsten (W)</td>
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<tr>
<td>Uranium (U)</td>
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<tr>
<td>Vanadium (V)</td>
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Operation on Plastic

Polypropylene 2 Amp Run

Graph showing the power output (Watts) over time (Minutes) with "Plastic Addition" and "Battery Mode" indicated on the graph.
Operation on carbon

Ran approximately 20 hours on single charge of carbon (no refueling attempted)
DOE Programs- Key Technical Tasks

Two Programs to look at key risk areas for Direct Coal using Liquid Tin Anode

1. Novel Coal Cooperative Agree. – Phase 1: 18 months
   – Contamination Evaluation–
     – Non-electrochemical
     – Electrochemical
   – Provide input to DOE Systems Analysis

2. Direct Coal SBIR – Phase 1: 9 months
   – Cell scale up analysis and design
Novel Coal Phase 1 – 18 Months

**Coal Tin Reactor Test:** Batch testing to establish equilibrium levels of contaminants

**Coal Electrochemical Test:** Evaluate impact of tin contaminants on YSZ. Use Gen 3.1 JP-8 cells.

**Phase 2:** Cell/Stack Testing in molten tin

**Co-funded by EPRI**
Phase 1 SBIR

Cell Scale Up

a) Use existing data to develop a polarization curve
b) Cell scale up to 1kW - Preliminary design
c) Cell Degradation SnO$_2$-YSZ plus contaminants
   i. Areas of concern, possible mitigation techniques
Summary – Liquid Tin Anode

- Tin “purification” decouples coal oxidation from power production
- Could achieve breakthrough efficiency and enable 100% CO₂ capture
- EPRI & DARPA programs have established feasibility of Direct Coal/JP-8
- Strong DoD support for small cells provides an R&D platform for coal
- DOE/CellTech programs focus on impurities and efficiency validation
- Cooperative programs planned for “balance of system” technology development