Bipolar Plate Cost and Issues at High Production Rate

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DOE Workshop on Research and Development Needs for Bipolar Plates for PEM Fuel Cell Technologies

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Bipolar Plate (BPP) Presentation Outline

• Overview of Recent Activities
• BPP Cost Breakdown
• Factors that Affect BPP Cost
• Issues and Limitations
  – Forming, Coating, Joining
• Ideal BPP Operation
• GLWN Report Findings
  – Observations
  – Supply Chain Readiness and Potential
  – Actions to Improve Competitiveness
Recent Activities

• Design for Manufacture and Assembly (DFMA) Studies
  – Annual SA reports on 80kWe (auto) and 160kWe (bus) systems
    • Identify a manufacturing process train detailing the specific materials, machinery, labor, utilities, and processing conditions
  – BPP analyses:
    • Forming Metal Plates
      – Progressive Stamping, Conventional Hydroforming, Borit’s Hydrogate™ Process (hydroforming)
    • Coating
      – TreadStone Gen 1-3 (PVD process), Amorphous Carbon (on Ti & SS), Au Nanoclad
    • Sealing/Joining
      – Laser welding

• Supply Chain & US Competitiveness Analysis
  – Team: GLWN (Prime), SA, E4Tech, DJW Technology
  – 35 interviews with OEMs and Suppliers
    – Global Fuel-Cell Trade-flows
    – Supply Chain Evolution
    – Global Component Cost Comparison
    – Global Supply Chain Strategies
    – US Competitiveness Analysis and Suggested Actions

Draft report with DOE for review
Bipolar Plate Cost as Fraction of System Cost

**FC System Cost Breakdown**

**Total $90/kWnet**
- Fuel Cell Stack: 55%
- Balance of Plant: 45%

**10,000 Systems/Year**
- Fuel Cell Stack: 52%
- Balance of Plant: 48%
- BPP Assy.: ~$8/kWnet

**Total $53/kWnet**
- Fuel Cell Stack: 52%
- Balance of Plant: 48%

**500,000 Systems/Year**
- Fuel Cell Stack: 50%
- Balance of Plant: 49%
- BPP Assy.: ~$8/kWnet

**FC Stack Cost Breakdown**

- **10,000 Systems/Year**
  - Catalyst: 36%
  - BPP: 20%
  - Membranes: 7%
  - MEA Frames/Gaskets: 8%
  - GDLs: 7%
  - Balance of Stack: 15%

- **500,000 Systems/Year**
  - Catalyst: 43%
  - BPP: 30%
  - Membranes: 5%
  - MEA Frames/Gaskets: 8%
  - GDLs: 6%
  - Balance of Stack: 15%
Wide range in OEM/Supplier BPP Price Estimates

Cost uncertainty may stem from misalignment of reporting:
- Does cost include forming, coating, and joining?
- Does it include gaskets?
- At what production rate?
- Costs quoted in $/kW but at what power density?
- Costs quoted in $/plate but at what plate size an active/total area ratio?
- Per BPP or BPP assembly?

(SA cost estimates for stamped SS316 plates from SA 2015 Cost Analysis Report)
Factors that Affect BPP Cost

• **Forming**
  - **Material**
    - SS316($3.50/kW_{net}$), SS304, titanium, carbon
  - **Power Density & Active/Total Area Ratio**
  - **Plate Design**
    - **Flow Field Design**
      - Fine Features (<1mm)
      - Course Features (>2mm)
      - “Fine Mesh” (Toyota)
    - **Forming Force (1,000 to 2,000 tons)**
      - Cost correlates with force
      - Strokes/min correlates with force
      - Coining vs. Bending

• **Coating**
  - Cycle time
  - Use of precious metals

• **Sealing/Joining (of the two BPP halves)**
  - Cycle time
  - Matching rates with forming and coating

• **Quality Control and Leak Testing**
SA Projected High Volume Process

**DFMA studies based on:**
- SS 316L metal plates
- Progressive die stamping
- Laser welding
- Treadstone PVD coating (outer faces of welded assembly)

**GLWN Study found:**
- Metal plates expected to dominate for auto FCVs
- Europe leads in BPP technology
- Coatings can be pre or post forming
- Laser welding most prevalent
  - Toyota is exception
- Concerns about welding and coating times and costs

**SA’s Baseline BPP Manufacturing Process Steps**

1. **Coil Unwind**
2. **Material Clean**
3. **5-Stage Progressive Stamp**
4. **Singulated Parts Bin**
5. **Non-contact Triangulation probe Quality Control**
6. **Laser Welding**
7. **PVD Coating**

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Strategic Analysis
SA Projected High Volume Cost Estimate

2016 Baseline Estimate

- 380M Plates/year (500k vehicles/year)
- 110 simultaneous processing lines needed for forming (30 lines if 24/7, no roll change-out time)
- Materials/manufacturing only (no markup included in estimate)
- $8/kWnet, ~30% of FC stack cost
- ~$3.40/kWnet (stamping only)

This is unsatisfactory. Need a faster process!

GLWN Project Interviewees report that parallel production lines are undesirable/unacceptable due to quality control concerns.
# Stamping vs. Hydrogate Parameters

<table>
<thead>
<tr>
<th></th>
<th>SA Baseline (5-stage Progressive Die Stamping)</th>
<th>Borit Hydrogate</th>
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</thead>
<tbody>
<tr>
<td>Plate Active Area</td>
<td>312 cm²</td>
<td>312 cm²</td>
</tr>
<tr>
<td>Plate Total Area</td>
<td>500 cm²</td>
<td>500 cm²</td>
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<tr>
<td>Plates per stamp</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>BPP Forming Force</td>
<td>16,000kN or 1,600 tons (2,000 bar over active area)</td>
<td>41,200 kN or 4,200 tons</td>
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<tr>
<td>Plate Material</td>
<td>316SS, 3 mils</td>
<td>316SS, 3 mils</td>
</tr>
<tr>
<td>Forming Machine Capital Cost</td>
<td>$1.8M (Prog. Stamp) $2.1M total system</td>
<td>$1M (Hydrogate) $89k (Cutting Press) $1.2M total system</td>
</tr>
<tr>
<td>Forming Rate</td>
<td>2.47 sec per plate</td>
<td>7.5 sec per 4 plates (1.88 sec/plate)</td>
</tr>
<tr>
<td>Labor</td>
<td>0.25 workers per press (min)</td>
<td>0.25 workers per press (min) (oversees Hydrogate &amp; stamping)</td>
</tr>
<tr>
<td>Stamping Die Set Lifetime</td>
<td>10M cycles</td>
<td>10M cycles (Cutting die)</td>
</tr>
<tr>
<td>Stamping Die Set Cost</td>
<td>$662k</td>
<td>$100k (Cutting die)</td>
</tr>
<tr>
<td>Hydrogate Die Set Lifetime</td>
<td>Not applicable</td>
<td>10M cycles</td>
</tr>
<tr>
<td>Hydrogate Die Cost</td>
<td>Not applicable</td>
<td>$60k</td>
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Issues and Limitations with Current Forming Methods

- **Progressive Stamping**
  - Difficult to maintain flatness for laser welding
  - +/-5µm tolerances (possibly requiring temp controlled room)
  - More complex flow fields require higher press force
    - Slower cycle time (2.5 sec/plate)
    - Higher capital cost (~ $1k/ton)
  - High tooling cost (>600k, 1,000s of hours to fabricate)
  - High # of simultaneous lines to meet capacity (100+)
  - BPP geometry limited by wall thinning issue

- **Hydroforming**
  - Must form more than 4 parts simultaneously to meet capacity (70+ lines for 4 parts/form)
  - Requires extra stamping to cut manifold holes and parts separation

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GLWN project reports that only a few worldwide companies have capacity to be credible high-volume BPP supplier to OEM.

Suppliers voice a concern.

Multiple parts per operation appears to be key step in improving cost and cycle time.
Coating of Metal Bipolar Plate

Coating

• **Two Purposes**
  – Increase Conductivity
  – Anti-Corrosion

• **Approaches**
  – Sub-Atmospheric/Vacuum Deposition
    • TreadStone Gen 1-3 (PVD process)
    • ImpactCoating (PVD)
    • PECVD Amorphous Carbon (on Ti plates for Toyota)
  – Atmospheric Deposition
    • Nitriding (ORNL)
  – Special alloys
    • Custom alloys with innate corrosion resistance
  – Liquid processes
    • Pickling
    • Polymer Matrix (Dana Reinz patents*)
  – Others?

Issues

• **Cycle time**
  – ~2-30 minutes

• **Batch vs. Continuous**
  – Parts per batch
    – a few to 100’s of parts
  – Can process be continuous?

• **Sputtering Targets**
  – Can add surprising amount of cost (beyond material price)

Metal BPP Joining Issues

• **Laser Welding**
  - Welding length
    - Perimeter & around manifold holes
    - Portion of active area (to connect BPPs for electrical contact)
  - Welding speed can be high (7-80 meters per min)
  - But total on-beam time still 0.2-5 min per BPP assembly
  - **Engineering solutions can be developed**
    - Multiple plates per station
    - Multiple stations
    - Multiple lasers per station
    - Multiple galvos per laser

• **Adhesives**
  - Practiced by Toyota/Mirai
  - Seals can fail (more frequently than welding)
  - Can be done R2R before part singulation
  - R2R can be very fast

Effective cycle time can be ~2 seconds per BPP assembly

Effective cycle time can be <2 seconds (at 20m/min.)
2 stations each with 2 plates, 2 lasers, and 4 galvos/laser to progressively weld the plates
Effective welding time: 1.8sec/station + index time 2.5s/station => total 4.3s/ two plates =>2.2s/welded plate assembly

Laser Welding Considerations

Low Volume Scenario

Stamp ed individual anode/cathode BPPs stacked in magazine

Pick-and-Place robot picks up and orientates anode and cathode BPPs into welding single fixture, then removes after welding. (20 seconds)

Manifold and perimeter welding time: ~30sec
Active Area Flow field welding time: 35sec (for 5% of the flow field length)

High Volume Scenario

Welding Station #1

Welding Station #2

Shaded active area represents small discontinuous welds over the plate (1/2 of the weld at each station)
Ideal BPP Fabrication
(inspired by Nissan concept)

Option #1:
- Coating from Coil with Re-roll
- Forming from Coil with Re-roll
- Joining from Coil Followed by part Singulation

Option #2:
- Coating from Coil with Re-roll
- Forming/Joining/MEA-Addition/Sing. All on Continuous Line

Key Points:
1) Delay singulation as long as possible.
2) Re-roll of formed plates would be an enabling technology.
3) Flow-field formation on the MEA would be an enabling technology.
4) R2R creation of a unitized cell (BPP plus MEA) would be an enabling technology.
5) Numerous configurations are possible.
Required Line Speed to Achieve 500k systems/yr

- Ideal line speed for BPP roll-to-roll processing and assembly
  - 380M parts/yr at 6,000 hrs/yr* and 10 lines => 0.57 sec/part
  - **Lines speed for single-wide BPP line** => 26cm x 19cm (down length)
    - (0.19m/part) / (0.57s/part) = 0.33m/s or ~20 m/min
  - **Line speed for double-wide BPP line** => 52cm x 19cm (down length)
    - (0.19m/part) / (1.14s/2 parts) = 0.167m/s or ~10 m/min

For 10 lines: Required line speed is ~10-20 m/minute.
For 1 line: Required line speed is ~100-200 m/minute.

* Assumes high utilization: 20 h/day, 300 days/year.
Bipolar plates will likely be supplied as welded and coated assemblies
- Gaskets/seals were not included as a key component but were noted as a significant challenge and cost item during interviews
- Gaskets can be included on bipolar plate assembly or as a separate framed MEA with sub-gasket

3-5 suppliers worldwide are currently capable of producing bipolar plates with the quality and reliability required by OEMs at high volume
- While stamping and welding technology is (in many ways) mature, achieving the required precision, quality control, and volume production dramatically limits the number of suppliers
- New production houses can be developed but it will require years to establish themselves as viable automotive suppliers

Factory likely to be sited near stack integrator/OEM at high volume
- At high volume, labor is not a cost driver
- However, shipping costs are very low
- Coating and forming/welding are different competencies, so these two operations may be separated
(Draft) Actions to Improve Competitiveness

**High Priority Manufacturing Opportunities (generally applied research)**

**Opportunity #5**: Development of (near-)continuous, high-speed process for BPP fabrication
- Sequential, roll-to-roll formation, coating, and joining of BPP assemblies
- Delay of part singulation so as to minimize part handling
- Develop processes capable of <1 sec per plate processing time (~3m²/min (based on total plate area))

**Opportunity #6**: Program to characterize and assess the problem of thinning of metal in BPP
- Investigate limitation of conventional sheet metal stamping due to metal elongation limits and thinning issues.

**Opportunity #7**: Development of alternate forming techniques that solve the metal thinning limitations of conventional stamping.
- Identify/Devise solutions to these limits so as to enable advanced BPP designs consistent with expected future stack performance (high power density, improved water management, low-pressure drop, low stoichiometric flow rates, etc.).

**Manufacturing R&D/Demonstrations**

**Opportunity #8**: Demonstration of high-speed, high accuracy, geometry-neutral fuel cell stacking system
- Equipment is needed by all vendors
- Provides quality control at high processing rates.

**Opportunity #9**: Demonstration of low-cost, high-speed, high-accuracy, geometry-neutral BPP welding systems
- Equipment is needed by multiple vendors.
- Current systems are costly due to low welding and indexing speeds.
- Desired system would leverage existing U.S. capabilities in welding and system automation to develop high-speed, high-accuracy automated systems that could be used by any fuel cell vendor.
Thank you.

Questions?