Next Generation Bipolar Plates for Automotive PEM Fuel Cells

2009 Department of Energy Hydrogen Program Annual Merit Review

Orest Adrianowycz, Ph.D.
GrafTech International Ltd.

May 21, 2009

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Overview

Collaborators
- GrafTech International Ltd.
  - Primary Contractor
  - Composite fabrication
- Ballard Power Systems
  - Fuel Cell design
  - Stack Testing
- Huntsman Advanced Materials
  - Resin Selection
- Case Western Reserve University
  - Single cell testing, HT MEA

Project Timeline
- Start date: March 1st, 2007
- End date: February 29th, 2009
- Extension date: August 31, 2009
- Percent complete: 90%

Budget
- Total project: $2.9 MM
  - 20% Cost Share
- Spending FY07: $760 K
- Spending FY08: $1,550 K
- Budgeted FY09: $590 K

Barriers (bipolar plates)
- A - Durability
  - Improved corrosion resistance
  - Decrease weight and volume
- B - Cost
  - Lower material & production costs
  - Increased power density
- C - Performance
  - Improved gas impermeability
  - Improved electrical and thermal conductivity
Program Objectives

Overall Project Objective
• Develop next-generation automotive bipolar plates based on an engineered composite of expanded graphite and resin capable of operation at 120 °C

Goals Year 1
• Develop graphite/polymer composite to meet 120°C fuel cell operating temperature
• Demonstrate manufacturing capability of new materials to a reduced bipolar plate thickness of 1.6 mm

Goals Year 2
• Manufacture high-temperature flow field plates for full scale testing
• Validate performance of new plates under automotive conditions using a short (10-cell) stack
• Show viability of published cost target through the use of low-cost materials amenable to high volume manufacturing
Approach

Task 1: Graphite Selection
- Raw Material Evaluation
- Intercalation Chemistry and Processing Optimization

Task 2: Resin Selection
- Resin Evaluation
- Resin Selection

Task 3: Small-Scale Composite Prep
- Develop Methods for Composite Plate Manufacturing and Testing
- Evaluate Properties
- Environmental Chamber Testing

Task 4: Composite Machining and Embossing
- Machined Plates for Single Cell Testing
- Validate Composite Properties
- Evaluate Small Embossed Test Plates
  - GO-no-GO Decision point

Task 5: Single Cell Testing
- Select High Temp Cell Components
- Develop Test Method for Leachates
- Perform Single Cell Testing and Analysis

Task 6: Design and Manufacture Full-size Bipolar Plates
- Design Flow Field Plate Molds
- Fabricate Full Size Embossing Die Set
- Manufacture Full-size Bipolar Plates

Task 7: Full-size Plate Short Stack Testing
- Short stack plate assembly
- Test Cells in Short-Cell Stack
- Post-Test Analysis
- Deliver Full Size Plate Stack to DOE

Task 8: Economic Assessment of New Technologies
- Perform economic assessment of the selected raw material and manufacturing processing
Flow Field Plate Functions

- Current collector
- Deliver and uniformly distribute fuel and oxidant over cell active area
- Facilitate membrane water management
- Maintain impermeable hydrogen barrier across membrane for higher power
- Stack structural support
- Heat removal & distribution
- Most bulky component in the PEM fuel cell stack by weight and volume
## Technical Targets: Bipolar Plates, Table 3.4.14

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Units</th>
<th>2005 Status</th>
<th>2010 Targets</th>
<th>2015 Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost b</td>
<td>$ / kW</td>
<td>10&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Weight</td>
<td>kg / kW</td>
<td>0.36</td>
<td>&lt;0.4</td>
<td>&lt;0.4</td>
</tr>
<tr>
<td>H₂ permeation flux</td>
<td>cm³ sec&lt;sup&gt;-1&lt;/sup&gt; cm&lt;sup&gt;-2&lt;/sup&gt; @ 80°C, 3 atm (equivalent to &lt;0.1 mA / cm²)</td>
<td>&lt;2 x 10&lt;sup&gt;-6&lt;/sup&gt;</td>
<td>&lt;2 x 10&lt;sup&gt;-6&lt;/sup&gt;</td>
<td>&lt;2 x 10&lt;sup&gt;-6&lt;/sup&gt;</td>
</tr>
<tr>
<td>Corrosion</td>
<td>μA / cm²</td>
<td>&lt;1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>&lt;1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>&lt;1&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>S / cm</td>
<td>&gt;600</td>
<td>&gt;100</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Resistivity&lt;sup&gt;e&lt;/sup&gt;</td>
<td>Ohm-cm</td>
<td>&lt;0.02</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Flexural Strength&lt;sup&gt;f&lt;/sup&gt;</td>
<td>MPa</td>
<td>&gt;34</td>
<td>&gt;25</td>
<td>&gt;25</td>
</tr>
<tr>
<td>Flexibility</td>
<td>% deflection at mid-span</td>
<td>1.5 to 3.5</td>
<td>3 to 5</td>
<td>3 to 5</td>
</tr>
</tbody>
</table>

---

<sup>a</sup> First year for which status was available. 2005 status is for carbon plates, except for corrosion status which is based on metal plates.

<sup>b</sup> Based on 2002 dollars and costs projected to high volume production (500,000 stacks per year)

<sup>c</sup> Status is from 2005 TIAAX study and will be periodically updated.

<sup>d</sup> May have to be as low as 1 nA / cm² if all corrosion product ions remain in ionomer

<sup>e</sup> Includes contact resistance

<sup>f</sup> Developers have used ASTM C-651-91 Standard Test Method for Flexural Strength of Manufactured Carbon and Graphite Articles Using Four Point Loading at Room Temperature.
## Flow Field Plate Technologies Comparison

<table>
<thead>
<tr>
<th>Technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| GRAFCELL® Resin Impregnated Flexible Graphite | Chemically inert  
Electrical conductivity  
Contact resistance  
Thermal conductivity  
Thin  
Lower Cost  
Proven performance | Strength  
Not as thin as metals |
| Graphite-Filled Polymers    | Known fabrication techniques  
Molded-in flow fields  
Low Density | Thermal conductivity  
Electrical conductivity  
Temperature capability  
Brittleness  
Molding with high filler content |
| Metals                     | Electrical conductivity  
Strength  
Temperature  
Thin  
Known fabrication techniques | Corrosion  
Poisoning of MEA  
Contact resistance  
Thermal conductivity  
Density  
Expensive alloys and coatings |
## Property Status for New Expanded Graphite FFPs

<table>
<thead>
<tr>
<th>Material Property</th>
<th>DOE Target Need</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Conductivity</td>
<td>Plate</td>
<td>Meets DoE 2015 Target</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>Balance of Plant</td>
<td>Meets DoE 2015 Target</td>
</tr>
<tr>
<td>Contact Resistance</td>
<td>Plate</td>
<td>Meets DoE 2015 Target</td>
</tr>
<tr>
<td>Temperature (120 °C)</td>
<td>MEA, Balance of Plant</td>
<td>R&amp;D needed</td>
</tr>
<tr>
<td>Gas Impermeability</td>
<td>Plate</td>
<td>R&amp;D needed</td>
</tr>
<tr>
<td>Mechanical Strength</td>
<td>Plate</td>
<td>R&amp;D needed</td>
</tr>
<tr>
<td>Corrosion</td>
<td>Plate</td>
<td>Meets DoE 2015 Target</td>
</tr>
<tr>
<td>Ion Leachability</td>
<td>System Durability</td>
<td>R&amp;D needed</td>
</tr>
<tr>
<td>Thickness</td>
<td>System Power Density</td>
<td>R&amp;D needed</td>
</tr>
<tr>
<td>Manufacturability</td>
<td>Technology Viability</td>
<td>R&amp;D needed</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Plate</td>
<td>Meets DoE 2015 Target</td>
</tr>
<tr>
<td>Weight</td>
<td>Plate</td>
<td>Meets DoE 2015 Target</td>
</tr>
<tr>
<td>Cost</td>
<td>All</td>
<td>R&amp;D needed</td>
</tr>
</tbody>
</table>
Approach to Meeting Remaining DOE FFP Targets

The “4 T’s”:

• Temperature
  ▪ New higher temperature resin systems

• Thickness
  ▪ Enabled through a combination of flake sourcing, flake processing, and composite processing

• Toughness
  ▪ Enhanced through resin-reinforcement

• Throughput
  ▪ Viable path to commercialization brought about by low cost manufacturing methodologies
Natural Graphite – Starting Material

- Mineral form of graphite
- Abundant deposits worldwide
  - 200 Sources
  - 800 MM Tons
- Secure source for high-quality deposits
- Graphitized “by nature”
  - Avoid high-temperature heat treatments.
  - Lower Cost
- Anisotropy (not isotropic)
  - Properties are directionally dependent.
Expanded Graphite – Composite Matrix

- Intercalation by “inserting” compounds between graphene planes
- Exfoliation by rapid heating to decomposes intercalant forcing graphene layers apart
- Calendaring, embossing, pressing
  - No binder required
- Compression re-aligns expanded graphite layers
  - Structurally anisotropic
- Conformable & sealable
- Light weight
- Thermally and electrically Conductive
- Near-zero in-plane CTE
- Chemically inert
Accomplishments

Task 1: Graphite Selection
Contributors: GrafTech, Ballard, Huntsman
- Define FFP specifications
- Potential natural graphite sources evaluated
- Candidate flakes selected
- Graphite processing response surface experiment completed

Task 2: Resin Selection
Contributors: GrafTech, Huntsman
- Resin specification table developed

Task 2: Resin Selection (cont)
- Resins selected for initial evaluation
  - Lab scale resin samples formulated
  - Neat resin properties evaluated
  - Mold release chemistry incorporated
  - Benzoxazine (9) & Epoxy (6) formulation evaluated
- Resin formulations down selected
  - Benzoxazine (2)
  - Epoxy (1)
## Accomplishments - Task 2: Neat Resin Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Catalyst</th>
<th>Gel Time @ 200°C</th>
<th>Softening Point</th>
<th>DMA Tg</th>
<th>TMA</th>
<th>TGA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tg</td>
<td>CTE</td>
<td>Decomp Temp</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>°C</td>
<td>µm/m°C</td>
<td>°C</td>
</tr>
<tr>
<td><strong>Benzoxazine Resin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>No</td>
<td>&gt;600</td>
<td>70.5</td>
<td>215</td>
<td>185</td>
<td>183</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>&gt;600</td>
<td>84.8</td>
<td>171</td>
<td>137</td>
<td>128</td>
</tr>
<tr>
<td>2A</td>
<td>No</td>
<td>&gt;600</td>
<td>Liquid</td>
<td>232</td>
<td>198</td>
<td>216</td>
</tr>
<tr>
<td>2B</td>
<td>No</td>
<td>&gt;600</td>
<td>Liquid</td>
<td>225</td>
<td>183</td>
<td>195</td>
</tr>
<tr>
<td>2G</td>
<td>No</td>
<td>364.9</td>
<td>88.1</td>
<td>282</td>
<td>252</td>
<td>247</td>
</tr>
<tr>
<td>2H</td>
<td>No</td>
<td>440.9</td>
<td>74.6</td>
<td>282</td>
<td>255</td>
<td>261</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>&gt;600</td>
<td>80.5</td>
<td>298</td>
<td>183</td>
<td>175</td>
</tr>
<tr>
<td>4</td>
<td>No</td>
<td>420</td>
<td>98</td>
<td>148</td>
<td>120</td>
<td>114</td>
</tr>
<tr>
<td>5</td>
<td>No</td>
<td>&gt;600</td>
<td>87</td>
<td>183</td>
<td>148</td>
<td>104</td>
</tr>
<tr>
<td><strong>Epoxy Resin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Yes</td>
<td>30.3</td>
<td>Liquid</td>
<td>205.0</td>
<td>178.0</td>
<td>172.0</td>
</tr>
<tr>
<td>2</td>
<td>Yes</td>
<td>170/150°C</td>
<td>Liquid</td>
<td>208.0</td>
<td>191.0</td>
<td>184.0</td>
</tr>
<tr>
<td>3</td>
<td>Yes</td>
<td>100/150°C</td>
<td>Liquid</td>
<td>242.0</td>
<td>210.0</td>
<td>197.0</td>
</tr>
<tr>
<td>4</td>
<td>No</td>
<td>155/150°C</td>
<td>Liquid</td>
<td>156.0</td>
<td>125.0</td>
<td>NA</td>
</tr>
<tr>
<td>5</td>
<td>Yes</td>
<td>31.3</td>
<td>Liquid</td>
<td>143.0</td>
<td>96.0</td>
<td>NA</td>
</tr>
<tr>
<td>6</td>
<td>No</td>
<td>&gt;600</td>
<td>Liquid</td>
<td>95.0</td>
<td>88.0</td>
<td>NA</td>
</tr>
</tbody>
</table>

**Selected Systems**
Resin Candidate

Benzoxazines

• Reaction product of amine, phenol, and formaldehyde
• High purity: No halogens
• Thermosetting chemistry
• High Tg (Glass Transition Temperature)
  ▪ Selected Resins have $T_g > 250 \, ^\circ C$
• Low coefficient of thermal expansion
  ▪ <70 $\mu m/m-^\circ C$
• Low moisture absorption.
• Electrical properties better than the epoxy analog
• Can react with epoxies and other thermoset resins
Accomplishments

Task 3 Composite Preparation
Contributors: GrafTech, Huntsman
• Un-embossed composites successfully fabricated
  ▪ Molding temperature
• Gas impermeability verified
• Resins selected for single cell and embossing studies
  ▪ Epoxy resin system eliminated due to processing issues
• Temp cycle and shock testing
  ▪ 2G resin system - no significant changes
  ▪ 2H resin composite - some degradation
• Key process variables identified

Task 4 Embossed Composites
• Contributors: GrafTech, Huntsman, Ballard
• Mechanical and physical properties
  ▪ ≥ Incumbent system
• Single cell plates machined
• Embossed plates evaluated
  ▪ Molded to single plate thickness < 0.8 mm.
  ▪ Nitrogen & helium gas permeability measured
  ▪ In-plane and through plane electrical resistance
  ▪ Dimensional processing changes (growth factors)
• One graphite eliminated based on high gas permeability results
<table>
<thead>
<tr>
<th>Property</th>
<th>Method</th>
<th>Units</th>
<th>FFP Average</th>
<th>2G Resin Average</th>
<th>2H Resin Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Density</td>
<td>ASTM C611</td>
<td>g/cm³</td>
<td>1.68</td>
<td>1.68</td>
<td>1.72</td>
</tr>
<tr>
<td>Thermal Conductivity (x,y)</td>
<td>ASTM D5470 Modified</td>
<td>W/m·K</td>
<td>275</td>
<td>286</td>
<td>294</td>
</tr>
<tr>
<td>Thermal Conductivity (z)</td>
<td>ASTM C714</td>
<td>W/m·K</td>
<td>4.67</td>
<td>4.03</td>
<td>4.03</td>
</tr>
<tr>
<td>Thermal Diffusivity</td>
<td>ASTM C714</td>
<td>cm²/s</td>
<td>0.039</td>
<td>0.033</td>
<td>0.033</td>
</tr>
<tr>
<td>Electrical Resistivity (x,y)</td>
<td>ASTM C611</td>
<td>µΩm</td>
<td>7.8</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Electrical Resistivity (x,y)</td>
<td>GTI Internal</td>
<td>µΩm</td>
<td>NA</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Electrical Resistivity (z)</td>
<td>GTI Internal, 1-Ply</td>
<td>µΩm</td>
<td>NA</td>
<td>934</td>
<td>937</td>
</tr>
<tr>
<td>Contact Resistance</td>
<td>GTI Internal</td>
<td>µΩcm²</td>
<td>2.1</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Electrical Conductivity (x,y)</td>
<td>GTI Internal</td>
<td>S/cm</td>
<td>1470</td>
<td>1002</td>
<td>1111</td>
</tr>
<tr>
<td>Electrical Conductivity (z)</td>
<td>GTI Internal, 1-Ply</td>
<td>S/cm</td>
<td>NA</td>
<td>10.7</td>
<td>10.7</td>
</tr>
<tr>
<td>Thermal Expansion Coefficient (x,y)</td>
<td>ASTM E1545</td>
<td>µm/m·K</td>
<td>1.31</td>
<td>0.95</td>
<td>0.98</td>
</tr>
<tr>
<td>Thermal Expansion Coefficient (z)</td>
<td>ASTM E1545</td>
<td>µm/m·K</td>
<td>97.2</td>
<td>81.8</td>
<td>74.1</td>
</tr>
<tr>
<td>Flexural Strength, -40 °C</td>
<td>ASTM D790</td>
<td>MPa</td>
<td>63.9</td>
<td>67.3</td>
<td>69.0</td>
</tr>
<tr>
<td>Flexural Strength, 23 °C</td>
<td>ASTM D790</td>
<td>MPa</td>
<td>57.5</td>
<td>58.7</td>
<td>61.8</td>
</tr>
<tr>
<td>Flexural Strength, 100 °C</td>
<td>ASTM D790</td>
<td>MPa</td>
<td>37.8</td>
<td>47.8</td>
<td>51.3</td>
</tr>
<tr>
<td>Flexural Strength, 120 °C</td>
<td>ASTM D790</td>
<td>MPa</td>
<td>NM</td>
<td>44.3</td>
<td>49.7</td>
</tr>
<tr>
<td>Tensile Strength, -40°C</td>
<td>ASTM D638</td>
<td>MPa</td>
<td>41.9</td>
<td>41.3</td>
<td>44.6</td>
</tr>
<tr>
<td>Tensile Strength, 23°C</td>
<td>ASTM D638</td>
<td>MPa</td>
<td>38.6</td>
<td>37.4</td>
<td>43.8</td>
</tr>
<tr>
<td>Tensile Strength, 100°C</td>
<td>ASTM D638</td>
<td>MPa</td>
<td>29.2</td>
<td>32.8</td>
<td>36.4</td>
</tr>
<tr>
<td>Tensile Strength, 120°C</td>
<td>ASTM D638</td>
<td>MPa</td>
<td>NM</td>
<td>32.6</td>
<td>37.4</td>
</tr>
</tbody>
</table>

NA - Not Available
NM - Not Measured
# Temperature Cycling Studies

<table>
<thead>
<tr>
<th>USCAR - III Environmental Test Protocol (Modified)</th>
<th>Shock Test</th>
<th>Normal Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycles</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>Step</td>
<td>1 2 3</td>
<td>1 2 3</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>125 -40 -40 87.5</td>
<td>125 87.5 125</td>
</tr>
<tr>
<td>Dwell, hrs</td>
<td>0.5 0.5 4 1.5 0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Ramp Rate, °C/minute</td>
<td>-328 328 4.25 1.25 -2.75</td>
<td></td>
</tr>
<tr>
<td>Hold Temp, °C</td>
<td>-40 125 87.5 125 -40</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity, %</td>
<td>50 NA 80-90 NA NA</td>
<td></td>
</tr>
<tr>
<td>Dwell, hrs</td>
<td>0.5 0.5 4 1.5 0.5</td>
<td></td>
</tr>
</tbody>
</table>
Benzoxazine Resin GRAFCELL® Composite Plates

Machined GRAFCELL® Composite Single Cell Flow Field Plate

Molded GRAFCELL® Composite Corrugated Flow Field Oxidant Plate
Mechanical Strength Testing Results

Scatterplot of Flexural Strength, psi vs Temperature, °C

Panel variable: Ply
Accomplishments

**Task 5: Single Cell Testing**  
Contributors: GrafTech, CWRU

- Leachate analysis method developed
- High Temp components selected and procured
  - MEAs delayed start
- Single Cell Testing results
  - 2G resin >1100 hrs at 120 °C
    - Multiple MEAs used
    - Typical MEA lasts approximately 100 hrs
  - 2H resin >200 hrs at 120 °C
    - Operation terminated due to MEA supply
- Post-test plate and effluent analysis still in progress

**Protocol**

- ETEK 1500 GDL
- 114 hrs @ 80 °C
  - 70% RH
- 86 hrs @ 120 °C
  - 24% RH
- Cells conditioned 24-48 hrs @ 80 °C
- Liquid samples collected

**Cell Resistance**

- 114 hrs @ 80 °C: 0.23 Ohm cm²
- 71 hrs @ 120 °C: 0.55 Ohm cm²
- 86 hrs @ 120 °C: 0.54 Ohm cm²
High Temperature Single Cell Testing Results

Graftech 2G Cathode Plate

- OCV
- 100 mA/cm²
- 150 mA/cm²
- 200 mA/cm²

Potential (V, uncorrected) vs. Time at 120°C (hours)

Cells:
- Cell 1
- Cell 2
- Cell 4
- Cell 6
- Cell 7
- Cell 8

Time: 0:00 to 120:00 to 240:00 to 360:00 to 480:00 to 600:00 to 720:00 to 840:00 to 960:00 to 1080:00 to 1200:00

1104.80 hours
Accomplishments – Task 6

Design and Manufacture Full-size Bipolar Plates
Contributors; GrafTech, Ballard

- Tested plate coolant durability
  - ASTM D739-99a permeation
  - Ethylene glycol coolant
  - 2G better than 2H
- Final review and selection of graphite, resin and processing conditions
  - 2G resin system and G3 graphite mat selected
- Selected and evaluated press for full-size plate fabrication
- Plate design approved
  - Bipolar plate assembled thickness below 1.6 mm
  - Plate area greater than 250 cm².
- Small test tools fabricated
  - Growth factors evaluated
  - Feature formation
- Full size embossing die sets fabricated
- Resin and graphite for full size plate produced
- Leak check device and glue fixtures fabricated
- Glue equipment commissioned
- Full-size bipolar plates embossed
- Compression stack hardware fabricated
- Membrane Electrode Assembly (MEA) and seal equipment selected and prepared
- Bipolar plate assemblies glued and inspected
# Summary of Composite Testing Results

<table>
<thead>
<tr>
<th>Property</th>
<th>Preferred Graphite</th>
<th>Preferred Resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Properties</td>
<td>No preference</td>
<td>Benzoxazine</td>
</tr>
<tr>
<td>Mechanical Properties</td>
<td>No preference</td>
<td>Benzoxazine</td>
</tr>
<tr>
<td>Nitrogen Permeability</td>
<td>G1P2S1T1E1</td>
<td>2G Benzoxazine</td>
</tr>
<tr>
<td>Growth Factor Analysis</td>
<td>G3P1S1T1E1</td>
<td>2G Benzoxazine</td>
</tr>
<tr>
<td>Preliminary Coolant Compatibility</td>
<td>No preference</td>
<td>2G Benzoxazine</td>
</tr>
<tr>
<td>Preliminary Leachate Analysis</td>
<td>No preference</td>
<td>2G Benzoxazine</td>
</tr>
<tr>
<td>Preliminary Single Cell Testing</td>
<td>No preference</td>
<td>2G OK</td>
</tr>
<tr>
<td>Preliminary Environmental Cycling</td>
<td>No preference</td>
<td>No preference</td>
</tr>
<tr>
<td>Final Selection</td>
<td>G3P1S1T1E1</td>
<td>2G Benzoxazine</td>
</tr>
</tbody>
</table>
Test Tool Plate Cross Section
Remaining Work – 2009

Task 7: Short Stack Test of Full-size Plates

- Final full stack testing preparations
  - MEAs fabricated and sealed (Complete)
  - Test station commissioned, duty cycle identified (Complete)
  - Assemble bipolar plates with sealed MEAs in compression stack hardware

- 10-Cell short stack testing
  - Durability testing targeting 1000 hours
  - Freeze testing

- Post test analysis
  - Cell Performance
  - Effluent stream leachate
  - Bipolar plate post mortem

- Deliver Full Size Plate Stack to DOE

Task 8: Economic Assessment of New Technologies
Summary

• All critical starting material evaluation and testing is complete
  ▪ Graphite and resin system for plate fabrication selected.
• New composite systems shown to have equivalent or improved dimensional stability and mechanical and thermal properties over the incumbent GRAFCELL® composite.
• Gas impermeability demonstrated to a single plate thickness of less than 0.8mm.
• Leachate, glycol and single cell testing results are positive or do not indicate any significant problems with cell operations at elevated (120 °C) temperature
• Critical processing parameters identified and optimized.
• Full-size embossing dies and leak-check device fabricated
• Full size bipolar plates embossed, sealed and glued
• Stack MEAs, hardware, and sealing device ready for assembly